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"Routing and Mobility Management Strategies in Personal Networking Environments"

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"You see not any imperfection in the creation of the Gracious God.
Return your gaze, do you see any flaw. Then return your gaze again and again.
Your gaze comes back to you dazzled, perplexed and fatigued,
Having found no incongruity"
The deeper we seek, the more is our wonder excited,
The more is the dazzlement for our gaze.

Dr. Abdus Salam
(Noble Prize in Physics, 1979)

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ABSTRACT

The ubiquitous trend to personalised communication is a symbol of our need for flexibility and freedom. To enable such personal and ubiquitous environments, the plethora of technologies and devices need to interwork to exchange large amount of information with widely varying content, utilising various types of access networks. Connectivity is thus the key word and research concentrates on efficient networking procedures in heterogeneous personal environments.

The recent proliferation of fixed and mobile access technologies and devices has enriched personal environment of the user. These innovative technologies and devices capture diverse needs and requirements of the mobile users. As a part of personal environment of the user, these heterogeneous components are desired to co-exist and cooperate with each other, in order to offer anytime, anywhere (i.e. ubiquitous) experience to the user. The always-on connectivity coupled with mobility within the personal environments imposes strong challenges on the heterogeneous elements (devices, networks) of personal environments, to self-adapt according to the ever-changing state of the network. It is thereby of imminent practical interest that the user's environment remains transparent from underlying changes in the environment (such as route change, handover and location updates) to ensure ubiquitous communication with uninterrupted services and minimum QoS degradation.

The aim of this thesis is to investigate methods and strategies for efficient routing and mobility management in personal environments. The concept of Personal Ubiquitous Environments (PUE) is introduced which accommodates heterogeneous devices and access networks of different users and sustain the notion of cooperation and sharing of resources in a distributed manner. A prerequisite for achieving the resource (devices, networks) sharing in personal environments is the deployment of suitable communication protocols which establish efficient multi-hop routes betweens the devices of the PUE. Personal Network Routing Protocol (PNRP) has been developed to perform policy-based routing in personal environments. Moreover, in certain personal networking scenarios, the infrastructure network components (i.e. gateways) are more than one-hop distance from the user's devices; Adaptive Distributed gateway Discovery (ADD) protocol is thereby proposed to efficiently discover the multi-hop routes towards the gateway in a totally distributed manner. All the more, since the personal environments regroups heterogeneous access networks, an efficient mobility management architecture is proposed which offers unified location management and seamless handover experience to dynamic personal nodes. The seamless handover strategy based on IEEE's 802.21 standard is further extended to accommodate multi-hop handovers in personal ubiquitous environments. The proposed routing and mobility management protocols are assessed by means of numerous communication scenarios; the simulation results demonstrate the applicability of the proposed protocols, keeping the user transparency by making blended personalised resources simultaneously available to the PUE users.

Keywords: Personal Networks, PAN, Multi-hop Routing, Network Profiles, Distributed Gateway Discovery, 802.21, Multi-hop Seamless Handover, End-to-End Network Selection, Unified Location Management

RESUME

L'objectif de cette thèse est d'étudier des méthodes et des stratégies efficaces pour le routage et la gestion de la mobilité dans le cadre des réseaux personnels. Dans un premier temps, nous proposons le cadre de nos études: Personal Ubiquitous Environments (PUE). Un PUE est constitué d'un ensemble d'utilisateurs ayant des terminaux disposant d'interfaces réseau hétérogènes, et dont l'objectif est de mettre en œuvre des mécanismes de coopération et de partage des ressources de manière totalement distribuée. Dans ce cadre, la thèse a proposé des solutions innovantes contribuant à améliorer la communication inter et intra réseau personnels. La première contribution porte sur le protocole PNRP (Personal Network Routing Protocol) dont le but est de développer un routage à base de politiques (policy-based routing) pour les environnements personnels. La seconde, intitulée ADD (Adaptive Distributed gateway Discovery), est un mécanisme totalement distribué pour la découverte de multiples chemins vers une passerelle vers un réseau opéré. De plus, étant donné que ces environnements sont hétérogènes par leurs compositions (réseaux d'accès, terminaux ...), une architecture de gestion de la mobilité qui permet une gestion unifiée de la localisation et de la mobilité sans coutures appliquant l'ensemble des nœuds a également été traitée. Les résultats d'évaluation par simulation démontrent l'applicabilité et l'efficacité des ces protocoles.

Mots-clés: Réseaux Personnels, PAN, Routage Multi-saut, Profiles Réseaux, Découverte Distribuée de Passerelle, 802.21, Seamless Handover Multi-saut, Selection de Réseau debout-en-bout, Gestion Unifié de la Localisation.

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Chapter 1

INTRODUCTION

1.1 The Emergence of Beyond 3G (B3G) Systems

The First Generation of Mobile Communication Systems (1G) revolutionized the entire communication industry. The users were no more tied to their wired telephone systems to make phone calls. The concept of "being connected" anytime and anywhere was first introduced and communication went wireless. The 1st Generation was still in its infancy when 2nd Generation hit the charts.

The 2nd Generation of Mobile Communication Systems (2G) was a huge success because of its fascinating cellular based technology, mass market deployment and innovative services. Soon after its emergence it became a universal network because of its global mobility support, high quality voice and handy terminals. Following the tradition of generation after generation, 3rd Generation Mobile Systems have been deployed in several parts of the world and we have also started talking about Beyond 3G (B3G).

However, in last few years we have witnessed that 3G was more a hype than an economic ripe. 3G could not generate as much revenues as 2G, and 2G is still considered as the major revenue source for the communication industry [3]. One reason for limited 3G success is that it has not brought any substantial new services for the end-user. Increase in data-rate is not all, the end-user wants.

Now we are at the door step of beyond 3G. B3G is no more a dream now, already knocking at the foyer of our information village. B3G promises to offer a vast range and diversity of converged devices, services and networks in order to revolutionize the way we communicate today. In contrast to what was originally expected, the future is not limited to cellular systems and B3G should not be exclusively understood as a linear extension of 3G [1][2][3], for instance, moving from UMTS (Universal Mobile Telecommunications System) to HSPA (High Speed Packet Access) systems. In concrete terms B3G is more about services than ultra-high speed broadband wireless connectivity. Not only that, B3G also influences the today's networking architecture where the inter-user communication is realized with the help of third-party communication infrastructure. In B3G, the centralized third-party controlled networking architecture emerges into a hybrid model, where a part of user-to-user interaction is envisaged by the short/medium range wireless communication systems. Moreover, B3G not only enables ultra-high data rates but also facilitates ubiquitous environmental paradigms, particularly interesting for the end-user with the help of various personalised and user-friendly services.

The widely agreed upon rule for success in B3G telecommunication markets is to visualize a cooperative service chain of multiple suppliers to satisfy the ever-growing requirements of end customers [4]. The evolution of B3G systems in a multi-dimensional facet provided a scrupulous platform for deriving advanced and innovative user-oriented and cooperative services. Embossed to high level perspectives and equally leveraging on technical dimensions, several aspects of cooperative services are recognised; those related to personal (or group centric) services, intelligent transport network services, cooperative community networks and large-scale ad-hoc network services. As shown in Figure 1.1, these cooperative and heterogeneous services accounts for the efficient B3G convergence platforms that renders clear cut benefits in terms of bandwidth, coverage, power consumption and spectrum usage.

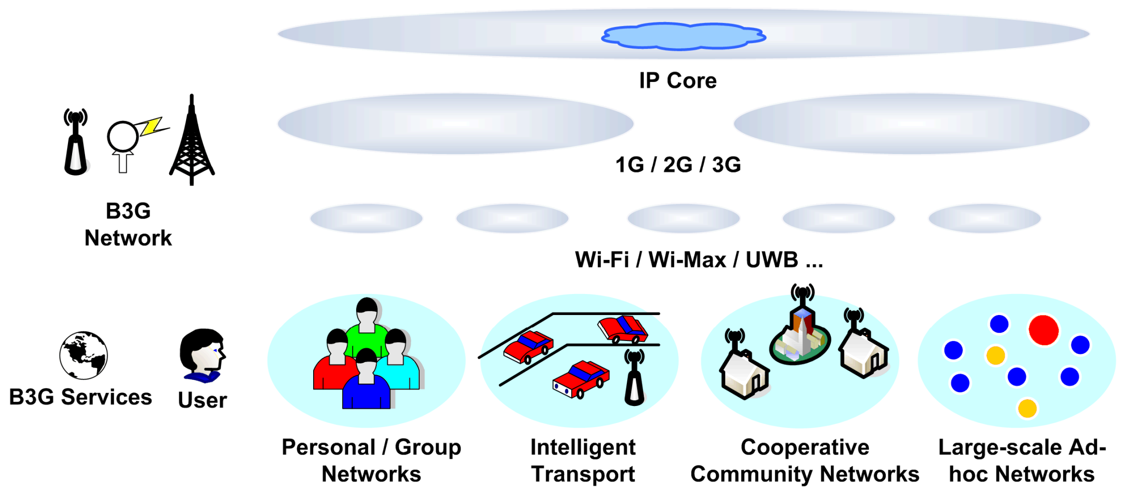


Figure 1.1: Taxonomy of B3G Services Landscape

The personal and group-centric communication models put forth a multitude of interesting services, benefiting from the "cooperative clouds" formed as a result of multi-level social groups based on self-organizing common objectives [5]. Within this context, various compelling services for smart-home networking, cooperative health care etc. are shaping up. One such service is the cooperative distribution of media content in stationary home networks, where the transparency enabled by the seamless and intelligent platform equips the home network to converge into an interdependent service ecosystem for the consumers [6]. Other services in group communication which exploits collaborative behaviour include symbolic resource sharing among communication groups (for example, user-centric dynamic content sharing similar to popular web services like MySpace or YouTube), ubiquitous and collaborative healthcare monitoring at home or hospitals etc [6].

The Intelligent Transport network is also an interesting setting for providing collaborative B3G services from a user perspective. The most interesting among them is the development of evolutionary cooperative multi-player games as a massive collaborative constellation for vehicular networks [7]. These self-evolving games are targeted at intelligent transport networks which range from private vehicle owners to public transportation system users. Other envisaged services include varying location-based services in offer on a cooperative basis, where the consumers could either locate their intended footage leveraging on the collaborative platform or the customers could market their business availing on cooperative advertisement options. This creates an open service ecosystem beneficial for the entire service value chain in vehicular transportation networks [8].

Wireless community networks (commercial, public and non-profit) have matured enough through the continuing evolution of mesh networks [12], which are now exploiting heterogeneity in a third generation mesh context with the use of multiple-radios (including different radios for downlink-uplink), dynamic interference detection and avoidance mechanisms, automatic location updating mechanisms etc [9]. This, along with the introduction of inter-community networking aspects has given new dimensions to collaborative service distribution in community networks. This includes community-based IPTV services, cooperative web-radio, collective surveillance etc apart from common service attributes like resource sharing among users. In general, large-scale user cooperation is an important aspect to the success of community networks triggering the collaborative service-profit chain and introducing competitive differentiation.

Moreover, large-scale mobile ad-hoc networks applications have made appealing progress, particularly in the field of wireless sensor networks. Many distributed applications are envisaged in sensor networks where collaborative computing [13] assumes the centre stage; smart messaging services for sensors, collaborative objects tracking etc, to name a few [10].

In the search for niche markets and opportunity for B3G systems, large organizations and policy makers converge to accept that the B3G landscape is not just be about defining higher data rates or innovative radios, but rather is shaped by the increasing integration and interconnection of heterogeneous systems, with different devices processing information for a variety of purposes, a mix of infrastructures supporting transmission and a multitude of applications working in parallel making the most efficient use of the spectrum [11]. On the contrary, users are getting more vary about the services that they require and the modes with which they prefer to communicate and cooperate, which also hugely influences the future of B3G commercialization. These developments led to think in the lines of personal/group services as the most appealing and predominant platform for the development of B3G; where the users collaborate in a distributed and cooperative fashion. This user-centric cooperation and supporting issues, which accounts for the development of cooperative, ubiquitous, personal communication environments is author's core motivation and nucleus of discussion in this thesis.

1.2 A New Communication Paradigm: Personal Environments

Personal Computing (PC) flourished faster than any other domain and by its marriage with networking world, it gave birth to a new era of computing called ubiquitous computing [13]. The ubiquitous computing domain can also be seen as a by-product of B3G systems. B3G is not the name of a single technology [3]; rather it is a cooperative platform [1] where a large range of heterogeneous wireless networks and services coexist. Under the auspices of B3G, the diverse devices, network and service elements find their way into the life of the end-user. This integration of B3G elements into the end-user environment should ideally go unnoticed to the user; so that the technology eventually focuses over the user and not the user focuses on the diversities and complexities of technology around him. It is pretty obvious that this preferably invisible and intelligent world of B3G technology [13] integrated into the user's world is only possible with the essence of cooperation, sharing, openness and trust, within the user's own devices and among the user's forming groups. The notion of cooperation in personal/group services may take various dimensions ranging from user-centric cooperation to group-centric cooperation.

1.2.1 User-Centric Cooperation – Personal Networks

There is a large array of actors in B3G service arena such as user, service/content provider, network operator, regulatory bodies, researchers and so on, who bind their own proper stakes with B3G's success. However, economically speaking, user is a major player; a centre of the entire B3G globe, whereas the other actors join hands to meet the expectations of the end-user. Taking the technological dimension, in the last few years, number of heterogeneous devices emerged and networked, ranging from mobile communication equipments to home electronics. This proliferation results into the availability of large range of choices to the user to communicate in highly diverse environments. As a result, in a B3G system, the user is surrounded by a variety of devices subject to offer a multiplicity of different services [1], as shown in Figure 1.2. Moreover, the utilization of these devices and services dramatically changes with the change in user's environment. Therefore, the devices and services in the B3G world should have a high deal of adaptation capabilities. "Personalization" [1] is a key word here. Since every user is unique in his roles, taste and likings; the B3G systems should be intelligent enough to fully understand the user and adapt the network and service elements according to user's preferences.

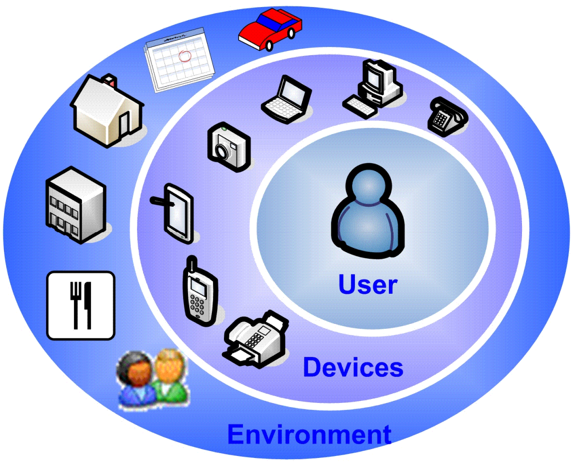


Figure 1.2: User Centric Cooperation

The personalization aspects of B3G systems are anonymous to the early concept of "Personal Computers (PC)". In the beginning of the computer age, the computers were seen as the specialized and complicated devices developed to fulfil specific business needs; the notion of personalization revolutionized the world and introduces the concept of "Personal Computer (PC)". PCs proved to be user-friendly and inexpensive, capable to meet a large range of user's personal needs.

In B3G systems, towards personalization and user-centric cooperation, the concept of Personal Computers (PCs) is generalized and extended towards Personal Network (PN) [19], first introduced in European Union's IST MAGNET project (2004-2005) [20]. Similar concept is also introduced in 3GPP standardisation organisation as a standalone work item called Personal

Network Management (PNM) [91] following an analysis of the AIPN (All-IP Network) specification [92]. PNM seeks to establish a means of managing, securing and facilitating communications between multiple devices with varying capabilities belonging to a single subscriber (PN-user). PN is a system/network owned and operated by one person i.e. the PN owner. The PN owner is the sole authority in his personal interconnected devices and can use the PN in a way he wants. The personal devices may be located, both in his close vicinity (forming a PAN) and at remote locations. Figure 1.3 presents the PN of Bob, which is composed of his home, office and car clusters. The owner of the PN can add new devices and personalised services in his Personal Network according to his will. The PN for its owner is a heaven of personalised services in the cyberspace and appears as a black box to the outside world.

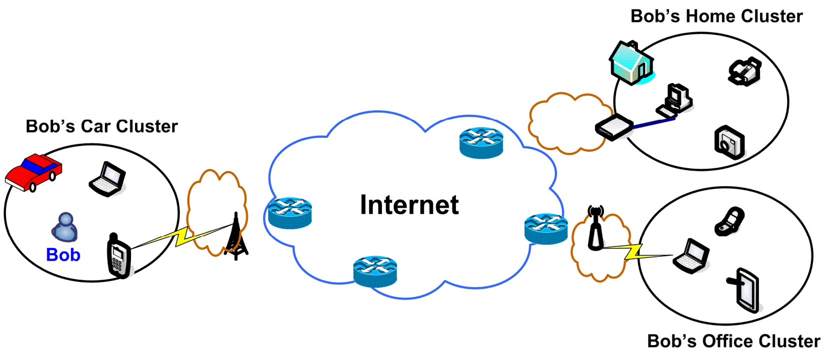


Figure 1.3: User Centric Cooperation - Bob's Personal Network (PN)

1.2.2 Group-Centric Cooperation – Federation of Personal Networks

Human nature does not promote "living in isolation". The emergence of communication networks is a sole proof of it. Group-centric cooperation is also referred as cooperation among the end-users who are organized in groups. This is somehow fundamentally opposite to the user-centric cooperation, where only the user's devices and environments cooperate, and this cooperation appears as a dark cloud for the outside world (for other users). In fact, the B3G services which can be made available to a single user (with user-centric cooperation) are limited and the users need to cooperate with the each other to extend their global services repository. In addition, many service-oriented patterns need to extend the boundaries of "user-centric cooperation" and involve the secure interaction of multiple users having common interests for various professional and private services. Moreover, in this federated users environment towards group-centric cooperative model, the distinct users can offer services to each other promoting the concept of "give and take".

In order to promote the group-centric cooperation in B3G systems, the concept of Personal Network Federations (PN-F) [18] has been recently introduced as an extension of EU IST MAGNET project entitled MAGNET Beyond (2006-2008). PN Federations addresses the interactions between multiple PN users with common interests for a range of diverse services. A PN Federation can be defined as a secure impromptu, situation-aware or beforehand agreed cooperation between a subset of relevant devices belonging to different PNs for the purpose of achieving a common goal or service by forming an efficient collaboration. As shown in Figure 1.4, a simple example of PN-F is the federation of PNs belonging to a group of students in a university restaurant, sharing lecture notes.

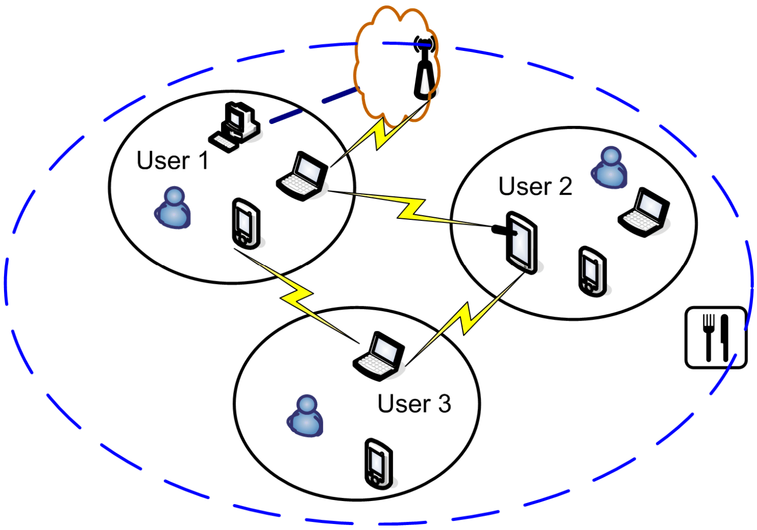


Figure 1.4: Group Centric Cooperation - Federations of PNs

1.2.3 Personal Ubiquitous Environment (PUE)

Both the user-centric and the group-centric cooperation are required in order to meet the long-awaiting expectations of B3G triggered ubiquitous networking world. The cooperation among the users, their devices and environments results into the development of a Personal Ubiquitous Environment (PUE) around the user, which permits the "ubiquitous global access" to a vast number and variety of information resources [18] [20]. This uniform and comprehensive sense of cooperation results into a vast base of services for all the users who are the part of this personal ubiquitous environment village. In the language of Personal Networking, we collectively define PN (Personal Network) and PN-F (PN Federation) as a Personal Ubiquitous Environment (PUE). Figure 1.5 explains the concept of PUE with the help of an example. As in Figure 1.5, three users join hands to share devices, services and environments to form a federation. Moreover, as highlighted in Figure 1.5, other two users, who are satisfied with their own proper resources and do not have any intention to cooperate in a federation; stays in their own user-centric environments i.e. PN.

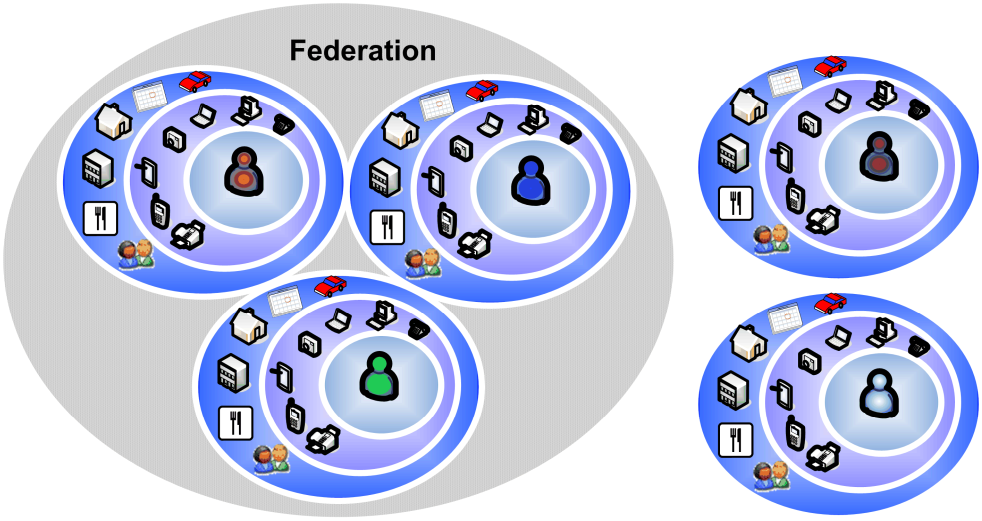


Figure 1.5: Personal Ubiquitous Environments

Personal Ubiquitous Environment (PUE) of a user first constitutes his own devices and services available in his Personal Network (PN). The user is the sole authority to extend his PUE (to form a PN-F) in order to accommodate the services and the devices available to other users in their own PNs. However, before really moving towards cooperating and forming groups, the user first looks at his motivation to cooperate. Adam Smith, the father of modern economics said, "Every man, as long as he does not violate the laws of justice, is left perfectly free to pursue his own interest his own way". If the user feels satisfied with the resources he has in his own PN, no desire to cooperate and to form federations will come on his way. The user shall only devise ways into federations when he looks for some service/resource which his PN (or current PUE) can not offer.

1.3 Background and Motivation

Mobile Ad-hoc NETworks (MANET) has experienced tremendous upsurge in the research world due to the proliferation of wireless devices, need for self-organization and high flexibility and demands for any-time any-where ubiquitous connectivity. Moreover, the increasing thrust of tether less communication also promotes MANET for the reduction of operations costs and infrastructure support for network operators, and in parallel, to improve the communication quality. The MANET working group [21], chartered in order to discuss and develop solutions for emerging MANET applications ranging from multi-hop routing protocols to addressing and Internet connectivity.

Personal Ubiquitous Environments (PUEs) are a particular type of MANETs in which the personal nodes are connected in a multi-hop fashion and dynamically join and leave the network without prior notice. Similar to MANETs, PUEs may operate in standalone fashion without any necessary fixed infrastructure, or may be connected to infrastructure networks such as Internet. The PUEs forms a collaborative networking environment where the mobile nodes are responsible for dynamically discovering other personal nodes, thus configuring a self-adaptive peer-to-peer network allowing direct communication between personal nodes as long as they are within transmission range of each other – provided adequate transmission and propagation conditions exist between the mobile-peers. Like MANETs, PUEs should be self-forming, self-organizing, and self-maintaining, capable to manage mobility, addressing and routing strategies for its internal communication.

In contrast, unlike MANETs, PUEs are built around a specific trust relation concept translated into rules and policies of cooperation. The interaction between the personal-peers within the PUE at every layer of the protocol stack relies on this defined trust relationships. Moreover, the self-organization in PUEs spans over multiple heterogeneous network technologies, largely distinguishes themselves from MANETs. Furthermore, PUEs have a specific wireless/wired geographically dispersed network topology, which, to a certain extent, rely on the fixed infrastructure.

As the PUEs concept get mature, there are several challenges emerged to be addressed which impose barriers for the technological and commercial viability of these networks. These challenges include mobility, time-varying topology and heterogeneity; secure policy-based interaction, trust models, lack of interesting business models and use cases and interaction with other service platforms etc. Since the PUE is composed of the devices of different users (PNs), cooperating for quite dissimilar objectives, the routing in PUE is an important factor governing the secure rule-based communication within the PUE. Moreover, the mobility in PUEs spans over multiple dimensions which include, mobility of heterogeneous personal nodes, mobility of PN users and the global mobility of the entire PUE nodes and members. These multi-facet mobility requirements coupled with rule-based interaction between the PUE nodes impose fundamental challenges to be addressed in order to take PUEs from concept to reality.

1.4 Aim & Organization of the Thesis

In the last few decades, the proliferation of fixed and mobile access technologies and devices has enriched the personal environment of the user. These innovative technologies and devices complement each other and capture diverse needs and requirements of the mobile users. As a part of personal environment of the user, these heterogeneous elements are desired to co-exist and cooperate with each other, in order to offer anytime, anywhere (ubiquitous) experience to the user. The user mobility and the need to communicate within the personal environments impose strong challenges on the heterogeneous components of PUEs, to adapt according to the ever-changing state of the network. It is thereby essential that the user's PUE remains transparent from the underlying changes in the environment (such as route change, handover, location updates etc.) to ensure ubiquitous communication with uninterrupted services and minimum QoS degradation.

To this end, the aim of this thesis is to investigate methods and strategies for efficient routing and mobility management in personal environments. The routing strategies in PUEs spans over different dimensions such as routing within the PN nodes (single user), routing between different PN nodes (multiple users) and the routing towards the infrastructure nodes (discovering the gateways in multi-hop manner). Each of these dimensions, coupled with the challenging characteristics of personal environments (such as mobility, heterogeneity, security), enforce different set of requirements on the design of routing protocol which is answered in this thesis. Moreover, since the personal environments are composed of diverse and dynamic network resources; the location updates, handovers and connection management techniques particularly designed for PUEs need to be developed as a part of unified mobility management strategy in order to offer seamless global roaming across heterogeneous networks.

To accomplish a logical thread in achieving author's aim, the thesis has been organised as follows. Chapter 2 exposed a variety of techniques deemed to be vital in realising the connectivity among the devices in the personal environments. The developed routing protocol i.e. PNRP (Personal Network Routing Protocol), elaborates messages exchange in order to discover and establish routes among the personal nodes. The rules and policies for PN to PN communication, defined in the PN profiles are enforced on the routing decisions. Chapter 3 goes further in routing and deals with the problem of gateway discovery in personal networking environments and present ADD (Adaptive Distributed gateway Discovery) mechanism. Being less resource consuming and capable to cope up with the ever changing conditions of the network, our distributed adaptive gateway discovery schemes outperforms the existing gateway discovery mechanisms and provides an excellent platform reducing gateway re-discovery and route maintenance overhead, as validated by the simulation studies. The effort of Chapter 4 concentrates on PUE Mobility Management (MM) architecture which enables uninterrupted communication experience within personal environments while transparently dealing with mobility management procedures. Finally, Chapter 5 exposed mechanism to realize the multi-hop seamless handover in the personal environments and proposed extension to IEEE 802.21's MIH (Media Independent Handover) model which enables multi-hop handover operation. Note that each chapter is concluded with a thorough summary on the achieved results, the author's contributions to the field, and the future research tailored to each particular chapter. Conclusions to the entire thesis are drawn in Chapter 6, which are accompanied by suggestions on future research taking the result of the whole thesis into account.

Chapter 2

ROUTING IN PERSONAL ENVIRONMENTS

2.1 Introduction

The concept of Personal Ubiquitous Environment (PUE) goes beyond PAN (Personal Area Network) and personalised networking, which imposes geographical and ownership constraints, respectively over the nodes forming the network [22]. Personal environments extend the local scope of personal networking and give it a global magnitude, by addressing virtual personal environments that span a variety of infrastructure as well as ad-hoc networks. PUE brings a solution for trusted communication between the many local and remote personal devices and users in view of the support of a variety of personalised and context-aware services. PUE is indeed a collection of interconnected heterogeneous active single or multiple user devices, which governs the notion of cooperation, openness and sharing resources.

The key to a successful realization of personal environments is a general connectivity layer architecture [19] which seamlessly bridges the heterogeneous resources (devices and networks) under a common service platform. This network layer mechanism not only permits the user to manage his own resources but also make available the resources of other users, who are willing to participate in the common personal environment. Since cooperation and sharing is exactly opposite to isolation and privacy, the network layer mechanism, while establishing connectivity channels, also ensures secure, situation-aware, on-demand communication between user(s) devices.

It is the aim of this chapter to propose a networking mechanism for routing data within the personal environment. Here, the routing is done at two stages i.e. among the personal nodes of a single user and between the personal nodes of different users participating in the same PUE. Since, the cooperation between different users is governed by specific rules and policies; the routing mechanism is triggered by the user profiles. These user profiles contain rules of cooperation such as who is or can become member of the PUE and, how and which resources are made available to the members of the environment. Based on these rules, the routing protocol establishes routes between different devices within the PUE. Moreover, as the devices in PUE own heterogeneous capabilities such as network interfaces, strong but loosely coupled cooperation is guaranteed in order to realise PUE services.

The main contributions of this chapter are twofold: (i) the Integrated CONvergence (ICON) layer for PUEs which offers the cooperation between heterogeneous interfaces available on the personal devices, and integrates the different MAC/PHY layers at the network layer to propose the desired transparency to the services platform (ii) the Personal Network Routing Protocol (PNRP) that proactively establishes the route among the personal nodes of a single user and, reactively perform rule-based on-demand routing between the devices of different users.

This chapter is structured as follows. First, some basic concepts and state of the art achievements related to routing and convergence in personal environments are presented. Emphasis is put on identifying the similarities and differences between personal and traditional ad-hoc networks. This shall aid in reusing and adapting the existing MANET routing protocols to perform the routing job in PUEs. Second, the integrated convergence addressing mechanism is presented, which hides the heterogeneous of personal devices and offer a homogeneous look to the routing and upper-layer components. Third, the Personal Network Routing Protocol (PNRP) is presented, which provides a secure connectivity platform to all the members of PUE. The proposed routing protocol is simulated and performance outcomes are reported under fourth and fifth. Finally, chapter specific conclusions are drawn, contributions are listed, and the most important results summarised.

2.2 Motivation and Related Works

In this section, we aim at presenting the state of the art achievements, which lie in the scope of our several contributions in this chapter. This section is further subdivided into two: convergence in heterogeneous networks and routing in personal networking environments.

2.2.1 Convergence in Heterogeneous Access Networks

Personal networking environments comprise of complementary wireless access technologies, which possess heterogeneous characteristics and offer a wide range of distinct communication services. The user in such environments owns several multi-mode, multi-functional and multi-interface mobile devices that are capable to connect with multiple access networks/devices at the same time. These heterogeneous interfaces offer access to different wireless networks subject to network availability, device characteristics and the applications used; all of which introduces the need for network interoperability and convergence at the multi-interfaces capable terminal. In simple terms, all the interfaces should be able to understand each others language in order to offer optimised services with mutual understanding.

The two main approaches for cooperation in heterogeneous access networks are: network layer cooperation, link layer cooperation. In [24], the concept of Virtual Network Interface (VNI) is introduced. VNI masks the presence of different connected interfaces to the application layer by providing the illusion of a unique virtual MAC (Media Access Control) interface. Generic Link Layer (GLL) concept considered in several European research projects such as BRAIN, MIND, AMBIENT [29] propose a MAC layer table which performs the L3/L2 mapping, providing a unique interface to Layer 3. Most of these solutions require changes to the lower layer (L1/L2) modules and therefore cannot be deployed by using commodity hardware. Moreover, the lower layer convergence solutions offer limited flexibility to meet the requirements of personal environments, such as on-demand policy-based routing and context-aware service provisioning and network selection. [26] and [27] discussed different approaches to perform the interface integration and proposed to use a unique IP interface for supporting heterogeneous network interfaces in mobile multi-hop networks. Hiding the heterogeneity behind a unique IP address requires considerable changes to existing networks, as in the commodity hardware; each MAC interface is represented by a unique IP address. The design of our ICON layer for PNs is influenced by the approach presented in [26] and [27] with the following two major enhancements: (i) ICON layer hides the lower-layer heterogeneity behind the PUE-level addressing (i.e. Personal Network (PN)-ID and Node-ID) in order to offer end-to-end abstraction. (ii) PUE's ICON layer extends the concept of ABC (Always Best Connected) [28] by leveraging the notion of "Global Interoperability" presented in [29]. In other words, apart from integrating the local heterogeneous resources, we also fusion the resources available on other personal devices present in the personal environment (in multi-hop manner) and make them available to all the PUE member nodes.

2.2.2 Routing in Personal Networking Environments

Since, the PUE comprises of Personal Networks (PNs) and PN Federations (PN-F), we discuss the state of the art achievements of routing protocols, separately in both cases.

Routing in Mobile Ad-hoc Networks (MANETs) has been extensively explored in the past, which results into several routing protocols standardized in IETF such as AODV, OLSR and DSR [30]. We have observed a number of similarities between the personal networks and MANETs such as self-organization, dynamic behaviour and spontaneity. However, existing solutions in MANETs cannot be adopted as is, due to the specific nature and context of personal networks/environments such as specific wireless/wired geographically dispersed network topology, reliance on the infrastructure (to a certain extent), routing information confined to the PN boundaries (in case of proactive routing) and forwarding the route request based on certain predefined policies (in case of federating PNs). Therefore, an ad-hoc multi-hop routing protocol specifically adapted for personal networking environments is needed.

While PN is focused on the communication between personal devices only, the group centric communication model addresses the need for interactions between multiple PN users. Routing is indeed a major component to realise this PN to PN (PN-F) interaction. Several MANET routing protocols based on distributed structures (clusters, spanning trees, dominating sets) have been proposed such as HOLSR, ZRP, CDS, HARP and SHARP [20] [30] [31] which partition the overall topology into small clusters and segregate the routing mechanism into Inter-cluster and Intra-cluster routing algorithms. These protocols share similarities to multiple-PN routing (as far as outlook is concerned), though they are very different in the following key aspects: (i) the cluster/zone formation depends on the dynamic network characteristics, for instance, "hot-destination" in SHARP, "Quality of Connectivity (QoC)" in HARP and "connectivity-graph" in CDS, whereas the PN formation is influenced by user-centricity and ownership (which is largely static) (ii) the hierarchy of clusters/zones are maintained/restructured because of random node mobility, whereas in a PN, group mobility is attributed, where nodes always assume membership to a single PN only (iii) the inter-cluster routes are maintained on a reactive or proactive basis, whereas in PNs the inter-PN routing is always on an "on-demand" basis triggered and assisted by the PN profiles, and (iv) the protocols are explicitly designed to solve the problem of scalability in large scale ad-hoc networks [31], which is not the case in PN-Fs.

Having its roots in MANETs routing protocols, Personal Network Routing Protocol (PNRP) is designed to support routing strategies in personal environments. Initially, it establishes proactive routes among the PN devices and then ensures policy-based routing between different PNs (PN-Fs) with the help of user profiles. Therefore, PNRP is a complete routing solution to realise the PUEs.

2.3 Integrated CONvergence (ICON)

In the last few years, mobile hosts are being increasingly equipped with multiple interfaces capacitating access to different wireless networks. This introduces the need for network interoperability in these heterogeneous environments. In order to offer transparency of the upper-layers from underlying wireless technologies and therefore, to provide seamless interoperability across heterogeneous access technologies in multi-mode terminal environments, we have designed an ICON layer adapted for personal environments. Figure 2.1 presents the ICON enabled protocol stack for Personal Networks with respect to the node-level view (a) and the PN-level view (b).

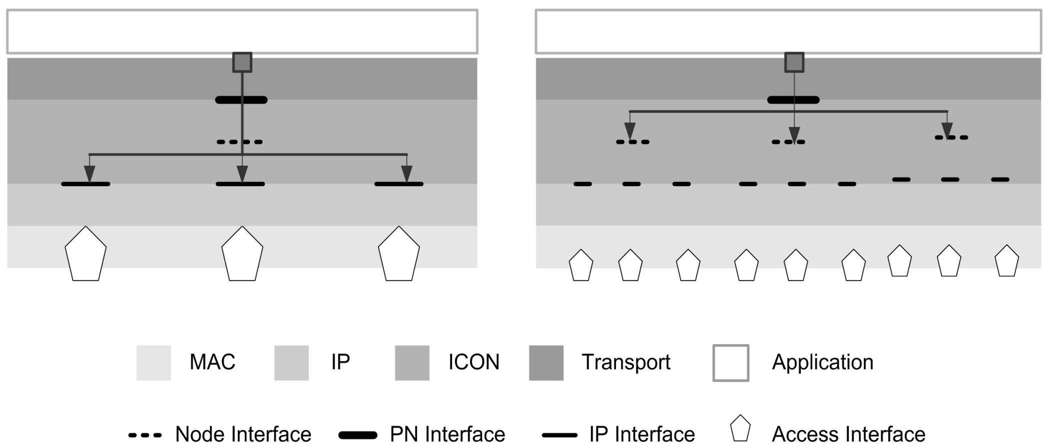


Figure 2.1: ICON Layer for PNs (a) Node-level view (b) PN/PAN-level view

To offer a considerable flexibility at the higher layers in order to meet the requirements of personal environments (by incorporating intelligent service layer information in the network selection and convergence techniques), we believe that the solution should be provided at the higher layers of the protocol stack. As presented in Figure 2.1, the ICON layer resides over the IP layer in the protocol stack. Each access network interface is represented by its MAC address and IP address. At the node level (Figure 2.1a), a single node interface handles different IP and physical interfaces. The mapping of IP/MAC interfaces on Node/PN interfaces is done at the ICON Layer. ICON hides the heterogeneity introduced by the multiple interfaces and the plurality of access technologies from the application-layer. In this personal networking architecture supported by ICON layer, an individual node is identified by its PN-ID and Node-ID, which makes the PN Interface, a top-level interface in the interface-hierarchy.

In contrast, the Figure 2.1b presents the PN level view of the ICON layer, where all the nodes of a PN (connected in single and multiple hops) are represented by a unique PN interface. This interface masks the presence of different personal nodes having heterogeneous capabilities by providing the illusion of unique entry point towards user's personal space (i.e. PN). All application flows targeted to the specific PN are addressed to its PN interface, which further spreads and redirects them on the appropriate personal node. Personal Network Routing

Protocol (PNRP) renders the pointers to all the resources accessible in the PN, available at each node in the PN. Hence, ICON layer coupled with the PNRP extends the concept of ABC (Always Best Connected) [28] by offering a large choice of options to connect to external networks via other PN nodes using multiple hops, as outlined in Figure 2.1b. Same analogy can be applied at the PUE level (having multiple PNs), where each PN has its own PN-ID, and each node is uniquely identified, hierarchically, by its Node-ID and PN-ID.

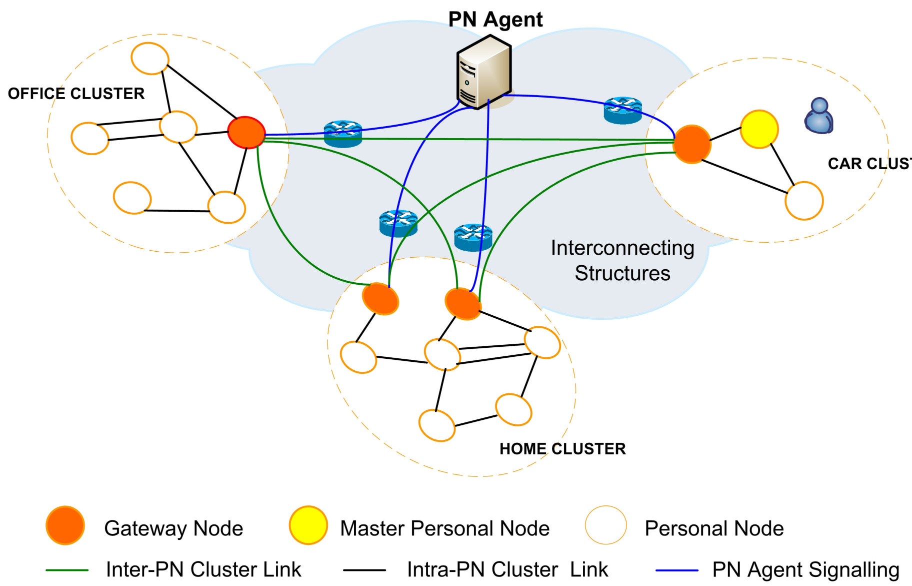


Figure 2.2: Personal Network Components and Organization

2.4 Personal Network Routing Protocol (PNRP)

2.4.1 Preliminaries

a) Terminology

We define a "personal node (pn)" to be a node that belongs to the owner of a PN. Each node is identified by its Personal Network Identification (PN-ID) and Node Identification (NID). All personal nodes of a PN owner share the same PN-ID. A "Gateway Node (GN)" is a personal node that enables the connectivity to the infrastructure network such as Internet or corporate LAN. A personal node is defined to be "Federation Manager (FM)", if it enables connectivity to the personal nodes of the other PN(s). A "PN Cluster" is a network of personal nodes located within a limited geographical area (such as house, office or car). One or more than one "PN cluster" of a single owner contributes to his PN. We repeatedly use the word "PN" to refer "PN Cluster". A "PN Agent" is an infrastructure-based management framework that keeps track of all clusters (and their devices) in a PN. A personal node is elected as a "Master Personal Node

(MPN)", with which the PN owner is directly interacting at a certain time. Figure 2.2 represents the PN entities introduced.

b) Personal Profiles

In order to interact between the PNs and to create trustable PN Federations (PN-Fs), rules and polices are needed to determine for instance, who is or can become member of the federation and how and which resources are made available to the PN-F members. Based on this, two different types of profiles have been identified to realise the concept of PN-F (PN to PN interaction), such as "PN-F profile" and "PN-F participation profile" [18]. As shown in Figure 2.3, the PN-F profile is common to the federation, created by the PN-F creator, which reflects the global information about the PN-F. Whereas, the "participation profile" is bound to the individual PN-F member and it reflects his local view regarding the PN-F. The PN-F is initiated by the PN-F profile, which is further updated with the help of participation profiles during the course of PN-F's existence.

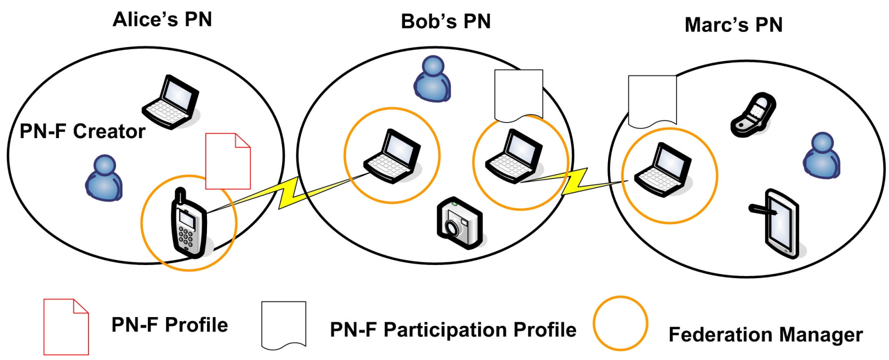


Figure 2.3: Personal Network Federation (PN-F) among Alice, Bob and Marc

In Figure 2.4, the structure of PN-F profile and PN-F participation profile at Alice's PN is presented. We consider an example (refer Figure 2.3), in which a PN-F is formed among the PN's of Alice, Bob and Marc, where Alice is the PN-F creator. The goal of the PN-F is to share the images stored at Bob's digital camera. As shown in Figure 2.4, Alice's profile is composed of the PN-F profile, and the PN-F participation profile. The PN-F profile represents the information about the PN-F members and creator, and the resources and services which are available in the PN-F. Whereas, the participation profile provides Alice's local view about her participation in the PN-F i.e. what resources she is sharing in PN-F and who is authorised to access them.

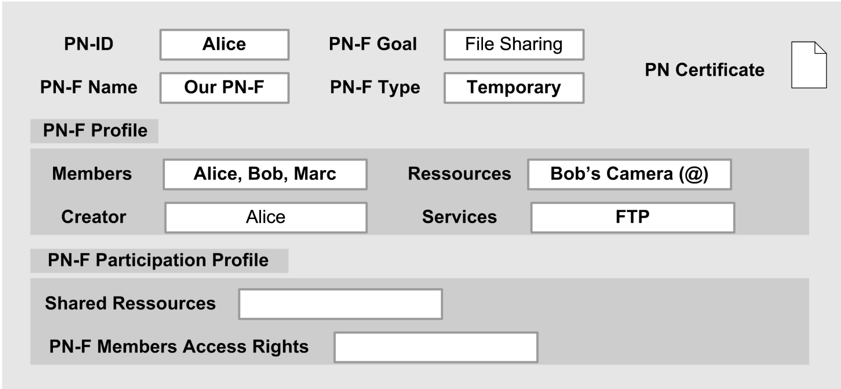


Figure 2.4: Snapshot of PN-F Profile at Alice's PN

2.4.2 Personal Network Formation

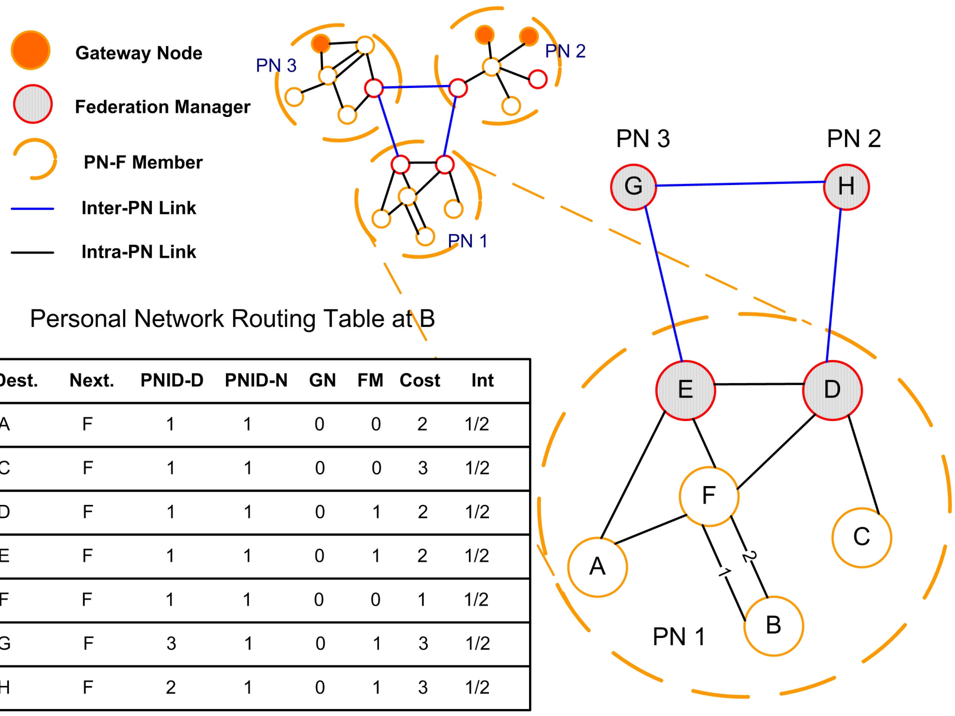
The initial logical step towards realising the personal environments is the formation of PNs (PN clusters) i.e. all the personal nodes that are in the close vicinity discover the routes towards each other. Once this is done, the formation of PN-Fs is triggered, which establishes policy-enforced routes between different PN nodes. To this end, the first step taken by Personal Network Routing Protocol (PNRP) is to proactively establish the routes between different nodes of a PN.

PNRP maintains the proactive topology of nodes which lie within the PN boundary, at every personal node of the PN. Moreover, the information on functionalities of the personal nodes such as Gateway Node (GN) and/or Federation Manager (FM) is also exchanged within the PN topology in order to facilitate PN's access to the outside world. In the following subsections, we discuss different steps that PNRP performs towards the formation of a PN.

a) Integrated Topology Discovery

The role of integrated topology discovery mechanism is to determine how the personal nodes are connected (using which interfaces in single/multi-hop) in order to provide routes for any source/destination pair in the PN. It first determines the direct connectivity among nodes and further exchanges this information to form a unified PN topology.

Neighbour discovery is incorporated into PNRP by allowing every personal node to periodically transmit "Hello" packets on all of its interfaces. "Hello" packet contains the PN-ID and the Node-ID of the source node which is processed at the destination node to identify the source of the "Hello" packet. It is possible that the personal nodes discover the non-personal nodes; therefore PN level authentication is performed. Every node maintains a 1-hop neighbour table and associated costs to each link with its direct neighbours and their PN identification. In PNRP, we have considered number-of-hops as a cost metric.



Dest.	Next.	PNID-D	PNID-N	GN	FM	Cost	Int
A	F	1	1	0	0	2	1/2
C	F	1	1	0	0	3	1/2
D	F	1	1	0	1	2	1/2
E	F	1	1	0	1	2	1/2
F	F	1	1	0	0	1	1/2
G	F	3	1	0	1	3	1/2
H	F	2	1	0	1	3	1/2

Figure 2.5 PNRP for PN Routing

Once the 1-hop neighbour topology is formed, it is exchanged with other personal nodes in order to form a complete snapshot (table) of the PN on its every single node. The topology information is only exchanged with the personal nodes i.e. among the nodes which belong to the same PN. To this end, every personal node periodically transmits the "PN topology (PNtopo)" message towards all its personal nodes (neighbours). On the reception of "PNtopo", the PN routing tables are formed/updated and further exchanged with the other neighbouring nodes. Figure 2.5 shows the PN routing table at a personal node constructed after the exchange of "Hello" and "PNtopo" messages. This table not only tracks the end-to-end routes between PN nodes but also their PN-IDs, gateway node status (GN flag), federation manager status (FM flag), end-to-end cost and network interfaces, as illuminated in Figure 2.5.

b) Gateway and Neighbouring PNs Discovery

In PNRP, each node advertises in the "Hello" message, whether it has connectivity with the infrastructure network or not. As can be seen in Figure 2.5, the exchange of integrated PN topology with the help of "PNtopo" message permits each node to maintain routes to all the existing Gateway Nodes (GNs) and the cost to reach them, in the PN routing table.

Discovery of the neighbouring PNs is also intrinsic to integrated topology discovery mechanism. During the exchange of "Hello" messages, if the destination node finds out that it is not the part of the source node's PN (with the help of PN-ID comparisons), the destination node sets itself as a Federation Manager (FM) to the source node's PN. The connectivity among the PNs is realised with the help of FMs. Once the integrated topology information is exchanged among all the nodes of the PN, every node knows the exit points (FMs) to communicate with other neighbouring PNs (refer to Figure 2.5), which further helps in PN to PN (PN-F) routing. In case of multiple GNs or FMs, the minimum cost option (for example, number of hops) is selected.

c) Route Discovery

PNRP differentiates the route discovery procedure, when the destination is a part of same PN as the source or when the destination is the part of different PN. In latter case, "PNRP for PN-F" mechanisms are triggered as discussed in the next section. In former case, since a proactive PN cluster-level topology is maintained at each PN node, the route to all the destinations in the PN are known before-time and the packets are routed accordingly.

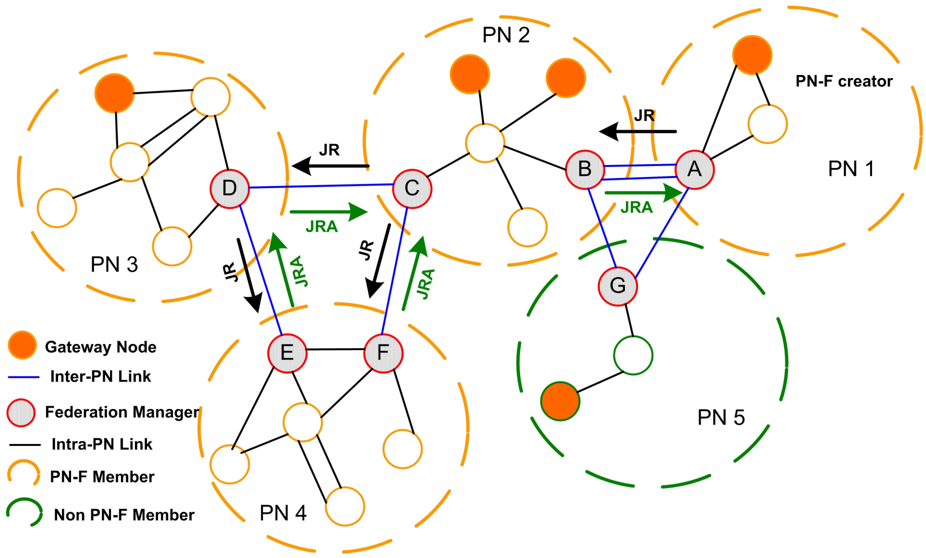


Figure 2.6: PN-F Topology Discovery in PNRP

2.4.3 PNRP for PN-Federations Formation

Unlike PNRP for PN formation, which is based on the principles of link-state routing, the Personal Network Routing Protocol (PNRP) for PN-F is a variant of on-demand multi-hop routing protocol such as AODV and DSR [30], which adapts to the personal networking environments for communication among PNs. The PN-F formation, by definition is on "on-demand" basis and is triggered by the exchange of PN profiles. The PN federation is initiated by some initiator PN (also called PN-F creator), who outlines the basic rules and potential members of the PN-F. This information about the PN-F is marked in the PN-F profile. The PN-F creator sends this initial PN-F profile to the potential PN-F members. On the reception of PN-F profile, if the initially proposed members decide to be the part of PN-F, they exchange their PN-F participation profile with the PN-F creator. This participation profile contains the conditions on which the PNs agree to participate in the PN-F. The PN-F routing mechanisms assist to determine the routes towards the desired PN-F members and provide means to establish and maintain PN Federations.

a) PN-F Topology Discovery, Formation and Routing

PN-F routing builds routes using a join request/reply query cycle. When a PN desires to create a PN-F with certain intended PN-F members, it creates a PN-F profile and sends to its FMs, piggybacked with a Join-Request (JR) message, leveraging the inter-cluster routes; thanks to PNRP's PN-cluster formation scheme. As show in Figure 2.6, in order to create a PN-F with PN2, PN3 and PN4, the PN1 (i.e. PN-F creator) sends the JR message to its FMs. The Join-Request (JR) message contains two lists of PN-IDs such as "destination-list", which stores the potential PN-F participants and "destination-attained-list", which represents the PNs already attained by the JR message. As FMs receive the JR, they investigate whether the PN-ID of their neighbouring PN is mentioned in JR message destination-list. In case of positive response, the JR is forwarded to the FM of the neighbouring PN. In contrast, if the FM does not find the adjacent PN in the destination-list and the potential participant PNs are not accessible through other FMs of the same PN, a "Connectivity PN-F" can be formed with the adjacent PN in order to relay the PN-F information towards the potential PN-F members.

On the reception of JR message, the neighbouring PN's FM first removes its PN-ID from JR's destination-list and then put this information in the destination-attained-list. Moreover it also sets up backward pointers in PN-F routing table, towards the PN which sent the JR, as a next-hop to reach all the PNs mentioned in the destination-attained-list. As shown in Figure 2.6, PN1's FM (i.e. A) forwards the JR to PN2's FM (i.e. B), which sets the entries in its PN-F routing table (Figure 2.7) that PN1 is reachable through its FM B.

The above presented mechanisms are repeated at each following PN until all the PNs mentioned in the JR destination-list are reached. Finally, on the reception of JR if the PN finds that the JR's destination-list is empty, it sends a Joint-Request-Ack (JRA) message (by replacing the entries of destination-attained-list with destination-list) backwards to the PN which forwarded the JR message. As in Figure 2.6, the JRA is initiated by PN4, which receives an empty destination-list. The mechanisms of setting backward pointers to the PNs declared in destination-attained-list and moving the PN-IDs from destination-list to destination-attained-list at every next PN are also repeated for JRA message until it reaches the PN-F creator, who triggered the PN-F formation. In this respect, PN4 initiates JRA message and sends to its neighbouring PNs i.e. PN3 and PN2. PN2 further forwards it only to PN1 and not to PN5, because it is not the member of established PN-F. Finally, JRA terminates at PN1 as it is the originator of PN-F (and it also receives an empty destination-list).

The exchange of JR and JRA messages facilitate the establishment of PN-F routing tables at the Federation Managers of PNs, which are participating in the PN-F. Figure 2.7 presents the PN-F routing table formed at PN2's FM after the exchange of JR and JRA messages. The table specifies end-to-end routes between PNs by going through the local node. The source PN is included in the table to guarantee access control, as not all source PNs are allowed to reach any other PN in the PN-F (subject to rules defined in the PN-F profile). FMs also exchange their PN-F routing table with the other nodes and other FMs in the PN. The "loop-free" mechanisms of PN-F topology updates are assured with the help of "sequence numbers" of JR and JRA messages (as in AODV routing protocol).

Dest. PN.	Src. PN	Next PN	Local-Node	Cost	Int
PN1	PN3	PN1	B	3	1
PN1	PN4	PN1	B	3	1
PN3	PN1	PN3	C	1	1
PN4	PN1	PN4	C	1	2
… … …					

Figure 2.7: PN-F Routing Table at PN2/Node C

b) Data Forwarding and PN-F Use

During the integrated PN-F topology discovery process, the entire participant PNs learns the routes not only towards the PN-F creator but also towards each other. These routes are stored in the PN-F routing table (as shown in Figure 2.7) and are leveraged to exchange, initially the PN-F profiles and then the PN-F participation profiles in order to form the PN-F. Once the PN-F is formed, the natural next step is to use the PN-F. The data packets destined to any other PN are first forwarded to the FMs, which further routes the data with the help of PN-F routing table. The profiles are stored at the FMs (the entry points of PNs), which are used to enforce

PN-F policies on the PN-F routing in order to ensure secure PN-F overlay concept. The profiles can also be backed up at other PN nodes to efficiently handle the dynamics of the Personal networks.

c) Integrated PN-F Topology Maintenance and Teardown

As long as the PN-F is in place, all the routes are persistently maintained with the help of periodic JR/JRA cycles. For inactive routes i.e. no data is traversing, the route time-out occurs and eventually it is deleted from the PN-F routing table. If a link break occurs while the route is active, the Route Maintenance (RM) message is sent to all the PN-F members to inform them of the unreachable destination PN(s). After receiving the RM message, if some PN desires a route, it can reinitiate PN-F topology discovery.

Moreover, PN-F can be teardown by the PN-F creator, who sends the Teardown-Request (TR) message to the all the PN-F participants. The participating PNs reply with Teardown-Request-Ack (TRA) message and meanwhile remove all the entries in PN-F routing tables. Finally, the PN-F creator also deletes its PN-F profiles to assure the full termination of PN-F.

2.5 Simulation Model

We implemented a Personal Ubiquitous Environment (PUE) (composed of multiple PNs and PN-F) with the proposed routing scheme in Ns-2.29 [35]. The main objective of our simulation study is to show the feasibility of our solution and to compare its performance with the existing MANET routing protocols.

2.5.1 Performance Metrics and Evaluation Model

The performance evaluation of ad-hoc routing protocols such as OLSR, AODV, HARP in an environment very similar to PNs, for instance small scaled scenarios, limited number of nodes with less coverage and very low mobility, is a part of previous works in IST MAGNET project. The lessons learnt from these simulations [20] motivated us to design a new routing protocol specifically adapted for personal ubiquitous environments.

It is the aim of our simulations to study the performance of PNRP for voice calls established in a Personal Network Federation using G.729 standard voice codec. G.729 experiences 20ms packetization delay with bit rate 8Kbps and "Mean Opinion Score (MOS)" of 3.65. We compared the performance of PNRP with the existing multi-hop routing protocols such as OLSR and AODV. Since, OLSR and AODV are not suited for personal environments and these protocols consider all the nodes in multiple PNs, as a flat network topology, therefore the performed simulations on OLSR and AODV, do not validate the functionality of personal environments. However, as the simulations are performed in a small-scale PN topology (only three PNs) with limited group mobility, we expect that PNRP should perform quite similar to flat routing protocols such as OLSR and AODV. The performance metrics which are evaluated are packet delivery fraction, average end-to-end delay and normalized routing load. The Packet Delivery Fraction (PDF) is defined as the number of successfully received data packets divided by the number of generated data packets. The end-to-end delay is the time instance t2 a data packet is received by the destination minus the time t1 the data packet is generated at the source. Finally, normalized routing load is defined as number of control messages generated divided by the number of successfully received data packets.

To the best of our knowledge, PNRP is a first step towards the development of routing protocols for personal environments; therefore we could not compare it with any existing protocols designed for similar applications. Moreover, we do not find it feasible to compare PNRP with existing hierarchical routing protocols such as SHARP, HARP or CDS, because of the significant differences in topology formation and maintenance, and routing mechanisms, such as user-centric formation, group mobility and on-demand profile assisted inter-cluster routing, as discussed in Section 2.2.

2.5.2 Simulation Scenario and Methodology

As shown in Figure 2.8, the simulation scenario consists of three Personal Networks (PNs) connected with each other forming a Personal Network Federation (PN-F). Each PN is formed by five nodes connected in multi-hop fashion. Every PN has at least one FM, which connects it to at least one neighbouring PN. The simulation model parameters employed in our study are summarised in the Table 2-1.

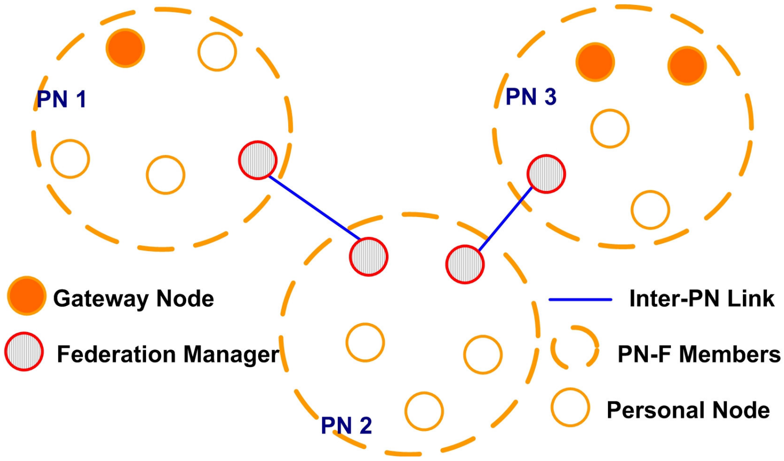


Figure 2.8: PNRP Simulation Scenario

For our simulation scenario, we have adopted the Group Mobility Model in a way that every PN remains connected with at least one of its neighbouring PNs with the help of it Federation Manager(s). The nodes move at a pedestrian speed (1-2 m/s) in reference to the PN's Master Personal Node (MPN) (i.e. a node where the PN owner is physically present and interacting). The Personal Network by definition is a group of nodes that belong to a single person and its environment, which remain intact and always move together. Therefore, the relative mobility among the nodes is very low.

Table 2-1: Simulation Model Parameters for PNRP

SIMULATION / SCENARIO		***MAC / ROUTING***	
Simulation Time	200s	MAC protocol	802.11 DCF
Simulation Area	600 x 600 m^2	Channel Capacity	2 Mbps
Number of PNs	3	Trans. Range	100m
Nodes in each PN	5	Traffic Type	VoIP (G.729)
Mobility Model	Group Mobility	Hello Interval	2s
Node Speed	1-2 m/s	PNtopo Interval	5s
Inter-PN VoIP Flows: 1, 2, 3, 4, 5, 6, 7			

2.6 Simulation Results and Analysis

We investigate the performance of PRNP and compare it with classical proactive and reactive routing protocols, OLSR and AODV respectively. Simulations were carried out with the variable number of inter-PN flows.

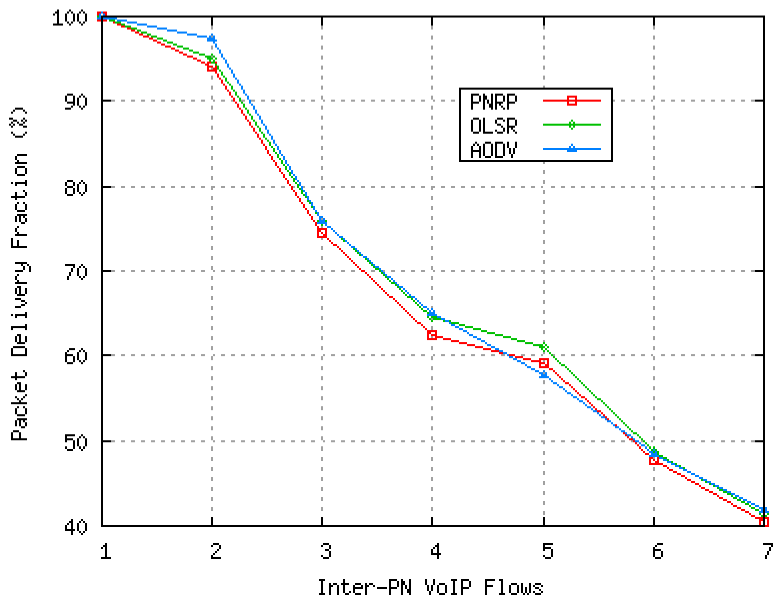


Figure 2.9: PDF versus Inter-PN VoIP Flows in PN-F

From Figure 2.9 and Figure 2.10, we clearly see that PNRP performs similar to OLSR and AODV routing protocols. In fact, the performance of reactive and proactive routing schemes differs significantly in high mobility scenario. However, since the simulations were carried out in a low-mobility environment (characteristic of PUE) with only three PNs, both OLSR and AODV perform almost alike in terms of packet delivery fraction and delay. Unlike OLSR and AODV, which consider the given scenario as a flat network of 15 nodes; PNRP divides the topology into three different networks belonging to three different owners. The multi-hop topology inside the PN is established on proactive basis at each node of the PN whereas the communication among the PNs is triggered by the exchange of PN-F profiles and the PN-F routing is established among the PNs on "on-demand" basis. Instead of the mix reactive and proactive strategies owed by PNRP, Figure 2.9 and Figure 2.10 does not present a considerable performance difference of PNRP with flat-topology routing such as OLSR and AODV in the given scenario.

Moreover, from Figure 2.10, we observe an unexpected performance gain in terms of end-to-end delay between the 4th and 6th Inter-PN Flows. This gain highlights the trade-off between the "number of hops" and the "delay". It was observed that the 5th flow incorporates only two-hops (on average) between the source and the destination pairs as compared to 4-hops (on average) for all the seven inter-PN flows. From these results, we learnt that the large number-of-hops through a single access technology in a PN results into a significant degradation in the overall application performance.

Moreover, as it can be noticed in Figure 2.10, the end-to-end delay for almost every inter-PN flow is much greater than the maximum acceptable delay requirement i.e. 150ms of typical VoIP applications; therefore it is clear that the VoIP flows shall experience very low MOS (Mean Opinion Score).

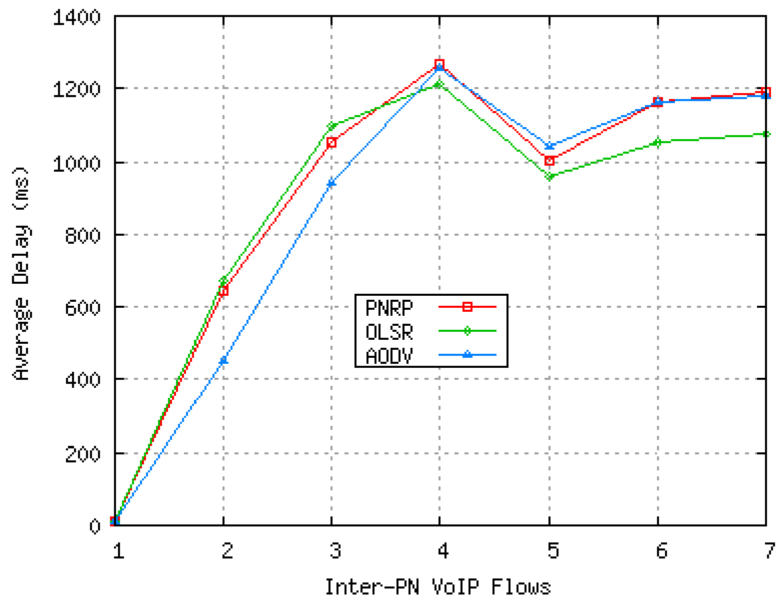


Figure 2.10: Average Delay versus Inter-PN VoIP Flows in PN-F

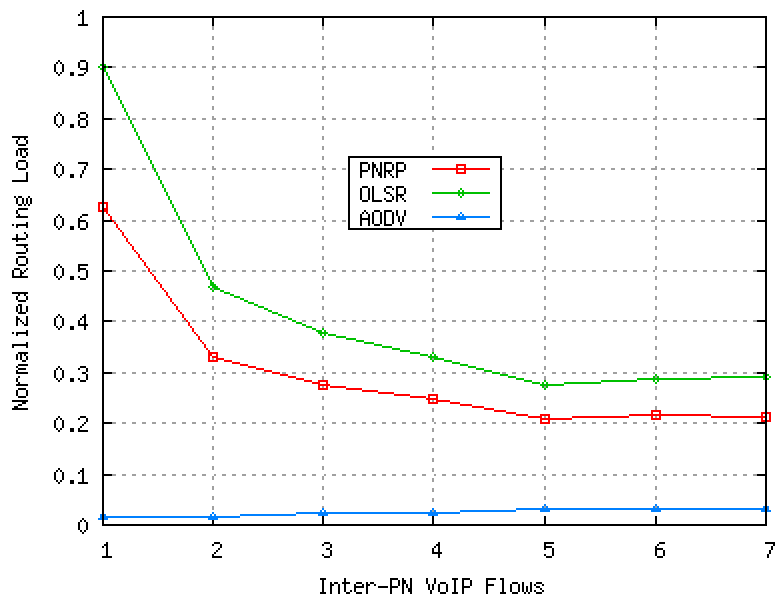


Figure 2.11: Normalized Routing Load versus Inter-PN VoIP Flows

Finally, looking next at Figure 2.11 as we expected, PNRP consistently generates less routing load (in terms of number of control messages) than OLSR by a significant margin, regardless of the number of inter-PN flows. This can be mainly attributed to PNRP's proactive routing mechanism within PN boundaries, whereas the reactive strategies are only attributed to establish inter-PN links on "on-demand" basis. In contrast, OLSR maintains the topology of complete network (i.e. all 15 nodes) irrespective of the ownership/privacy of nodes, which results in high routing load and large routing tables at each node. On the other hand, AODV generates very limited overhead as compared to PNRP and OLSR, which is attributed to its reactive route discovery mechanism.

2.7 Conclusions

2.7.1 Summary

This chapter exposed a variety of techniques deemed to be vital in realising the connectivity among the devices in the personal environments. The developed routing protocol i.e. PNRP, elaborates messages exchange in order to discover and establish routes among the personal nodes. The rules and policies for PN to PN communication, defined in the PN profiles, are used to enforce defined polices on the routing decisions. Since, PUE is composed of heterogeneous devices, PNRP is relied upon Integrated CONvergence (ICON) layer, which guarantees transparency of lower-layer heterogeneity from the routing and service layers.

In Section 2.1, a sufficiently concise introduction to the topic of routing in personal environments has been given. It was shown that the routing protocol is indeed an essential component to bridge the personal devices and PNs in the personal environments. It was also discussed that the rules and policies of cooperation, defined by PUE members, are to be accommodated in the routing layer architecture in order to guarantee privacy and trusty-worthy communication in PUEs.

In Section 2.2, a comprehensive study of related works is presented. It was highlighted that the concept of personal environments is relatively novel, and no efficient routing strategy adapted for personal networks had been developed so far. All previous works on routing protocols were targeted to MANETs and had no direct application to personal environments. In this section, the state of the art achievements of attaining cooperation between heterogeneous access networks is also presented. The inferences drawn from this analysis helped to develop Integrated CONvergence (ICON) mechanism, proposed in this chapter.

Section 2.3 constitutes an important milestone as it presents the ICON layer concept to offer transparency of the upper-layers (service, routing) from underlying wireless technologies and therefore provide seamless interoperability across heterogeneous access technologies at mobile nodes in PUEs. The higher level addressing mechanism for PUEs has also been defined as a part of ICON layer.

The role of Section 2.4 is twofold; first, our proposed routing protocol PNRP follows proactive approach towards establishing routes within the PN's personal nodes; second, PNRP pursue on-demand policy-based routing mechanism to support routing within PNs (forming PN-F). In case of PN-F routing, the cooperation profiles are created and exchanged among the potential members of the PN-F. The routing is performed taking into account the rules and regulations of cooperation, notified as a part of PN-F profiles after exhaustive consensus among PN-F members.

Section 2.5 and 2.6 presents the simulation model and results, respectively. The developed routing protocol is implemented in a personal environment setup and its performance is compared with MANET routing protocols. Our simulation results show that PNRP efficiently manages the user's personal environments i.e. PNs and PN-Fs. Moreover, it performs almost similar to traditional routing protocols such as OLSR and AODV, in terms of packet delivery ratio and delay under a scenario having three PNs, forming a PN-F, while consistently generating less routing load than any flat proactive routing protocol such as OLSR.

2.7.2 Contributions

This chapter opens the way to intelligent routing strategies for personal and ubiquitous environments. To this end, the research contributions can be summarized as follows:

1. The distinct characteristics of personal environments has been analyzed in the light of existing ad-hoc routing protocols; the directions have been given on adapting these protocols to work in personal environments.

2. An explicit converge addressing model has been proposed for PUEs which takes care of lower level heterogeneity and offers transparency for higher level components.

3. An explicit routing protocol has been developed which yields the formation of personal networks and their federations.

4. The above mentioned routing protocol is cross-layered with the personal profiles, in order to take rule-based and preferences-based routing decisions, when communicating with other PUE members.

2.7.3 Future Research

Numerous questions and problems remain open in the field of routing for personal environments. In this respect, the following topics are deemed to be worthwhile pursuing as future research:

1. <u>Multi-Interface Simulations.</u> As learnt during the PNRP simulation analysis, the large number-of-hops through a single access technology results in a significant degradation in the overall application performance. Since the maximum per-node throughput is bounded by the number of interfaces on each node [32], there is an obvious gain to analyse the performance of PNRP in multiple heterogeneous interfaces PN scenarios.

2. <u>Seamless Handover.</u> Moreover, for timely detection of the network service environments and to avoid additional delays during handover procedures generally due to layer treatments, we advocate the need to accommodate seamless fast handover mechanism such as IEEE 802.21 [34] in personal network routing design.

3. <u>Impact of PUE Size on Routing Performance.</u> As the number of PNs in a PUE increase, the time to converge on a certain group communication policy also increases exponentially. The simulation studies needs to be performed to analyse, how the PUE size impacts the efficiency of the PUE routing protocol and to identify certain scenarios, where convergence never takes place.

4. <u>Routing with Dynamic Policy Engine.</u> Routing in highly heterogeneous environments, assisted by profiles is a novel research theme [33]. The routing protocol need to consider how a certain dynamic policy engine assisted by PN-F profiles would be governing the access control and data forwarding job. To this end, profiling the routing in ad-hoc networks is an interesting domain, and should be explored further in the context of dynamic policy engines.

5. Socio-Technical Dimension of Cooperation. The personal environments encourage cooperation among the different users and their devices. However, it is social networking question, when and why the users intend cooperation? Why the user wants to extend his PUE in order to accommodate the other users, what he is interested in and more importantly, what he would be able to get after forming the PN-F with other users and what price the user may have to pay for these services. This socio-technical dimension, which may limit or support cooperation in PUEs, needs to be analysed with the help of sociology and economics theories.

Chapter 3

MULTI-HOP GATEWAY DISCOVERY

3.1 Introduction

In recent years, wireless networks have witnessed a tremendous upsurge. This is mainly attributed to an increasing demand of high data-rates anywhere and at anytime, which has been partially realized by a variety of commercially viable multimedia applications. Traditionally, most of the existing services are based on the single-hop infrastructure-based architecture. A network infrastructure is deployed by the service providers, with many base-stations or access-points connected to the core network. This traditional approach worked fine in the past but commences to exhibit some serious drawbacks, such as high cost, low scalability, limited throughput, and, last but not the least, high power consumption.

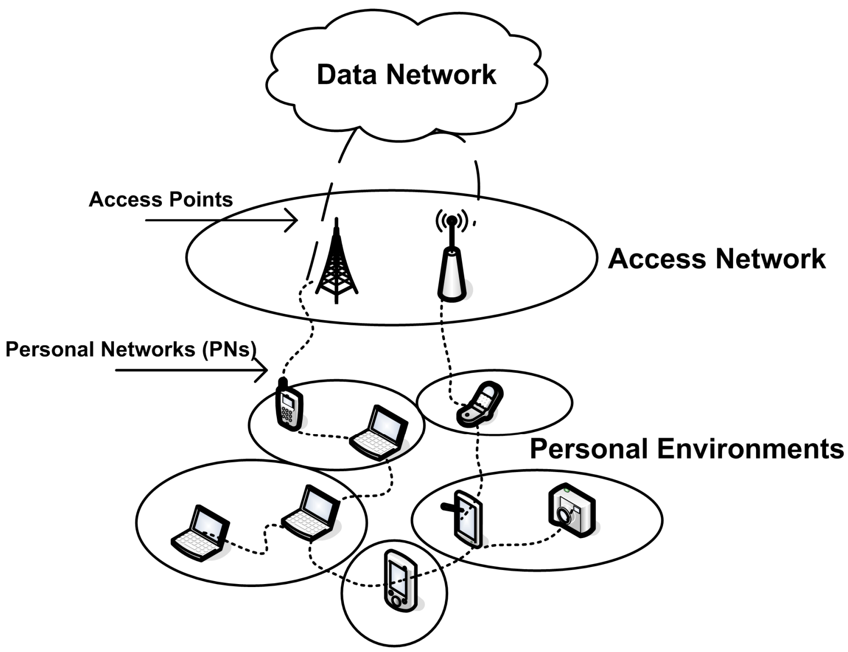


Figure 3.1: Multi-hop Personal Environments

An alternative are Mobile Ad-hoc Networks (MANETs), where packets are forwarded by other mobile stations to reach their destinations in a multi-hop fashion. Despite their low cost, fast deployment and remarkable self-organization capabilities, MANETs face several performance problems related to QoS degradation and scalability [30]. The research studies [36] have proved that in arbitrary ad-hoc network, in which every node communicates to another arbitrary node, the throughput capacity of the network approaches zero as the network becomes larger i.e. number of hops increase. This phenomenon suggests that MANETs are inherently non-scalable. Moreover, as the number of hops between the source and destination pair increases; high signalling overhead, problems with security and limited network control occur. In addition, business models for real world deployments of MANETs are fairly complicated, having prevented a commercially viable deployment to date.

Personal Ubiquitous Environments constitutes a special type of MANETs, which aims at fusing both of the infrastructure and ad-hoc wireless paradigms, as shown in Figure 3.1, in order to construct a single network with personalised flavour, having high flexibility and improved network performance [38]. PUEs reduce the network deployment cost and improve the throughput performance and power consumption of infrastructure-based networks. The PUE members (i.e. PNs) share networking and computational resources with each other, thus reducing the load at the operator's deployed infrastructure components. For instance, in Figure 3.1, certain PNs do no have one-hop (direct) connectivity with the access network, therefore, they discover other PNs (having connectivity) to connect them to the infrastructure network in multi-hop fashion. Moreover, through multi-hop personal networking, as in Figure 3.1, a constant hop-count can be attained towards the infrastructure connectivity, which finally improves the scalability and QoS performance of the entire system [37]. All the more, the infrastructure network integrated to PUEs also ensures considerable network control and security.

For the personal nodes in PUEs/PNs to access certain service provided by the network such as Internet, a gateway discovery mechanism is required in order for the personal nodes to connect to access network in single or multi-hop fashion as shown in Figure 3.2. This gateway discovery is required not only by the nodes within PN boundary but also by the nodes located within other PNs having no network connectivity to discover the network in multi-hop fashion passing through neighbouring PNs (already in established PUE). Here, a challenging problem is, as drawn in Figure 3.2, i.e. for the continuously moving multi-hop PNs to find and maintain a route towards the gateway/access-point, either directly or through other PNs in an efficient way. As compared to infrastructure-based networks such as 3G and traditional WLANs, where the base-station/access-point is always at a single-hop, the problem of gateway discovery in multi-hop personal networks is challenging and node mobility, power constraints and stringent QoS requirements makes it even more complex [38]. It is important to note that the gateway discovery solutions proposed in the context of Figure 3.2 can be seamlessly applied to the gateway discovery problems in hybrid or wireless mesh networks. In this chapter we first aim at discussing a range of existing gateway discovery schemes available in the literature, and highlight their performance trade-offs. This survey of existing approaches also motivated us to design a novel adaptive distributed gateway discovery scheme for personal networks presented in this chapter.

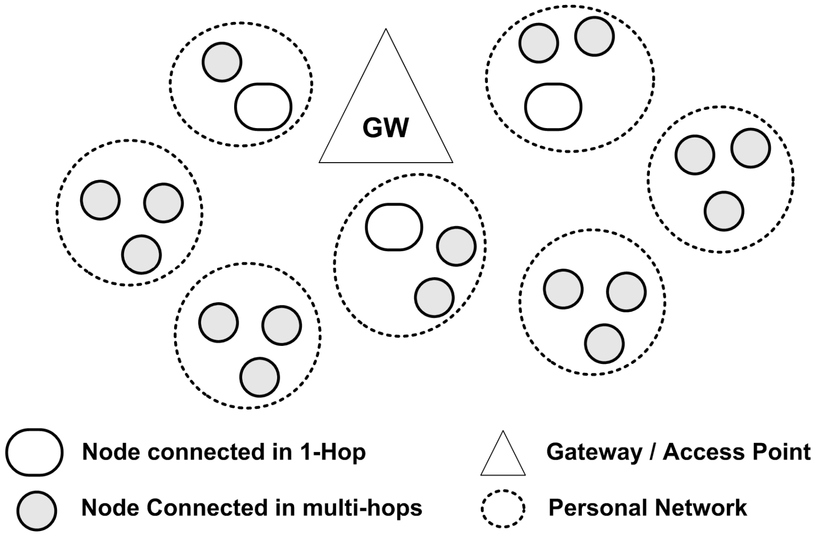


Figure 3.2: Multi-hop Gateway Discovery in Personal Environments

The intended contributions of this chapter are twofold. First, we describe and pragmatically compare the operation of most well-known approaches towards gateway discovery. Second, and the most important, we present a novel adaptive gateway discovery scheme called ADD (Adaptive Distributed gateway Discovery) for multi-hop personal networks and environments to discover routes towards the network (i.e. access-point/base-station) in multi-hop fashion. In our algorithm, the adaptation of the scope of Gateway ADVertisement (GWADV) messages, sent by the access-points/gateway is done in a fully distributed manner. To the best of our knowledge, this scheme is a first step towards the distributed adaptation of gateway discovery in a multi-hop personal network. Additionally, the presented algorithm can be directly applied to gateway discovery in Hybrid Wireless Networks (HWNs) and Wireless Mesh Networks (WMNs) [12]. Both HWN and WMN support the principle of integrating mobile multi-hop ad-hoc network with the infrastructure components such as Internet gateways (therefore called hybrid or mesh).

This chapter is structured as follows. As first and second, the problem of gateway discovery in personal environments is formulated and state of the art achievements related to gateway discovery in hybrid multi-hop networks are presented. Emphasis is put on comparing the adaptive and non-adaptive discovery schemes, which motivates the need of distributed adaptive algorithms. Third, the Adaptive Distributed gateway Discovery (ADD) is presented, which adapts the scope of gateway advertisement messages in a totally distributed manner. Fourth, the analytical model of ADD is presented and compared with the other existing schemes. The proposed gateway discovery algorithm is simulated and performance outcomes are reported under fifth and sixth. Finally, chapter specific conclusions are drawn, contributions are listed, and the most important results summarised.

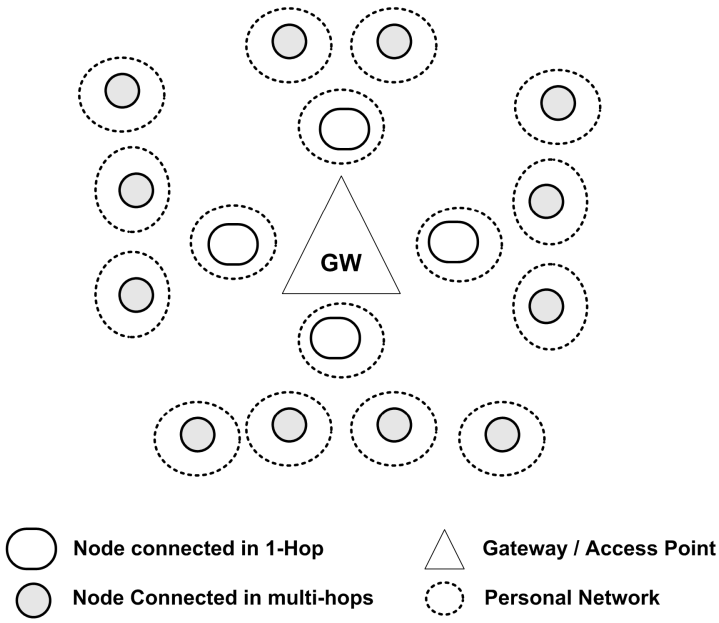


Figure 3.3: Single-node PNs - Multi-hop Gateway Discovery

3.2 Problem Formulation

Consider that all PNs in a PUE are composed of only one personal node, as shown in Figure 3.3. Moreover, let's assume that one of the PN intends to access the Internet. If this PN does not have one-hop connectivity with Wi-Fi Access Point (Gateway) (offering Internet service), it would have to discover the network through neighbouring PNs. In this respect, the gateway (AP) is discovered in multi-hop fashion, passing through other PNs. If we closely analyze this problem, it is analogous to the problem of gateway discovery in hybrid or mesh networks. Therefore, in this chapter we aim at discussing the problem of gateway discovery in PUE (assuming each PN has only one personal node, as highlighted in Figure 3.3) as the problem of gateway discovery in hybrid networks. This latter argument also sounds reasonable as it permits us to compare our proposed algorithm with the existing algorithms designed for hybrid/mesh networks.

3.3 Motivation and Related Works

The problem of gateway discovery in multi-hop network has already been known for some years; and a sufficient number of algorithms have been proposed. This problem is mostly targeted from Hybrid Wireless Network (HWN) perspective, where the deployed gateway offers the Internet connectivity to all the nodes in the ad-hoc network (in multi-hop fashion). With the emergence of Wireless Mesh Networks (WMNs), these algorithms again discovered their life and certain level of improvements have been proposed. Therefore, all the state of the art achievements consider HWN or WMN scenarios; however, these algorithms are directly applicable to personal networks. To this end, we present the gateway discovery algorithm proposed in the literature, as a part of our related works and further motivation towards developing an efficient algorithm for personal environments.

There is a significant effort going on to standardize mesh network protocols for different wireless access technologies. Several standardization bodies are actively working to define specifications for wireless mesh networking, targeting different types of networks. IEEE 802.11s Task Group (TG) defines a default protocol entitled Hybrid Wireless Mesh Protocol (HWMP) [48] which enables the Mesh Portal (MPP)/gateway (i.e. 802.11-based access-point connected to the Infrastructure network) to periodically broadcast its presence to other mesh access-points. In contrast, IEEE 802.16j TG is created for Mobile Multihop Relay (MMR) to study the possibility of supporting mobile stations through using multi-hop relaying techniques [12]. However, multi-hop connectivity of mobile nodes to the access-point/router is out-of-scope of the above mentioned standardization activities and as yet only active in the research domain.

Gateway discovery is one of the major components in order to realize multi-hop personal environments. Gateways are generally the specialized nodes, which lie in the multi-hop network and also have connectivity with the fixed network, such as Internet. With the help of gateway discovery mechanisms, nodes in the personal environments discover the route towards the gateway for different reasons, for instance, to communicate with a node in the fixed network or to access the Internet or Intranet.

In the existing literature, different proposals for gateway discovery have used either reactive or proactive mechanisms [38]. In proactive approaches, the gateway periodically sends the Gateway Advertisements (GWADV) messages, which are flooded throughout the entire multi-hop network. On the other hand, in reactive approaches, the nodes which require connectivity to the gateway broadcast the Gateway Solicitation (GWSOL) messages. These solicitation messages are responded by the gateways.

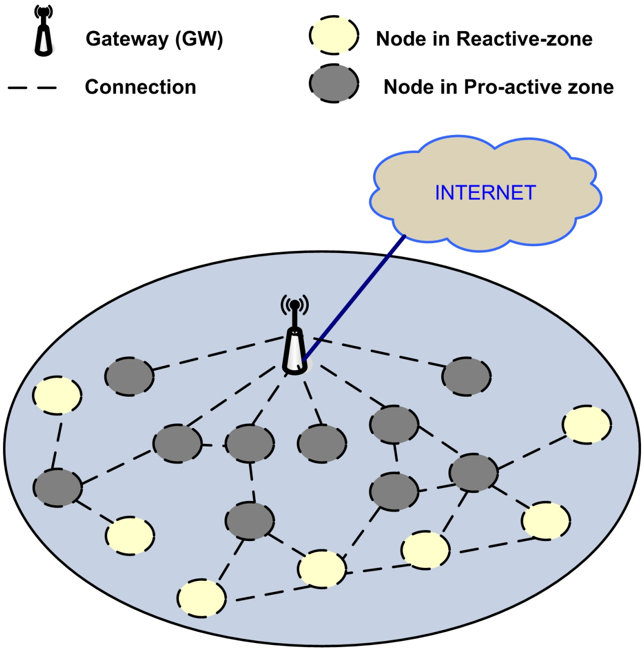


Figure 3.4: Hybrid Gateway Discovery in Hybrid Networks

In the recent studies, hybrid schemes have also been proposed. In hybrid gateway discovery, part of the nodes in ad-hoc network discovers the gateway proactively, whereas the rest do it reactively [39]. As shown in Figure 3.4, all the nodes which are located in two hops (i.e. TTL=2) of the gateways periodically receive the GWADV from the gateway whereas the other nodes reactively discover the gateway. Although, in most of the cases, a hybrid scheme outperforms the reactive and proactive mechanisms [41]; the definition of a hybrid scheme is quite vague i.e. defining the optimised TTL value. Therefore, the hybrid scheme should incorporate a certain level of adaptation in order to dynamically respond to the network changes [42]. Moreover, in a multi-hop personal environment, the overhead to maintain the routes towards the gateway is much more expensive than initially discovering the route [41]. To this end, an adaptive gateway discovery is a simple but powerful concept, which pledges to offer an efficient and cost-effective gateway discovery and route maintenance scheme.

In [41], the gateway is initially discovered reactively, furthermore for route maintenance the scope of the gateway advertisements i.e. TTL, is adapted according to the active sources in the network. By simply looking at the IP header of the data packets, the gateway keeps track of the number of hops at which each of its active sources is located. The gateway adaptively selects the

TTL value such that all the active sources receive the periodic advertisements from the gateway. This latter approach is referred as Maximum Source Coverage (MSC).

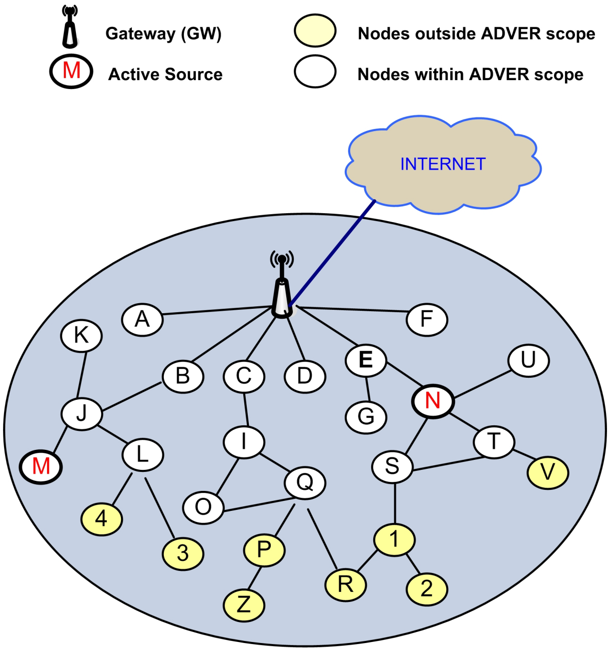


Figure 3.5: Maximum Source Coverage (MSC) Scheme - Adaptive GW Discovery

Figure 3.5 presents a hybrid networking scenario with Maximum Source Coverage (MSC) scheme for gateway discovery. Here, nodes M and N are data sources which are active and sending data to some node in the fixed network (Internet). Initially, the active sources reactively discover the routes towards the gateway and initiate the data transfer. By analyzing the data packet, the gateway keeps track of the number of hops each of these data sources are far from the gateway, for instance, in this example M is at 3 hops and N is at 2 hops. As shown in Figure 3.5, since source M is farthest away from the gateway i.e. 3 hops, the gateway sets TTL=3 for GWADV in order to cover all the active sources. Now, in spite of sending periodic advertisements to all the nodes in the network, the gateway only covers the active sources which are located within 3-hop radius.

Maximum Source Coverage (MSC) may suffer from suboptimal performance in certain networking scenarios such as when a small number of sources are at a large number of hops from the gateway. The worst case is that, only one of these sources is at a very large distance. In that case, in spite of generating excessive overhead to cover that source it may be more cost-effective not to expand the advertisement area and let that source find the gateway on its own.

In [40], the authors proposed to send gateway advertisements, only upon the detection of a change in topology. In [42], the authors present a similar approach as [41] in which TTL is calculated as an average of the number of hops the active sources are away from the gateway. In addition, they propose to start with a full-proactive approach, then move to adaptive TTL and during the network life, if the number of sources drop less than three, then full-proactive approach is triggered. Furthermore, they also propose to shorten the gateway advertisement interval (i.e. from 15s to 10s), if a gateway finds that the average number of hops (per source) is greater than eight. However, the static settings of their approach are widely unjustifiable.

In all the adaptive gateway discovery schemes presented in the literature, the gateway stores the information of active connections i.e. the address of data sources and number of hops, these sources are away from the gateway. To this end, the adaptation is done centrally at the gateway. In a more dynamic network such as PUE, where the network conditions change drastically, the central adaptation may result into far from optimal performance. It is quite possible that one part of the network has considerably large number of active sources than the other. Therefore, one adaptive TTL value may be useful for a certain sub-network but not for the whole network. Inspired by "think-global and act-local" principle, distributed adaptation should be considered, where the decisions are taken locally and in a totally independent fashion, according to the local-view of the network with the objective of achieving global performance.

3.4 Adaptive Distributed gateway Discovery (ADD)

Adaptive Distributed gateway Discovery (ADD) algorithm is a fully distributed approach towards gateway discovery in multi-hop networks. This algorithm is inspired by a hypothesis that the gateway advertisements should only be targeted to those nodes, which are looking for the gateway (such as active data sources); and other nodes should not be hampered with the periodic gateway advertisements. However, unlike other adaptive discovery mechanisms where the adaptation is performed centrally at the gateway and a single TTL value is used for the whole network, we advocate a totally distributed approach in our ADD scheme. In addition to the adaptive support of gateways, ADD also involves the participation of common nodes (called intermediate nodes) which are used as relays to forward the data packets from the source towards the gateway, for an adaptive gateway discovery. In other words, intermediate nodes act as multicast group members in order to forward the gateway advertisements only to the active sources in a multicast fashion. Therefore, the TTL value for GWADV is adapted at each hop in the network towards the active data source in a distributed manner, in order to cover all the active data sources with minimum annoyance for the other nodes in the multi-hop network.

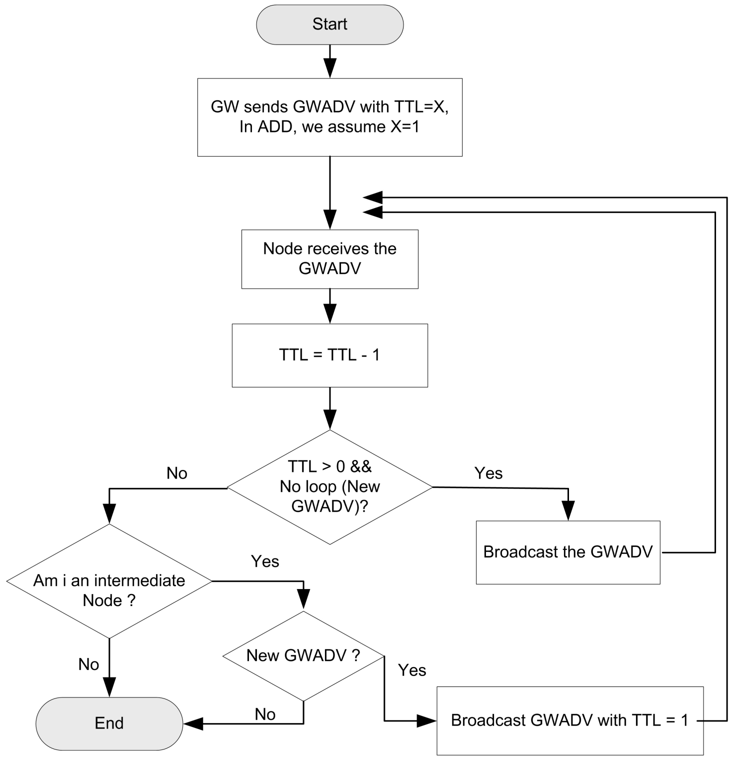


Figure 3.6: ADD Flow Chart

In ADD algorithm, initially, the potential source node reactively discovers the gateway. Once the route towards the gateway is known, the source node starts sending the data packets. By simply looking at the IP header of the data packets, the gateway keeps track of the number of hops at which each of its active sources is located. Based on this information, a source_table is constructed at the gateway. Apart from this, each intermediate node between the source and the gateway also captures the following information from the IP header of the data packet: the number of hops the source is away from the intermediate node and the source address. With the help of this information, the corresponding source node is marked as "active" in the routing table of the intermediate node. As a result of data packet analysis, those nodes, which are relaying the data packets learn that they are intermediate nodes for some given source in the network. This information is further leveraged in the gateway rediscovery and route maintenance scheme.

During the periodic gateway advertisement, initially the gateways sends the GWADV message with TTL=1. Then, on the reception of the GWADV message, each node verifies whether it is an intermediate node. If the node finds that it is already relaying data of an active source towards the gateway, it learns that it is an intermediate node. In case if it is an intermediate node, it forwards the GWADV message further with TTL=1, otherwise it does nothing. Following this procedure, all the intermediate nodes broadcast the GWADV message. This distributed gateway discovery adaptation ensures that all the nodes (active sources) which are actively sending data towards the gateway and are actually willing to maintain the route towards the gateway, receives the GWADV message, traversing hop-by-hop through all the intermediate nodes. Other nodes in the network, which are not interested in knowing the route towards the gateway, are not hindered with GWADV messages; therefore the control overhead is significantly decreased. The step by step working of ADD gateway advertisement mechanism is presented in Figure 3.6. This per hop distributed adaptation for gateway discovery and route maintenance is the essence of our proposed scheme.

It is a known fact that overhead generated by unicast in wireless networks of type CSMA/CA is almost same as the overhead of broadcast with TTL=1. Therefore, the intermediate nodes in ADD broadcast GWADV message with TTL=1 rather than unicast it towards the active source. Therefore, all the one-hop neighbours of the intermediate nodes (either active sources or not) receives the advertisement messages. This later results into the formation of an active region comprises of all the nodes between the gateway and the active source. We formally define an active region as a logical sub-network which has at least one active source, and where all the nodes know the route towards the gateway. Apparently, the GWADV messages received by the nodes in an active region, which are neither active source nor intermediate node, seems "excessive overhead" because these nodes are not interested in localizing the gateways. However, in case of high mobility, these nodes may help the active sources in order to adapt to the continuously changing network topology. As the active source moves, the intermediate nodes also change which eventually results into the movement of the active region. To this end, an active source always remains intact with the active region, and the active region adapts itself according to the movement of the active source. During the dynamic changes in the network, if an active source looses a valid route to the gateway, it can query any of the active region nodes to learn an updated route towards the gateway. This characteristic of ADD helps the active sources to quickly learn the updated route towards the gateway in a dynamic and mobile multi-hop network, without generating an excessive overhead.

Adaptive Distributed gateway Discovery (ADD) scheme is further explained with the help of rectangular lattice as shown in Figure 3.7. We assume that the nodes are uniformly distributed in a rectangular lattice covering a certain area. Each vertex of the lattice is a possible location for a node, however only one node can be at a concrete vertex. The node in the middle of the rectangular lattice represents the gateway, whereas "black" nodes represent the active sources and "white" nodes are the intermediate nodes for the given active sources. The established (active) routes between the gateway and the active sources are shown in "solid" lines. These routes are established initially, with the help of reactive gateway discovery. Once the data flow is established, the data packets are analysed and intermediate nodes are marked. For the gateway rediscovery and route maintenance process, the gateway broadcasts the GWADV within its one-hop neighbours. Furthermore, only the intermediate nodes broadcast the GWADV within its own one-hop neighbourhood. By doing so, not only all the active sources receive the GWADV message but also the active regions are formed. In the lattice shown in Figure 3.7, the shaded regions represent the active regions formed by the intermediate nodes between the active sources and the gateway. The concept of active region introduced in ADD scheme can be very useful in case of high mobility, network partitioning and for load balancing in multi-hop hybrid networks (such as personal environments).

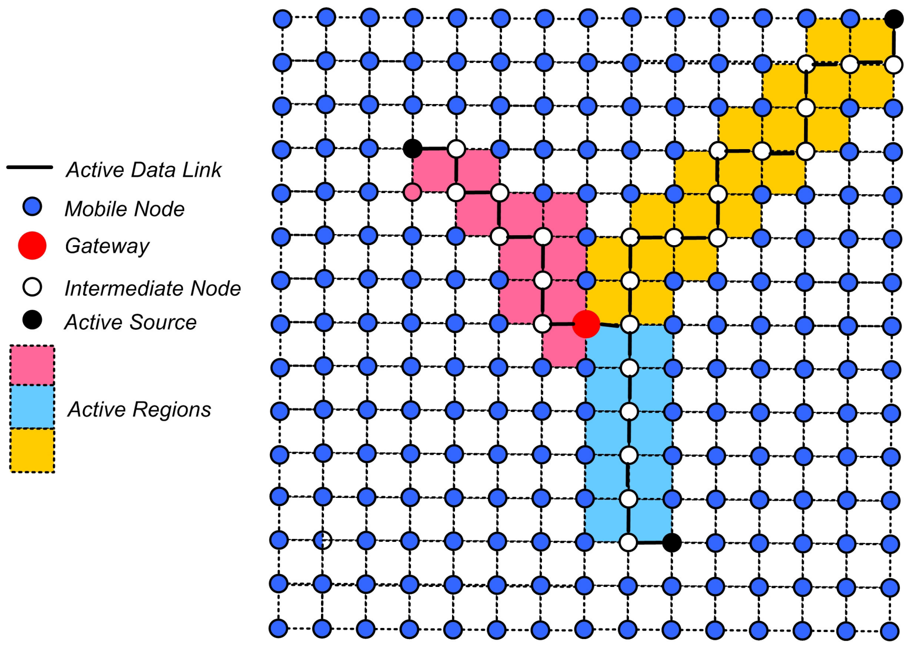


Figure 3.7: Concept of Active Regions - ADD Scheme

3.5 Analytical Model

In this section, we devise an analytical model for the proposed gateway discovery scheme and compare it with other existing algorithms, using a rectangular lattice shown in Figure 3.7. The nodes are placed in the d^{th} centric ring centred on the node *n* (i.e. gateway), where *d* is the distance in number-of-hops from *n*. Since in the rectangular lattice, each node in the rectangular lattice has 4 neighbours, the total number of nodes N_i including *n* at a distance of *d* hops from *n* is given by (1) [41].

$$N_i\,(d) = 1 + \sum_{j=1}^{d} 4_j = 1 + 2d\,(d + 1) \qquad (1)$$

Similarly, in a hybrid gateway scheme, given a broadcast GWADV (Gateway Advertisement) message with time to live (TTL) equal to *d*, the total number of nodes receiving the GWADV message i.e. N_r can also be represented by equation (1).

Moreover, the total number of nodes forwarding the GWADV message i.e. N_f in hybrid gateway discovery is given by equation (2).

$$N_f\,(d) = 1 + \sum_{j=1}^{d-1} 4_j = 1 + 2d\,(d - 1) \qquad (2)$$

Furthermore, the total number of GWADV messages generated at a time instance *t* i.e. Ω_t generated in hybrid scheme with a given value of TTL = *d* can be calculated as (3). Note that equation (3) also includes the duplicated GWADV messages generated as a part of network advertisements sent by the gateway i.e. node *n*.

$$\Omega_t = 4\,N_f\,(d) \qquad (3)$$

As discussed earlier, apart from dynamic adaptation of TTL value i.e. *d*, the Maximum Source Coverage (MSC) scheme is exactly similar to hybrid gateway discovery scheme. Therefore equations (1), (2) and (3) can be directly applied to MSC with a given value of *d*, where *d* represents the distance of the farthest node from the node *n* i.e. gateway.

Now, we draw the analytical model of our proposed Adaptive Distributed gateway Discovery (ADD) algorithm. Since in ADD, only the intermediate nodes are permitted to broadcasts GWADV message, the total number of nodes receiving the GWADV message i.e. N_r can be calculated by equation (4) derived from equation (1).

$$N_r\,(d) = 4 + 3\,(d - 1) = 1 + 3d \qquad (4)$$

In the above equation (4), d represents the distance of the active-source in number of hops from the node *n*.

In contrast to hybrid schemes, the total number of nodes forwarding the GWADV message i.e. N_f in ADD is exactly equal to *d*. This latter is due to the fact that only the intermediate-nodes are allowed to forward the GWADV message. Therefore, the total number of generated GWADV messages i.e. Ω_t generated in ADD scheme with a given N_f (d) can be calculated by equation (3). The analytical evaluation drawn in equation (1) to (4) clearly demonstrates that the ADD scheme largely outperforms the hybrid and MSC algorithms, in terms of control overhead.

3.6 Simulation Model

In this section, we present the evaluation of our proposed Adaptive Distributed gateway Discovery (ADD) scheme and we compare it with the hybrid [39] and Maximum Source Coverage (MSC) [41] gateway discovery algorithms. For this evaluation, we conduct extensive simulation under a variety of 802.11-based multi-hop networking scenarios.

3.6.1 Performance Metrics and Evaluation Model

The performance evaluation of reactive, proactive, hybrid and adaptive gateway discovery schemes has been extensively simulated and evaluated in the past. The lessons learnt from these studies [38] [41] motivated us to design a novel adaptive gateway discovery scheme, where the adaptation is performed in a totally distributed and decentralized manner. In order to evaluate and assess the effectiveness of the different gateway discovery mechanisms compared to our ADD scheme, the performance metrics which have been evaluated are packet delivery fraction, average end-to-end delay, and normalized routing load. The Packet Delivery Fraction (PDF) is defined as the number of successfully received data packets divided by the number of generated data packets. The end-to-end delay is the time instance t2 a data packet is received by the destination minus the time t1 the data packet is generated at the source. Finally, normalized routing load is defined as number of control messages generated divided by the number of successfully received data packets.

To the best of our knowledge, ADD is a first step towards the distributed adaptation for gateway discovery in multi-hop wireless networks; therefore we could not compare it with any other distributed adaptation approach. To this end, we compare ADD with a hybrid gateway discovery scheme and with one centralized adaptation scheme such as Maximum Source Coverage (MSC), presented already in Section 3.3.

3.6.2 Simulation Scenarios and Methodology

It is difficult to capture the details of gateway discovery schemes in an analytical model, since the real-time behaviour of the multi-hop network can not be accurately quantified. For that reasons we evaluate and analyze the performance of ADD in the 802.11-based hybrid network, using the ns-2 simulator snapshot ns-2.29 [35]. We use locally modified and extended version of ad-hoc routing protocol AODV called AODV+ from Hamidian et al. [46], which implements the interconnection between a MANET and the Internet. AODV+ already provides the hybrid gateway discovery scheme. We further extend the AODV+ with our proposed adaptive distributed scheme i.e. ADD and a centralized adaptive gateway discovery scheme such as Maximum Source Coverage (MSC). The radio channel capacity for each mobile node is 2Mbps, using the IEEE 802.11b DCF MAC layer and a communication range of 250m. In addition, there are two gateway; located at the coordinates (100, 250) and (700, 250) respectively. In the hybrid and Maximum Source Coverage (MSC) approaches, both gateways use TTL=2 for network advertisements as it is recommended in [39]. A fixed node, which is the eventual destination node in the simulation scenarios, is connected directly to one of the gateways, whereas both the gateways are interconnected. All the fixed links have a bandwidth of 10Mbps.

For our simulated scenario, we use a random waypoint model by CMU [47]. During initial phase of simulation, the nodes are static for pause-time seconds. Then, they pick up a random destination inside the simulation area and start moving to the destination at a speed uniformly distributed between 0 and 10m/s (maximum speed). In the simulated scenarios, some mobile nodes are randomly selected as active sources, which communicate with the fixed node located across the Internet (i.e. gateway). The traffic under consideration is Constant Bit Rate (CBR) traffic. Each of these randomly selected CBR sources start sending data at a uniformly distributed time within the first 10 seconds of the simulation and lasts until the end of simulations (i.e. 300 secs). Each of the sources generates 512 bytes data packets at a rate of 5 packets per second (20Kbps). The simulation model parameters employed in our study are summarised in Table 3-1.

Table 3-1: Simulation Model Parameters for ADD

Simulation / Scenarios		**MAC / Traffic / Mesh-Router**	
Simulation Time	300s	MAC protocol	802.11 DCF
Simulation Area	800x500 / 1300x800	Channel	2 Mbps
Mobile Nodes	10 – 90	Trans. Range	250m
Traffic Sources	5 – 45	Traffic Type	CBR
Mobility Model	Random way	Traffic Rate	20 Kbps
Maximum Speed	10 m/s	GWADV Interval	5s
Pause Times: 0, 2, 15, 30, 60, 120, 240, 300			

3.7 Simulation Results and Analysis

The first set of simulations measure the performance of the scheme in terms of variable mobility patterns (i.e. changing pause-time). Seven different pause-times were used: 0, 15, 30, 60, 120, 240 and 300 seconds. A pause-time of 0 seconds corresponds to a continuous motion whereas a pause-time of 300 seconds corresponds to a static scenario. This behaviour is repeated several times for the whole duration of the simulation. The simulated scenario consists of 15 mobile nodes randomly distributed over an area of 800x500 m^2, out of which 5 nodes are randomly selected as active data sources.

The performance results for the first simulation set are shown in Figure 3.8. The simulation results show that our proposed approach is able to offer a Packet Delivery Fraction (PDF) as high as the other approaches with a much lower overhead than the hybrid and adaptive gateway discovery i.e. maximum source coverage approaches. Moreover, our approach experiences only a slightly higher delay as compared to the other more proactive approaches, as illustrated in Figure 3.8.

The high packet delivery fraction of hybrid and MSC is attributed to their proactive way of advertising the gateway information throughout the network. In contrast, ADD only serves the gateway information to the active sources i.e. nodes in communication with the gateway. From Figure 3.8, we can intuitively see that in terms of normalized load, ADD consistently generates very less overhead and outperforms the hybrid and MSC gateway discovery mechanisms. This more than two times gain compared to MSC and more than four times gain compared to Hybrid is mainly attributed to the distributed adaptation mechanism of ADD which permits to periodically inform only the active sources about the route towards the gateway. Predictably, load performance of hybrid, MSC and ADD schemes experience a steep improvement with increasing pause-time.

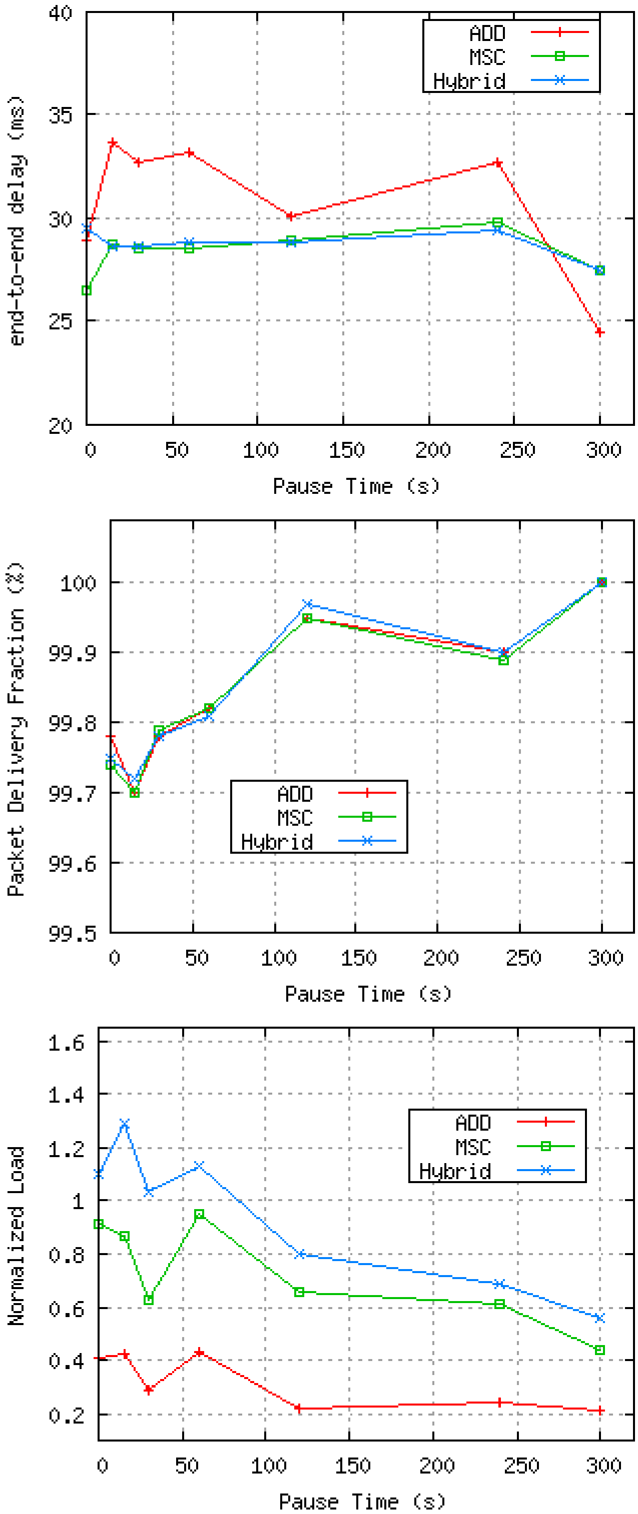


Figure 3.8: Performance of ADD under variable mobility-patterns (pause-times)

The high packet delivery fraction of hybrid and MSC is attributed to their proactive way of advertising the gateway information throughout the network. In contrast, ADD only serves the gateway information to the active sources i.e. nodes in communication with the gateway. From Figure 3.8, we can intuitively see that in terms of normalized load, ADD consistently generates very less overhead and outperforms the hybrid and MSC gateway discovery mechanisms. This more than two times gain compared to MSC and more than four times gain compared to Hybrid is mainly attributed to the distributed adaptation mechanism of ADD which permits to periodically inform only the active sources about the route towards the gateway. Predictably, load performance of hybrid, MSC and ADD schemes experience a steep improvement with increasing pause-time.

In contrast, since both of the hybrid and MSC schemes are inherently based on the proactive gateway advertisement principles, in case of high mobility, the nodes quickly learn the updated routes towards the gateway at the expense of high overhead. Whereas, ADD broadcasts the gateway advertisements only towards the active sources, thereby the learning of new routes is comparatively slower in case of high link breaks and low node-density (i.e. 15 nodes). However, this slight increase in delay can be reduced with the help of active regions concept introduced by ADD with considerable node-density. In case of high mobility with significant node-density (reasonable assumption in PUEs), the active sources learn routes towards the gateway by simply asking the neighbouring nodes within the active region. The low node-density (as studied in the first simulation set) influences the stability of the active regions in ADD.

In the second set of simulations, the scalability is measured in terms of increasing node-density with both static and variable traffic patterns (number of active sources). The simulation area is extended to 1300x800 m^2, while the number of mobile nodes in the given area is uniformly increased from 10 to 50 nodes. As a part of second simulation set, we simulated two different scenarios i.e. static and variable traffic patterns. In the static pattern, we randomly selected 5 active sources, which constantly send data during the entire simulation time. In the variable traffic pattern, in order to properly model increasing network size, the number of active sources are also increased proportionally with an increase in the number of nodes so that the average active nodes in the network is kept constant (i.e. 50% of the total nodes). The performance results for the second simulation set are shown in Figure 3.9 and Figure 3.10.

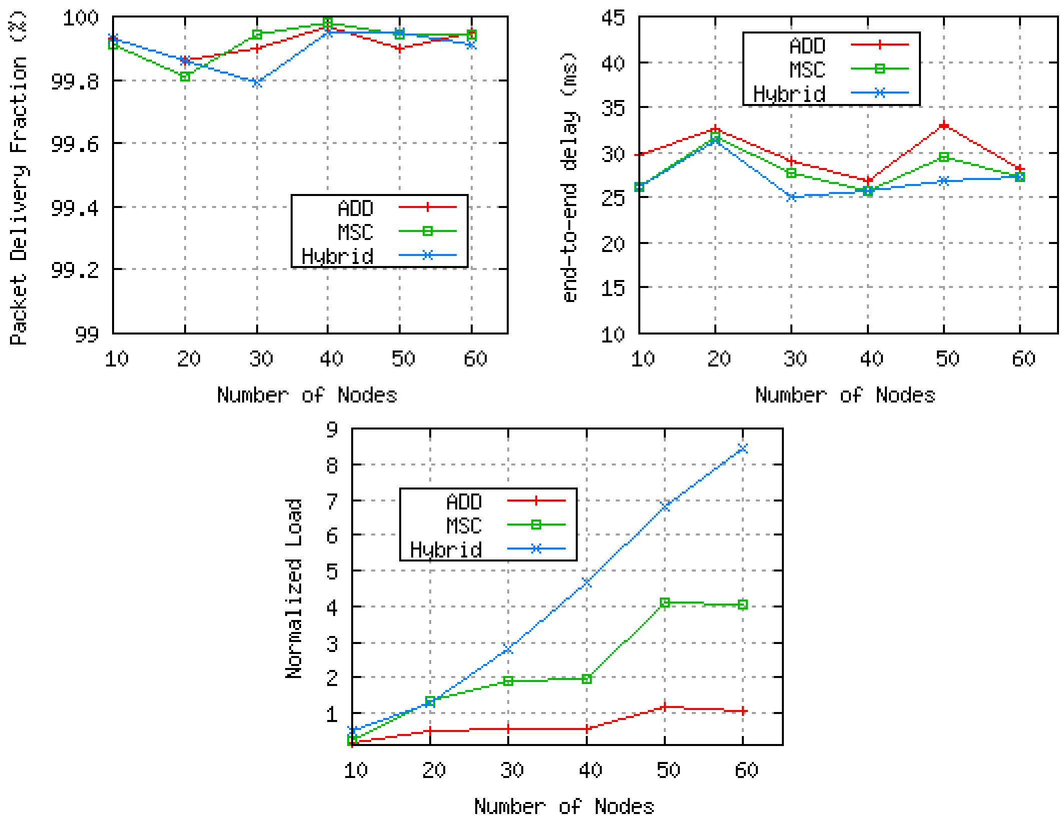


Figure 3.9: Scalability of ADD under increasing node-density with static traffic pattern

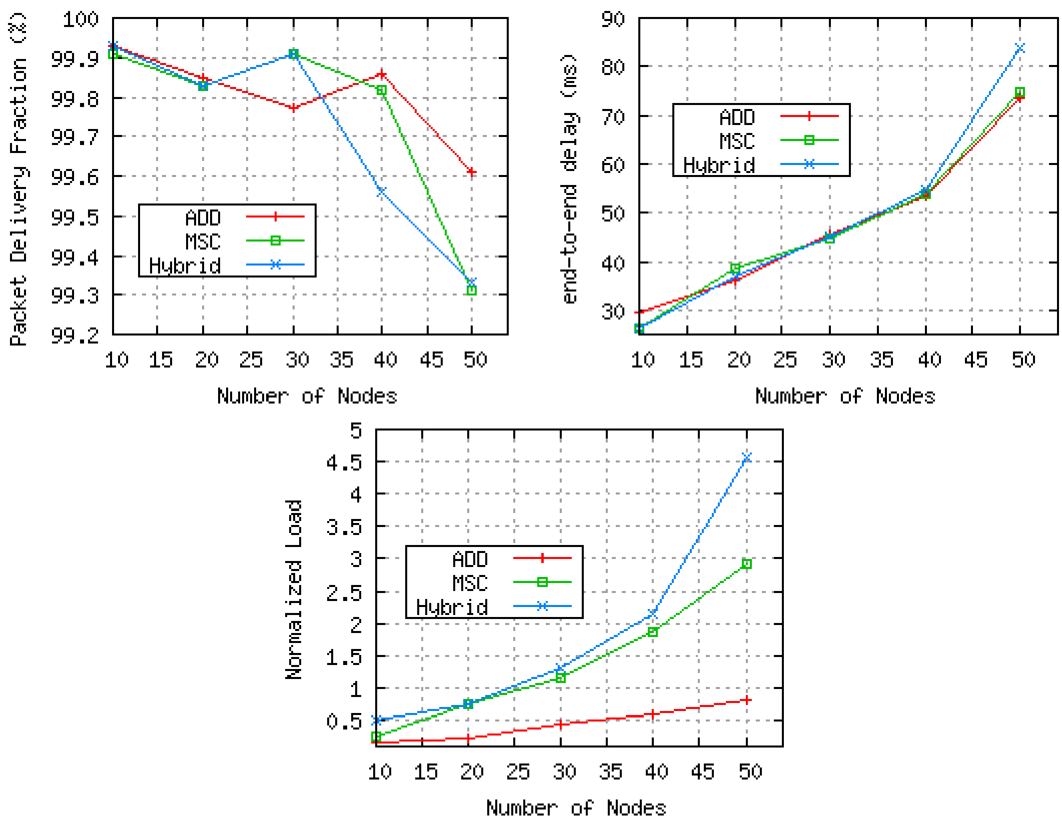


Figure 3.10: Scalability of ADD under increasing node-density with variable traffic pattern

As can be seen in Figure 3.9, the Packet Delivery Fraction (PDF) and end-to-end delay attains a level of stability for all the gateway discovery schemes as the node density increases with static traffic pattern (i.e. 5 active sources). The normalized routing loud is largely affected by the increasing node density which is quite predictable. Similar to the first case, ADD scheme incurs very low control overhead as compare to MSC and hybrid gateway discovery mechanisms. In contrast, analogous attributes for normalized load has been experienced with variable traffic pattern scenario as reported in Figure 3.10. However, the end-to-end delay is drastically increased for all the schemes with the increase in number of nodes with the eventual increase in number of active sources (50% of the total nodes). Similarly, PDF consistently decreases with more clients joining and actively sending data across the multi-hop network. In terms of delay and PDF, all the simulated gateway discovery approaches have almost the same results. With the careful analysis of the simulation results shown in Figure 3.10, we noticed that ADD depicts a minor gain in terms of PDF and delay, when there are 50 nodes in the network out of which 25 nodes are active sources. This later observation motivated us to do further simulation in even higher node-density multi-hop networking scenario with high mobility.

Finally, the third set of simulations assesses the performance of gateway discovery schemes by merging the first and second simulation sets i.e. high node-density and node-mobility. The mobility model is configured at pause-time of 2 seconds and maximum-speed of 10 m/sec. The node-density is further increased, as compared to second simulation set, and raised until 90 mobile nodes. Similar to the second scenario of preceding simulation set, half of the total simulated nodes are randomly selected as active data sources and 1300x800 m^2 terrain area is employed.

The simulation results reported in Figure 3.11 show considerable overall gain in terms of normalized load, delay and PDF for ADD scheme under high mobility and node-density. As it can be seen from the Figure, ADD predictably outperforms in normalized load. In contrast, before reaching a density of 45 nodes, ADD scheme offers a slightly low PDF and high delay as compared to other simulated schemes, however just after 45 nodes, there is a noticeable improvement. Starting from a node density of 45 at high-mobility, ADD outperforms MSC and Hybrid schemes in terms of delay and packet delivery fraction. This latter result validates our hypothesis that the concept of active regions introduced by ADD is very useful towards overall performance optimization in high mobility and high density multi-hop hybrid networking scenarios. As noticed, the active regions formed during distributed gateway discovery helps

ADD to also outperform in terms of delay and successful packet delivery, in case of significant mobility and network density scenarios.

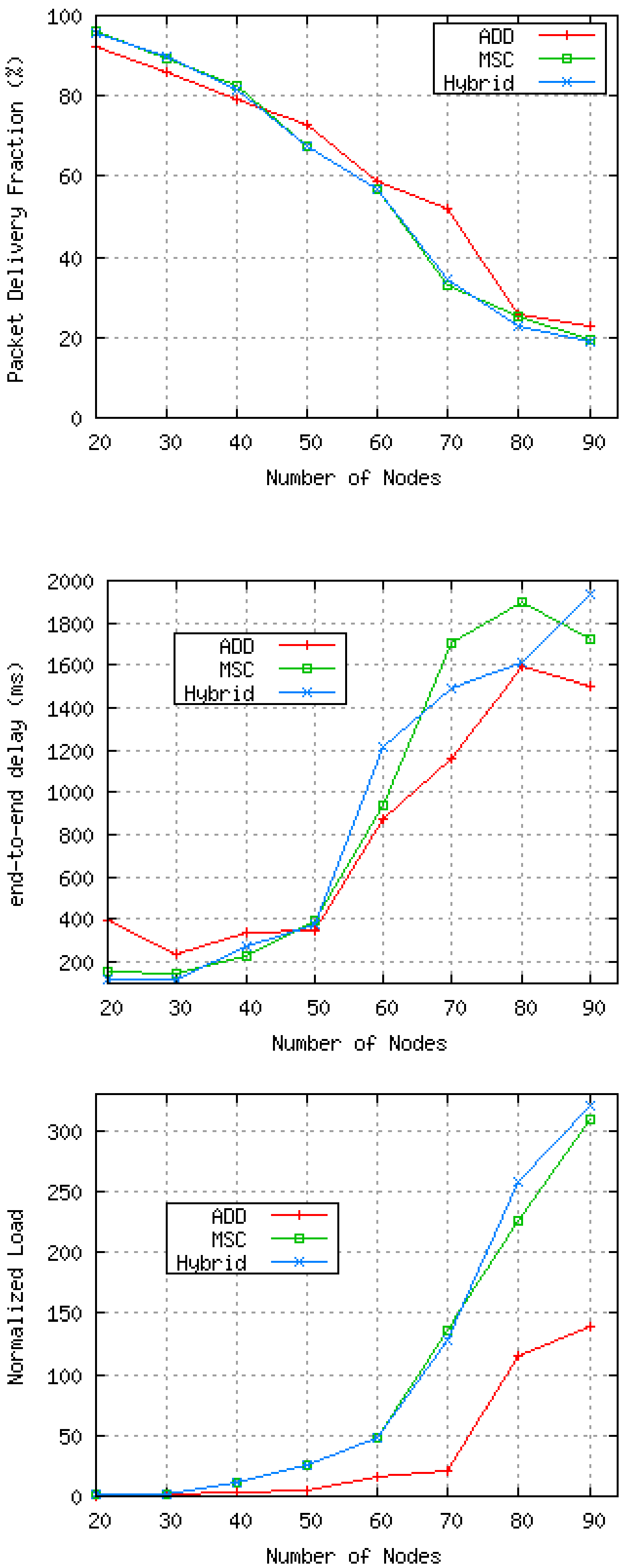


Figure 3.11: Performance of ADD under high mobility, variable traffic and increasing node density

3.8 Conclusion

3.8.1 Summary

Personal Ubiquitous Environments (PUEs) are emerging as a promising new type of multi-hop hybrid networks, benefiting from both fixed and ad-hoc networks technologies whilst alleviating some critical problems in these networks. This chapter exposed the problem of gateway discovery in personal networking environments, while discussing the existing mechanisms of gateway discovery in the hybrid networks ranging from reactive, proactive and hybrid discovery to adaptive discovery schemes. Furthermore, we present ADD (Adaptive Distributed gateway Discovery) mechanism which is, according to the best of our knowledge, the first attempt towards distributed adaptation for discovering gateways in multi-hop hybrid networks. Being intelligent and capable to cope up with the ever changing conditions of the network, our distributed adaptive gateway discovery schemes outperforms the existing gateway discovery mechanisms and provides an excellent platform reducing gateway re-discovery and route maintenance overhead, as validated by the simulation studies.

In Section 3.1, a sufficiently concise introduction to the topic of gateway discovery in multi-hop hybrid networks has been given. It was shown that an efficient gateway discovery algorithm is indeed an essential element to maintain good connectivity with the gateway at significantly low control overhead. It was also discussed that the problem of finding a multi-hop route towards the gateway is common in different type of networks such as Hybrid Wireless Network (HWN), Wireless Mesh Network (WMN) and Personal Ubiquitous Environment (PUE); therefore, the gateway discovery solutions proposed in any of these networks are directly applicable to other networks.

In Section 3.2, the problem of gateway discovery in PUEs is formulated in terms of gateway discovery in multi-hop hybrid networks. This problem formulation permits us to leverage the gateway discovery mechanism, proposed so far for mesh and hybrid networks, and design our own discovery algorithm for PUEs.

In Section 3.3, a comprehensive study of related works is presented. It was shown that the problem formulation per sé has already been known for some years; however, no satisfactory distributed adaptive gateway discovery algorithm had been developed so far. All previous algorithms were either non-adaptive or centralized adaptive (adaptation at the gateway), which yields high control overhead.

The role of Section 3.4 is twofold; first, Adaptive Distributed gateway Discovery (ADD) algorithm developed here was justified as quite efficient; adapting the scope of gateway advertisement messages in a distributed manner; second, the concept of active-regions was introduced, decreasing the gateway rediscovery delay in case of high mobility. The later is formed between the source node and the gateway, with the help of distributed adaptation capabilities of ADD algorithm.

Section 3.5, 3.6 and 3.7 constitutes major milestones as they present the analytical and simulation models, and simulation results, respectively. ADD algorithm was first analysed analytically and compared with hybrid and centralized adaptive (i.e. MSC) algorithms, where ADD exhibits significant gain in terms of control overhead. Then, all these gateway discovery schemes were implemented in a simulator settings and their performance was evaluated. Our results show that ADD is able to offer a Packet Delivery Fraction (PDF) comparable to the other schemes, but with 3 to 4 times lower control overhead. Moreover, in case of high mobility and reasonable node density scenario, ADD also exhibits gains in terms of delay and PDF.

3.8.2 Contributions

This chapter opens the way to efficient gateway discovery strategies for multi-hop hybrid networks, particularly for personal environments. To this end, the research contributions can be summarized as follows:

1. A comprehensive study of the state of art achievements for gateway discovery in hybrid multi-hop networks is presented. It has been advocated that a certain degree of adaptation is required in hybrid schemes, so that they adjust themselves according the network dynamics. Moreover, the motivation behind distributed adaptive strategies has been thoroughly discussed.

2. An explicit distributed and adaptive gateway discovery algorithm is proposed for personal environments, which outperforms the existing adaptive and non-adaptive algorithms; and this proposed algorithm is equally applicable to mesh and hybrid wireless networks.

3. The distinct characteristics of above mentioned gateway discovery algorithm has been analyzed, which forms active regions between the active data source and the gateway. This active region is quite useful in case of network mobility, as the mobile active source

can simply consult its neighbouring nodes (part of its active region) to discover the new route towards the gateway.

3.8.3 Future Works

Numerous questions and problems remain open in the field of gateway discovery for multi-hop hybrid networks. In this respect, the following topics are deemed to be worthwhile pursuing as future research:

1. Virtual Group Mobility. As learnt with the analysis of ADD, it forms active regions between the active source and the gateway. Therefore, when the source node moves, its active region also moves along. This special mobility pattern can be defined as virtual group mobility, as the nodes in the active region are changing but the virtual group (region) remains intact with the active source. It is thus desirable and interesting to do further simulation study under different mobility models and propose extensions to the existing group mobility models.

2. Stability of Active Regions. Similarly, the stability of active regions could be investigated from the random-way and group mobility models perspectives.

3. Hybrid Routing Protocol. So far, in this chapter we proposed the gateway discovery algorithm for multi-hop hybrid networks. A further study could incorporate this gateway discovery scheme into routing protocol for hybrid networks.

4. Network-oriented Policies. Gateway discovery needs to adapt to the policies defined by the network operator to attain the network-oriented performance objectives.

5. Gateway Selection. Since personal environments or mesh networks are composed of multiple gateways; it is thus desirable to develop an efficient and dynamic gateway selection scheme to choose among multiple gateways. This selection can be based on the available QoS [45], network policies and/or user preferences.

6. Selection of Relay Nodes. So far, every node connected to the gateway is considered as a potential candidate to relay the traffic of other nodes towards the gateway. A certain criteria needs to be defined, for instance, the connectivity-level (QoS) of the relay node, its willingness to relay the traffic etc.

Chapter 4

MOBILITY MANAGEMENT STRATEGIES

4.1 Introduction

In the last few decades, the proliferation of fixed and mobile access technologies and networks has provided a large choice to the network operators to offer a variety of services. These emerging access technologies and networks complement each other and offer different data rates and coverage that captures the needs and requirements of mobile users. For instance, the new generation of wireless networks such as Wi-Fi, WiMax, UWB etc offer high data rates at low cost but does not guaranty a global coverage and high mobility, whereas the Bluetooth technology offers lesser data rates compared to hotspot technologies, but saves on the power consumption required for wireless access. In contrast, the traditional and advanced cellular networks such as GSM/GPRS and UMTS provides wide area coverage and high mobility at high cost but does not offer high data rates.

To this end, the emergence of multi-functional mobile computing devices such as smart phones, wireless handhelds, palmtops etc and the proliferation of access network technologies such as Wi-Fi, Wi-Max, UMTS, UWB etc. assists to create ubiquitous environments around the user [49]. As a part of personal environment of the user, these technologies are desired to co-exist and cooperate with each other, in order to offer a ubiquitous experience to the user. In such personal environment, the concept of being always connected becomes always best connected [28] [56]. This refers to being not only connected, but also being connected in the best possible way dynamically exploiting all possible resources of the personal environment, in order to enhance user's quality of experience. This latter characteristic of personal environments imposes the need of an efficient mobility management mechanism, which enables global seamless roaming across heterogeneous networks and devices within user's environment.

Since Personal Ubiquitous Environment (PUE) is composed of diverse devices and networks, the user mobility in such environments imposes strong challenges on the heterogeneous components of PUE, to adapt according to the ever-changing state of the network. It is thereby essential that the user's PUE remains transparent from the handovers and location updates to ensure ubiquitous communication with uninterrupted services and minimum QoS degradation. This can only be achieved by efficient mobility management scheme.

In this chapter, we intend to address the design of PUE-led Mobility Management (PUE-MM) framework that leverages IP-based technologies to achieve global roaming among increasingly heterogeneous networks and devices of today. In order to make this roaming pervasive for the user, the efficient PUE mobility management framework is proposed. As a part of PUE-MM architecture, the first step is the addressing and the formation of PUE. For this purpose, we use ICON (Integrated CONvergence) and PNRP (Personal Network Routing Protocol) algorithms respectively, as presented Chapter 2. Furthermore, for location management and network selection, we propose solutions entitled Unified Location Management (ULM) and 3E (End to End Environment-aware) Network Selection. Moreover, IEEE's Media Independent Handover (MIH) standard [55]coupled with Mobile IPv6 [53] provides seamless handover support to our PUE-MM architecture.

This chapter is structured as follows. As first, the need for mobility management is highlighted and state of the art achievements related to IP connection management, seamless handover, location management and best network selection in heterogeneous wireless networks are presented. Second, the PUE Mobility Management architecture is presented, and its fundamental components are discussed in details. The proposed PUE-MM architecture is implemented in simulator settings, different real-time heterogeneous personal network scenarios are evaluated and performance results are reported under fifth and sixth. Finally, chapter specific conclusions are drawn, contributions are listed, and the most important results summarised.

4.2 Mobility Management Fundamentals and Related Works

Mobility Management is the process of keeping track of and locating users so that calls arriving for them can be directed to their current location [63]. In wireless data networks, mobility management involves changing the point of attachment, and hence the IP addresses, of a mobile host. A change in IP address gives rise to the challenges in maintaining an uninterrupted data flow while the mobile host is changing its address, minimizing loss of packets and network switching delay, identification of newer location and selection of best network (in case multiple networks are available) [62]. We discuss each of these fundamental components of mobility management in heterogeneous networks/environments, coupled with their state of the art achievements, in the following:

4.2.1 Connection Management

On changing the point of attachment, the mobile host acquires a new IP address. However, the Corresponding Node (CN) keeps on sending data to the old IP address until it is not notified. Connection Management mechanism informs the CN about the change occurred at the mobile host side and re-establishes the connection.

Connection management in homogeneous and heterogeneous networks has been comprehensively studied in the past. The connection management solutions are generally classified into three different categories: network layer solutions, link layer solutions and cross layer solutions [53]. Network layer solutions such as Mobile IP and its different flavours HMIP, HAWAII, CIP and IDMP, provide mobility features at the IP layer, without relying on underlying wireless technologies. Link layer solutions ensure seamless connection reestablishment when mobile host changes its position within the scope of an access router. Cross layer solutions aim at introducing some sort of intelligence at the IP layer such as signal strength reports, movement detection, and speed of mobile host. With the help of this useful link layer information, network layer mobility is improved.

Mobile IP (MIP)

Mobile IP is a standard mobility protocol for the global Internet. It is proposed to redirect the packets of the mobile host towards its current location and creates a feeling of an uninterrupted communication between the CN and the mobile host. In Mobile IP version 4, when a mobile host moves into a new subnet it receives unsolicited Agent Advertisements messages from the Foreign Agent (FA). On discovering that it is in foreign network, mobile host obtains a new Care-of-Address (CoA) from the FA. The mobile host registers the new CoA with its Home Agent (HA), which further updates its binding tables by associating the CoA of the mobile host with its permanent address. The packets sent by CN to a mobile host are first intercepted at HA, which further encapsulates them and tunnels them to the host's CoA. The packets reach the FA, which decapsulates the packets and forward them to the mobile host.

The MIPv4 protocol capabilities and definitions have been extended in MIP version 6 to enhance the support of IP mobility. The significant optimizations include route optimization (no triangular routing via HA), stateless address auto-configuration capability, co-located CoA and separation of mobility in micro and macro domains [53].

4.2.2 Seamless Handover

When mobile host hands over from one point of attachment to another, there is switching time involved which affects the performance of already established flows in terms of packet loss, delay and jitter. In order to make this handover experience seamless, intelligent triggers are required which notifies the possibility of handover, and makes the mobile host to prepare the handover before it really takes place.

Seamless handover solutions can be classified into various categories such has horizontal handover (between homogeneous networks), vertical handover (between heterogeneous networks), soft handover (make before break), hard handover (break before make), cross network handover (move from one network to another), cross device handover (between devices). The essence of most of the handover techniques proposed so far rely on intelligent cross layer information which can make higher-layer to take proactive handover decisions, therefore reducing the switching delay and packet drops. Several activities are also undergoing in standardization bodies and research projects to ensure fast handover among heterogeneous access technologies, just to name a few; DNA [64], Mipshop and Mobopts Working Groups (WG) in IETF are working on defining intelligent lower-layer triggers for fast handover, European projects such as BRAIN, MIND, AMBIENT, MAGNET Beyond, DAIDALOS are advocating Generic Link Layer (GLL) solutions for heterogeneous handovers [29], IEEE 802.11 and 802.16 propose intra-technology handover mechanisms under their different subgroups. The foremost of these efforts is IEEE 802.21 WG's Media Independent Handover (MIH) [55] function which aims at offering seamless handover across heterogeneous access networks by having strong collaboration with other task forces within in IEEE and other standardization bodies such IETF and 3GPP.

Media Independent Handover (MIH), IEEE 802.21

The IEEE 802.21 Working Group (WG) defines Media Independent Handover (MIH) in order to offer seamless handover across heterogeneous networks [34]. MIH defines a framework to support information exchange that aids mobility decisions, as well as a set of functional components to execute those decisions. MIH shields link-layer heterogeneity and provides a unified interface to upper-layer applications in order to support transparent service continuity. The handover scenarios considered in 802.21 WG include wired as well as wireless technologies, the complete IEEE 802 group technologies and 3GPP and 3GPP2 access network standards.

The MIH framework provides methods and procedures to gather useful information from the mobile terminal and the network infrastructure in order to facilitate handover between heterogeneous access networks. MIH provides network discovery procedures which help the mobile terminal to determine which networks are available in its current neighbourhood. Mobile terminal selects the most appropriate network with the help of the gathered information such as link type and quality, application class, network policy, user profiled and power constraints.

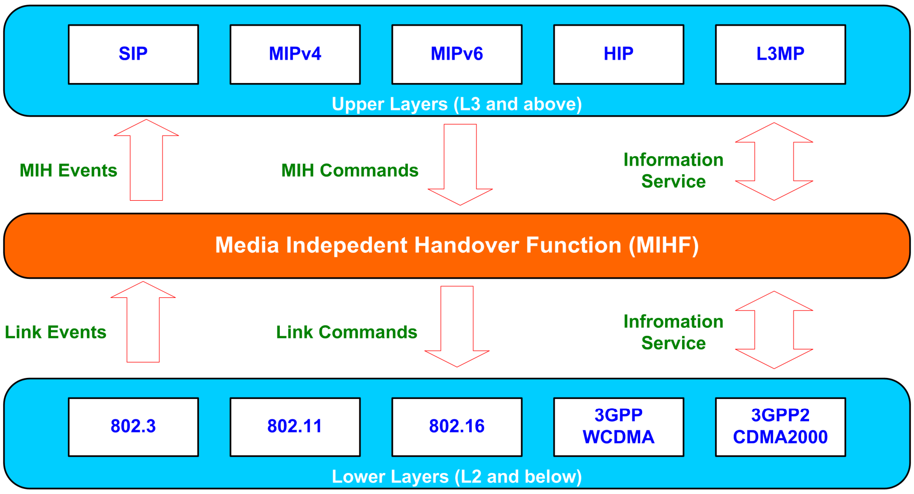


Figure 4.1: MIH Architecture and Functional Components

MIHF (Media Independent Handover Function) lies in the heart of MIH architecture and performs an intermediary or a unified interface between the lower-layer heterogeneous access networks (IEEE 802 group, 3GPP and 3GPP2 technologies) and higher-layer components, as shown in Figure 4.1. MIH provides generic access-technology independent primitives called Service Access Points (SAPs). SAPs are APIs (Application Programming Interfaces) through which the MIHF can communicate with the upper and lower layers entities. Definition of higher layer entities (L3 and above) is out of the scope of IEEE 802.21 standard; MIHF provides intelligent lower layer information to standardised upper layers components such as Session Initiation Protocol (SIP), Mobile IP (MIP) and Layer 3 Mobility Prediction (L3MP), in order to perform optimised handover and mobility management procedures.

The MIHF facilitates three services namely Media Independent Event Service (MIES), Media Independent Command Service (MICS) and Media Independent Information Service (MIIS), which are responsible for signalling state changes at lower layers, control by higher layers and provision of information regarding the neighbouring networks and their capabilities, respectively, as highlighted in Figure 4.1.

Media Independent Event Service (MIES): Media Independent Event Service (MIES) provides timely lower-layer events (triggers) to the upper layers in order to optimize the handover performance. The events can be local i.e. took place within a mobile client or remote i.e. sent by the network component. The event model works according to notification/subscription principle. Since events are advisory and not mandatory, registration to a specific event is needed for an entity to be notified whenever such event occurs. MIES may be broadly classified into two categories, link events and MIH events. Both link and MIH events typically traverse from a lower layer to higher layer. Link events are defined as events originate from event source entities below the MIH function and typically terminate at MIH function. Within the MIHF, link events may be further propagated, with or without additional processing, to upper layer entities that have registered for the specific event. Events that are propagated by the MIH to the upper layers are defined as MIH events. Some of the common events include, "Link Going Down", L2 Handover Imminent", "Link Parameters Change", etc. On the reception of certain event, the upper layer makes use of the command service to react to the change in the network state.

Media Independent Command Service (MICS): MICS refers to commands sent from the higher layers to the lower layers in the MIH framework. MIH commands are use to subscribe to certain information from the lower layers such as gathering information about the status of connected links, as well as execute higher layer mobility and connectivity decisions at the lower layers. Similar to MIH events, commands can also be local and remote. Analogous to MIES, MICS can also be divided into two categories i.e. MIH commands and link commands. Both of these types of command follow the same principle as explained for MIES. Some of the common commands include "MIH Poll", "MIH Scan", "MIH Configure", "MIH Switch", etc.

Media Independent Information Service (MIIS): Media Independent Information Service (MIIS) is used by a mobile node or a network entity to discover and obtain homogeneous and heterogeneous network information. The purpose of Information Service is to acquire a global view of the heterogeneous networks to facilitate seamless handover across those networks. For instance, when a mobile nodes is about to move out of the coverage of the current network, it queries the network (MIIS) about the available neighbouring networks in order to optimize the handover process. MIIS provides access to both static and dynamic information. The static information may include names and providers of the neighbouring networks. Examples of dynamic information include channel information, MAC address and security information. MIIS stores the information in a standardized format such as ASN.1 or XML. Common higher layer mechanism such as MIIS to offer information about the neighbouring networks of heterogeneous access technologies alleviates the need for specific access-dependent discovery method.

4.2.3 Location Management

On performing the handover, the moving mobile host updates its current location to the network so that the network can locate and deliver calls to it, at any time. This location management is performed at a central entity in the network.

Location management is one of the key challenges for global mobility management in all-IP heterogeneous wireless networks, which consist of keeping track of mobile user roaming across networks. Since a personal environment consist of heterogeneous devices capacitating access to different networks; each of these networks independently performs their own specific mobility management procedures. For instance, in cellular networks, HLR/VLR (Home Location Register / Visit Location Register) is updated in order to reflect the actual position of the user's device, whereas in wireless data networks using Mobile IP (MIP), the concept of home agents and foreign agents is governed. This totally independent and isolated approach for location management obstructs the way toward ubiquitous networking vision. The devices develop strong bonding with their particular networks and do not leverage the benefits of developing personal environments. Moreover, the existing mechanisms for location management [53] only tracks the location i.e. Point of Attachment (PoA) of the device and does not know anything about the other characteristic of the device including the networking and computational capabilities. In addition, with existing mechanisms the user needs to worry about the plethora of addresses, each of which associated with specific device/network of the receiver, for instance, cell-phone number for UMTS phone, SIP address for Wi-Fi phone etc. To this end, a unified location management mechanism should be defined for heterogeneous networks (environments).

4.2.4 Best Network Selection

Network selection mechanism in all-IP networks is an intrinsic component of the mobility management architecture. The best network is selected at two different times during the communication session: Initially, when the sender plans to reach the receiver and during their communication, and when the network conditions change (and handover occurs), for instance due to mobility. Since, the personal environments are composed of heterogeneous resources ranging from wireless access networks to multi-capability devices; in case of mobility, if the current network link goes down, which network to connect out of all available networks?; it is a difficult question to answer. In this course, best network selection algorithm compares the available networks and selects the best among all, in terms of different already defined quality parameters.

The problem of radio access network selection in heterogeneous environment has been considered as a part of seamless handover venture. In traditional cellular networks, the handover mechanism mainly focus on link quality measurements i.e. SNR (Signal to Noise Ratio), Error rate, RAN (Radio Access Network) load etc. These classic mechanisms are insufficient to meet the challenges of B3G and 4G networks. Thus, new techniques are needed to manage user mobility between different types of networks. The research community has refocused on the requirements of these heterogeneous networks to develop an efficient algorithm for handover and network selection, which accommodates the dynamics of B3G networks such as service type, monetary cost, network conditions, systems performance and mobile node conditions.

Towards this end, several research studies are available in the current literature. [54] motivates the need of policy based handover and network selection for the multi-connectivity mobile terminal. In [57], a mechanism of traffic classification for handover design between WLAN and CDMA networks is presented. POLIMAND in [65] exploits the Generic Link Layer (Layer 2.5) information; to design a policy based delay-aware handover mechanism. A dynamic policy-based mobile-initiated network interface selection mechanism is proposed in [59] that consider the traffic characteristics based policy to decide the best network. Moreover, they provide a dynamic framework that permits to create and modify interface selection policies.

Some efforts also leverage the economics knowledge to design a user-driven handover and network selection mechanism. Utility-based functions as in [58] [66] are employed to express the best network selection rating relationships by number of metrics. The user preferences, pricing schemes and network assisted QoS is quantitatively inserted in to the proposed metrics to calculate the equilibrium position for network and user gains. [72] proposes a terminal-initiated network selection strategy based on the consumer surplus for non real-time applications.

Inline with the vision of personalised ubiquitous environment, the context-based mechanisms have been very recently employed in heterogeneous access networks. These context-aware techniques use both static and dynamic context information regarding user devices, applications, preferences and location, network environment and offered QoS in handover and network selection decisions. [73] presents a context-aware vertical handover designed for future pervasive environments. They have outlined some intelligent rules/ policies which evaluate the dynamic and static context information to decide on the handover. ContextWare architecture has been proposed in EU project Ambient Networks [67], which provides a common framework for context awareness across all functions of Ambient Control Space. [68] provides a general handover framework that takes into account the network and the user context. The generic framework illustrates the mechanism of centralizing the context information into a common repository called context collection point, and illustrates the technique of compiling the context information and disseminating it towards the handover decision point for optimized handover and network selection.

Until very recently, the research efforts in the context-aware handover and network selection were only considering the context of the local terminal and the networks to which the terminal has direct access to. There is a very limited research literature on End-to-End context awareness for network selection and Handover (HO). Sun et al. in [69] has presented a policy based criteria for the best local and remote network selection. Their objective in end to end context awareness is to utilize the local context information in order to measure the end to end Network QoS (bandwidth, RTT, jitter) and User QoS (QoS perception, Terminal capability) parameters. They base their network selection and handover mechanism on the end-to-end QoS information collected from the source and destination nodes.

In the latest work as a part of MIRAI architecture [70] [71], the idea to centralize (i.e. "MIRAI Agent") the context information of caller and calle has been presented. Utilizing the centralized context information, the system in advance of communication, shows a caller and its calle, the applications that are available through the network they can get access to. For example, If User A wants to make a video call to User B. The MIRAI agent will inform the user A that the user B does not have the possibility to establish a video call, though voice call can be established. Therefore, the user A launches the voice call considering the context of the user B. Meanwhile, the context of both users is periodically updated at the MIRAI agent. If at some point in time, the User A finds that the User B can now establish a video call (i.e. the context has been changed) then the User A launches a video call. The underlined objective of MIRAI approach is to exploit the end to end context information in order to verify the application level compatibility between the caller and the calle.

In [60] Warabino et al. propose an end to end context based media selecting method for future Vehicle to Vehicle (V2V) communication. The method adopts an approach to select the most suitable medium from several types of media (e.g., ad-hoc, spot (WLAN) and cellular communication) based on the vehicle locations, available media and communication quality. In this approach, the source sends a request to the destination node to acquire its media profile (location, available networks, preferences etc) and selects the best network to communicate with the destination. The idea of [60] is based upon totally distributed context exchange, which can results in unreliability and high delay because of the considerable mobility in the end to end nodes. Moreover, their approach only considers the V2V communication which has significantly different challenges as compare to mobile communication environment.

In summary, existing network selection and handover solutions do not take the benefit of heterogeneous resources available in the user's personal environment to decide for the optimal end to end connection. They only consider the resources available at the terminal directly connected to the infrastructure network. Therefore the decision taken for the network selection is local (based on the terminal resources) and is not global (no consideration of the user's environment). Moreover, there are very limited works on end to end context consideration, which we deem essential for the accurate end to end connectivity decision. The existing end to end context mechanisms only utilize this information to achieve some defined goals like end to end QoS, application compatibility and V2V interface availability mapping. They do not consider the resources available in the neighbourhood; consequently the network selection and hand over decisions taken in this context are far from optimal.

Therefore, a need for a generic end to end environment-aware network selection algorithm is apparent that not only builds a pervasive and intelligent networking infrastructure, but also efficiently manages and utilizes the resources available in the terminal and equally in the neighbourhood.

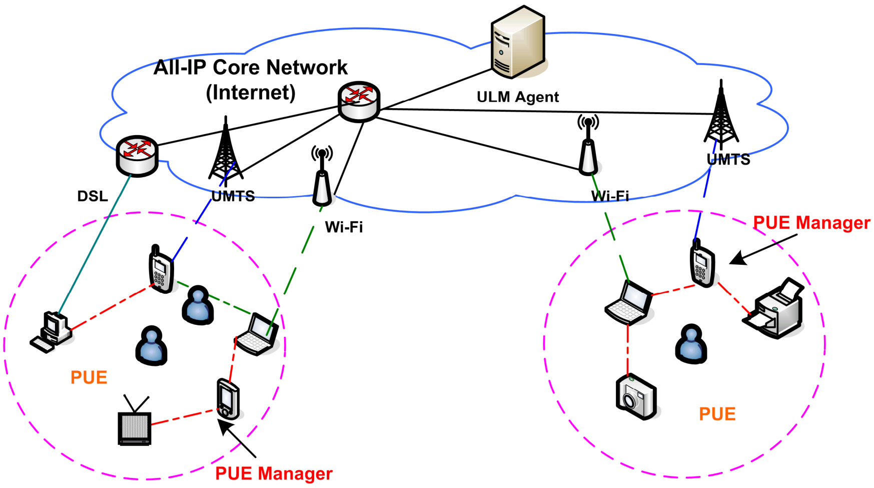


Figure 4.2: PUE Mobility Management Architecture and Components

4.3 PUE Mobility Management (PUE-MM) Architecture

Our proposed PUE Mobility Management (PUE-MM) architecture is shown in Figure 4.2. The heterogeneous devices in user's PUE capacitate access to different networks such as Wi-Fi, UMTS and DSL. In our proposed architecture, one of the user's PUE devices assumes the role of PUE Manager, as in Figure 4.2. It is a personal device with which the user interact the most and is the central point of contact for the user to manage his PUE. For example, the cellular phone can take the role of PUE Manager, as it is one of the devices which the user always keeps with her. Apart from local resource monitoring, PUE Manager also assists in mobility management and network selection decisions within the user's PUE. In this architecture, different wireless networks are integrated through a novel third party, the Unified Location Management (ULM) agent, as shown in Figure 4.2. ULM agent stores the location updates of heterogeneous devices in user PUEs and performs call delivery. All the more, ULM agent also serves in end-to-end network selection between a sender/receiver pair of PUEs. Our PUE-MM architecture (from Figure 4.2) can integrate any number of PUEs and different type of access networks.

The logical first step towards mobility management in personal environments is the formation of PUEs. Then in order to deal with mobile personal nodes in PUEs, different functions of PUE-MM architecture triggers such as IP connection management, seamless handover, location management and best network selection, as discussed in the following.

4.3.1 PUE Formation and Converged Addressing

In order to offer mobility management in personal environments, the initial step is the formation of a PUE topology i.e. all the personal devices that are in the close vicinity discover routes towards each other. The devices which offer connectivity with the external networks are identified and the capabilities of each of these devices are exchanged within the PUE. For this purpose, as discussed in Chapter 2, Personal Network Routing Protocol (PNRP) [51] is developed. Moreover, PNRP is coupled with Integrated CONvergence (ICON) mechanism to hide device and access network heterogeneity from the higher-layer PUE components.

4.3.2 Connection Management and Seamless Handover

Inherently, PUE asks for the interconnection of different wireless networks which adopt heterogeneous access technologies and protocols. Since IP offers complete transparency to different radio technologies and provides a globally successful infrastructure for supporting applications in a cost-effective way [53], PUE architecture employs IP as a common inter-connection protocol. Using IP as a common platform in PUE architecture requires no modifications to the existing heterogeneous networks and makes the reuse of standard IP-based solutions. To this end, in order to promote the reuse of maximum standard solutions, we employ Mobile IP (MIP) for IP connection management and a cross-layered Media Independent Handover (MIH) function [55] designed for seamless handover across heterogeneous networks, in our PUE-MM architecture.

4.3.3 Unified Location Management (ULM)

PNRP enables all devices within the PUE to learn about other devices and their capabilities. In order to motivate user-to-user interaction and environment-aware mobility management, the PUE's devices update their locations at a central networking entity called Unified Location Management (ULM) agent. Out of all PUE devices, the device having permanent external connectivity (such as PC or 3G phone) assumes the responsibility of updating information on the behalf of other PUE nodes and periodically updates the entire PUE information at the ULM agent. The ULM agent binds together all the information related to a unique PUE by maintaining the global information about the networking and computational capabilities of different personal environments. For a source PUE to reach a destination PUE, only the PUE identity of the destination is required. The ULM agent takes care of continuously changing state of different devices in the PUE and the corresponding user need not to worry about the current location of the host user (and his devices). In case of larger networks, there can be multiple

ULM agents connected in a peer-to-peer fashion, distribute and share information similar to DNS (Domain Name Service) architecture.

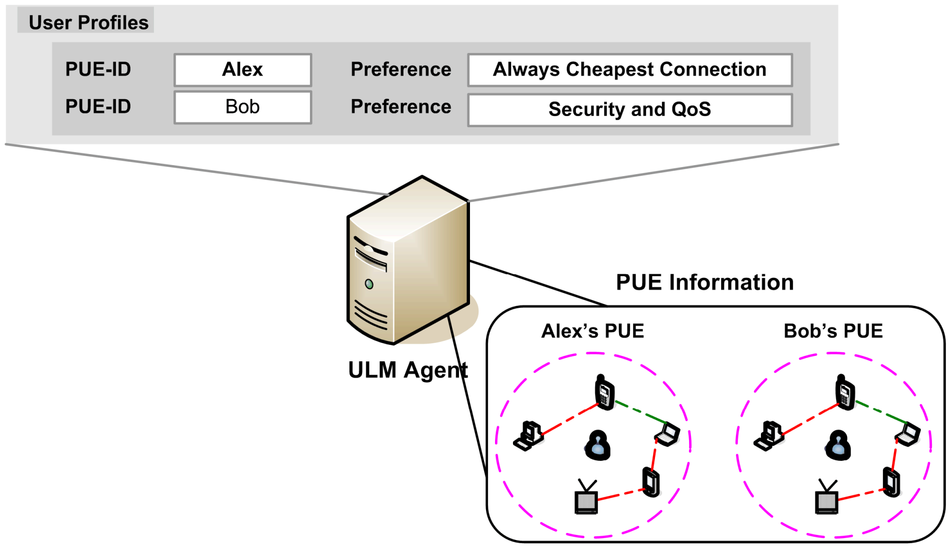


Figure 4.3: ULM Agent - PUE Information and User Profiles

As shown in Figure 4.3, ULM agent maintains the PUE information of all the users connected to the IP network. This information contains both the networking and computational capabilities of the PUE devices. Moreover, the ULM agent also contains the information about the subscription and policy profiles of the user. This latter information is used to understand user preferences while performing 3E (End-to-End Environment-aware) network selection. For instance, as in Figure 4.3, Alice defines "communication cost" as the most important criteria for choosing her network, whereas Bob is concerned about the offered QoS and Security.

4.3.4 End-to-End Environment-aware (3E) Network Selection

In order to offer best network selection in case of changes in the personal environments, we propose an End-to-End Environment-aware (3E) network selection mechanism. In our 3E mechanism we not only consider the environmental characteristics of the corresponding node but also of the host node in order to select the best network connection on end-to-end basis. "Best" is a relative term here and it applies differently for different users. Therefore, we make use of user profiles and network policies in order to define, what might be the best for the user in a given scenario. In 3E network selection mechanism, in order to communicate with the host node, the corresponding node sends a request to the ULM agent. The request message contains the PUE-ID of the host node and the type of application (voice, video, file transfer etc.), the corresponding node wants to establish. The ULM agent is not only aware of the PUEs of corresponding and host nodes but also the preferences of each user, as reflected in their user profiles. The ULM agent selects the best end-to-end network for the corresponding/host nodes pair to establish the session according to the preferences of each user, their environment, and available QoS.

While corresponding node and host node are communicating, the PUE of both users can change because of mobility and network dynamism. In this case, PUE managers at the PUEs of corresponding and host user carry out local mobility management decisions, and the ULM agent is updated about the local handover decisions. In case if ULM agent discovers a better end-to-end route for the corresponding/host pair, it feedbacks this information to the PUEs in consideration. The PUE manager takes further steps accordingly in order to initiate local handover.

4.4 Simulation Model

In this section, we present the evaluation of our proposed PUE Mobility Management architecture. For this evaluation, we conduct extensive simulation under a variety of heterogeneous wireless networking mobility scenarios.

4.4.1 Performance Metrics and Evaluation Model

We implemented the PUE mobility management architecture with the proposed algorithms such as ICON, PNRP, ULM and 3E network selection in the network simulator, NS-2.29 [35]. The main objective of our evaluation study is to show the feasibility and the proof-of-concept of our proposed architecture and to evaluate its performance when working with IP mobility management and fast handoff schemes. Mobile IP version 6 (MIPv6) [74] and Media Independent Handover (IEEE 802.21) [55] are integrated in the PUE mobility architecture to facilitate IP connection management and seamless handover, respectively. For simulating heterogeneous wireless access interfaces such as IEEE 802.11b (Wi-Fi), IEEE 802.16 (Wi-Max), UMTS and IEEE 802.3 (Ethernet), we used the integrated simulation platform in NS-2 contributed by NIST [75].

In order to evaluate and assess the performance of our mobility management architecture, the performance metrics which have been evaluated are throughput and end-to-end delay, packet drop and switching delay. The throughput is defined as number of bits of successfully received data by number of bits of load offered. The end-to-end delay is defined as the time t2 the data packet is received by the destination, minus the time t1 this data packet is generated at the source. The packet drop is calculated as the number of packets sent by the source, which are not successfully received by the destination. Finally, switching delay is defined as the time difference between, the last packet successfully received (before handover) at the old point of attachment and the first packet successfully received at the new point of attachment (after handover).

4.4.2 Simulation Scenarios and Methodology

With the objective of evaluating various characteristics of PUE-MM architecture, we simulated three different scenarios. First scenario evaluates the capability of 3E network selection mechanism and ULM agent to select the best network out of the available, keeping into account user preferences. Second scenario analyses the impact of seamless handover and connection management in case of different traffic types such as constant data and Voice over IP (VoIP). Finally, third scenario assesses the impact of frequent heterogeneous handovers in terms of packet drop and switching delay.

For mobility scenarios, we defined our own straight-line mobility model, where the random speed is varied between 0 and 5m/s (maximum speed). Three different traffic types are considered. Constant Bit Rate (CBR) at 2Mbps, VoIP codec G.729 (8Kbps), VoIP codec G.711 (64Kbps). Each of these traffic sources start sending data within the first 5 seconds of the simulation and lasts until the end (i.e. 100 secs). All the access points (UMTS, Wi-Fi and Wi-Max) are 802.21 and MIPv6 enabled. The simulation model parameters employed in our study are summarised in Table 4-1.

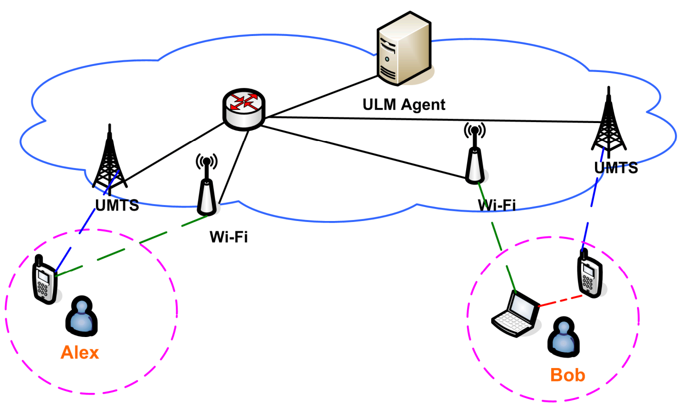


Figure 4.4: Scenario 1 – Selecting the best network between Alex and Bob

Table 4-1: Simulation Model Parameters for Heterogeneous PUEs

	Network Topology	
WiFi coverage area	50 m	
Wi-MAX coverage area	500 m	
UMTS coverage area	Entire simulation map	
Node Type	Mobile type	
	Core Network Configuration	
Bandwidth	10 Mbps	
Queue Type	Drop-Tail	
	Wi-Fi Configuration	
Type	802.11b	
MAC Spec.	Multiple Access Scheme	CSMA/CA
	Gross Data rate	11 Mbps
	Threshold Limit	1.2 (Trigger Link Going Down)
PHY Spec.	Propagation model	Two-Ray Ground Model
	Antenna Type	Omni-Direction
	Frequency Range	2.4 GHz
	Wi-MAX Configuration	
Type	802.16-2004 / 802.16e-2005	
MAC Spec.	UCD Interval	5 ms
	DCD Interval	5 ms
	Threshold Limit	1.1 (Trigger Link Going Down)
PHY Spec.	Propagation model	Two-Ray Ground Model
	Antenna Type	Omni-Direction
	Frequency Range	3.5 GHz
	UMTS Configuration	
PDCP Spec.	TCP/IP Header compression	No
RLC Spec.	Transport channel	Dedicated Channel (DCH)
	RLC Mode	Acknowledge Mode
	Payload Size (Bytes)	40
	RLC Header (Bits)	16
	Uplink Bit Rate	384 Kbps
	Uplink TTI	20 ms
	Downlink Bit Rate	384 Kbps
	Downlink TTI	20 ms
MAC Spec.	MAC Header (Bits)	0
PHY Spec.	Error Model	Uniform Distribution
	Mobility Model	
Type	Pedestrian	
	Velocity (m/s)	5 m/s
	Path	Straight Line
	Traffic Model	
Type	CBR	
	Maximum Payload Size (bytes)	512
	Transfer Rate	2Mbps
	Packet Interval	2 ms
Type	G.729 VoIP Codec	
	Data rate	8Kbps
	Packet Size (bytes)	20
	Packet Interval	20 ms
Type	G.711 VoIP Codec	
	Data rate	64Kbps
	Packet Size (bytes)	160
	Packet Interval	20 ms

4.5 Simulation Results and Analysis

We simulated different application scenarios to reflect the seamless and pervasive features of our PUE Mobility Management architecture. PUE of the user is observed to be quickly adapting to the changing environment and selects the best communication medium (device/network) for each user. The evaluated application scenarios are presented below:

4.5.1 Scenario 1 – 3E Network Selection

The first scenario evaluates the End-to-End Environment-aware (3E) network selection capabilities of the mobility management architecture. Alex sends a data file (at the data-rate of 2Mbps) to Bob, stored on his cell-phone, as shown in Figure 4.4. After investigating from the ULM agent, the end-to-end Wi-Fi connection is selected as the best (inexpensive, suited for large file transfers, high data-rate) route to realize the given application scenario. The throughput results are shown in Figure 4.5.

As can be seen from Figure 4.5, unlike the traditional approach, where UMTS network is selected; the 3E network selection mechanism seamlessly transfers data through the end-to-end Wi-Fi connection. The selected Wi-Fi network between Alex and Bob results into high data-rate (i.e. less transmission time) and user satisfaction (i.e. low price to pay as compare to UMTS network). It is to be noted that the choice of the network is completely transparent to the user.

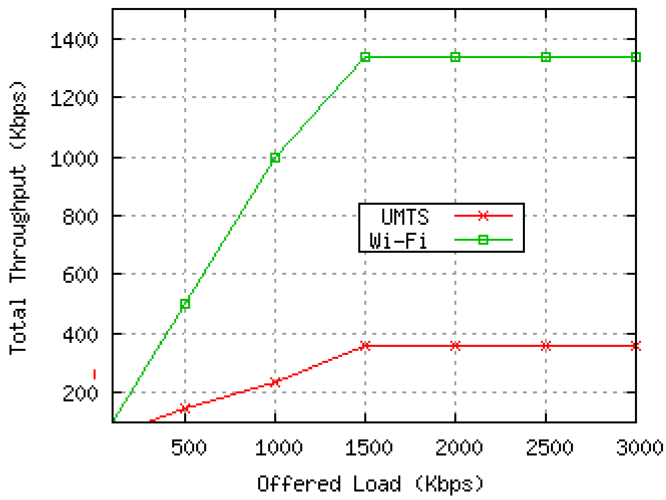


Figure 4.5: UMTS versus Wi-Fi Throughput - 3E Network Selection

4.5.2 Scenario 2 – Seamless Handover from UMTS to Wi-Fi

The second application scenario is analogous to a Fixed-Mobile Convergence (FMC) set-up and similar to services such as Unik (Orange) [76] and BT Fusion (British Telecom) [77] offered on top of a Unified Mobile Access (UMA) solution [78]. In our scenario, as shown in Figure 4.6, while communicating with Bob, Alex enters his house. Consequently his personal environment changes and the PUE manager switches the communication session from UMTS to the best available option i.e. Wi-Fi access-point installed in Alex's house. Figure 4.7 and Figure 4.8 evaluates the impact of handover from UMTS to Wi-Fi network in PUE mobility management architecture using 802.21 and MIPv6.

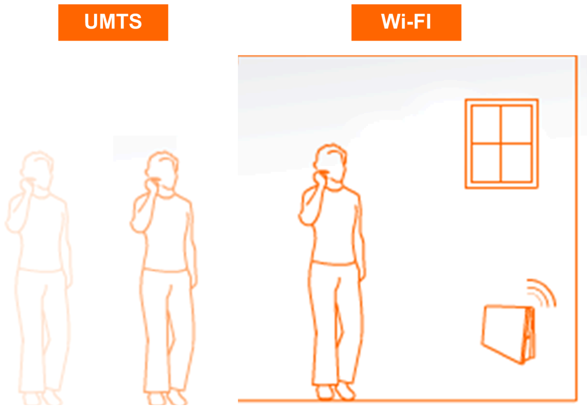


Figure 4.6: Scenario 2 - Fixed Mobile Convergence

Figure 4.7 and Figure 4.8 shows results from two different scenarios when Alex hands over from UMTS to Wi-Fi network (a) Alex sending data files to Bob (data-rate 2Mbps) and (b) Alex is on a voice call (G.729 codec, data-rate 8Kbps and G.711 codec, data-rate 64Kbps), respectively. Here, we evaluated the impact of handover from UMTS (outside) to Wi-Fi network (inside the house). As shown in Figure 4.7, for CBR traffic case, the handover occurs between 90 to 100secs, which results into the slight degradation of "total throughput" due to handover delay and packet drop. Furthermore, just after the handover, "total throughput" drastically increases, which is quite understandable (Wi-Fi offers higher data-rate than UMTS). In contrast, from Figure 4.8, we clearly see that the handover occurs at 100 secs (simulation time). In case of G.729 VoIP codec, as shown in Figure 4.8 (a), the handover has an effect on the quality of voice session as 8 voice packets are dropped during the handoff process, whereas 11 packets are dropped with G.711 VoIP codec, as in Figure 4.8 (b). Moreover, the experienced switching delays for voice and data scenarios are: 75 ms for data (CBR), 74 ms for VoIP (G.729) and 78 ms for VoIP (G.711), as reported in Table 4-2. As it is quite understandable, the higher packet-drop and switching delay in case of G.711 codec is attributed to its high rate of sending packets i.e. 64Kbps.

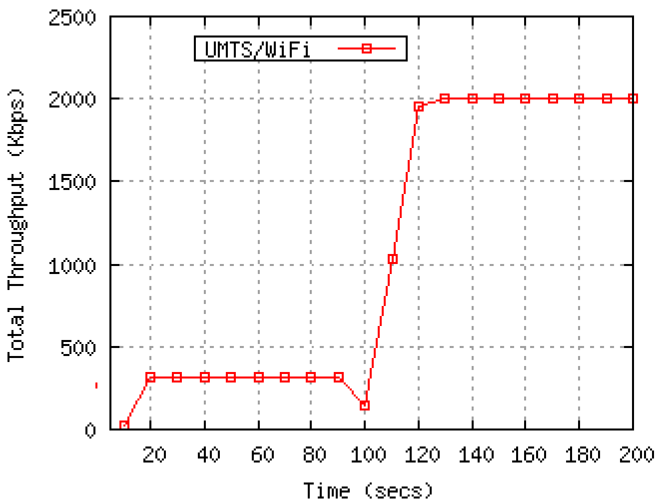


Figure 4.7: Handover from UMTS to Wi-Fi - CBR Traffic at 2Mbps

In summary, the switching delay and packet drop during UMTS to Wi-Fi handover has a minor impact on the overall application performance for both data and voice scenarios. The obtained result in this scenario portrays the usefulness of our PUE mobility management architecture when integrated with fast hand off (IEEE 802.21) and IP connection management (MIPv6) techniques.

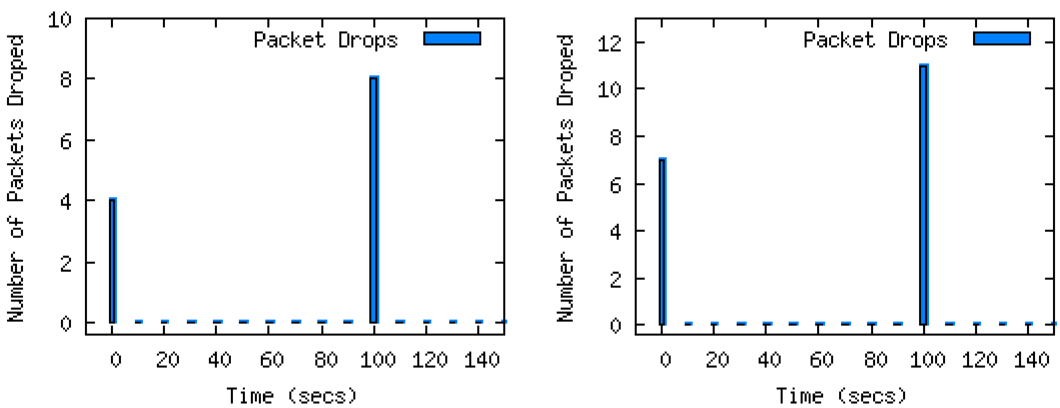


Figure 4.8: Packet Drops in UMTS/Wi-Fi Handover (a) G.729 VoIP Codec, (b) G.711 VoIP Codec

4.5.3 Scenario 3 – Multiple Handovers b/w Wi-Fi, Wi-Max and UMTS

In this everyday application scenario shown in Figure 4.9, while on communication, Alex roams across different wireless access networks such as Wi-Fi, Wi-Max and UMTS. The PUE of Alex adapts itself according to the changing personal environment in order for Alex to remain always best connected. The results of the study are presented in Figure 4.10 and Figure 4.11.

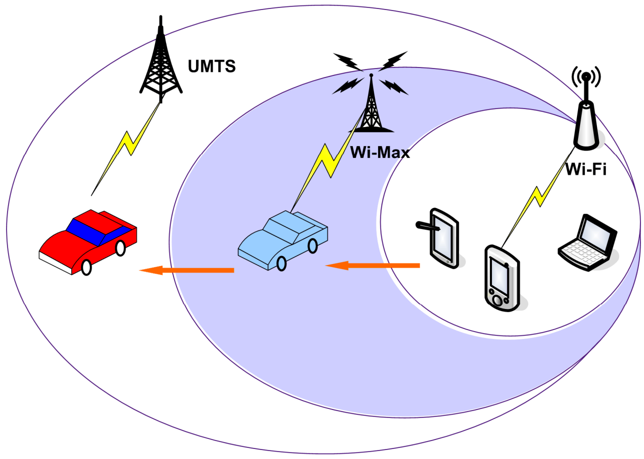


Figure 4.9: Frequent Heterogeneous Handovers (Wi-Fi/Wi-Max/UMTS)

Figure 4.10 and Figure 4.11 illustrates the delay for voice packets before and after the handovers using VoIP codecs G.729 and G.711 respectively using IEEE's 802.21 standard for handover. The delay (per packet) equal to zero represents packet drop. From Figure 4.10, using G.729 codec, eight packets (packet-IDs 36-43) are dropped when voice session switches over from Wi-Fi to Wi-Max network and the end-to-end delay for the received packets remains between 40 to 50 ms (suitable for voice applications). Moreover, six packets (packet-IDs 128-133) are dropped when the session handovers from Wi-Max to UMTS, with per packet end-to-end delay varied from 39 to 41 ms. In contrast, as shown in Figure 4.11, using G.711 codec, ten packets (packet-IDs 737-746) are dropped during Wi-Fi to Wi-Max handover and the end-to-end delay remains between 40 to 50 ms. Furthermore, seven packets (packet-IDs 173-179) are dropped when the session handovers from Wi-Max to UMTS, with per packet end-to-end delay varied from 50 to 60 ms. The switching delay for these multiple heterogeneous handovers is reported in Table 4-2. Using G.729, Wi-Fi to Wi-Max handover experiences switching delay of 65 ms and in Wi-Max to UMTS handover, the voice flow takes 81 ms to switch. In contrast, using G.711, Wi-Fi to Wi-Max handover experiences switching delay of 70 ms and 98 ms in Wi-Max to UMTS handover.

As learnt from the study, the PUE-MM architecture understands the continuously changing environment of the user and always selects the best available connectivity option for the user. Moreover, as proved by our results, the experienced delay and packet drop due to seamless handover between multiple heterogeneous access networks, using PUE mobility management architecture, does not impose strong challenges to meet the stringent QoS requirements of the applications by offering seamless handover across heterogeneous access technologies. With a close analysis of our results, we find that during the handover; more than half of the packets drop is not because of the handoff switching delay but due to inefficient IP connection management i.e. packets marked with old IP addresses are dropped and not re-routed.

Table 4-2: Switching Delay for 802.21-based Handover in PUEs

Scenario	*Handover*	*Traffic Type*	*Delay*
2	UMTS to Wi-Fi	CBR Data	75 ms
2	UMTS to Wi-Fi	G.729	74 ms
2	UMTS to Wi-Fi	G.711	78 ms
3	Wi-Fi to Wi-Max	G.729	65 ms
3	Wi-Max to UMTS	G.729	81 ms
3	Wi-Fi to Wi-Max	G.711	70 ms
3	Wi-Max to UMTS	G.711	98 ms

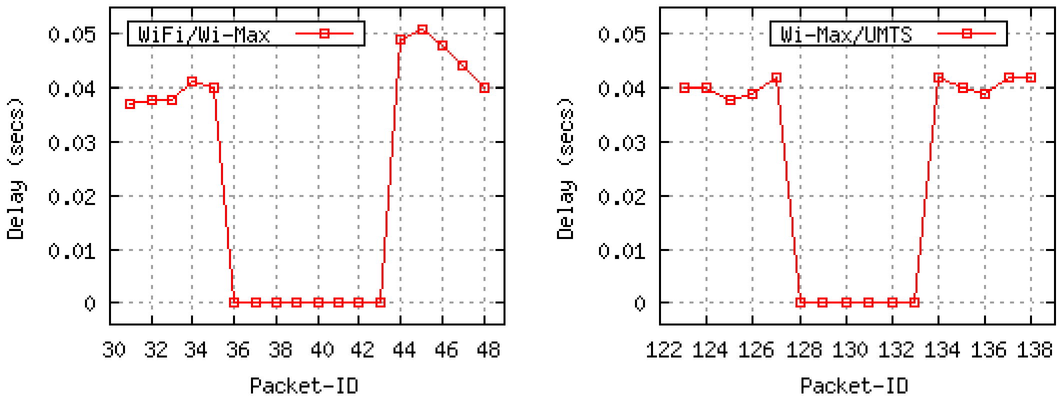


Figure 4.10: Per Packet E2E Delay and Packet Drops using G.729 VoIP Codec

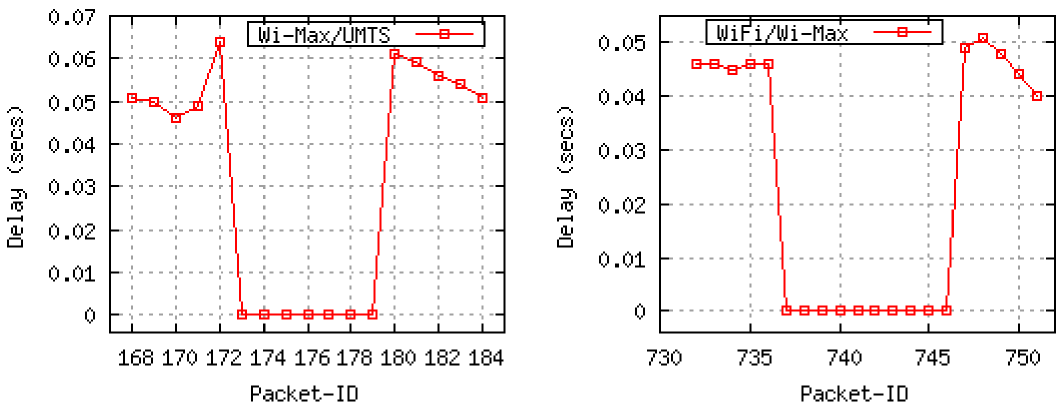


Figure 4.11: Per Packet E2E Delay and Packet Drops using G.711 VoIP Codec

4.6 Conclusion

4.6.1 Summary

This chapter exposed a variety of techniques deemed to be vital for seamless global roaming in heterogeneous personal environments. The proposed PUE Mobility Management (MM) architecture enables uninterrupted communication experience while transparently dealing with mobility management procedures. In case of mobility, the location information is updated, the seamless handover is performed towards the best available network and the existing connections are re-established. This is made possible due to different components and protocols of PUE-MM, such as Unified Location Management (ULM) agent, End to End Environment-aware (3E) network selection, IEEE 802.21 and MIPv6, presented in this chapter.

In Section 4.1, a sufficiently concise introduction to the topic of mobility management in personal environments has been given. The heterogeneous elements of the PUEs are identified and the mobility requirements of personal nodes are highlighted. This latter discussed motivated the need of a unified mobility management architecture to offer seamless and global roaming to the heterogeneous mobile personal devices of the PUE.

In Section 4.2, a comprehensive study of related works is presented and background is given. The fundamentals of mobility management are illustrated in a tutorial manner and the relevant state of the art achievements are described. It was highlighted that, since the concept of personal environments is relatively novel, no mobility management architecture had been developed so far. All previous works on mobility management were targeted to one single with multiple interfaces and had no direct application to personal environments. While discussing each of the components of mobility management architecture such as connection management, seamless handover, location management and network selection; we discussed the proposed solutions and their applications to personal environments. The inferences drawn from this analysis helped to develop mobility management architecture for personal environments.

Section 4.3 constitutes an important milestone as it presents the PUE Mobility Management (MM) architecture. Each of the components and protocols of PUE-MM are described separately and discussed with the help of examples. For seamless handover and connection management, existing standard approaches such as Media Independent Handover (MIH) and Mobile IP (MIP) respectively, are integrated to PUE-MM. Moreover, for PUE formation and addressing, Personal Network Routing Protocol (PNRP) and Integrated CONvergence (ICON) mechanisms, presented in Chapter 2 have been used. Furthermore, two new components such as Unified Location Management (ULM) and End-to-End Environment-aware (3E) network selection are developed for location management and network selection, respectively.

Section 4.4 and 4.5 presents the simulation model and results, respectively. A heterogeneous Personal Ubiquitous Environment (PUE) comprises of IEEE 802.11b (Wi-Fi), IEEE 802.16 (Wi-Max), UMTS and IEEE 802.3 (Ethernet) access networks, augmented with PUE-MM architectural components are implemented in a simulator settings and their performance is evaluated. Our simulation results show that the PUE-MM architecture improves the resource utilization and efficiently offers the seamless interoperability in heterogeneous environments with very limited impact (in terms of delay and packet drop) on the application QoS performance due to frequent heterogeneous handovers.

4.6.2 Contributions

This chapter opens the way to mobility management strategies particularly for personal environments. To this end, the research contributions can be summarized as follows:

1. The distinct heterogeneous characteristics of personal environments have been analyzed and the motivations behind mobility management and best network selection in these environments have been highlighted.

2. An explicit unified location management strategy has been proposed for heterogeneous networks

3. An explicit network selection mechanism is proposed, which considers the end to end environment information and user's preferences for best network selection

4. IEEE 802.21 standard has been presented and accommodated in our mobility management architecture. To the best of our knowledge, this is the first ever attempt to integrate 802.21 in a comprehensive mobility management architecture.

5. Performance evaluation is performed in an integrated heterogeneous networking model in NS-2, which simulates 802.11, 802.16, 802.3 and UMTS, simultaneously. This model also integrated 802.21 and MIPv6.

6. All the above components have been integrated as a part of PUE Mobility Management architecture; a proof of concept is given as simulation results.

4.6.3 Future Research

Numerous questions and problems remain open in the field of PUE mobility management. In this respect, the following topics are deemed to be worthwhile pursuing as future research:

1. Improving Seamless Handover: 802.21. As learnt during simulation analysis, during the handover, non-negligible packet-drop and switching delay is experienced. A further study could incorporate additional primitives in IEEE 802.21 standard that can further make the handover even faster and more seamless.

2. 802.21 Extension for Multi-hop Scenarios. Since the personal environments generally consist of multi-hop connectivity between the personal nodes, 802.21 should be extended to support not only one-hop handover scenarios towards the network but also accommodate multi-hop cross-device handovers. Some efforts towards this end are reported in Chapter 5.

3. Application-Environment Interfacing. In certain scenarios, the change in personal environment has an impact on the application-type of established flows. For example, when Alex enters in his car, the voice session transfers from his PDA to the multimedia communicator installed in the car and furthermore, he is also provided with an option to switch from voice to video call. It is desirable to study these scenarios and analyse the modifications required (if any) to PUE-MM architecture.

4. Selection of PUE Manager. So far, for the simulations, PUE manager is randomly selected. Thus, it is the question of further research, as how the PUE Manager is selected in the PUE and in case existing PUE manager leaves how the re-election process is performed.

5. ULM Agents: So far, we assume only one ULM agent in the network. However, since all the PUEs information is updated at the ULM, in reality there could be multiple ULM agents. A further study could incorporate multiple ULM scenarios.

Chapter 5

MEDIA INDEPENDENT SEAMLESS MULTI-HOP HANDOVER

5.1 Introduction

One of the foremost objectives towards next generation IP networks is to provide seamless network services with various wireless and wired terminals. With the proliferation of devices and access network technologies, the user is surrounded by heterogeneous elements (networks and devices) offering complementary services and resources. For optimized resource management, it is essential to regroup all these resources as one unit and utilize them efficiently. For instance, if we could switch among different user terminals and networks adaptively according to their availability, quality, cost and usability, the most appropriate resource (device/network) can always be used. Here, the main idea is to create a Personal Ubiquitous Environment (PUE) that allows user to access the network without being aware of individual network and devices in his environment.

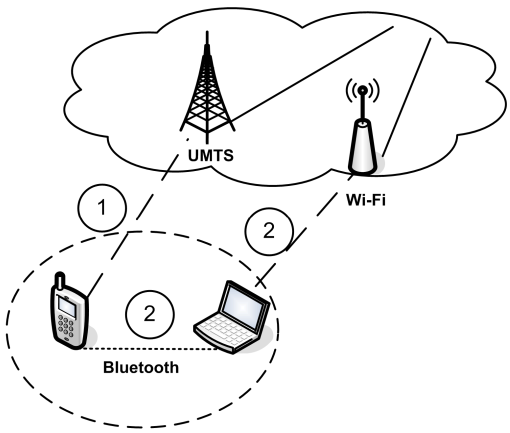


Figure 5.1: Sharing Resources in personal environments

Traditionally, the devices capacitate access to networks in a one-hop manner, for instance, the UMTS terminal connected to the base-station. In case of multiple interface devices, the network resources can be shared among the interfaces of the same device. However, in order to regroup resources within the user's environment, a communication channel is required which facilitates interaction among different devices within the environment. This interaction is tuned over high data-rate, low-range unlicensed spectrum technologies such as Bluetooth, Wi-Fi and UWB (Ultra Wide Band). The inter-device communication makes any device to access any resource within the PUE. For instance, as shown in Figure 5.1, the dual-mode (UMTS/Bluetooth) terminal connected to UMTS network connects to its Wi-Fi-enabled notebook via Bluetooth in order to switch over to inexpensive Wi-Fi network in multi-hop manner. However, how to offer seamless uninterrupted communication during this multi-hop handover is an open question, which is answered in this chapter.

The PUE concept allows users to move freely between different networks (through different devices) while maintaining application continuity. However, as discussed in Chapter 4, mobility management in heterogeneous networks is a challenging problem and frequent handovers yields noticeable delays and packet drops. In our proposed mobility management architecture for PUEs, a seamless experience to handovers is offered with the help of Media Independent Handover (MIH) function, designed to support fast handovers in heterogeneous access networks. However, MIH function is mainly designed for "client-network" one-hop scenarios and not applicable to multi-hop connectivity model, as we oversee in personal environments. The heterogeneous multi-hop connectivity/handover towards the infrastructure network imposes serious concerns over application performance, as the latency and packet drop increases. To this end, seamless multi-hop handover mechanism is desired to be developed, which extends the one-hop intelligent handover procedures towards multi-hops in order to guarantee uninterrupted application behaviour during frequent handovers (single/multi-hop).

In this chapter we aim at extending the MIH function towards accommodating both the one-hop and multi-hop mode of operation in 802.21-enabled heterogeneous networks. This extended model is further included in our PUE-MM architecture. Here, our objective is not to modify the 802.21 protocol by and large, but to effectively use the specific services and respectively, messages associated to these services, offered by 802.21 so as to enhance the scope of 802.21 and contrastingly, enable multi-hop heterogeneous networking.

This chapter is structured as follows. As first, the problem of seamless multi-hop handover in personal environments is highlighted and state of the art achievements related to the seamless integration of infrastructure and multi-hop network is presented. Second, the IEEE's 802.21 Media Independent Handover (MIH) is extended to enable heterogeneous seamless multi-hop handover. Third, the usage scenarios for multi-hop handover using MIH event, command and information service are presented and end-to-end signalling traces are discussed. The proposed extension of MIH is simulated with NS-2 and its performance is compared with AODV+ (reactive and proactive gateway discovery schemes), and performance results are reported under fifth and sixth. Finally, chapter specific conclusions are drawn, contributions are listed, and the most important results summarised.

5.2 Motivation and Related Works

Integration of infrastructure and multi-hop networks has attained maturity in the research domain and various solutions related to mobility management and routing has been proposed [38]. An integrated protocol for IPv6-based hybrid wireless multi-hop networks based on Cellular IP and AODV routing protocol [87] has been proposed in [81]. The performance of Mobile IP integrated with AODV has been studied in [82]. In [83] Hierarchical MIPv6 protocol is proposed, which piggybacked with AODV protocol offers mobility management in hybrid wireless networks. Moreover, [84] propose the personal Access-Point (AP) concept, where the entire context of old connection is transferred from the old AP to the new AP.

The existing state of the art achievements towards the integration of multi-hop and infrastructure networks only aims at Interworking and connectivity without considering the seamless experience towards handover in these networks. Most of the solutions are based on layer-3 messages exchange, which results into high delay and packet loss in case of handover. Moreover, if in case layer-2 information is used [83] [85], no standardized cross-layering mechanism is proposed, which may affect the design, compatibility and extendibility of the entire system. Efficient cross layering mechanisms are required to exchange updated information about the link level characteristics and also from the applications, so that the routing and mobility management protocols can tune their performance and take handover decisions according to the application and link layer characteristics. This information will further improve the performance of handover (i.e. reduce packet loss and switching delay).

IEEE 802.21 MIH function [79] acts as a 2.5 layer between the network and link layers; where the main functionality is to mount the link and physical layer events towards applications and to execute commands initiated from the higher layers for the lower layers. In 802.21, the MIH functionality supports 'client-network' connectivity thus shielding the PUE resources to be exchanged among all PUE member devices. Therefore, the handover procedures and thereby the resources are limited to the extent of the availability of the network entity. Now, this causes an inconvenience to MN's when there is no available direct network connectivity, but the presence of other MN's having network access. This scenario can be averted by introducing a 'client-client' connectivity aspect to the MIH function and adapting the different 802.21 services accordingly. In this multi-hop 802.21 scenario, the multi-hop handover information can be useful for the routing and mobility management protocols to offer seamless experience to multi-hop handover. Apart from that, distributing the 802.21 MIH function capacitates more flexibility to the heterogeneous personal environment, such as more choice of networks (exploiting the resources available at the neighbouring nodes) and selection of the best network (single/multi-hop) in terms of required-QoS levels.

5.3 MIH Support for Multi-hop Heterogeneous Networking Scenarios

5.3.1 MIH Architecture and Communication Model

The MIH function is to communicate between the MN (Mobile Node's) and the heterogeneous access networks available to the MN's. Each access technology either advertises its MIH capability or responds to MIH specific queries. There are mainly 5 communication reference points defined for MIH function which are under the scope of 802.21, as illustrated in Table 5-1. These reference points specifies the essential communication between the MIH functions of MN's, MIH PoS's (Point of Service) and network PoA's (Point of Attachment). The three 802.21 MIH function services: the Event Service (ES), Command Service (CS) and the Information Service (IS) are defined in the 802.21 draft standard [80] to facilitate the handovers across heterogeneous networks.

Table 5-1: Summary of 802.21 Communication Reference Points

Reference Point	*Description*	*Scope of Definition*
R1	Between the MIH on an MN and an MIH PoS on the Network Entity of the serving PoA.	In scope of 802.21
R2	Between the MIH on a MN and a MIH PoS on the Network Entity	In scope of 802.21
R3	Between the MIH on a MN and a MIH PoS on a non-PoA network entity.	In scope of 802.21
R4	Between a MIH PoS and a non-PoS MIH function instance in distinct network entities.	In scope of 802.21
R5	Between two MIH PoS instances in distinct Network Entities.	In scope of 802.21

To introduce the multi-hop aspect and the 'client-client' connectivity into 802.21 MIH, we define a new reference point, R6 which assigns new roles to the MIH functions of MN's. This is shown in Figure 5.2. Reference Point R6 refers to MIH procedures between MN's. R6 may encompass communication interfaces over both L3 and L2 and above, and content passed over R6 maybe related to the extended Information Service, Command Service or Event Service. The extended IS, CS and ES are defined for enabling client-client communication and directly depends on the MIH IS, MIH CS and MIH ES, as defined in the 802.21 standard.

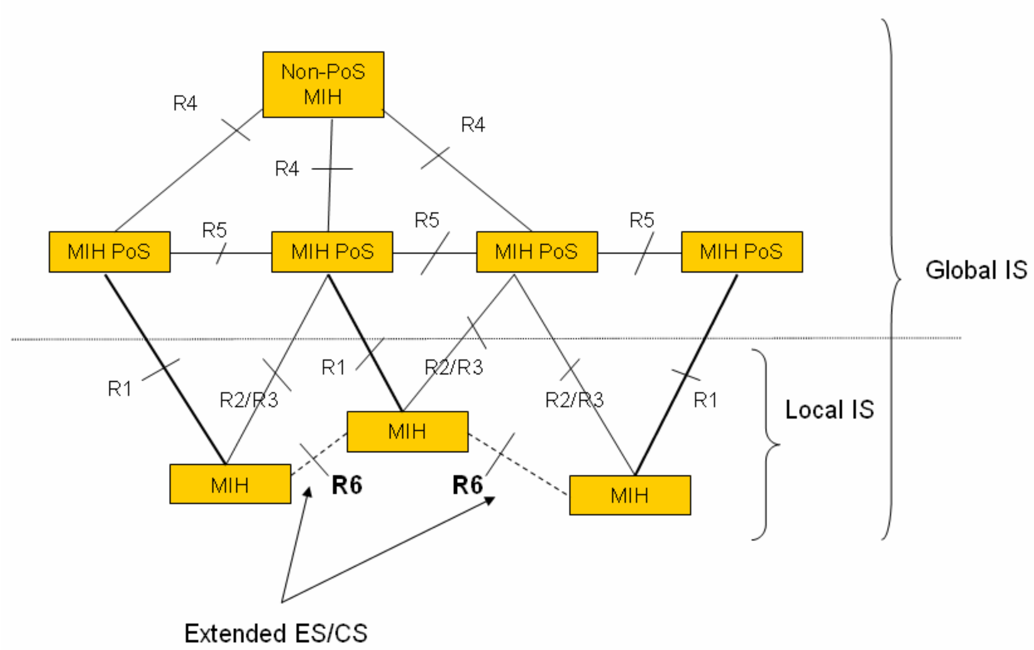


Figure 5.2: Extended 802.21 MIH Communication Model

For each of the functional services, different extensions introduced for extended MIH support are described below.

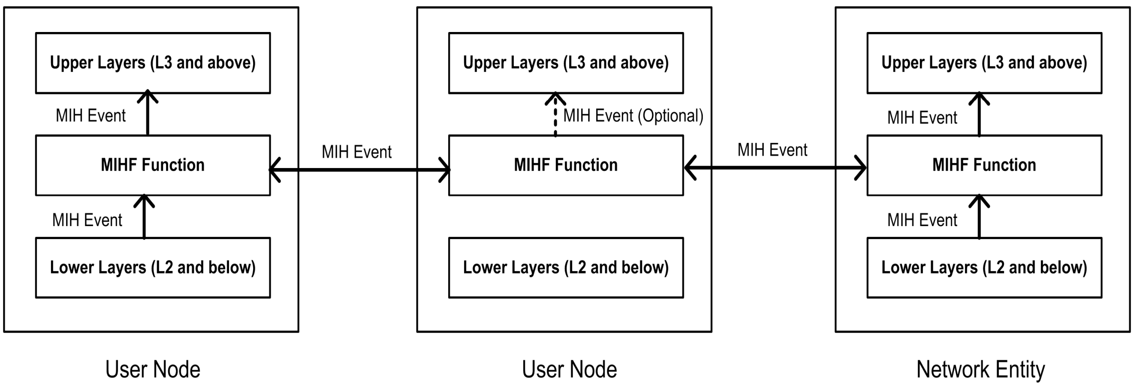


Figure 5.3: Multi-hop MIH Event Service

5.3.2 MIH Event Service (ES)

Media Independent Event Service refers to the events sent from lower layers to the layers in the MIH reference model. The distributed handovers can be initiated by the MN in the case of absence of access network or perhaps in the event of specific QoS policies. The extended ES are used to initiate and help optimize this distributed handover process.

The multi-hop operation of MIH Event Service is shown in Figure 5.3. The remote MIH events initiated at the user node, which does not have direct connectivity with the network, are relayed by an intermediate user node towards the network. Similarly, the remote events produced at the network are relayed towards the user node (not having one-hop connectivity) in a multi-hop fashion. The local events are largely unaffected by this extension as they stay within the node (or network) itself. The events can also be reported between the nodes (i.e. user node can send the information about certain threshold reached (event) to the neighbouring node(s)), as highlighted by MIH Event (optional) at the intermediate user node in Figure 5.3.

5.3.3 MIH Command Service (CS)

Media Independent Command Service refers to the commands sent from the higher layers to the lower layers in the MIH reference model. In case of client-client communication, the extended CS maybe used by the upper layers and other MIH users (particularly, MN's) to determine the status of links, control handover, and control the multi-mode device for optimal performance. The optimal handover policies may also be facilitated by the command service.

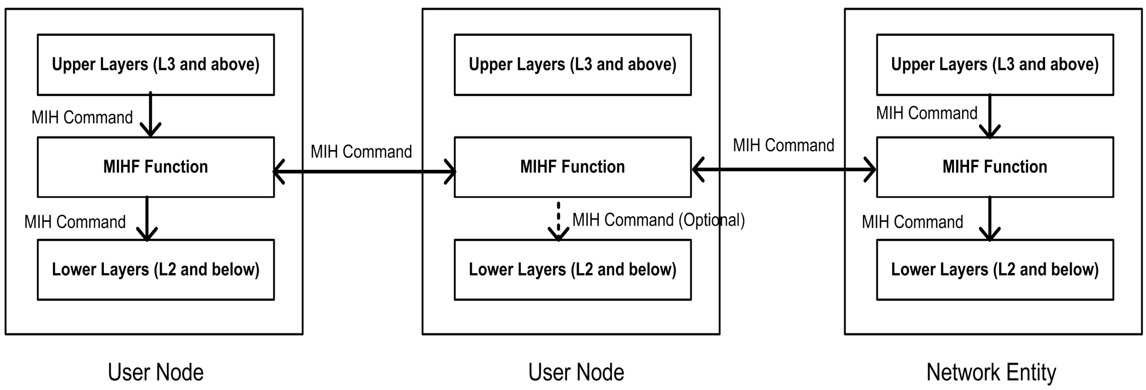


Figure 5.4: Multi-hop MIH Command Service

The multi-hop operation of command service is shown in Figure 5.4. In case of local commands, there is no change since the message exchange stays within the node (or network) itself. Whereas, the remote commands can be send hop-by-hop from the network to the user and vice versa. The multi-hop operation extension not only permits the communication between user and network but also between different users. As in Figure 5.4, the user node can also send commands to the neighbouring nodes in order to execute certain optimization functions, however this functionality is declared as optional.

5.3.4 MIH Information Service (IS)

The Media Independent Global IS is used by a mobile node or a network entity to discover and obtain homogeneous or heterogeneous networks to facilitate seamless handovers across the networks. The purpose of information service is to acquire a global view of the heterogeneous networks to facilitate seamless handovers across those networks. In order to obtain MIH information service, two basic type of IS messages are exchanged: MIH Information Request and MIH Information Response. The IS usage governs storing the following information elements (but are not limited to this): general access network information (list of networks, neighbour graph, etc.), information about point of attachments (address, location, data-rate, channel-range, etc.) and other vendor specific information.

We classify the existing IS element in MIH as the Global Information Service (Global IS). The extended MIH IS is termed as Local IS, and has the purpose of acquiring and exchanging local information of the MN's. The local IS messages are exchanged between MN's by virtue of the HELLO messages defined at L3 or perhaps by using L2 beacons (or by using wireless ad-hoc routing protocols [86]). The Local IS request messages are also defined similar to MIH Global IS: the MIH Local Information Request and MIH Local Information Response. The local IS related information is stored at the user nodes and shared with other nodes (when requested). The local IS information includes: available networks, neighbouring nodes topology (network graph), available QoS at each of networks etc. The local IS information is analogous to multi-hop routing protocol information stored at the node, extended with further useful information about the available networks (such as security, QoS and so on). This information is very useful for the nodes that only have multi-hop connectivity with the access network. In such case, the node queries its neighbouring nodes, if they can make the node to reach the network. The neighbouring node replies after consulting its local information service and provides the list of networks available to it.

5.4 Mobile Node Architecture

In order to ensure multi-hop exchange of MIH messages among mobile nodes, a certain set of interfaces between different mobile node components are required. Local Information Service

(IS) is a new entity which is proposed, as a multi-hop enabler of MIH messages. Ad-hoc routing protocol and gateway discovery modules are required to discover routes towards other mobile nodes and infrastructure components respectively. The proposed architecture of mobile node in multi-hop MIH model is presented in Figure 5.5.

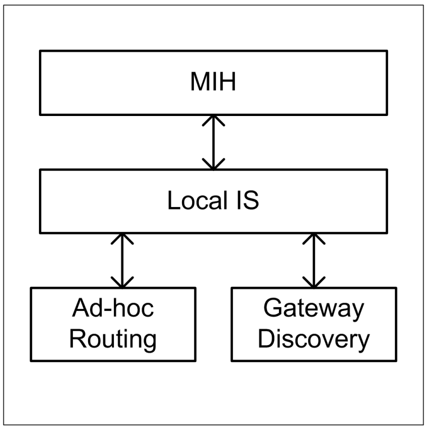


Figure 5.5: MIH multi-hop Mobile Node Architecture

5.4.1 Local Information Service (IS)

When a mobile node looks for a resource, which is not in its one-hop reach, it consults its Local IS in order to scan the multi-hop environment. The Local-IS having its interfaces with Ad-hoc routing and gateway discovery protocols discover the neighbouring resources. Moreover, the detailed information about available network entities (in single/multi-hop) such as type of AP, its data rate, load, range and address and other information such as Cell-ID (for GSM), SSID (for 802.11), and BSID (for 802.16) is stored at Local IS and acquired from the Global IS (running at network entities). The ad-hoc routing protocol coupled with gateway discovery make the mobile node to connect to different network entities in multi-hop manner in order to maintain the interface between Global and Local IS.

5.4.2 Ad-hoc Routing Protocol

The role of ad-hoc routing protocol is to detect and to establish routes between the mobile nodes in multi-hop network. These routes can be on a single ad-hoc air interface such as 802.11 or on multiple 802.11 and 802.15. As shown in Figure 5.5, the local IS consults the established routes and further looks for available resources (networks/devices) within multi-hop topology.

5.4.3 Gateway Discovery Protocol

The gateway discovery protocol mainly serves to discover the multi-hop routes towards the infrastructure entities such as AP, BS etc in multi-hop hybrid (mix of ad-hoc and infrastructure) networks. Gateway discovery model can be regarded as a part of ad-hoc routing protocol, if we consider gateways as specialised multi-hop ad-hoc network's node. Since Local-IS needs to always stay intact with the infrastructure entities (either in single/multi-hop) in order to exchange information service messages, gateway discovery protocol does this job while discovering and establishing the end-to-end routes towards the dedicated gateways.

5.5 MIH Multi-hop Usage Scenarios

In this section, we present the multi-hop usage scenarios of MIH, where the MIH information is exploited in multi-hop manner for seamless handover and QoS-triggered handover, respectively.

5.5.1 Seamless Multi-hop Handover

As shown in the scenario drawn in Figure 5.6, User node A is connected to the Network N and data flow is established. Further, due to the mobility of node A, it moves out of the range of network N and it finds no one-hop connectivity to the network nodes. It soon discovers a link (Personal Area Network) with a neighbouring node B, which has connectivity with network M. Now, the node A connects to the network M in multi-hop manner. The extension of MIH permits this seamless multi-hop handover.

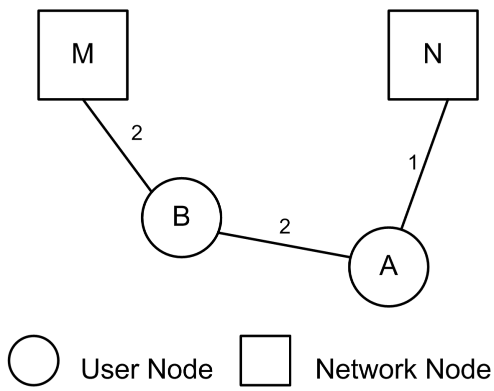


Figure 5.6: User A moves out of coverage and performs multi-hop handover

Figure 5.7 presents the MIH messages (event, command and information) exchanged among user nodes and network elements. Once the node A detects a link with node B, it sends a query to node B in order to know which resources are available at B. After consulting its local IS node B replies to A's query, telling that it has connectivity with network M. Node A further acquires information about network M from the connected network (i.e. network N). Node A also learns, at the same time, that the link to network N is going down. After consulting (reserving) the resources available at the network M, node A performs authentication and association procedures with network M, whereas node B helps in relaying the MIH messages generated at node A towards the network M. Once the link with network M is established, the handover takes place and node A starts sending data to network M in multi-hop fashion, passing through node B.

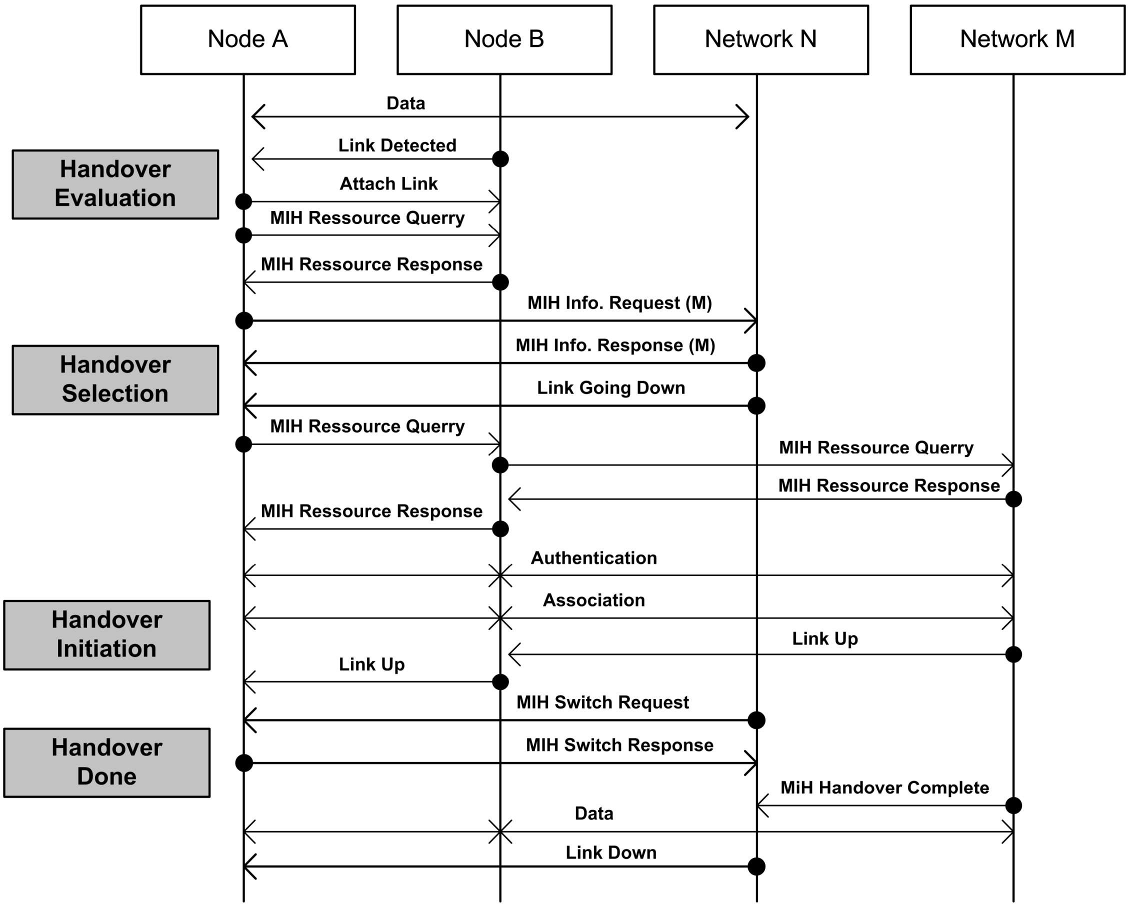


Figure 5.7: MIH Messages Exchange for Seamless Multi-hop Handover

5.5.2 QoS-triggered Multihop handover

As shown in the scenario drawn in Figure 5.8, User node A is connected to the Network M in a multi-hop fashion and data flow is established. At the same time, node A notifies its QoS requirements to the network. When node A reports to the network that its QoS demands are not met, the network instructs node A to perform handover and connects to the network which is most suitable in terms of QoS (i.e. network N). The multi-hop MIH permits this QoS-triggered multi-hop handover.

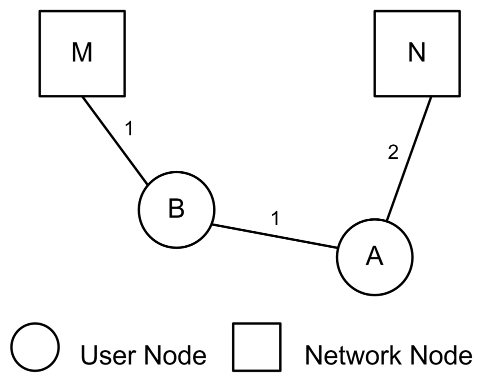


Figure 5.8: User A handovers to Network N for QoS needs

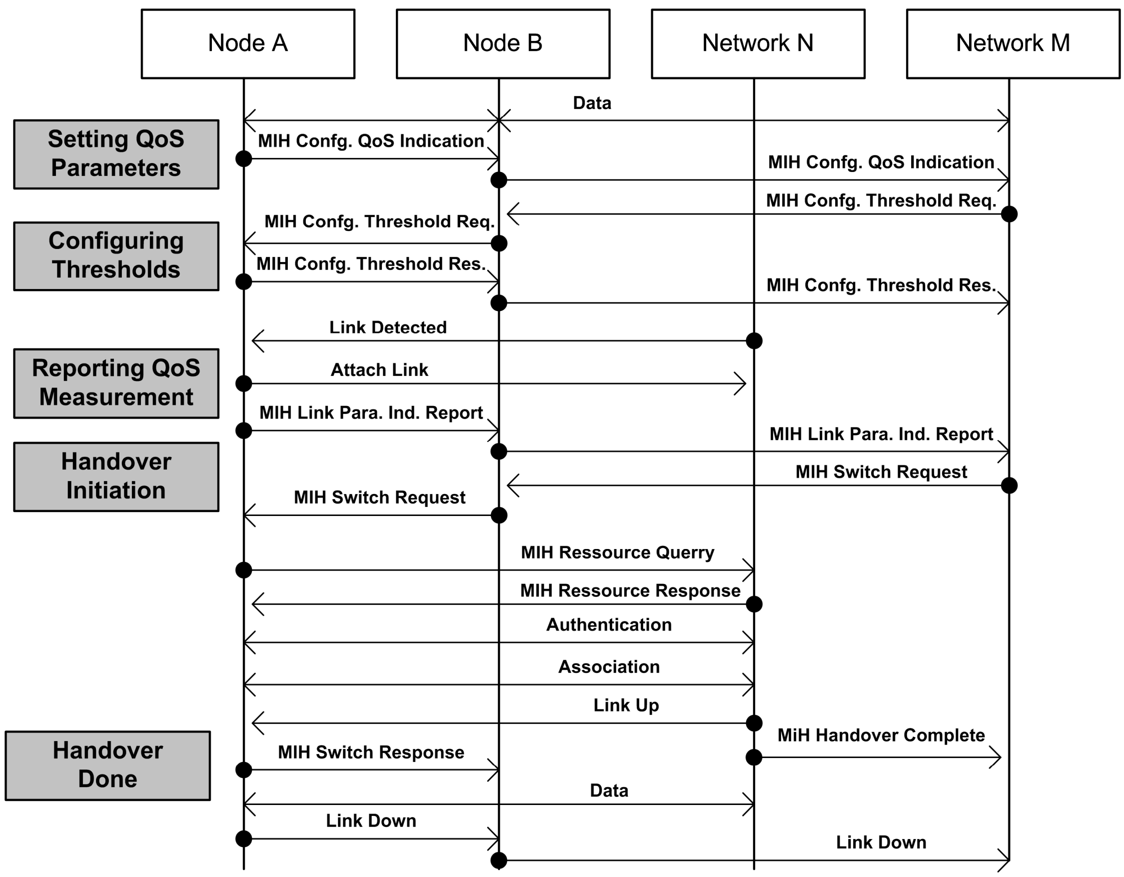


Figure 5.9: MIH Messages Exchange for QoS-triggered multi-hop handover

Figure 5.9 presents the MIH messages (event, command and information) exchanged among user nodes and network elements. While communicating with network M in multi-hop manner (passing through B), node A communicates its QoS requirements to the connected network M. Based on the QoS requirements, the network M configure node A's threshold for different QoS parameters. Meanwhile, the direct link is detected between node A and network N. As the threshold (set by network M) is crossed for a particular QoS parameter, the link parameter indication report is sent to network. On this event information, network M instructs the node A to perform the handover and connect to the most suitable network, which meets the QoS demands. After reserving the resources at network N, authentication and association is performed and QoS-triggered handover is executed. Upon success, the old network (i.e. network M) is notified by the current network (i.e. network N). The application running at node A keeps on operating at an optimal QoS level (and is not interrupted with this handover).

5.6 Simulation Model

In this section, we evaluate the performance of media independent seamless multi-hop handover mechanism.

5.6.1 Performance Metrics and Evaluation Model

We evaluate and analyze the performance of multi-hop 802.21 in the 802.11-based hybrid network, using the NS-2 simulator snapshot ns-2.29 [35]. We use 802.21 simulation model contributed by NIST [75], as a part of its integrated simulation platform for NS-2. The 802.21 model is extended with multi-hop operation for event and command services. Furthermore, for multi-hop gateway discovery, we use locally modified and extended version of ad-hoc routing protocol AODV called AODV+ from Hamidian et al. [46], which implements the interconnection between multi-hop network and the Internet. MIPv6 is used for IP connection management. MIPv6 uses the services provided by the 802.21 to manage, determine and control the state of the difference interfaces in the multi-hop scenario. The radio channel capacity for each mobile node is 2Mbps, using the IEEE 802.11b DCF MAC layer and a communication range of 250m. In addition, there are two interconnected gateways (Wi-Fi APs). A fixed node, which is the eventual destination node in the simulation scenarios, is connected directly to one of the gateways. All the fixed links have a bandwidth of 10Mbps. All mobile nodes and APs are 802.21, MIPv6 and AODV+ enabled.

In order to evaluate and assess the performance of seamless multi-hop handover mechanisms, we compare the multi-hop MIH with reactive and proactive gateway discovery protocols based on AODV+. The performance metrics which have been evaluated are packet drop, switching delay and application experienced delay. The packet drop is calculated as the number of packets sent by the transmitter, which are not successfully received by the receiver. The switching delay is the time difference between, the last packet successfully received (before handover) at the old point of attachment and the first packet successfully received at the new point of attachment (after handover). The switching delay is calculated at the transmitting node. Finally, receiver experienced delay is defined as time elapsed between the last packet successfully received on the old connection to the first packet received on the new connection. This latter delay is calculated at the receiver.

Table 5-2: Simulation Model Parameters for Multi-hop 802.21

SIMULATION / SCENARIO		***MAC / ROUTING***	
Simulation Time	100s	MAC protocol	802.11 DCF
Simulation Area	600 x 600 m^2	Gross Data Rate	11 Mbps
Traffic Type	CBR	Trans. Range	50m
Data-rate	64 Kbps	Node Speed	1-5 m/s
Packet-size	160 bytes	Mobility Model	Random Way

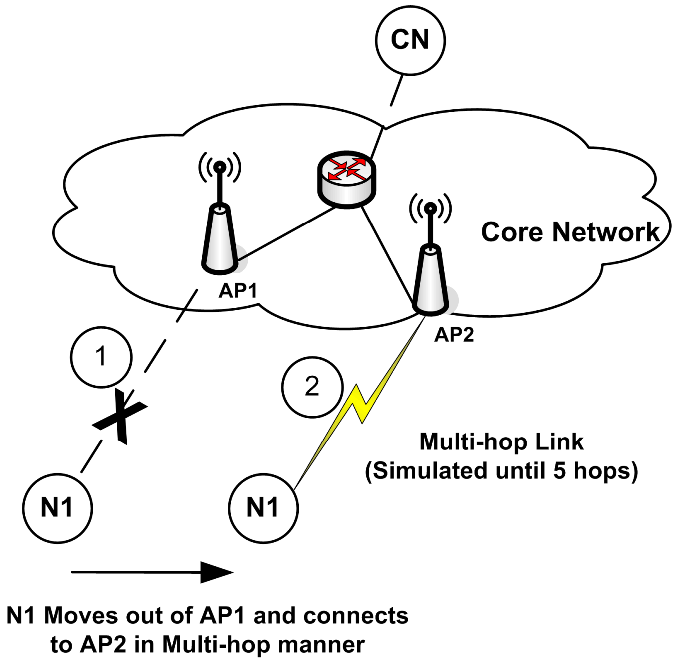


Figure 5.10: Simulation Scenario - Multi-hop Handover

5.6.2 Simulation Scenarios and Methodology

As shown in Figure 5.10, the simulation scenario consists of a mobile node N1 which is connected to a Wi-Fi AP1 in infrastructure-mode, and sending data to a CN (Corresponding Node). Then, this node moves away from its AP1 and connects to another AP2 in multi-hop manner. Different simulation scenarios are performed by varying the number of hops connectivity, when mobile node connects with new AP i.e. AP2. Since increase in the number of hops exponentially reduces the end-to-end QoS [51], therefore very large number of hops is not practical in terms of application's performance. Simulations are thereby carried out with number of hops varied until five.

For our simulation scenario, we have adopted the random way point mobility model in a way that the movement is from the old AP to the new AP. The mobile node moves at a speed varied from 0 to 5 m/s. The CBR traffic is generated at the rate of 64 Kbps with 160 bytes packet size. The simulation model parameters are presented in Table 5-2.

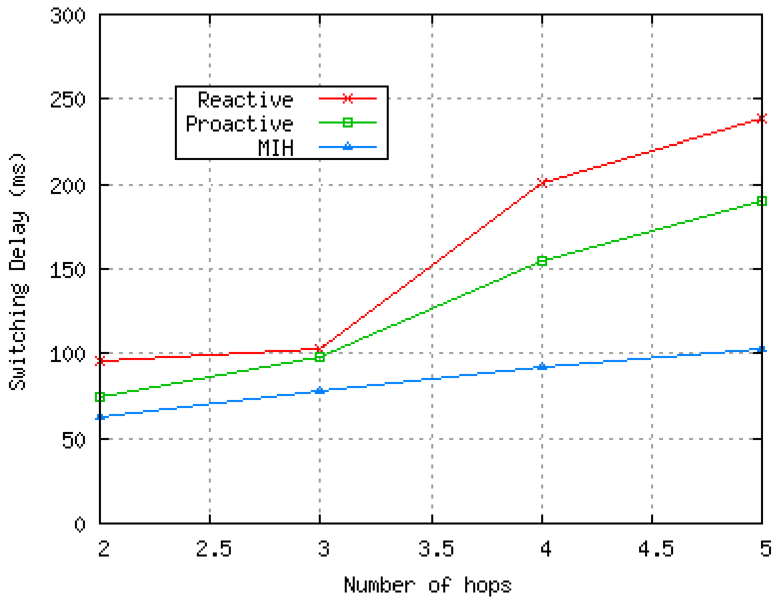


Figure 5.11: Switching Delay versus Number of hops

5.7 Simulation Results and Analysis

We investigate the performance of extended 802.21 and compare it with classical proactive and reactive and proactive gateway discovery protocols. Simulations were carried out with the variable number of hops.

From Figure 5.11, we clearly see that MIH outperforms proactive and reactive discovery protocols in terms of switching delay. MIH experiences the switching delay of 60ms at 2-hops scenarios and it goes until 100ms for 5-hops scenarios. As expected, reactive discovery experiences more switching delay than proactive mechanism. This performance gain of proactive mechanism is attributed to its control overhead, by periodic gateway advertisements.

The packet drops evaluation during the handovers is reported in Figure 5.12. Reactive discovery experiences the highest number of packet drops from 2 packets at 2 hops to 10 packets at 5 hops. Whereas, proactive and MIH mechanisms exhibit almost similar behaviour with 2 packet drops until 3 hops, which further increases to 7 at 5 hops.

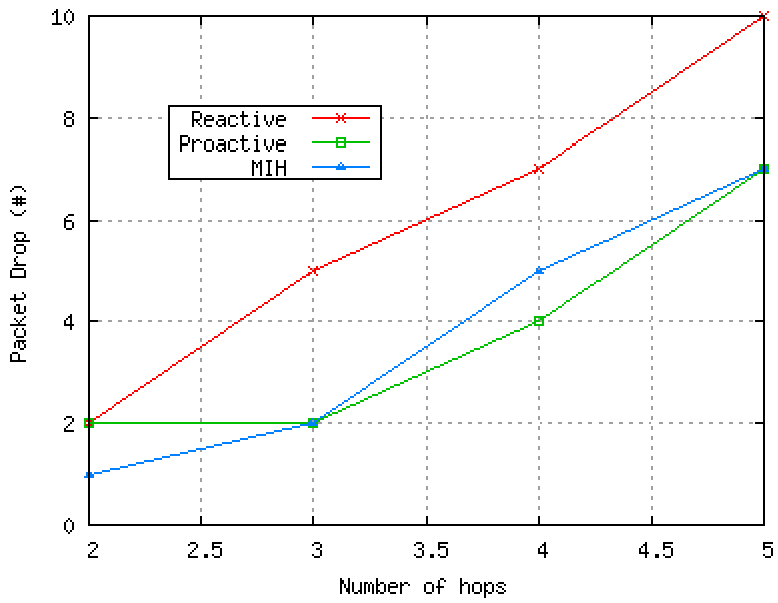


Figure 5.12: Packet Drops versus Number of hops

Finally, the receiver experienced delay is studied in Figure 5.13. The reported results are quite similar to the switching delay case. MIH outperforms both reactive and proactive discovery approaches and varies between 80ms to 460ms, for 2-hop to 5-hop scenarios, respectively. In contrast, proactive performs better than reactive, where reactive approach exhibits very high receiver (application) experienced delay.

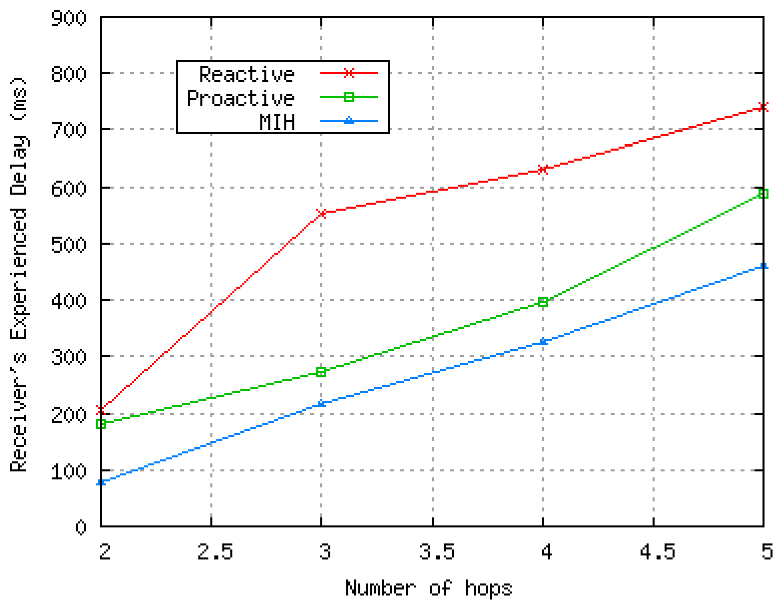


Figure 5.13: Receiver's Experienced Delay versus Number of hops

The end-to-end delay can be analysed by comparing switching delay and receiver experienced delay in Figure 5.11 and Figure 5.13, respectively. The receiver experienced delay is much higher than the switching delay, for instance, in case of MIH for 5 hops the receiver experienced delay is 460 ms, whereas the switching delay is only 100 ms. These results are quite understandable, as a certain delay is associated with every single hop added in the end-to-end route between the AP and the mobile node. This per hop delay increases the end-to-end delay experienced by each packet, while traversing from the mobile host to the Corresponding Node (CN). Moreover, the time to re-establish the end-to-end route, after handover takes place, also contributes in the increase of receiver experienced delay.

5.8 Conclusions

5.8.1 Summary

This chapter exposed a variety of techniques deemed to be vital in realizing the multi-hop seamless handover in the personal environments. IEEE 802.21 WG is developing Media Independent Handover (MIH) function which offers seamless handover across heterogeneous access networks. The existing MIH model only governs direct connectivity to the infrastructure components (such as base-stations) and handover between them. The proposed extension to MIH model enables seamless multi-hop handover in heterogeneous networking scenario. The developed model elaborates messages exchange to enhance the functionality of event, command and information service of MIH. This extension to MIH results in offering seamless experience to heterogeneous handover in both single and multi-hop networking scenarios.

In Section 5.1, a sufficiently concise introduction to the problem of multi-hop handover in personal environments has been given. IEEE 802.21 efforts towards seamless handover in heterogeneous have been described and the motivation to extend MIH model to work in heterogeneous multi-hop scenarios is presented.

In Section 5.2, a comprehensive study of related works is presented. It was highlighted that the problem of seamless multi-hop handover is relatively novel, and no seamless handover strategy adapted for multi-hop environments had been developed so far. All previous works on multi-hop networks were targeted to routing and gateway discovery and no sufficient attention is given to seamless handover problem. Following the notion of reuse, we motivate to extend 802.21 model for multi-hop handover; the benefit of distributed MIH model is presented and the direction to extend it has been given. The inferences drawn from this analysis helped to develop media independent seamless multi-hop handover model for personal environments.

Section 5.3 is the heart of this chapter as it presents the MIH extension for seamless multi-hop handover. The MIH architecture and communication model is presented, which is extended by a new reference model. This reference model introduces the communication channel between the nodes and not only between the network and the node. MIH event and command services are presented and possible enhancements are proposed, which enables multi-hop exchange of intelligent information with in the mobile network. The information service model proposed in 802.21 standard is further classified into local and global information service. A local information base is stored at each node, which contains the information about its neighbouring nodes and the resources available onto them.

Section 5.4 illustrates the example usage scenarios of the proposed 802.21 multi-hop model. The first scenario illustrates multi-hop MIH message exchange of the node, which is first connected to the 802.11 AP in one-hop, and then due to mobility, the initial link disconnects and it gets connected to another node, which relays its traffic towards another 802.11 AP in multi-hop manner. Multi-hop enabled 802.21 model guarantees seamless handover in this scenario. In the second scenario, the node notifies its QoS needs to the network, while in communication with a corresponding node in multi-hop manner. As soon as the network analyses that the required QoS demands are not met, it directs the node to handover to another route which meets the QoS needs. For both scenarios, the MIH multi-hop messages exchange is illustrated with the help of message sequence diagram.

Section 5.5 and 5.6 presents the simulation model and results, respectively. First, we develop an integrated multi-hop networking model for seamless handover, where the extended 802.21 is used for fast handover, MIPv6 is used for IP connection management and AODV+ is used for multi-hop gateway discovery and routing. The performance of MIH is compared with reactive and proactive gateway discovery mechanisms. Our simulation results show that MIH outperforms reactive and proactive discovery schemes in terms of switching delay and receiver's experienced delay. Whereas proactive scheme and MIH experiences almost similar number of packet drops during handover. Eventually, proactive scheme outperforms reactive discovery scheme; this is attributed to its periodic exchange of discovery and advertisement messages with the gateways.

5.8.2 Contributions

This chapter opens the way to seamless multi-hop handover strategies particularly for personal environments. To this end, the research contributions can be summarized as follows:

1. The problem of handover in multi-hop networks is analyzed and the motivations behind seamless multi-hop handover in personal environments are highlighted.

2. The MIH communication model is extended with a new reference point called R6, which triggers node to node communication channel.

3. An explicit multi-hop extension to MIH event and command services has been proposed.

4. The information service is further classified into local and global information service. The different networks related information is stored as a global information (as in classical 802.21 model), whereas the information related to neighbouring nodes and their connectivity is stored locally at each node in the network.

5. Two different usage scenarios for extended MIH model have been identified, such as seamless multi-hop handover and QoS-triggered handover.

6. A simulation model is developed, which identifies the basic components required to enable multi-hop seamless handover. These components include, fast handover scheme, multi-hop gateway discovery and routing protocol, and IP connection management scheme.

5.8.3 Future Research

Numerous questions and problems remain open in the field of seamless multi-hop handover. In this respect, the following topics are deemed to be worthwhile pursuing as future research:

1. <u>Heterogeneous Multi-hop Handover.</u> As the personal environment is composed of heterogeneous resources, it is desirable to analyze the exchange of event and command service messages between the nodes which are connected to the network on multi-hop heterogeneous interfaces. This is to study how one access network interpret the event/command generated by the other access network.

2. Heterogeneous Multi-hop Simulations. So far, we simulated only Wi-Fi network (both infrastructure and ad-hoc mode) for multi-hop handover. It is thus desirable to extend this simulation studies over multi-hop heterogeneous networks.

3. Integration Testing of Multi-hop Model. As the multi-hop seamless handover model is composed of routing/gateway discovery module, IP connection management scheme and fast handover component; the Interworking of these components should be analyzed, so that one component does not affect the performance of the other or the entire model.

4. Tight Coupling. Similarly, these components of multi-hop seamless handover model should be coupled tightly, aim at reducing the redundancy and duplicate exchange of similar information among nodes/network.

5. Control Overhead Evaluation. As the MIH-enabled nodes exchange periodic routing, handover and IP connection management information with each other and with the network, it is desirable to evaluate the associated control overhead in order to fine tune the different components of the multi-hop model such as MIPv6, AODV+ and MIH.

6. Multi-hop routing and Local IS. Local Information Service (IS) is stored at each node, which constitutes the information about routes to its neighbouring nodes and their available networks. This Local IS shares many similarities with the routing table of ad-hoc routing protocol. Therefore, it is needed to analyze how the routing protocol can be extended to form this location information base at each node.

7. New Usage Scenarios. Identification of further usage scenarios for multi-hop seamless handover model based on MIH is desirable.

Chapter 6

CONCLUDING REMARKS

The development of the modern day computer was the result of technological advancements and man's need to compute. In the beginning of the computing wave when computers were first introduced, they were quite huge in size and were generally referred as "mainframes" or "central data repository", linked to users through less powerful devices such as workstations. It was a general belief that these computing devices were specialized machines developed to fulfil specific high computational needs and were of no use for an ordinary user. However, this notion was totally wrong, as computers proved to be user-friendly and inexpensive, extendable to meet a large range of user needs. The later was an outcome of the emergence of Internet which glued together these so called "personal computers" and introduced the culture of cooperation, sharing, openness and trust. This tradition of convergence put together by Internet and its marriage with personal computers, gave birth to the personal computing paradigm. Personal computing age flourished faster than any other domain, connecting hundreds of millions of people all over the world making their work available for others on the global information village i.e. Internet. Thanks to the notion of cooperation added to the personal computers, personal computing is now dominating the entire computing industry.

In 1908, Nicola Tesla said "The wireless art offers greater possibilities than any invention or discovery heretofore made, and … we can expect with certitude that in the next few years wonders will be brought by its applications". Tesla's words are so true even today. Wireless communication is not less than a magic for someone who does not know its technical details. It has simply revolutionized the way we communicate today. It enables us to communicate anytime, anywhere in any form (data, voice …). However, wireless technology is not only limited to communication, it can offer much more than just a phone call. The limits of wireless communication are still unpredictable and unimaginable.

The father of radio communication Heinrich Hertz once said "I do not think that the wireless waves I have discovered will have any practical applications." The inventor of first wireless telegraph system Guglielmo Marconi said "Have I done the world good, or have I added a menace?" These early giants of wireless communications were not so sure about the usefulness of their work and were underestimating the power of wireless. They might have envisaged that without the essence of convergence and sharing, no technology can be economically and socially viable. The cooperation and resource sharing in wireless technologies is a key to discover a variety of unforeseen innovative applications.

During the last few years, we have experienced a tremendous upsurge at various dimensions of information and communication technologies ranging from software and hardware developments to wireless access technologies and networks. The user of today's communication arena is situated at the core of these diverse technologies, finding their way into the user's personal environment. Convergence of these technologies as a part of user's environment with the aim of offering personalised blended communication services in a simple and secure way, impose serious technical challenges. One of the key questions is as how to integrate these diverse and heterogeneous technologies as a unified platform in order to make different services simultaneously available to the user. In this thesis, we advocate the concept of personal environments as a glue to integrate technologies and networks together by offering seamless and ubiquitous access to the personalised blended services. Personal Ubiquitous Environments offer high degree of technological and social flexibility, infinite freedom of choice and cooperation among the users and a potential mega-revenue source for the industrial players to offer simultaneous integrated personal services.

It was the aim of this thesis to pose and answer many unsolved questions relating to the networking of personalised user environments. As with any scientific work, it has brought up more questions than it has solved, some of which are illuminated below. Before that, however, the contributions of the thesis are glued together to give a better picture of the choice of research conducted.

In this thesis, the concept of Personal Ubiquitous Environments (PUE) has been introduced which accommodates heterogeneous devices and access networks of different users and sustain the notion of cooperation and sharing of resources in a distributed manner. A prerequisite for achieving the resource (devices, networks) sharing in personal environments is the deployment of suitable communication protocols which establish secure and efficient multi-hop routes between the devices of the PUE. Personal Network Routing Protocol (PNRP) has been developed to perform policy based routing in personal environments. In certain personal networking scenarios, the infrastructure network components (i.e. gateways) are more than one-hop distance from the user device; Adaptive Distributed gateway Discovery (ADD) protocol is thereby proposed to efficiently discover the multi-hop routes towards the gateway in a totally distributed manner. Since the personal environments regroups heterogeneous access networks, an efficient mobility management architecture is proposed which offers unified location management and seamless handover experience to dynamic personal nodes. The seamless handover strategy based on IEEE's 802.21 standard is further extended to accommodate multi-hop handovers in personal ubiquitous environments. It has been demonstrated that the proposed routing and mobility management protocols yield significant performance gains, keeping the user transparency by making blended personalised resources simultaneously available to all users of the PUE.

Formation of PUEs with the help of proactive route establishment among the PN's personal nodes and on-demand policy based routing between different PNs, is the sole purpose of Chapter 2. The routing in PUEs is performed taking into account the rules and regulations (defined as a part of user profiles) of cooperation among different PUE users towards unifying PUE resources and offering seamless access to them. The proposed routing strategies are validated under simulated personal environment; the simulation results demonstrate the capabilities of our routing protocol to form and manage PUEs and to offer policy-enforced multi-hop connectivity among different personal nodes.

The routing protocol has then been extended to multi-hop discovery of the gateways in Chapter 3. Since, one of the most demanding resources in personal environments is the access to the infrastructure network such as Internet or cellular network; we pledged to design a gateway discovery protocol, which offers good multi-hop connectivity at minimal control overhead. The merits of the proposed distributed gateway discovery algorithm are its simplicity, bandwidth and power efficiency and good end-to-end connectivity. The distributed algorithm was assessed by means of numerous communication scenarios, all of which confirmed that significant gains in terms of control overhead, packet delivery and end-end delay when comparing to state of the art gateway discovery schemes.

In contrast to previous works, Chapter 4 was dedicated to mobility management strategies in Personal Ubiquitous Environment (PUE). The location management, handover and connection management technique, as a part of PUE Mobility Management (PUE-MM) architecture are proposed. The aim was to develop a unified architecture, while reusing the off-the-shelf standardized components for IP mobility such as IPv6 and seamless handover such as IEEE 802.21, to offer seamless global roaming in highly dynamic heterogeneous personal environments. The performance of the proposed architecture was assessed under different communication scenarios; the results prove that the PUE-MM improves the resource utilization and efficiently offers seamless interoperability in heterogeneous personal environments.

Our investigation into seamless handover goes further in Chapter 5 to expose a variety of techniques deemed to be vital in realising the multi-hop handover in personal environments. IEEE 802.21 developed Media Independent Handover (MIH) function for seamless handover across heterogeneous networks; we propose modifications to the existing standard so that it also accommodates multi-hop handover scenarios (intrinsic to personal environments). The aim was to make the nodes connect to the network (gateways) in multi-hop manner and quickly switch routes, as soon as a better route is available. This switching needs to be seamless with minimal QoS degradation. The assessment of our proposed 802.21 model confirms significant gains in terms of switching delay, packet drop and receiver's experienced delay when comparing to the reactive and proactive route establishment algorithms.

From this summary it is clear that research on routing and mobility management in personal environments is far from complete. The investigated routing protocol here considers single interface nodes, for instance, 802.11 in our simulations, which performs fraction of functionality needed to realise personal environments. The multi-interface case therefore needs to be considered, where each node have multiple heterogeneous interfaces, thus increasing the end-to-end throughput of the entire system. Moreover, dynamic policy engines over the routing algorithm need to be invoked, which is here accomplished by means of static policy profiles, i.e. PN-F profile and PN-F participation profiles, to efficiently govern the dynamic access control and real-time routing of data packets.

Gateway discovery algorithm is mainly responsible for finding the single/multiple hop route towards the fixed infrastructure network such as access-points or base-stations, for each personal node. The proposed gateway discovery protocol here adaptively discovers the route towards the gateway only and does not perform node to node routing. The hybrid routing protocol over distributed gateway discovery algorithm need to be developed, which learn end-end routes between different personal nodes connected to network gateways in single/multiple hop(s). Moreover, the proposed algorithm here forms distributed active regions, which are quite useful in case of highly dynamic network. Clearly, the herein introduced concept of active region is the bases for any further work on virtual group mobility models, where the active region is virtually associated with the active nodes in the network.

Of imminent practical interest is the further analysis of mobility management architecture for personal environments, under real-time test bed settings. Realistic networks have several integration issues, when different components are put together to propose a unified architecture. The mobility management components such as PUE formation, connection management, seamless handover, multi-hop gateway discovery and location management, desired to be tightly coupled, aim at reducing the redundancy and duplicate exchange of similar information among personal nodes/networks. Finally, the 802.21-based multi-hop seamless handover model needs to be extended to heterogeneous networking scenarios; Steps taken in Chapter 5 considers homogeneous interfaces i.e. 802.11, which performs a part of functionality needed to make personal environments really happen.

In conclusion, the ultimate purpose of this thesis was to positively contribute to the scientific knowledge; investigate several aspects relating to routing and mobility management in personal environments, and hopefully, to pose many questions that may catch the imagination of future researchers.

Chapter 7

RESUME DETAILLE DE LA THESE

7.1 Introduction

L'évolution des réseaux mobiles vers le B3G a permit de fourni un ensemble de fonctionnalités avancées et novatrices avec des services coopératifs, riches en contenu et personnalisés pour répondre aux besoins des utilisateurs [4]. Plusieurs aspects liés à la coopération et la personnalisation des services ont déjà vu le jour, par exemple, les communications interpersonnels (réseaux personnels), les réseaux de véhicule (appelé également Intelligent Transportation System), les réseaux communautaires ainsi que les réseaux maillés. Ces systèmes coopératifs bénéficient des plates-formes de convergence B3G qui ont démontré leurs performances en termes d'optimisation de l'utilisation de la bande passante, de couverture et de la disponibilité.

Les modèles de communication pour les réseaux personnels propulsent une multitude de nouveaux services qui tirent avantage des "nuages coopératifs" résultant de l'émergence des réseaux sociaux et communautaires [5]. Dans ce contexte, de nouveaux domaines d'application sont envisageable comme dans les réseaux domestiques (la maison digitale), et aussi pour la santé (Health care). Un exemple concret de service qui illustrera de tels concepts est la distribution coopérative de contenu multimédia dans des réseaux domestiques [6]. Un autre service qui exploite le comportement coopératif des réseaux incluent le partage de ressource dans des groupes de communauté (par exemple, un utilisateur partageant un contenu dynamique semblables aux services Web populaires comme MySpace ou YouTube).

Les réseaux de Transport Intelligent (ITS: Intelligent Transportation System) est également aussi un cadre intéressant pour fournir des services collaboratives. Un des services intéressant dans ce contexte est les jeux coopératifs entre voyageurs qui se trouvent dans le même réseau routier [7]. D'autres exemples de services incluent des services à base de localisation, comme le covoiturage et la publicité.

Les réseaux communautaires sans fil (commercial et public) ont atteint un stade assez mature grâce principalement aux avancées réalisées avec les techniques de réseaux maillés [12], qui ont atteint actuellement des performances intéressant avec la troisième génération. En effet, cette dernière a vu l'introduction de multiples-radios et des antennes directives, une gestion améliorée des interférences et des mécanismes de localisation etc. [9]. Cette évolution, couplée avec l'apparition de réseaux inter-communauté a donné de nouvelles perspectives aux services coopératifs dans des réseaux communautaires. Cela inclut des services comme IPTV (Internet Protocol Television) communautaire, la radio Web coopérative, la surveillance collective etc.

Comme on l'a présenté clairement ici, la coopération entre utilisateurs à grande échelle dans les réseaux B3G est sans doute un aspect important pour leur succès. C'est la motivation principale pour ce travail de recherche où on s'est intéressait à la conception et au développement de solutions et techniques pragmatiques qui permettront la mise en place des réseaux personnel coopératifs.

7.2 Les Réseaux Personnels

Le mariage du concept de «Personal Computer» avec le monde de réseau a donné naissance à une nouvelle ère appelé le « Ubiquitous Computing » [13]. On peut également voir ce domaine comme une sous partie des systèmes B3G. En effet, les réseaux B3G sont plutôt une plate-forme coopérative [1] où différent technologies de service et de réseau sans fil et filaire hétérogènes coexistent.

Dans ce contexte, le concept de « Personal Computer » est généralisé et étendu vers le Réseau Personnel « Personal Network (PN) » [19], développé principalement dans le cadre du projet IST MAGNET [20]. Un concept semblable est aussi en cours d'étude dans l'organisation de standardisation 3GPP au niveau du groupe de travail autonome PNM (Personnel Network Management) [91]. PNM cherche a développé des solutions qui facilite la gestion, la sécurisation et la communication entre des équipements avec des fonctionnalités hétérogènes, appartenant à un utilisateur unique (PN-User).

On définit un PN comme un réseau qui est possédé et exploité par une seule personne. Le PN-User est l'autorité unique dans son environnement personnel, il peut utiliser le PN comme il le souhaite. Les équipements personnels peuvent être localisés, soit dans son voisinage proche (Personal Area Network (PAN)) ou distants. La Figure 7.1 présentes un exemple concret d'un PN dont l'utilisateur est Bob. Il est composé des 3 clusters, à sa maison, dans son bureau et dans sa voiture. Le PN-User peut ajouter de nouveaux équipements et services dans son PN selon ses souhaits.

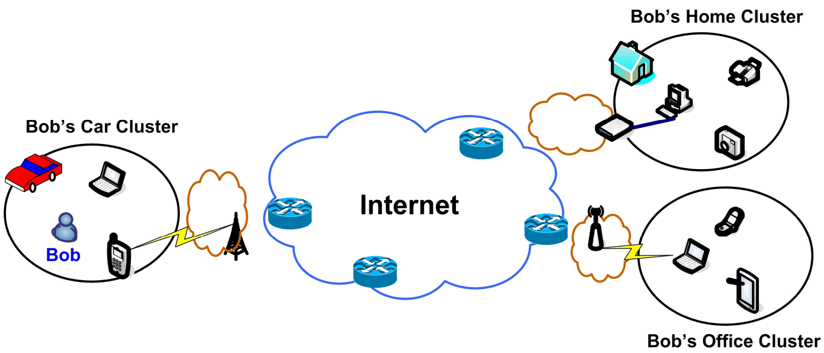


Figure 7.1: Réseau Personnel de Bob

D'un point de vue d'architecture, le PN pour son propriétaire est considéré comme un ensemble d'équipements offrant des services personnalisable, et vu comme une boîte noire au monde extérieur.

7.3 Fédération de Réseaux Personnels

Après avoir défini la notion de réseau personnel (PN) ou les équipements d'un seul utilisateur coopèrent entre eux pour la fourniture de services personnalisables. Il est question maintenant de voir comment projeter cette vision au niveau d'un groupe d'utilisateurs. En effet, La coopération de groupes (Fédération) est vue aussi comme étant la coopération entre des utilisateurs organisés dans des groupes.

En fait, les services dans les réseaux B3G qui peuvent être rendus disponible à un utilisateur unique sont potentiellement limités, les différents utilisateurs doivent coopérer les uns avec les autres pour étendre la fourniture des services. Ainsi, de nouvelles propositions doivent être développées pour étendre les frontières de la coopération des utilisateurs ayant des intérêts communs et faciliter l'interaction sécurisée pour le partage des ressources et services.

Ainsi, le concept de Fédération de Réseaux Personnels «Personal Network Federation (PN-F)» [18] a été récemment présenté comme une extension du concept de réseau personnel (PN). PN-F traite les interactions entre de multiples PN avec des intérêts communs. Une Fédération de PN peut être définie comme une relation de coopération spontanée et sécurisée entre un sous-ensemble d'équipements appartenant à des différents PN, dans le but est de réaliser un objectif ou de fournir un service commun, en formant un système de collaboration efficace. La Figure 7.2, montre un exemple simple de PN-F qui est la fédération des trois PNs appartenant à un groupe de 3 étudiants pur le partage de fichiers (cours par exemple).

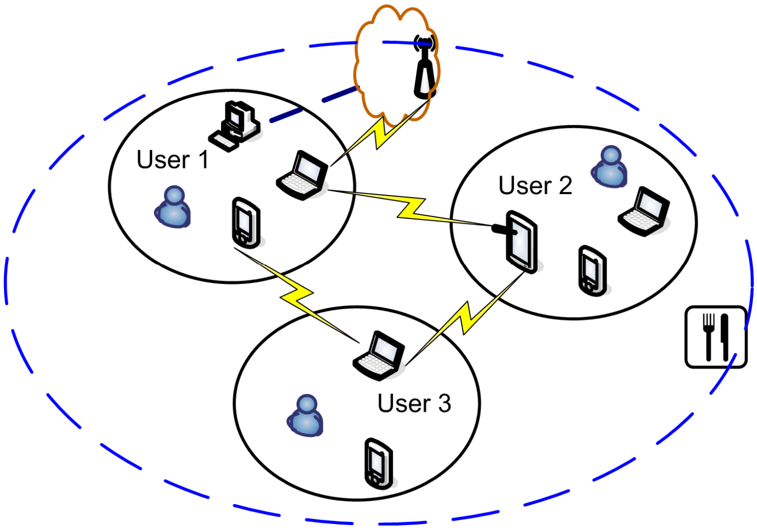


Figure 7.2: Federation de Réseaux Personnels

7.4 Personal Ubiquitous Environment (PUE)

La coopération entre les utilisateurs, leurs équipements et leur environnement résulte dans le développement d'un environnent ubiquité personnel « Personal Ubiquitous Environment (PUE) » autour de l'utilisateur, qui permet un accès global et simple à un nombre important et à une variété de ressources et de services [18] [20]. Ainsi, nous définissons le PN (le Réseau Personnel) et PN-F (Fédération de PN) comme un Environnement Ubiquité Personnel (PUE).

La Figure 7.3 mis en évidence le concept de PUE. Comme dans la Figure 7.3, trois utilisateurs se coopèrent pour partager des équipements, des services et des environnements pour former une fédération. Dance contexte, d'autres deux utilisateurs, satisfaits de leurs ressources propres, n'ont pas d'intention de coopérer dans une fédération; restant ainsi dans leurs environnements d'utilisateur (PN).

Le « Personal Ubiquitous Environment (PUE) » d'un utilisateur est constitué d'abord de ses ressources propres (équipements) et des services disponibles dans son Réseau Personnel (PN). L'utilisateur est l'autorité unique pour étendre son PUE (et former une PN-F) avec l'objectif est de rendre ses services et ses ressources disponibles à d'autres utilisateurs dans leur propres PNs. Généralement, un utilisateur participera dans des fédérations uniquement s'il est à la recherche d'un certain service/ressource que son PN (ou le PUE) ne peut offrir.

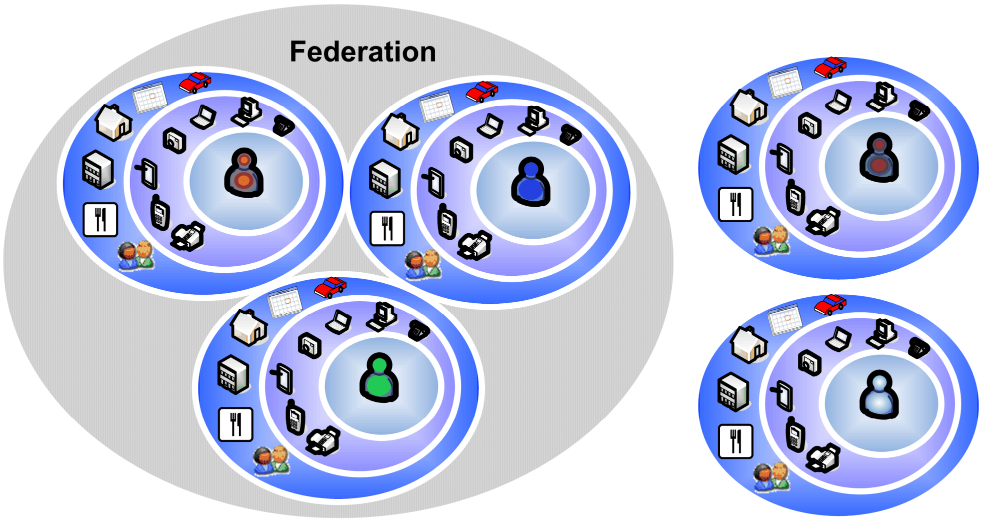


Figure 7.3: Personal Ubiquitous Environments

7.5 Contexte et Motivation

Les réseaux maillés multi-sauts ad hoc (MANET) ont suscité un intérêt important dans le monde de la recherche en raison de la prolifération des équipements sans fil, le besoin de l'auto-organisation et une demande croissante pour une connectivité sans couture (seamless connectivity). Les réseaux MANET sont étudiés dans le groupe de travail d'IETF [21], dont l'objectif est de proposer des solutions pour la mise en place des MANET, comme les protocoles de routage, l'adressage et la connectivité Internet.

Le « Personal Ubiquitous Environment (PUE) » est un type particulier de MANET dans lequel les nœuds des réseaux personnels sont connectés en multi-sauts. Très semblable à MANET, PUE peut fonctionner d'une façon autonome sans aucune infrastructure fixe, il peut également être connecté à un réseau avec infrastructure comme Internet. Le PUE est formé grâce à la collaboration de réseaux personnels où les nœuds mobiles sont responsables de découvrir l'arrivée et le départ d'autres nœuds dynamiquement. Comme MANET, PUE possède les propriétés d'auto-formation, auto-organisation et l'auto-maintenance, capable de gérer la mobilité, l'adressage et des mécanismes de routage.

Cependant, à l'opposé des réseaux MANET, PUE est construit autour d'un concept de confiance spécifique, traduit par des règles et des politiques de coopération. De plus, les PUE fonctionnent sur des réseaux hétérogènes, ce qui le différencie des réseaux MANET qui sont généralement homogène. En outre, le PUE possède une topologie spécifique de réseaux sans fil/filaires, géographiquement éloignés, et qui sont interconnectés via l'infrastructure fixée.

Autour du concept, nous étudions un certain nombre de problématiques à résoudre pour assurer la viabilité de ces réseaux. Ces problématiques sont la mobilité, le routage et l'interopérabilité, la définition de modèles de confiance et de coopération à base de politique, etc. Puisque le PUE est composé d'équipements appartenant à différents utilisateurs (PNs), qui coopèrent pour des objectifs tout à fait différents, le routage dans les PUE est un défis important qui drive la communication à base de règles de coopération. De plus, la mobilité dans PUE recouvre des dimensions multiples qui incluent, la mobilité des nœuds personnels hétérogènes, la mobilité des utilisateurs des PN et enfin la mobilité globale des nœuds et des membres de PUE. Ces besoins divers de mobilité couplés avec l'interaction à base de règle entre les nœuds de PUE, présentent clairement des contraintes et problématiques incontournable à considérer dans le cadre de ce travail.

7.6 Objectifs et Organisation de la Thèse

Le but de cette thèse est d'étudier et de proposer des mécanismes de routage et de gestion de mobilité efficaces dans les environnements personnels. Les mécanismes de routage dans PUE se recouvrent à plusieurs niveaux: le routage dans les nœuds PN (un seul utilisateur), le routage entre des nœuds de PN différents (des utilisateurs multiples) et le routage vers les l'infrastructure (la découverte des passerelles). Chacune de ces dimensions, couplées avec les caractéristiques inhérentes aux environnements personnels (comme la mobilité, l'hétérogénéité, privacy), révèlent les différents requis que le protocole de routage doit considérer. De plus, puisque les environnements personnels sont composés de ressources de diverses réseau; les mises à jour de localisation, le handover et des techniques de gestion de connectivité (network selection), particulièrement conçues pour PUE doivent être développés pour offrir une mobilité globale sans couture à travers ces réseaux hétérogènes.

Cette thèse est organisée comme suit. Dans le Chapitre 2, un ensemble de techniques considérées comme essentielles pour la connectivité entre les nœuds dans les environnements personnels sont détaillés. Le protocole de routage développé, PNRP, (Personal Network Routing Protocol) permet en outre de considérer les règles et les politiques nécessaires pour la coopération et l'établissement des routes et la communication PN à PN. Le Chapitre 3 traite le problème de découverte de passerelle dans PUE et présente le protocole ADD (Adaptive Distributed gateway Discovery). ADD est un protocole offre des avantages importants, avec une meilleure gestion de ressources en fonction des conditions du réseau. La solution a été validée par simulation et montre un gain considérable en surcoût (overhead) par rapport aux solutions actuelles. Le Chapitre 4 se focalise sur l'architecture de la gestion de mobilité dans

PUE (PUE-MM), l'objectif est d'offrir une expérience de communication ininterrompue dans des environnements personnels. Finalement, le Chapitre 5 présente une nouvelle solution pour permettre un handover multi-saut dans les environnements personnels à base des mécanismes du standard IEEE 802.21 MIH (Media Independent Handover). Il est à noter que chaque chapitre est conclu avec un résumé détaillé sur l'ensemble des résultats obtenus, les contributions de l'auteur et les perspectives futures.

7.7 Contributions Principales

7.7.1 Routage dans les Environnements Personnels

Dans notre première contribution, nous avons proposé PNRP (Personal Network Routing Protocol) qui est un protocole de routage dans les PN-F adapté au requis des environnements personnels. PNRP est un protocole hybride qui prend en compte les politiques de fédération/coopération entre les réseaux personnels.

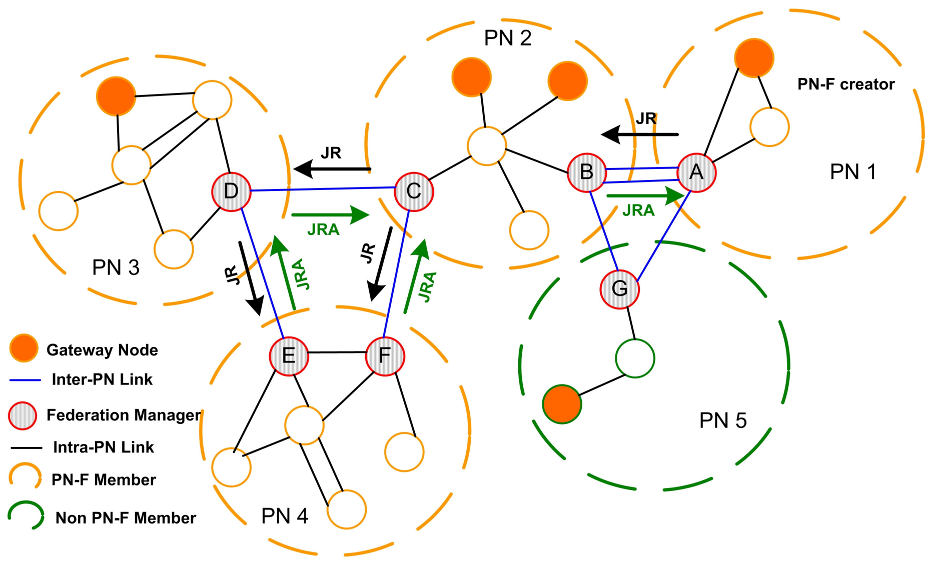


Figure 7.4: Découverte de la topologie PN-F

En effet, il maintient pro-activement la topologie du réseau au sein d'un PN au niveau de chaque nœud. De plus, Afin de faciliter l'accès au autres PNs et au monde extérieur, des informations sur les fonctionnalités des nœuds personnels comme, le Gateway Node (GN) ou le Federation Manager (FM) sont également véhiculés dans les messages de contrôle nécessaires pour la formation de la topologie du PN.

La formation de PN-F étant par définition "à la demande" est déclenchée par l'échange de profiles entre les PN. Une PN-F est créée par un PN, appelé PN-F creator, qui décrit les règles de base de la fédération et les membres potentiels du PN-F. Ces informations sur le PN-F sont intégrées dans le profile du PN-F. Le PN-F creator envoie ce profile initial aux membres potentiels de PN-F. Sur la réception du profile, si les membres initialement proposés décident de faire partie du PN-F, ils vont mettre à jour et échanger leurs profiles PN-F avec le PN-F creator. Ce profile de participation contient les conditions sur lesquelles le PN consent à participer au PN-F.

En conséquence, PNRP devrait permettre de déterminer à la demande les routes vers les membres du PN-F et également fournir les mécanismes nécessaires pour établir et maintenir cette fédération.

PNRP construit des routes utilisant les join request/reply messages entre les PN. Quand un PN lance le processus de création d'un PN-F avec les autres membres du PN-F. Il crée un profile de PN-F et l'envoie à son FM (Federation Manager), il l'intègre dans le Join-Request (JR) message, utilisant les routes inter-cluster (inter-PN). Comme le montre la Figure 7.4, pour créer un PN-F avec PN2, PN3 et PN4, Le PN1 (PN-F créateur) envoie le message JR à son FM. Le message JR contient deux listes de PN-IDS comme "la liste des destinations", qui stocke les participants potentiels au PN-F et "la listes des destinations visitées", qui représente le PN qui ont déjà reçu et transféré le message JR. Quand un FM reçoit le JR, il examine si le PN-ID de ses PN voisins est mentionné dans "la liste des destinations" du message JR. Si oui, le JR est transféré au PN voisin. Dans le cas contraire, si le FM ne trouve pas de PN adjacent dans la liste des destinations et le participant potentiel PNs n'est pas accessible par d'autre FM du même PN, "une Connected PN-F" peut être formée avec un PN adjacent qui servira de relais (bien qu'il ne participe pas dans la fédération) pour retransmettre les informations PN-F vers les autres membres potentiels du PN-F.

Sur la réception de message JR, Le FM d'un PN voisin d'abord supprime son PN-ID de "la liste des destinations" de JR et ensuite mis cette information dans "la liste des destinations visitées". De plus, il va mettre à jour la table de routage PN-F avec les informations de JR. Comme indiqué dans la Figure 7.4, le FM de PN1 (nœud A) transfère le JR au FM de PN2 (nœud B), qui mettra à jour la table de routage PN-F, c-à-d que PN1 est accessible par son FM (nœud B).

Dans cette première contribution, nous avons traité la problématique de formation de PUEs en utilisant un système de routage hybride, proactif entre les nœuds du PN couplé avec un routage à la demande à base de politiques entre les différent PNs. Le routage dans PUEs tient compte des politiques (définis comme partie de profile de l'utilisateur) de la coopération de différents utilisateurs de PUE, il permettra ainsi d'unifier les ressources de PUE et y facilitera l'accès. Les mécanismes de routage proposés sont validés par simulation; les résultats obtenus montrent l'intérêt de notre approche de routage pour former et contrôler efficacement les PUEs.

7.7.2 Découverte des Passerelles

Dans notre deuxième contribution nous proposons ADD, Adaptive Distributed gateway Discovery. C'est un protocole entièrement distribué pour la découverte de passerelles dans les réseaux multi-sauts. Cet algorithme est driver par le fait que les annonces périodiques des passerelles devraient être destinées uniquement aux nœuds, qui cherchent une passerelle (comme les sources actives de données); et que d'autres nœuds inactif ne devraient pas être inondés avec ces messages d'annonce périodiques.

À la différence d'autres mécanismes de découverte adaptatifs où l'adaptation est centralisée au niveau de la passerelle, ou une valeur unique de TTL est utilisée pour le tout le réseau, nous préconisons une approche totalement distribuée. En effet, la valeur de TTL pour les messages d'annonce est réajustée à chaque saut dans le réseau vers la source active de données de façon entièrement distribuée, pour couvrir toutes les sources avec un surcoût minimal.

Une fois que la route vers la passerelle est connue (la première fois, la recherche est fait par le nœud source de façon réactive), le nœud commence à envoyer ces données. Par une simple analyse de l'en-tête IP des paquets de données, la passerelle saura le nombre de sauts qui la séparent de chacune de ses sources actives. En se basant sur ces informations, une table "source_table" contenant les sources actives est construite au niveau de la passerelle. En plus, chaque nœud intermédiaire entre la source et la passerelle stocke aussi le nombre des sauts vers la source, c'est ainsi que le nœud source correspondant est marqué comme "actif" dans la table de routage du nœud intermédiaire. Il est à noté que ces informations sont réutilisées également dans la redécouverte de passerelle et la maintenance des routes pour les autres nœuds du réseau.

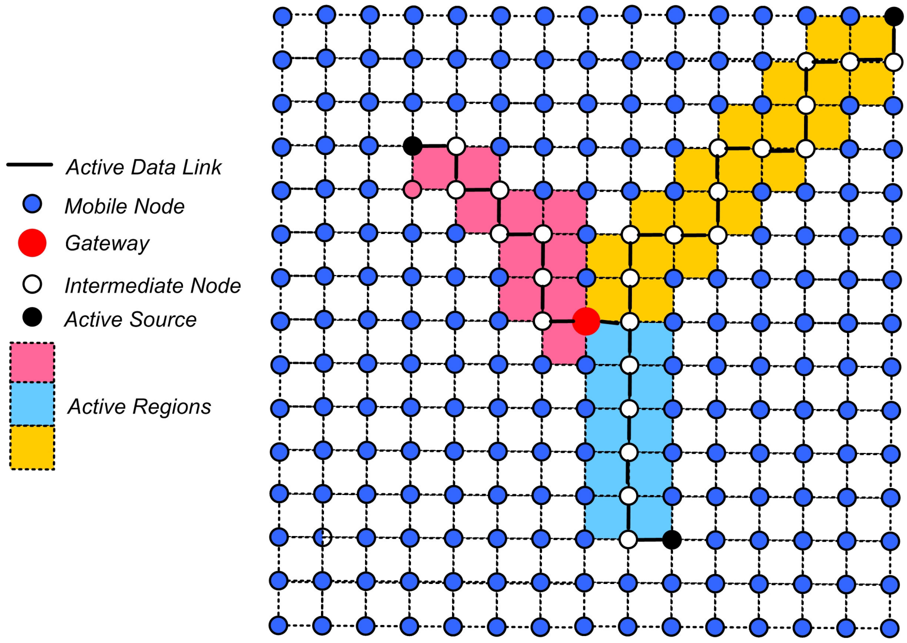


Figure 7.5: Découverte distribué des passerelles – ADD

L'annonce périodique des passerelles se fait en utilisant le message GWADV (Gateway Advertisement). Initialement, une passerelle envoie le message GWADV avec TTL=1. Sur la réception d'un message GWADV, chaque nœud vérifie si c'est un nœud intermédiaire. Pour ce faire, le nœud vérifie s'il est retransmet actuellement des données d'une source active vers la passerelle, si c'est le cas, il est alors un nœud intermédiaire, Il transfère donc le message GWADV plus loin avec un TTL=1, autrement il ne fait rien. Cette adaptation distribuée de découverte de passerelle assure que toutes les sources actives qui envoient des données vers la passerelle et sont intéressées à maintenir une route vers la passerelle, reçoivent le message GWADV. Les autres nœuds dans le réseau, qui ne sont pas intéressés par une route vers la passerelle, ne seront pas inondés par les messages GWADV. En conséquence, le nombre des paquets de contrôle envoyé sur les réseaux est significativement réduit. Ces mécanismes d'adaptation distribué pour la découverte de passerelle et la maintenance des routes est l'essence de notre protocole ADD. La Figure 7.5 montre clairement comment l'annonce d'une passerelle est diffusée dans le réseau de façon optimale, en ciblant uniquement les sources actives à un instant donné.

Dans cette contribution, nous avons proposé un protocole de découverte de passerelle distribué et adaptatif. De plus de sa simplicité, l'évaluation des performances conduite en utilisant de nombreux scénarios de simulations, a montré des gains significatifs en termes de surcoût, le nombre de paquets reçus et le délai de bout à bout, en comparaison avec les algorithmes existants de découverte de passerelle.

7.7.3 Architecture de Gestion de la Mobilité

Notre architecture de gestion de mobilité pour les PUE est présenté dans la Figure 7.6 Étant donné l'hétérogénéité des technologies d'accès dans les PUE, différents réseaux vont coexister (par exemple Wi-Fi, UMTS et DSL). Dans notre architecture, un des nœuds du PUE de l'utilisateur assurera le rôle de PUE Manager. C'est le point central de contact utilisé par l'utilisateur pour gérer son PUE. Le PUE Manager participe dans la gestion de la mobilité et la décision de sélection de réseau en remontant des informations sur l'état des ressources dans le PUE. Dans cette architecture, différents réseaux sont intégrés via un nouveau mécanisme appelé ULM (Unified Location Manager, Figure 7.6). ULM stocke les mises à jour des localisations des différents nœuds du PUE. En plus, ULM participe aussi dans le processus de sélection de réseau entre deux entité dans différent PUE.

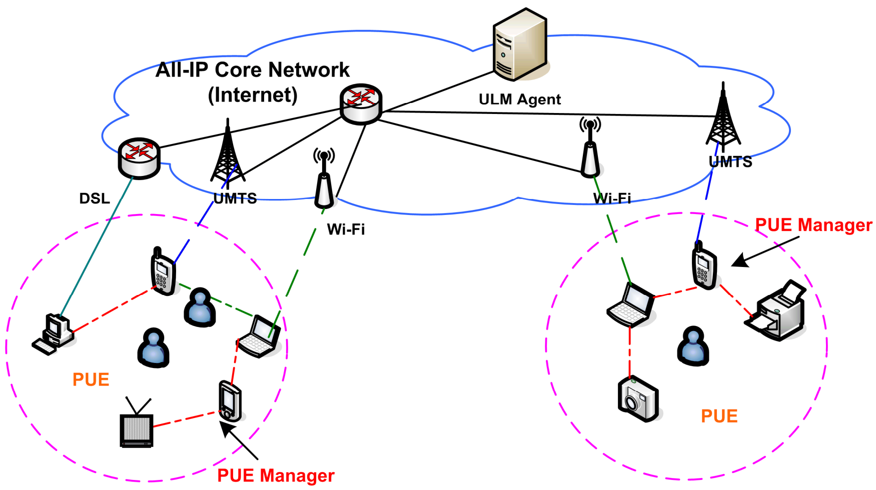


Figure 7.6: Architecture de gestion de la mobilité – PUE

Ainsi, notre architecture de gestion de mobilité offre la flexibilité nécessaire pour gérer plusieurs utilisateurs avec différent accès hétérogènes.

En pratique, l'architecture utilise IP comme un protocole d'interconnexion commun pour s'affranchir de l'hétérogénéité de réseaux l'accès dans le PUE. Nous préconisons également l'utilisation de Mobile IP (MIP) pour la gestion des connexions IP, et les fonctions de MIH (Media Independent Handover) basées sur le standard 802.21 [55] pour accélérer le processus du handover sans couture.

Dans cette contribution, nous avons focalisé sur les mécanismes de la gestion de mobilité dans les PUE (Personal Ubiquitous Environment). Les performances de l'architecture proposée ont été évaluées sous différents scénarios de simulations; les résultats montrent que le PUE-MM améliore substantiellement l'utilisation de ressource et offre l'interopérabilité nécessaire dans les environnements personnels hétérogènes.

7.7.4 Handover Multi-Saut sans Couture « Seamless »

Le concept de PUE permet aux utilisateurs de se déplacer librement entre des réseaux différents tout en assurant une continuité au niveau du service. Toutefois, comme discuté dans le Chapitre 4, la gestion de mobilité dans des réseaux hétérogènes est un problème important et des handover fréquents introduit des délais et des pertes des paquets considérables. Dans notre architecture de gestion de mobilité, une expérience de handover sans couture est assurée avec l'utilisation de Media Independent Handover (MIH), ce dernier permet en effet de fournir des handover rapides dans des réseaux d'accès hétérogènes. Cependant, MIH est principalement développé pour des scénarios à un saut "client- serveur" et non applicable pour le modèle de connectivité multi-saut, comme nous pouvons l'observer dans des environnements personnels. Avec les augmentations observées de la latence et la perte de paquets, la connectivité/handover multi-saut hétérogène vers des réseaux avec infrastructure imposent d'importants défis notamment au niveau des performances des applications. Ainsi, un handover multi-saut (sans couture) doit être développé, qui étend les procédures de handover intelligentes à un saut vers le multi-saut pour garantir la continuité de service pendant des handover fréquentes (un saut /multi-saut).

Notre avons étendu notre solution pour « seamless handover » dans le chapitre 5. Nous avons exposé une variété de techniques considérées pour être essentielle pour réaliser le handover multi-saut dans les environnements personnels. Nous proposons en effet des extensions de la fonction « Media Independent handover » (MIH) de la norme IEEE 802.21 de sorte qu'elle s'adapte également aux scénarios multi-sauts (intrinsèques aux environnements personnels). Le but était de faire que les nœuds soient connectés au réseau (passerelle) en multi-sauts avec des routes dynamique. Le changement de route en cas de handover doit d'effectuer avec un minimum de dégradation en QoS.

L'évaluation de note extension multi-sauts du 802.21 montre des gains significatifs en termes de temps de changement de route, le délai et le taux de perte de paquets en comparaison aux algorithmes réactifs et proactifs existants.

7.8 Conclusions et Perspectives

Il est clair que la recherche sur le routage et la gestion de la mobilité dans les environnements personnels est loin d'être un domaine mature, et que pleine de piste reste à creuser. En effet, les travaux entamés dans cette thèse devraient être complétés par d'autres travaux afin d'optimiser les performances des solutions proposées.

Sur le protocole de routage PNRP, bien qu'il supporte l'hétérogénéité des technologies, les simulations ont été faites avec des nœuds ayant une seule interface 802.11. Le cas de multi-interface est clairement intéressant à considérer, où chaque nœud dispose de plusieurs interfaces hétérogènes. Par ailleurs, la mise en place de moteur dynamiques de politique au-dessus de l'algorithme de routage est également à étudier pour refléter plus fidèlement des mécanismes de contrôle d'accès qui évoluent dans le temps. Dans notre étude on se limite à des politique et des profiles statiques de, e.g. le Profile de PN-F et le profile de participation de PN-F.

Notre algorithme de découverte de passerelle a les facultés de distribution et de l'adaptation aux conditions du réseau. Il forme des régions actives, où la région active est virtuellement associée aux nœuds actifs dans le réseau, ce qui rend notre protocole très adapté pour les réseaux fortement dynamiques. Néanmoins, il reste indépendant du protocole de routage. Une interaction entre le protocole de routage et le protocole de découverte est à développer,

Une analyse poussée et pratique avec des plateformes de test de notre architecture de gestion de mobilité est également une piste à entreprendre. Un déploiement réel de telle solution d'architecture unifiée sur des technologies hétérogènes soulève plusieurs problématiques d'intégration.

Les composants de gestion de mobilité tels que la formation de PUE, le routage,, la « seamless handover », et la gestion de la localisation, conçus pour être étroitement accouplé, afin de réduire la redondance dans les échanges entre des nœuds/réseaux personnels. Egalement, notre solution de handover multi-sauts à base du 802.21 doit être étendue aux scénarios hétérogènes. Dans notre étude (chapitre 5), nous avons considéré uniquement des interfaces homogènes, 802.11.

En conclusion, dans cette thèse, plusieurs aspects autour des réseaux personnels ont été développés, et des solutions, pour le routage et la gestion de mobilité dans les environnements personnels ont été proposées. Elle a également soulevé d'autres questions qui ouvrent de nouvelles perspectives de recherche.

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Routage et Gestion de la Mobilité dans les Réseaux Personnels

Résumé :

L'objectif de cette thèse est d'étudier des méthodes et des stratégies efficaces pour le routage et la gestion de la mobilité dans le cadre des réseaux personnels. Dans un premier temps, nous proposons le cadre de nos études: Personal Ubiquitous Environments (PUE). Un PUE est constitué d'un ensemble d'utilisateurs ayant des terminaux disposant d'interfaces réseau hétérogènes, et dont l'objectif est de mettre en œuvre des mécanismes de coopération et de partage des ressources de manière totalement distribuée. Dans ce cadre, la thèse a proposé des solutions innovantes contribuant à améliorer la communication inter et intra réseau personnels. La première contribution porte sur le protocole PNRP (Personal Network Routing Protocol) dont le but est de développer un routage à base de politiques (policy-based routing) pour les environnements personnels. La seconde, intitulée ADD (Adaptive Distributed gateway Discovery), est un mécanisme totalement distribué pour la découverte de multiples chemins vers une passerelle vers un réseau opéré. De plus, étant donné que ces environnements sont hétérogènes par leurs compositions (réseaux d'accès, terminaux ...), une architecture de gestion de la mobilité qui permet une gestion unifiée de la localisation et de la mobilité sans coutures appliquant l'ensemble des nœuds a également été traitée. Les résultats d'évaluation par simulation démontrent l'applicabilité et l'efficacité des ces protocoles.

Mots-clés: Réseaux Personnels, Routage Multi-saut, Découverte Distribuée de Passerelle, 802.21, Handover Multi-saut, Selection de Réseau de bout-en-bout.

Routing and Mobility Management Strategies in Personal Networking Environments

Abstract :

The aim of this thesis is to investigate methods and strategies for efficient routing and mobility management in personal environments. The concept of Personal Ubiquitous Environments (PUE) is introduced which accommodates heterogeneous devices and access networks of different users and sustain the notion of sharing resources in a distributed manner. A prerequisite for achieving the resource (devices, networks) sharing in personal environments is the deployment of suitable communication protocols which establish efficient multi-hop routes betweens the devices of the PUE. Personal Network Routing Protocol (PNRP) has been developed to perform policy-based routing in personal environments. Moreover, in certain personal networking scenarios, the infrastructure network components (i.e. gateways) are more than one-hop distance from the user's devices; Adaptive Distributed gateway Discovery (ADD) protocol is thereby proposed to efficiently discover the multi-hop routes towards the gateway in a totally distributed manner. All the more, since the personal environments regroups heterogeneous access networks, an efficient mobility management architecture is proposed which offers unified location management and seamless handover experience to dynamic personal nodes. The proposed protocols are assessed by means of numerous communication scenarios; the simulation results demonstrate the applicability of the proposed protocols.

Keywords: Personal Networks, Multi-hop Routing, Distributed Gateway Discovery, 802.21, Multi-hop Handover, End-to-End Network Selection.