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Prise de décision de handover vertical pour la gestion de mobilité dans les réseaux hétérogènes sans fil

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Abstract

Mobility management over heterogeneous wireless networks is becoming a major interest area as new technologies and services continue to proliferate within the wireless networking market. In this context, seamless mobility is considered to be crucial for ubiquitous computing. Service providers aim to increase the revenue and to improve users' satisfaction. However there are still many technical and architectural challenges to overcome before achieving the required interoperability and coexistence of heterogeneous wireless access networks.

Indeed, the context of wireless networks is offering multiple and heterogeneous technologies (e.g. 2G to 4G, WiFi, Wimax, TETRA,...).
On the one hand, this rich environment allows users to take profit from different capacities and coverage characteristics. Indeed, this diversity can provide users with high flexibility and allow them to seamlessly connect at any time and any where to the access technology that best fits their requirements. Additionally, cooperation between these different technologies can provide higher efficiency in the usage of the scarce wireless resources offering more economic systems for network providers.

On the other hand, the heterogeneity of technologies and architectures and the multiplication of networks and service providers creates a complex environment where cooperation becomes challenging at different levels including and not limited to mobility management, radio resource provisioning, Quality of Service and security guarantees.
This thesis is focusing on mobility management and mainly on decision making for Vertical Handover within heterogeneous wireless network environments.

After the analysis of the related state of the art, we first propose a reputation based approach that allows fast vertical handover decision making. A decision making scheme is then built on that approach. Network's reputation, is a new metric that can be gathered from previous users' experiences in the networks. We show that it is an efficient construct to speed up the vertical handover decision making thanks to anticipation functionalities.

While the main objective remains guaranteeing the best Quality of Service and optimal radio resource utilization, economical aspects have also to be considered including cost minimization for users and revenue maximization for network providers.
For this aim, we propose, in the second part of the thesis, a game theoretic based scheme that allows maximizing benefits for both networks and users. In this solution, each available network plays a Stackelberg game with a finite set of users, while users are playing a Nash game among themselves to share the limited radio resources. A Nash equilibrium point, that maximizes the user's utility and the service provider revenue, is found and used for admission control and vertical handover decision making. The analyses of the optimal bandwidth prices and the revenue at the equilibrium point show that there are some possible policies to use according to user's requirements in terms of QoS and to network capacities. For instance, we pointed out that networks having same capacities and different reputation values should charge users with different prices which makes reputation management very important to attract users and maximize networks' revenue.

In the third part of this thesis, we provide and discuss two different architectural and implementation solutions on which our proposed vertical handover decision mechanisms can be integrated. The first proposed architecture is a centralized one. It is based on the IEEE 802.21 standard to which some extensions are proposed. The second proposed architecture is distributed. It is based on an overlay control level composed of two virtualization layers able to make reasoning on behalf of physical entities within the system. This architecture allows higher flexibility especially for loosely coupled interconnected networks.

Key words: Heterogeneous wireless networks, mobility management, vertical handover, fast vertical handover, game theory, reputation based systems.

Résumé

L'évolution des technologies réseaux sans fil, des terminaux mobiles ainsi que des contenus et des services créent des environnements hétérogènes de plus en plus complexes. Dans ce contexte, un compromis entre la mobilité, la transparence et la performance apparaît.
Les utilisateurs mobiles, ayant différents profils et préférences, voudraient être toujours connectés au meilleur réseau à tout moment, sans avoir à se soucier des différentes transitions entre réseaux hétérogènes.
Face à cette complexité, il parait nécessaire de proposer de nouvelles approches afin de rendre ces systèmes plus autonomes et de rendre les décisions de handover vertical plus efficaces.
Cette thèse se concentre sur la gestion de mobilité verticale, plus précisément sur la prise de décision de handover vertical dans un environnements de réseau hétérogènes sans fil.

Après l'identification des différents paramètres de prise de décision et l'analyse de l'état de l'art relié à la gestion de la mobilité verticale, nous avons proposé un système de réputation qui permet de réduire les délais de prise de décision. La réputation d'un réseau est introduite comme une nouvelle métrique de prise de décision qui peut être recueillie à partir des expériences précédentes des utilisateurs sur ce réseau. Nous montrons que la réputation est une métrique efficace qui permet l'anticipation du handover et accélère la prise de décision.
Bien que l'objectif principal soit de garantir la meilleure qualité de service et l'utilisation optimale des ressources radios, les aspects économiques doivent également être considérés, y compris la minimisation des coûts pour les utilisateurs et la maximisation des revenus pour les fournisseurs de services ou les operateurs.
Nous proposons alors, dans la deuxième partie de la thèse, un mécanisme de prise de décision basé sur la théorie des jeux. Ce dernier permet la maximisation des utilités des réseaux et des utilisateurs.
Dans cette solution, chaque réseau disponible joue un jeu de Stackelberg avec un ensemble d'utilisateurs, tandis que les utilisateurs jouent un jeu de Nash entre eux pour partager les ressources radios limitées.
Un point d'équilibre de Nash, qui maximise l'utilité de l'utilisateur et les revenus des fournisseurs de services, est trouvé et utilisé pour le contrôle d'admission et la prise de décision

de handover vertical.
□ans la troisi□me partie de cette th□se, nous proposons et discutons deux diff□rentes solutions architecturales sur lesquelles nos m□canismes de prise de d□cision propos□s peuvent □tre int□gr□s.
□a premi□re architecture propos□e est bas□e sur la norme IEEE □□2.2□ □laquelle nous proposons certaines extensions.
□a seconde architecture propos□e est bas□e sur un niveau de contr□le compos□de deux couches de virtualisation. □a virtualisation est assur□e via des agents capables de faire un raisonnement et de prendre des d□cisions pour le compte d'entit□s physiques qu'ils repr□sentent au sein du syst□me. □ette architecture permet une plus grande flexibili□.

Mots clés: r□seaux h□t□rog□nes san fil, gestion de mobilit□, prise de d□cision, handover vertical, th□orie des jeux, syst□mes de r□putation.

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□□□t□□ts

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□□st □□□ab□□s

Glossary

2G	Second Generation
3G	Third Generation
3GPP	3rd Generation Partnership Project
ABC	Always Best Connected
ACL	Agent Communication Language
AHP	Analytic Hierarchy Process
AP	Access Point
API	Application Program Interface
BER	Bit Error Rate
BS	Base Station
CDMA	Code Division Multiple Access
CDPD	Cellular Digital Packet Data
CN	Correspondent Node
CoA	Care-of-Address
EDGE	Enhanced Data Rate for Global Evolution
FIS	Fuzzy Inference System
FLC	Fuzzy Logic Control
GGSN	Gateway GPRS Support Node
GI	Generalized Identifier
GPRS	General Packet Radio Service
GRA	Grey Relational Analysis
GRC	Grey Relational Coefficient
GSM	Global System for Mobile Communications

□□□	Horizontal Handover
□□	Host Identity
□□□	Host Identity Protocol
□□	Home Network
□□□□	Institute of Electrical and Electronics Engineers
□□□□	Internet Engineering Task Force
□□□□	Location Independent Network Architecture for IPv6
□A□□	Multiple Attributes Decision Making
□A□□	Mobile Assisted Handover
□□□□	Mobile Controlled Handover
□□□	Markov Decision Process
□□□□	Modified Elman Neural Network
□□□	Multiplicative Exponent Weighting
□□□□	Media Independent Command Service
□□□□	Media Independent Event Service
□□□	Media Independent Handover
□□□□	Media Independent Handover Function
□□□□	Media Independent Handover User
□□□□	Media Independent Information Service
□□	Mobile Terminal
□A□□	Network Assisted Handover
□□□□□	Network Controlled Handover
□□	Nash Equilibrium
□□	Neural network
□□□	Overlay Reputation Manager
□□□	Quality of Service
□A□	User Service Identity Module
□□□	Received Signal Strength

SAW	Simple Additive Weighting
SCTP	Stream Control Transmission Protocol
SGSN	Serving GPRS Support Node
SINR	Signal-to-Interferences plus Noise Ratio
SIP	Session Initiation Protocol
TN	Target Network
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
UBPC	Utility-Based Power Control
UMTS	Universal Mobile Telecommunications System
USIM	User Service Identity Module
VHME	Vertical Handover Management Engine
VHO	Vertical Handover
WLAN	Wireless Local Area Networks
WMAN	Wireless Metropolitan Area Networks
WMC	Weighted Markov Chain
WPAN	Wireless Personal Area Networks
WWAN	Wireless Wide Area Networks

Chapter 1

Introduction

1.1 Introduction

The evolution of the Internet and the advances in wireless access networks and devices have made a tremendous impact on people lifestyles around the world. Wireless services have seen increasing demands since the introduction of cellular communications in the early 80's.
Since then, cellular networks have evolved through 1G (Cellular Digital Packet Data (CDPD)), 2G (Global System for Mobile Communications (GSM) data), 2.5G (General Packet Radio Service (GPRS)), 2.75G (Enhanced Data Rate for Global Evolution (EDGE)) to 3G (Universal Mobile Telecommunications System (UMTS)) and have provided data rates from the 9.6 kbps of CDPD and GSM to the 2 Mbps rate of UMTS.
The first generation (1G) mobile systems started with cellular systems using analog transmissions. It was primarily designed for low voice services and low data rate communications [1]. The 1G standard considered horizontal handover specifications and allowed Mobile Terminals (MTs) to hand over to the Base station (BS) that received the highest signal from this mobile. By the end of the 80's, the analog cellular communication framework was no more able to handle the increasing demands of wireless communications.
The second generation (2G) was then introduced using digital technology for wireless communications and offering voice as well as low bit rate data services. The architecture of the 2G system was similar to the 1G system but it used the medium in higher efficiency and increased the capacity of the network by the deployment of smaller cells. In addition, mobile-assisted handover was introduced in 2G networks and allowed MTs to sense the surrounding BS signals and initiate a handover.
The 2.5 generation has then seen the light as an extension of the 2G systems. It provided circuit switching for voice services and packet switching for data transmissions. It was essentially considered as a bridge between the 2G and the third generation (3G).

In response to the increasing demand for multimedia wireless services, □G was proposed as a first step towards the broadband wireless communications. The primary goal of □G networks was to incorporate Internet access and video telephony. Nowadays, it offers high data rate services, high medium utili□ation efficiency and supports different service classes.

Nowadays, it is widely agreed that no single technology is able to meet the known and

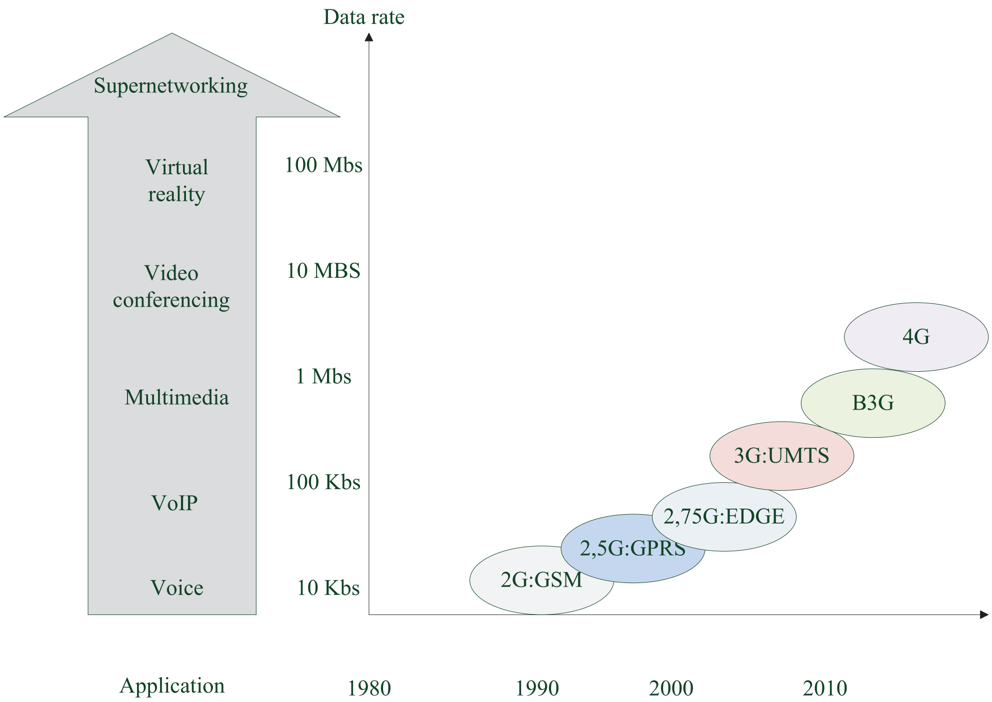


Figure □.□□Evolution of wireless networks □□□

the future challenges in the telecommunication domain. At the contrary, the research community considers that future solutions will be based on the coexistence of multiple heterogeneous technologies. In the context of heterogeneous wireless networks we do not have a set of formally agreed end-to-end standards developed in the traditional top-down way that the telecommunications industry has used for years □□□. In heterogeneous wireless networks we are subject to multiple air interfaces and various mobile terminals with multihoming capabilities. Heterogeneous wireless networks are intended to provide mobile users with an Always □est □onnected (A□□) facility, good Quality of Service (QoS), high bandwidth and low cost. It is based around five main elements to offer a personali□ed and pervasive network to the users□availability at any time and anywhere, seamless mobility, affordable cost, uniform billing and convergence of networks, technologies and services.

Heterogeneous wireless networks may incorporate Wireless □ocal Area Networks (W□AN), Wireless □ersonal Area Networks (W□AN), Wireless Metropolitan Area Networks (WMAN) and Wireless Wide Area Networks (WWAN) including cellular networks and satellite. The main promise of these heterogeneous networks is to provide high performances by achieving high data rate and supporting video telephony, streaming and multicasting with high QoS. The characteristics of these different networks are illustrated in figure [illegible]2.

Network	Standard	Data rate	Frequency band
Cellular networks	UMTS. 3G.	Up to 2 Mbps	1990-2025 MHZ
	4G	100 Mbit/s (high speed) 1 Gbit/s (stationnary conditions)	
WLAN	IEEE 802.11b	1-11 Mbps	2.4 GHz
	IEEE 802.11n	100-540 Mbps	2.4 GHz, 5GHz
Wireless Personal Area Networks (WPAN)	IEEE 802.15.3	11-55 Mbps	2.4 GHz
Zigbee	IEEE 802.15.4	20-250 Mbps	868 Mhz, 915 Mhz
Wireless Metropolitan Area Networks (WMAN)	IEEE 802.16.a	75 Mbps	2-11 Ghz
WiMAX	IEEE 802.16c	134 Mbps	10-66 Ghz
Wireless Wide Area Networks (WWAN)	IEEE 802.20	2.25 - 18 Mbps	3.5 Ghz

Figure [illegible]2 Existing wireless technologies [illegible].

[illegible] Motivations and challenges

Integrating heterogeneous wireless network invokes many technical challenges that should be faced to ensure good QoS and service continuity and to satisfy user's preference while moving through different networks with different characteristics.

In this vision, many technical issues including seamless vertical handover, good QoS, mobility management, authentication, security, resource management and pricing should be considered.

Mobility management is at the core of the whole system design and requires an efficient integration of the heterogeneous wireless access networks and services. The design and the implementation of efficient mobility protocols and decision solutions is hence compulsory to insure sessions' transfer from one access network to another and to support multihoming.

Mobility management can be split into several subtopics, namely *mobility and interworking scenarios, handover decision metrics and mobility parameters, handover decision mechanisms, handover performance measures and mobility protocols*. Thus, to achieve seamless

mobility, the system design has to particularly consider the vertical handover process which combines these subtopics. This process is critical and calls for high efficiency and low delays to ensure seamlessness while switching from one access network to another. To achieve this goals , an appropriate vertical handover decision mechanism that considers services' requirements, users' preferences, terminals' capabilities as well as location information and networks' capacities should be adopted.
From the services' requirements aspect one has to find a balance to ensure good QoS with data privacy and information integrity, on the one hand, and guarantee efficient resource allocation while considering terminals' capabilities and networks' capacities on the other hand.
In this vision, an efficient context discovery should be driven to collect information about different actors implied in the mobility management process. For instance, a user profile should be established to define his preferred networks and networks' parameters should be collected to find the appropriate radio access technology a mobile user should connect to, according to his running class of service and to his preferences. The context discovery may be realized either on the terminal side or on the network side, or on both of them.
A good and efficient interworking architecture is also required in this field to make sure of getting advantages of the combination of all heterogeneous technologies and avoid their standalone weakness. For instance, a low-cost and high-data rate may be provided by a service provider through the integration of WLAN/WiMAX that may be an extension of a cellular network.

1.3 Mobility Management and Vertical Handover Considerations

1.3.1 Definitions

Horizontal Handover

The Horizontal Handover (HHO) or intra-technology handover is performed when a MT switches its connection between access points or base stations belonging to the same wireless access technology. Generally, this kind of handover is only based on the network's received signal strength and channels availability.

Vertical handover

The Vertical Handover (VHO) or inter-technology handover is performed between heterogeneous networks. In this case, the networks involved in the handover process implement different technologies and have different characteristics. In the literature, two main classifications concern the VHO:

- Upward and Downward VHO [□□]: Upward VHO is performed while moving from a small coverage and high data rate network to a wider coverage and lower data rate network. A Downward VHO occurs in the opposite direction.
- Imperative and Alternative VHO [□]: Imperative VHO occurs due to low link quality detection. In this case, the handover decision and execution must be as fast as possible to avoid applications' disconnections. Other VHOs that occur to provide users with better quality of service or lower cost are considered as alternative handover. The latter can tolerate longer handover latency. Fig. □.□ presents the difference between imperative and alternative VHO.

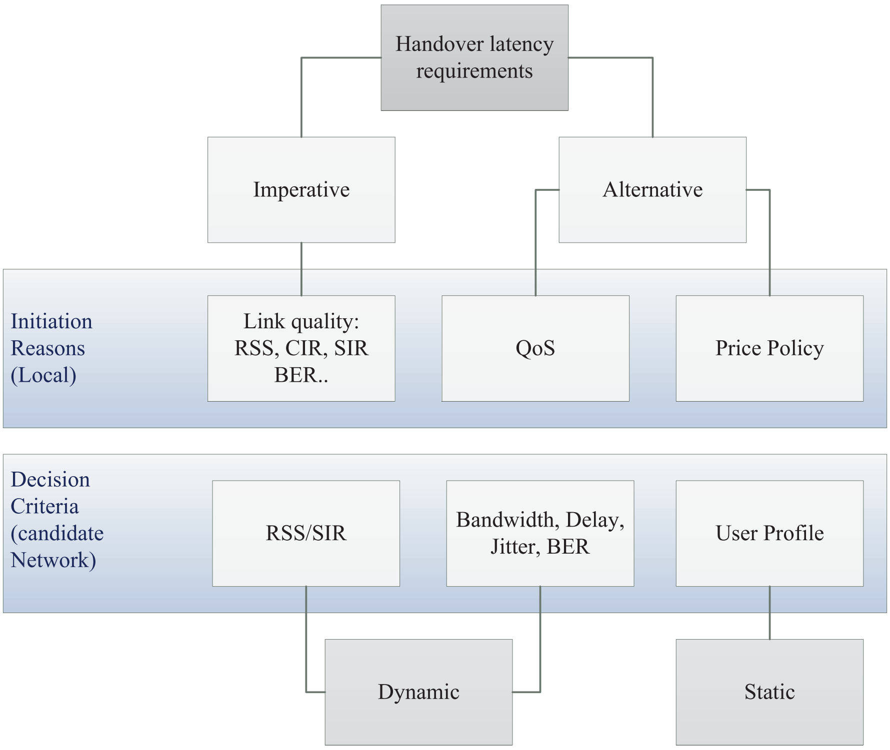


Figure □.□: Imperative and alternative vertical handover

Micro mobility

Micro mobility refers to mobility between different networks belonging to the same administrative domain. It is also known as intra-domain mobility.

Macro Mobility

Macro mobility (inter-domain mobility) refers to mobility between different administrative domains. It is global and independent of underlying mechanisms such as routing protocols, link layer access techniques, and security architectures.

Vertical Handover Process Overview

The VHO process has to evaluate context information (related to mobile devices and their capabilities, application requirements in term of QoS, network coverage and capacities as well as user's location and preferences) to decide whether a handover is required or not. The process is also responsible of the selection of the best suitable network to which we should handover. Required adaptations to apply at the service level to maintain the ongoing connection QoS is also a concern. This process is generally described in three main steps [illegible], namely, system discovery, handover decision, and handover execution.

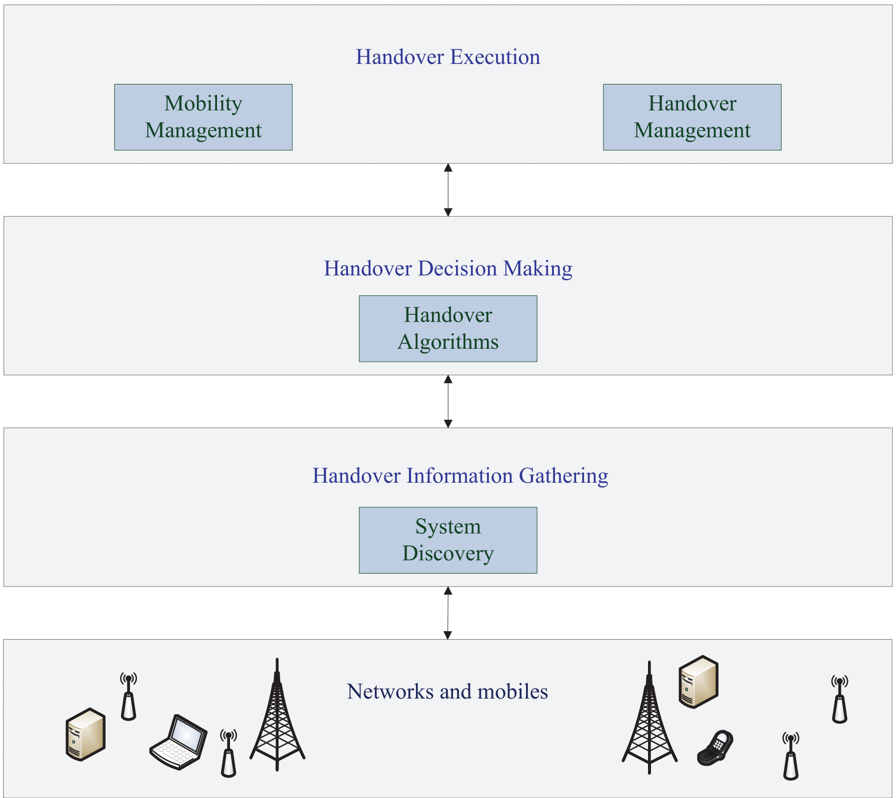


Figure 1.4: Vertical Handover Process

System Discovery

During the system discovery, also called *vertical handover information gathering*, the system periodically checks for a more suitable available network to which a mobile terminal can be handed over. In some cases, the discovery process may be initiated only when the current network is no more able to handle the ongoing connection, meaning that the radio conditions and/or the QoS are decreasing below a certain defined threshold. In other cases, the discovery process continuously collects indicators about QoS and available networks to provide the VHO algorithm with the necessary data required to make decisions during the handover selection step.

Handover Decision

The VHO decision making is a process during which the available wireless access networks are evaluated. The outcome of this process is the selection of a network to which a mobile terminal should be handed over while considering the criteria gathered during the system discovery phase. While standards do not detail decision algorithms, many proposals are available in the literature. The complexity and the reliability of these algorithms depend on the availability and the dynamicity of their considered criteria.

Handover Execution

This is the last phase in any handover procedure where signaling messages are exchanged to reroute the user call from one network to another. The handover is executed based on a preplanned approach and has to take into consideration the implementation issues.

Vertical Handover Management

Different approaches may be considered to manage the handover execution. Indeed, a handover may be characterized as *hard* or *soft* handover. IP mobility solutions relate the terminology to network layer phenomenon such as packet latency and packet loss. In this case, a handover may be characterized as *fast*, *smooth*, *seamless* and *lossless* handover.

A *hard* handover is also known as a *break-before-make* handover. It is a handover for which the connection with the target network is established only when the connection with the current network is totally released. In other words, a mobile node is allowed to be connected to only one point of attachment at any given time.

A *soft* handover is also called a *make-before-break* handover. In this kind of handover, the connection with the current network is not released till the connection with the target network is established. In other words, the connection in the current network is retained and used for a while in parallel with the connection in the target network.

Lossless handover means that no packets are lost while making the handover. *Fast* handover refers to low packet latency that's why it is also called *low-latency* handover. *Smooth* handover is a handover with a minimum packet loss and *seamless* handover means that the transition to a new point of attachment is transparent to the user, it is the combination of fast and smooth handover.

Regardless of the mobility scenario and the handover type, four handover control strategies may be considered to manage the handover execution phase as well as the handover decision phase.

Network-Controlled Handover (NCHO) is initiated and controlled by the network, a resolution that is usually adopted by operators for load balancing and traffic management.

Mobile-Controlled Handover (MCHO) is initiated and controlled by the mobile device. It is generally used in □□2.□□technologies where mobile nodes permanently measure the signal of available access points and initiate the handover when needed.

Mobile-Assisted Handover (MAHO) is adopted mainly in wide area wireless networks where a mobile node monitors the signals of available base stations and the network decides whether or not to make a handover.

Network-Assisted Handover (NAHO) is performed when the network collects information that can be used by the MT in a handover decision.

Figure □.□gives a view on the different aspects related to Vertical Handover management in heterogeneous wireless access networks. It summari□es different information from other sections, as follows□

- Mobility scenarios are given in section □.□.□
- Handover Types and handover control methodologies are described in section □.□.□
- Mobility □rotocols are provided in section 2.□2.
- Handover Algorithms are described in section 2.4.2.
- Handover decision criteria are summari□ed in section 2.4.□
- Handover □erformance Metrics are given in section 2.4.□

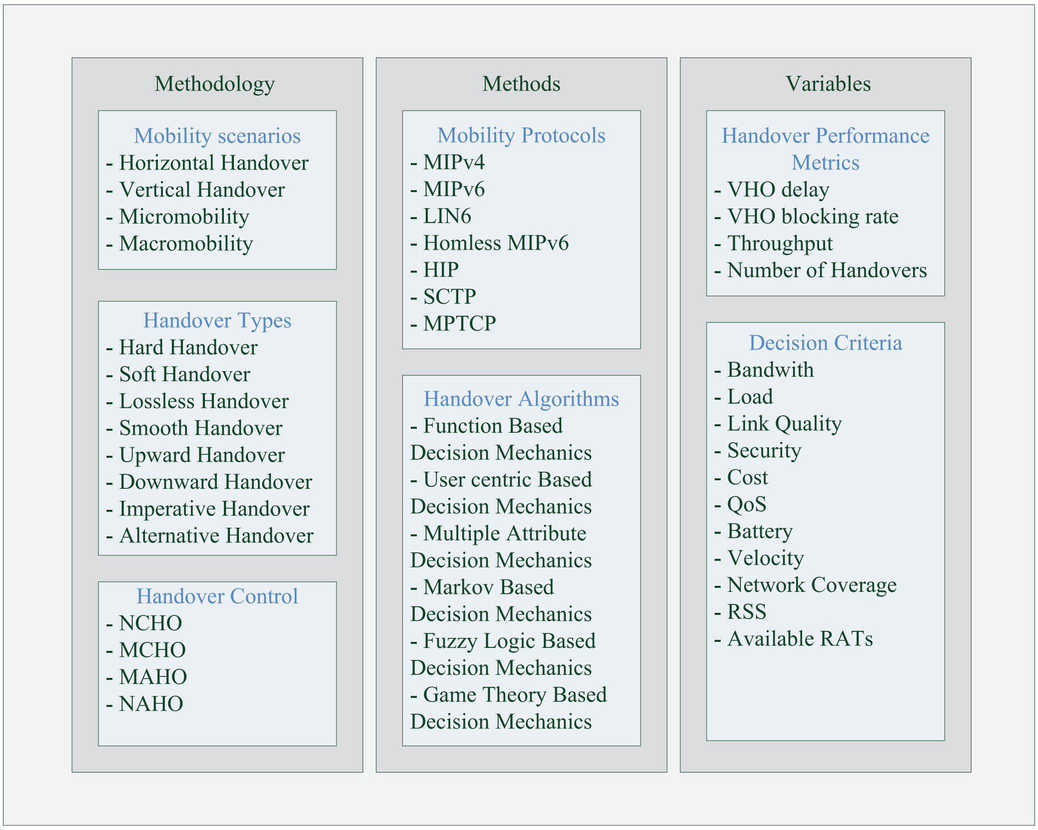


Figure [illegible] Vertical handover management in Heterogeneous Networks

1.4 Thesis contributions

The first contribution in this thesis aims to provide a new VHO decision metric to speed up vertical handover (VHO) decisions in complex heterogeneous wireless environments. We propose a Reputation system that computes global reputation values for each network. Reputation is conducted from previous users' experiences. It is based on simplified rating functions reflecting contextual QoS.
Then we propose a vertical handover decision making scheme based on the computed reputation values and we show that this new algorithm reduces vertical handover latency and provides good performances.

While the main objective remains guaranteeing the best Quality of Service and optimal radio resource utilization, economical aspects have also to be considered including cost minimization for users and revenue maximization for network providers.
Thus, in our second contribution, we consider both technical and economical aspects to address vertical handover and pricing issues in heterogeneous wireless networks. We propose a game theoretic scheme where each available network plays a Stackelberg game with a finite

set of users, while users are playing a Nash game among themselves to share the limited radio resources. A Nash equilibrium point is found and used for vertical handover decision making and admission control.

In addition to networks' reputation, we introduce in the proposed model user's requirements in terms of quality of service according to the running application and other decision parameters, namely, available bandwidth and networks' prices. Then, we study the effect of these parameters on the network pricing and the revenue maximization problems.

In the third contribution architectural aspects are considered. We propose two solutions on which the proposed VHO decision algorithms may be integrated and discuss the main issues related to energy consumption and reputation trust. The first one is based on the IEEE 802.21 standard that enables a multihomed mobile node to get information on its neighboring access networks from any single active interface, which considerably saves the mobile node energy consumption.
The second proposed solution is a virtualization agent based overlay solution that is integrated into an existing two-layered virtualization overlay architecture using software agents.

Outline of the thesis

• ***Chapter I: Introduction***
This chapter outlines the motivation and the scope of the work.
• ***Chapter II: State of the Art***
This chapter introduces interworking in heterogeneous networks. It also tackles the VHO decision making and presents an overview on the most interesting existing vertical handover mechanisms and mobility protocols. In addition, it provides some comparative analysis based on performance and complexity criteria.
• ***Chapter III: On the use of Network Reputation for Vertical Handover Decision Making***
The first part of this chapter introduces the use of Networks' reputation as a new subjective metric that relies on previous users' experience and observations in similar contexts to minimize vertical handover latency and provide good throughput. It proposes a reputation system that computes a global reputation value for each network. The second part of the chapter provides a VHO decision mechanism based on the already computed reputation values. Reputation is introduced as an already experienced satisfaction reflector and is integrated as a relevant construct in vertical handover decision mechanisms within complex networking environments.
• ***Chapter IV: A Nash Stackelberg Approach for Network Pricing and VHO Decision Mak-***

ing

This chapter models the VHO problem as an hierarchical game among heterogeneous available networks and multiple users running various services and having different requirements. It addresses both technical and economical aspects as it deals with vertical handover and pricing issues in heterogeneous wireless networks. This chapter proposes a scheme where each available network plays a Stackelberg game with users to maximize the service provider revenue, while these latter are playing a Nash game among them selves to maximize their utilities. The obtained equilibrium point is then used for vertical handover decision making and admission control.

• ***Chapter V: Architectural and Implementation Solutions***

In this chapter, we focus on the architectural and implementation issues related to the VHO decision making. We provide and discuss two different solutions on which our vertical handover decision mechanism, provided in chapter □, can be integrated.

The first proposed architecture is a centralized one. It is based on the IEEE 802.21 standard to which some extensions are proposed. The second proposed architecture is distributed. It is based on an overlay control level composed of two virtualization layers able to make reasoning on behalf of physical entities within the system. This architecture allows higher flexibility especially for loosely coupled interconnected networks.

Important issues are discussed, mainly trust and energy consumption considerations are discussed in both proposals.

Chapter [illegible]

State of the art

[illegible] Introduction

Wireless networks, applications and devices have been undergoing a breathtaking evolution over the last decade. A single wireless technology is thus no more efficient to provide mobile users with high data rate and good QoS, every where.
Indeed, to answer the increasing demand of mobile users, next generation wireless systems are relaying on heterogeneous wireless networks allowing the users to be connected at any time and anywhere.
Several issues related to the heterogeneity of such a wireless environment should be addressed, namely, vertical handover, mobility and multihoming management, resource allocation, security, pricing and high QoS support.
The major requirements, in this context, is the ability to hand over the user's session or call as he (she) travels across different wireless access technologies. The process by which a user gets handed over from one wireless network to another is called vertical handover.

Traditionally, the handover process has been studied among access points (AP) or networks using the same access technology. This process, denoted by the horizontal handover, is mainly based on the Received Signal Strength (RSS).
With the emergence of a multitude of overlapping wireless networks, Mobile Terminals (MTs) have to switch their connections between different access technologies offering different capabilities and characteristics. In this case, the handover process is more complex and is denoted by vertical handover.
To acheive efficient VHO, the network state, the application requirements and the MT resources should be continuously tracked and many VHO decision criteria should be collected. In a heterogeneous environment, this is very challenging and difficult to achieve. Indeed, a plethora of access networks have to be inter-connected in an optimal manner such that the

users can be *always best connected* (ABC) .
To meet the ABC requirements, different vertical handover decision mechanisms and mobility management protocols have been proposed in the literature.
In this chapter, we introduce interworking in heterogeneous networks, we summarize the most interesting existing vertical handover mechanisms and mobility protocols and we provide some comparative analysis based on these mechanisms performances and the complexity of their adopted criteria.

2.1 Interworking in heterogeneous networks

Interworking heterogeneous wireless technologies means connecting two or more distinct access networks to achieve seamless mobility. Each of these technologies has its advantages and its limitations. Thus, allowing mobile users to switch among different integrated technologies would be advantageous to be always best connected according to their own preferences and to the ambient conditions. The attention of the research community and standardization bodies has been mainly caught by the interworking between 3GPP and WLAN which may be classified into loose and tight coupling architectures.

In a loosely coupled system, the 3GPP and WLAN networks remain autonomous domains. They may share a common Authentication, Authorization and Accounting (AAA) server but data flows don't go through the Gateway GPRS Support Node (GGSN) or Serving GPRS Support Node (SGSN) core network of UMTS. In tightly coupled integration, the WLAN access points are connected to the SGSN and behaves like a node B (i.e., a 3G base station). These integration methods may also be applied to interconnect WiMAX with 3GPP networks. In consequence, the integration of WiMAX and 3G/UMTS may be considered as equivalent to that of WLAN and 3G/UMTS.

2.1.1 Loose coupling architectures

In the loose coupling architecture, the networks remain independent and provide independent services [illegible]. In this scheme, the interworking point is after the interface of the Gateway GPRS Support Node (GGSN) and Mobile IP is used to provide mobility between WLAN, WiMAX, and 3G/UMTS networks [12]. This approach requires the introduction of WLAN and Wimax interconnection gateways to handle billing and authentication for roaming services. In this vision, the WLAN and WiMAX may be considered as complementary to the 3G/UMTS network. However, their data flows do not go throughout the 3G/UMTS core network. Furthermore, the WLAN and WiMAX networks may be owned by a third party, with

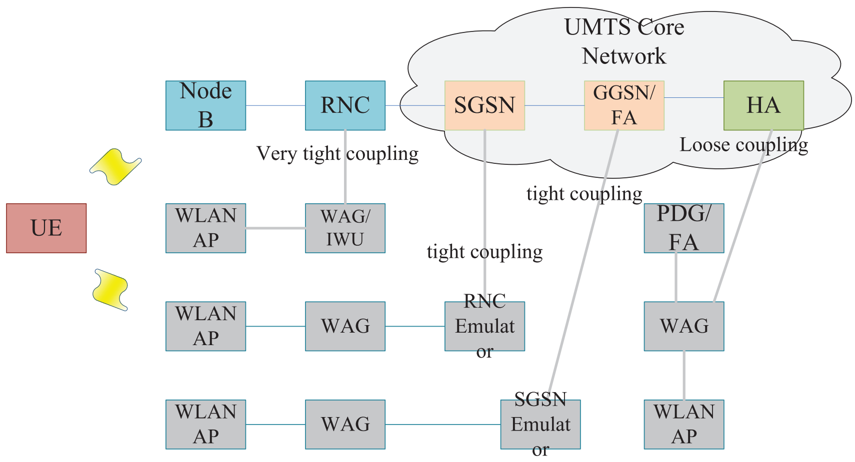


Figure 2.□□□MTS-W□AN interworking approaches

roaming and mobility enabled via dedicated connections between the □G□□ network and the W□AN or WiMA□, or over an existing public network, such as Internet □□□. The basic loose coupling interworking architecture between W□AN and □MTS is depicted in Figure 2.2. The W□AN and □MTS are assumed to be in different I□ address domains.

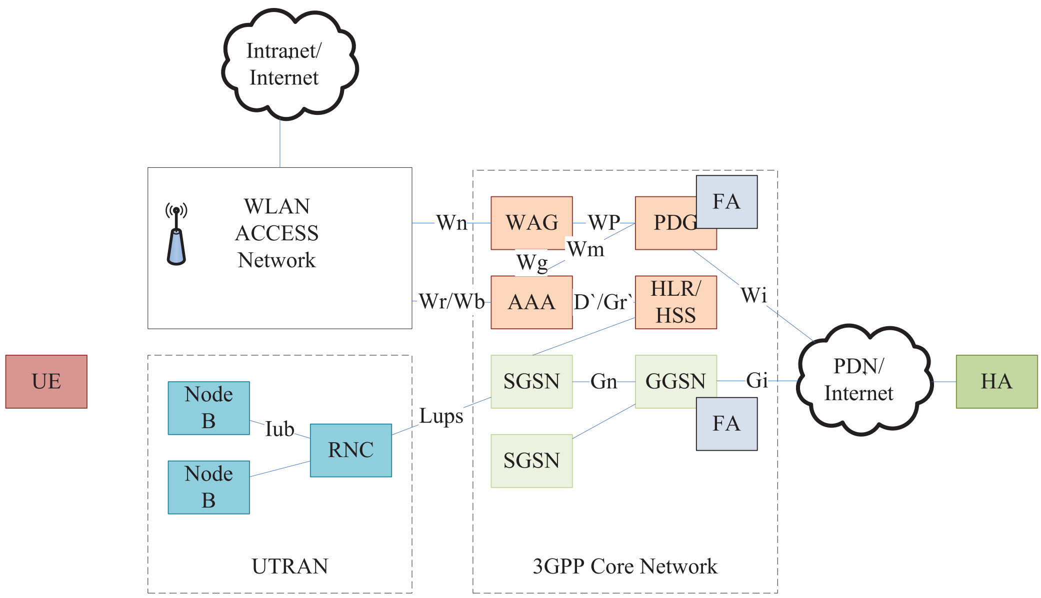


Figure 2.2□□□MTS-W□AN loose coupling approach

□oose coupling integration approach has several advantages. For instance, it allows independent deployment and traffic engineering of W□AN, WiMA□ and □G networks and can be simply adapted to the existing communication systems □□□, □2□which enables □G operators to take advantage of other W□AN or WiMA□ providers by minimi□ing the deployments efforts and investments.

In this vision, mobile subscribers may get profit of having only one service provider for all network access technologies based on some roaming agreements to avoid having different accounts with different providers in different regions [illegible]. They may also use their User Service Identity Module (USIM) card to access services over the WLAN or WiMAX networks [illegible].

Tight coupling architectures

With the tight coupling approach, the WLAN and the WiMAX network are connected with the 3G/UMTS core network and operate as virtual Radio Access Networks (RANs) that are able to execute 3G RAN available functions. WLAN and WiMax gateways are introduced to hide these networks' details to the 3G/UMTS core network and to achieve integration while implementing all the 3G required protocols (mobility management, authentication, etc). In this vision, unlike in the loose coupling scheme, the data traffic of WLAN and WiMAX networks' users goes through the 3G/UMTS core network before reaching the Internet or other IP networks. In this scheme, the interworking of the WLAN and the WiMAX networks with the 3G/UMTS is made at the core network level (i.e., GGSN or SGSN) or at the access network level (i.e., RNC) of UMTS [illegible].
In the first case, as defined in the interworking reference model architecture depicted in figure 2.[illegible], the RNC/SGSN emulators provide equivalent functionalities to those of an RNC/SGSN in order to hide WLAN particularities from the UMTS. In the second case, it is a very tight coupling and the WLAN is considered as a part of the UMTS Terrestrial Radio Access Network (UTRAN).
In this interworking scheme, the ownership of the WLAN is one of the most important issues. An envisioned resolution is that the 3GPP operator owns the WLAN part. Very tight coupling also requires the introduction of an InterWorking Unit (IWU) between the WLAN APs and the RNC for scalability issues. It should be implemented in the WLAN AP to either act as a pure traffic concentrator or be further responsible for control and supervision functionality.
Tight coupling architectures enable the support of integrated authentication, accounting and network management. However, several modification and adaptation in the integrated networks' protocols and interfaces should be performed in tight coupling architectures to support the interworking requirements. That's why it is considered as more complex than the loose coupling approach.
Indeed, the injection of the WLAN and WiMAX networks traffic into the 3G/UMTS core network directly affects the setup of the entire network and requires not only several extensions in SGSN and GGSN nodes but also new network elements' configuration and design.

2.3 Vertical handover and standardization (3GPP, IEEE, IETF)

To construct efficient vertical mobility solutions,many aspects have been considered, within standardization bodies, including convergence, cooperation, interoperability, integration and interworking...
Several approaches have been proposed at different layers of the ISO/OSI reference model.

2.3.1 3GPP related activities

Regarding heterogeneity, the 3GPP is mainly focusing on the interworking between 3GPP Systems and WLANs at different levels. In [4], six different scenarios of 3GPP-WLAN interworking, are given.
-*Scenario 1:* Common billing and customer care
-*Scenario 2:* 3GPP system-based access control and charging
-*Scenario 3:* Access to 3GPP system packet-switched services
-*Scenario 4:* Service continuity
-*Scenario 5:* Seamless services
-*Scenario 6:* Access to 3GPP circuit-switched services
These scenarios deal with systematic increase of network integration, starting from simple 3G/WLAN interworking with common billing and customer care (loose coupling) to letting access to 3GPP system packet-switched services over WLAN (very tight coupling). Figure 2.[illegible] summarizes the main characteristics of each scenario. The 3GPP/WLAN system integration framework also deals with other important features such as interworking security aspects and charging management.

2.3.2 IEEE related activities

Within the IEEE, two working groups are dealing with vertical handover and heterogeneous network cooperation.

IEEE 802.21

the main proposal of this working group [illegible] is the Media Independent Handover (MIH) standard to support seamless mobility. The group proposes a new MIH Function (MIHF) to be integrated as a new logical entity between layer 2 and upper layers in the protocol stack. The main task of this MIHF is to assist the vertical handover decision making by providing the required information to the mobility management entities. It provides three main services:

Scenarios:	Loose	Loose	Loose	Tight	Very tight	Very tight
Service & operational capabilities:	Scen.1: Common Billing & Customer Care	Scen.2: 3GPP system based access control & charging	Scen.3: Access to 3GPP system PS based services	Scen.4: Service continuity	Scen.5: Seamless services	Scen.6: Access to 3GPP system CS based services
Common billing	♦	♦	♦	♦	♦	♦
Common customer care	♦	♦	♦	♦	♦	♦
3GPP system based Access Control		♦	♦	♦	♦	♦
3GPP system based Access Charging		♦	♦	♦	♦	♦
Access to 3GPP system PS based services from WLAN			♦	♦	♦	♦
Service Continuity				♦	♦	♦
Seamless Service Continuity					♦	♦
Access to 3GPP system CS based services with seamless mobility						♦

Figure 2.□□W□AN□□G interworking scenarios defined within □G□□ □2□

Media Independent Event Service (MIES), Media Independent □ommand Service (MI□S) and Media Independent Information Service (MIIS) . These services are, respectively, responsible of a) reporting dynamic changes in link conditions and quality, b) enabling MIH users to manage and control parameters related to link operation and c) gathering static information about the characteristics of the current network and other available networks. Figure 2.4 illustrates the IEEE □□2.2□general reference model.

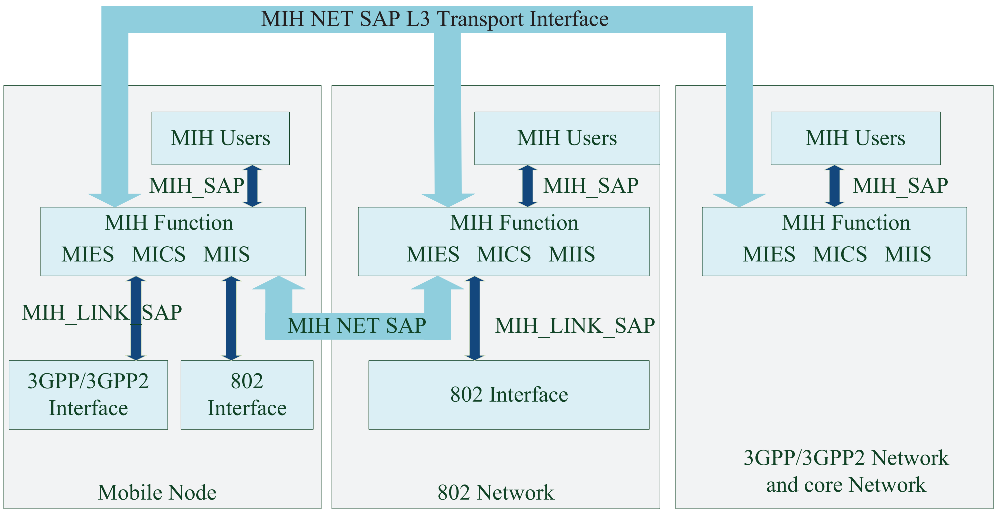


Figure 2.4□IEEE □□2.2□general reference model

[illegible]

This standard describes architectural building blocks including network and device resource managers and exchanged information between these building blocks. It enables network-device distributed decision making for optimized radio resource management in heterogeneous wireless access networks. Initially, the standard was limited to the architectural and functional definitions [illegible]. Then it tackled policies [illegible] and protocols definition associated with interoperability and information exchange over heterogeneous wireless networks [illegible]. The purpose of this standard is to improve the overall capacity and quality of wireless services based on information exchange between networks and mobile terminals under the simultaneous coverage of multiple radio access technologies.

[illegible] IETF related activities

The main focus of IETF in the context of heterogeneous integration is on the Network Layer (L3) and above. The IETF Working Group "Mobility for IPv4" dealt with system integration in the sense of macro mobility support [illegible] and mobility for IPv6 [illegible]. Mobile IP, allows a node to keep using its permanent home address as it moves. It supports transparency above the IP layer, including active TCP connections' preservation and UDP port bindings. The Mobile IP procedure is also referred to as L3 handover. In addition to the basic Mobile IP protocols, the IETF is working on several other drafts dealing with optimization, security, extensions, Authentication, Authorization, Accounting (AAA) support and deployment issues.

2.4 Vertical handover in the literature

The research community has been making considerable efforts towards the convergence of heterogeneous wireless access networks technologies. As a result, there are different proposals in the literature that addressed mobility scenarios in heterogeneous networks, protocols, vertical handover techniques and algorithms, metrics, and procedures. In this section, we mainly focus on the vertical handover decision making. In section 2.4.1 we provide a summary of the different criteria used for VHO decision making. Section 2.4.2 describe the most interesting VHO mechanisms and section 2.4.3 presents the main VHO performance evaluation metrics.

2.4.1 VHO decision criteria

These criteria are presented in fig.2.[illegible] and may be classified as follows:

Network related criteria

These refer to network conditions and system performances. More largely, these indicators may be used for load balancing and congestion control management.

- Network coverage and received signal strength: Network coverage is tightly related to the signal strength received by a mobile terminal. It is a crucial metric to indicate whether a wireless network is available or not for a given user. The signal strength received by a mobile terminal is also important as it is directly related to the service quality. In [illegible], Horrich et al. precise that the coverage metrics may differ depending on the network. For instance, it is defined as the received energy per chip divided by the power density in the band(CPICH Ec/NO) in UMTS networks and as the RSS in WLANs. In practice, these parameters are measured at the physical layer and are continuously updated by the mobile terminal to ensure that the current network is still available.

- Bandwidth: Available and offered bandwidth are important parameters that have direct effects on the QoS. In the case of coexistence of two technologies with acceptable signal levels (e.g. WLAN and 3G overlapping), the difference in bandwidth availability becomes an important criteria.

- Load: Network load is another important criterion in vertical handover decision making. In fact, in WLANs for example, since the bandwidth is fairly shared between users, the more the number of users increases, the more the allocated bandwidth decreases. Thus, having information about the load within each network may prevents the acceptance of new connections once the load is high and helps to insure acceptable throughput for each served user. In UMTS, considering load information as a handover metric prevents a mobile terminal from being downgraded or rejected by the load control mechanism of the network. The load on UMTS is defined as the ratio of the total Base Station (BS) downlink power to the maximum BS downlink power and on WLAN it is defined as the buffer occupation of an AP.
- Link quality

Many metrics may be considered as link quality indicators. These include:
- *Bit Error Rate (BER):* The BER informs about the link reliability and the ability of the network to support or not a specified application. For instance, a network with a high BER won't be able to support an interactive application that requires high reliability.
- *Signal-to-Interferences plus Noise Ratio (SINR) :* It is the ratio of the received strength of the desired signal to the received strength of undesired signals (noise and interference).

In wireless communication Systems, co-channel interference is one of the main sources of

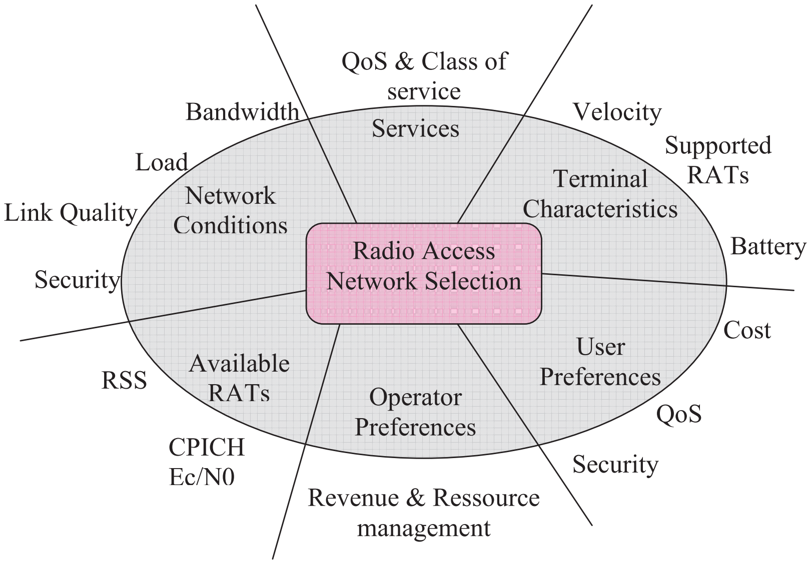


Figure 2.□□Vertical handover decision criteria

performance degradation as well as of system capacity limitations. The knowledge of such information affects the VHO decision especially with applications that require high reliability and good quality of service.

- Security□security may be considered when making vertical handover decisions. This should depend on user preferences and application types. Generally, security risks are more important in wireless technology compared to wired networks.

□□□□□ □r□ □a□r□at□□

These include terminal capabilities and mobility patterns□

- Velocity□the velocity of the mobile and its mobility pattern are crucial decision parameters. Actually, fast moving mobile may cross over a W□AN coverage rapidly. Thus, handing it over from a cellular network to a W□AN could cause quick successive handovers which may result in high signaling overheads and delays.

- □attery power□□ower consumption is a crucial issue particularly when a mobile terminal's battery is low. In such conditions, it is preferable to handover to a network that consumes less energy to extend the battery lifetime.

- Supported radio access technologies□Terminals are more and more equipped with more than one radio technologies. These are referred as multi-modal terminals.

Service type

Heterogeneous wireless networks support different classes of service that require various combinations of latency, reliability and data transfer rates. Thus, it is important that VHO decision algorithms take the service type into consideration.

User preferences

User's preferences in term of QoS and cost may also affect the VHO decision making.

- QoS: according to the running application, users may have different requirements on the preferred QoS.

- Monetary cost: Network providers apply different billing schemes and rates. Obviously, this directly influences user's preferences. Most of research papers propose decisions algorithms that consider a trade-off between cost and QoS.

Most of these handover decision parameters are highly correlated and cannot be addressed separately. Thus, a multi criteria based handover would be preferable as it would have a higher potential to achieve the required performances and to satisfy service provider goals, user preferences and system requirements. However, considering a very large set of criteria would considerably increase the complexity of the decision algorithm. This can affect the decision delay, its cost and reliability.

VHO decision algorithms

There are many existing algorithms that treated the handover decision problem in the literature. The complexity and the performances of these algorithms depend on the accessibility and the dynamicity of the used criteria as indicated in section 2.4.[illegible]. In the following, we present the most relevant existing vertical handover decision strategies:

Function based decision algorithms

These strategies are based on utility functions. The goal is to connect to the best available network that maximizes the objective function which is a weighted sum of QoS, cost, trust, compatibility, preference and capacity parameters. In [2[illegible]], Koundourakis et al. propose an objective function where all actors involved in the decision making process participate in the gathering of input parameters. For instance, MTs are asked for the received signal strength of the available Access Points (APs), the requested services and their requirements in terms of bit rate and delay tolerance. From the network side, the available bandwidth at each wireless interface and the delay at the queue between the access router and the backbone are collected. Weights are determined through policies to define the relative importance levels of each of the collected parameters. Both users and service providers can have their own weights.

[illegible] User centric decision algorithms

These strategies are mainly concerned with user than network satisfaction. Globally, we consider that users are the first concerned and should define by them selves the trade-off between QoS and Cost. In [2[illegible]], Ormond et al. propose a user-centric solution for non real-time traffic. Users track the available wireless access networks and predict the transfer rates of each of them by computing the average of the last five data transfers. After that, they evaluate a utility function that expresses the relationship between their budget and their flexibility in term of transfer completion time. Finally, users compute, for each available network, a consumer surplus function, which is the difference between the utility and the cost charged by the network and connect to the best one.
In [22], Calvagna et al. describe a user centric decision algorithm that gives the end user the control on the selection of the wireless access network that best fits his (her) preferences. Authors consider that "good" or "best" connectivity is relative to the user preference. For instance, the user may prefer to ensure a good QoS for his ongoing applications as long as possible, no matter the cost. He may also opt for saving on the connection cost even if the session continuity is not guaranteed. Alternatively, the user may prefer to find some compromise between sessions' continuity and cost saving. Authors propose two handover decision policies between GPRS and WiFi networks: According to the first one, the MT avoids connection blackouts and prefers to keep connected to GPRS. However, in the second one, he searches for only WiFi access points and tolerates connection blackouts. It is proven that the user's preference in term of cost can be satisfied if suitable handover decision policies are adopted.

[illegible] Multiple Attribute Decision Making (MADM)

Like in function based techniques, this handover strategy is based on the definition of utility functions. Here, it is formulated as a MADM problem as it aims to select a candidate network from a set of available ones with respect to different criteria. Through the litterature, the most popular MADM methods are the following:

• Simple Additive Weighting (SAW)□the overall candidate networks' scores are given by a weighted sum of all the considered metrics □2□,24□.
Each candidate network i score is given by adding the normali□ed contributions of each considered metric r_{ij} multiplied by the weight it is assigned w_j. The selected network is the one that maximi□es this score as follows□

$$A^*_{SAW} = arg\ max\ _{i \in M} \sum_{i=1}^{N} w_j.r_{ij}$$

where N is the number of metrics, and M is the number of available candidate networks.
• Technique for Order Preference by Similarity to Ideal Solution (TOPSIS): the selected candidate network is the closest one to the ideal solution which is obtained by considering the best value for each metric [24, 25].
Let's denote the relative closeness of an available candidate network i to the ideal solution by c^*_i. The selected network A^*_{TOP} is chosen as follows:

$$A^*_{TOP} = arg\ max\ _{i \in M}\ c^*_i$$

• Analytic Hierarchy Process (AHP): decomposes the network selection problem into sub problems that are given weights and evaluated as decision factors [25, 26]. An example of AHP applications is provided in section 3.3.4.
• Grey Relational Analysis (GRA): builds a Grey relationship between different networks and ranks them to select the one with the highest ranking. The ranking of GRA is performed by elaborating grey relationships with a positive ideal network [26, 27]. A normalization process to deal with benefit and cost metrics is required and a Grey Relational Coefficient (GRC) of each network is calculated. The GRC is the score considered to describe the similarity between each available candidate network and the ideal one. The selected network is the one that is the most similar to the ideal network [25]. The selected network A^*_{GRA} is:

$$A^*_{GRA} = arg\ max\ _{i \in M}\ K_{0,i}$$

where $K_{0,i}$ is the GRC of network i.

• Multiplicative Exponent Weighting (MEW): The score of each network is determined by the weighted product of the considered decision metrics as follows:

$$S_i = \prod r_{ij}^{w_j}.$$

The selected network is the one that maximizes the ratio of this score by the positive ideal network score. The ideal network is defined as the one that have the best values in each metric [25].

These methods and the combination of some of them have been widely studied in the literature. In [25], Stevens-□avarro et al. make an interesting comparison between different MA□M methods. In [26], AHP and GRA are combined to propose a decision mechanism that chooses the network that offers the best trade-off for user's preference, service's requirements, and network's capabilities. It considers different □oS factors related to network availability, throughput, timeliness, reliability, security and cost. AHP defines the weights of the □oS parameters based on user's preference and service application and GRA considers these weights to rank the available networks. In [2□], a □HO algorithm that combines SAW and AHP is proposed. The algorithm is based on the Signal to Interference and □oise Ratio (SI□R) and considers as decision parameters: the traffic cost, the required and the available bandwidth of the reachable wireless access networks.

2.4.2.4 Markov based decision algorithm

Markov decision schemes are dynamic processes able to model optimization problems where decision epochs follow a probability distribution. In [2□], Stevens-navarro et al. propose a □HO decision algorithm for heterogeneous wireless access networks. The problem is formulated as a Markov □ecision Process (M□P) where a link reward function is defined based on the applications' □oS requirements. It also considers a signaling cost function associated with the processing load and the signaling overhead of the vertical handover accomplishment. The goal is to maximize the expected total discounted reward. The M□P model consists of five elements which are the following: decision epochs, states, actions, transition probabilities, and rewards.
At each decision epoch, the mobile terminal has to decide whether to keep connected to its current network or to hand over to another one. The decision (or action) depends on the current status of the available access points which are maintained in the M□P states that carry information on network I□, bandwidth and delay in the co-located networks. A Markovian state transition probability function is adopted to predict the next state. Given the current state and the chosen action, the reward function of a network is defined based on the link reward and the signaling cost.
This model is adaptive and applicable to a wide range of conditions as it presents different link rewards and signaling functions that depend, respectively, on the applications' class of service and on the complexity of the re-routing operation and its incurred signaling load on the network.

In [30], an Enhanced Media Independent Handover framework is proposed. It integrates, in addition to the link layer's measurements and triggers on which is based the IEEE 802.21 MIH, information from the application layer and the user context. Authors propose two Weighted Markov Chain (WMC) decision making approaches to choose the best network considering delay, jitter, packet loss, load, cost per byte and bandwidth as decision criteria. The decision process goes through four steps which are the following:

a) Normalization of decision factor weights.
b) Construction of a weighted Markov chains transition matrix MC.
c) Computation of the stationary distribution vector S□.
d) Selection of a favorite network.

It is shown that the performance of these approaches is better than TOPSIS in term of delay.

2.4.2.□ Fuzzy logic based decision algorithm

Fuzzy logic deals with uncertainness and is quite good to handle decision process issues. The advantage of such a representation is its capacity to analyze imprecise data such as the behavior of the RSS, the load or the BER,... It is generally combined to other decision methods to determine the best choice.

In [3] (figure 2.6), Horrich et al. proposed a fuzzy multi-criteria vertical handover algorithm which is based on a Fuzzy Logic Control (FLC). It takes into account multiple criteria (RSS, the received energy per chip divided by the power density in the band (CPICH Ec/I0), load and Mobile terminal velocity) and considers a set of predefined "if...then" rules describing the desired behavior of the system. This FLC based solution has been enhanced by a multi-layer perceptron Neural Network (NN) that learns the relationship between the FLC parameters and adapts them to the traffic variation and the environment fluctuation.

In [31] (figure 2.7), an adaptive multi-criteria VHO decision algorithm for heterogeneous radio networks is proposed. This algorithm is based on a Fuzzy Inference System (FIS) and a Modified Elman Neural Network (MENN). The FIS considers the bandwidth, the MT's velocity and the predicted number of users as input parameters and makes handover regarding predefmed "if... then" rules. The MENN is involved in the prediction of the number of users of the after-handover network, which is a pivotal variable of the FIS.

In [32, 33], □ekri et al. and □assar et al. propose Context aware vertical handover algorithms that combine fuzzy logic and other MADM like SAW and AHP. Fuzzy logic is just used for vertical handover initiation.

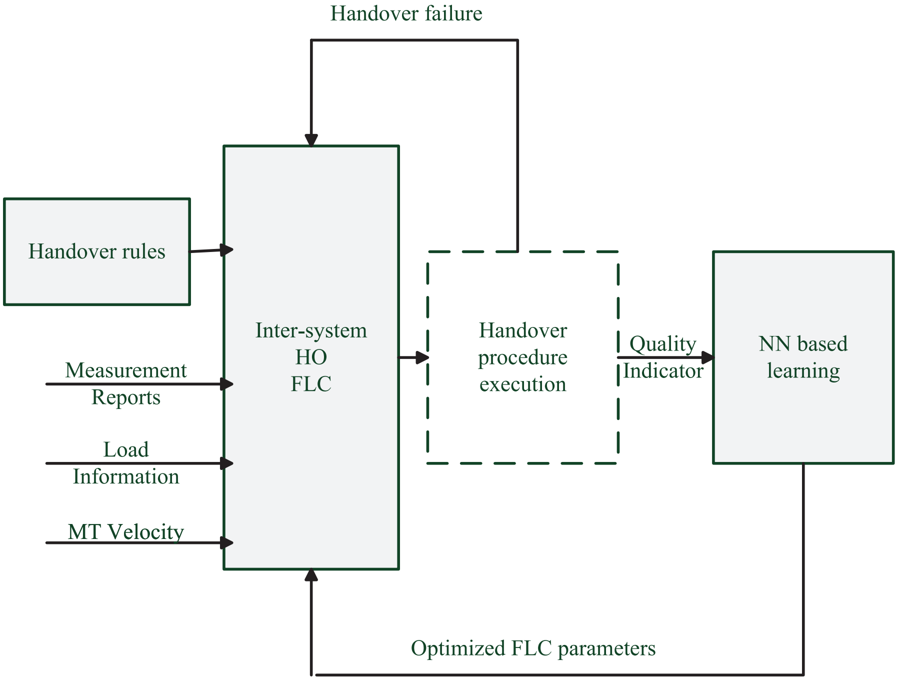


Figure 2.6: Fuzzy multi-criteria vertical handover scheme [3]

2.4.2. Game theoretic approach for decision making

The ability of a MT to connect simultaneously to multiple wireless access networks is one of the most important characteristics in next generation networks based on the coexistence of heterogeneous technologies. This introduces new challenges in resource allocation among mobiles and thus in VHO decision making. The vertical handover problem can be seen as a competition between actors (users and networks), where users are willing to get the best access network with minimum cost while networks are willing to maximize their incomes (short and/or long term scales). In [34], Niyato et al. propose a cooperative bandwidth allocation algorithm based on bankruptcy game. It is a N-person cooperative game where networks cooperate to provide new connections with the required bandwidth using coalition form and characteristic function. The stability of the allocation is analyzed by referring to the core concept and the amount of allocated bandwidth is obtained using Shapley values. The objective of each network is to maximize the offered bandwidth in order to get more revenue from new connections. In [35], the same authors describe the bandwidth allocation problem as an oligopoly market competition. A Cournot game is used to model this market competition and Nash equilibrium is considered to provide a stable solution. Two algorithms are proposed to obtain the Nash equilibrium, iterative and search algorithms. In both papers, the authors provided an admission control mechanism, based on the proposed bandwidth allocation scheme, to provide both new and vertical and horizontal handover connections with good QoS.
In [36], Haddad et al. propose a hierarchical distributed learning framework for vertical han-

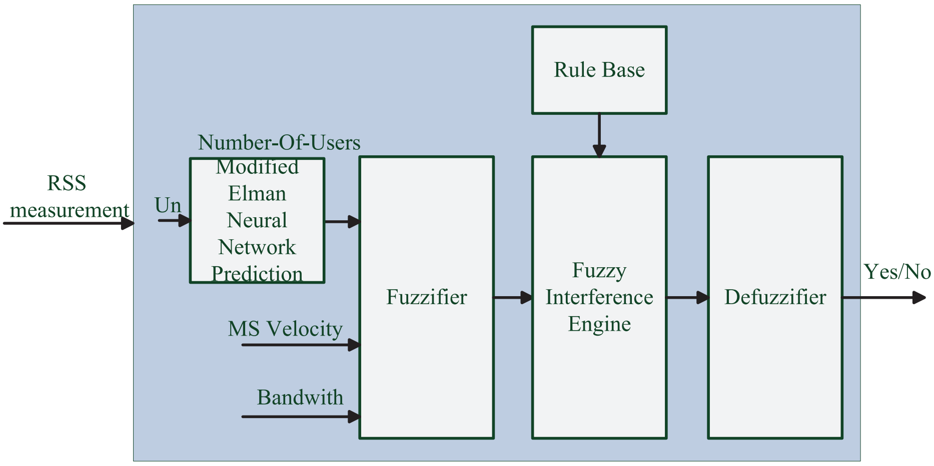


Figure 2.7: Adaptive multi-criteria vertical handoff decision algorithm

dover decision making in heterogeneous cognitive networks. They model the problem as a Nash-Stackelberg fuzzy Q-learning. The network is considered as a leader that aims at maximizing its revenue and the mobile nodes as followers that aim to maximize their QoS.

2.4. Vertical handover performance evaluation metrics

In this paragraph we describe the most representative VHO evaluation metrics used in the literature. VHO decision mechanisms may be evaluated by measuring handover delays, number of handovers, VHO cost, VHO blocking rate, and the overall throughput of a session over a mobility pattern.

VHO delay: Refers to the duration of the vertical handover process considering its three phases: information gathering, decision and execution phases. This metric is tightly related to the VHO complexity and the considered decision criteria. It must be reduced especially for real time applications.

Number of handovers: Reducing the number of handovers is usually preferred to avoid ping-pong effects and preserve network resources.

Throughput: It is usually preferred to handover to networks offering higher throughput.

VHO blocking rate: It is due to incorrect decisions. For instance, it occurs when the target network is no more available or does not offer enough resources (e.g. overloaded). Table 2.1 illustrates the VHO evaluation metrics used in the VHO decision mechanisms described in the previous sections.

Table 2.1: □ertical handover evaluation metrics

□□□ strateg□	□□□ dela□	□□mber o□handovers	□hro□gh□□t	□□□ blocking rate
[20]	lower delay	Less extra handover	better throughput	□ot provided
[21]	□ot provided	□ot provided	provides users with higher throughput	□ot provided
[26]	□ot provided	□ot provided	high throughput and high reliability networks are preferred	□ot provided
[2□]	□ot provided	Less handovers compared to SAW and GRA	□ot provided	□ot provided
[30]	□etter delay than TOPSIS	□ot provided	□ot provided	□ot provided
[3]	□ot provided	□ot provided	TCP throughput is enhanced	□ot provided
[34]	□ot provided	□ot provided	□ot provided	□locking rate is weak when the traffic intensity is not important
[36]	□ot provided	□ot provided	□ot provided	□locking rate is not important and stabilized after some iterations

2.4.4 □□nthesis

Traditional handover mechanisms based on the RSS and other physical layer parameters are no more efficient with the emergence of heterogeneous wireless networks. Whereas, the user still would like to be served through the access network that best fits his preferences, additional constraints should be considered including service requirements, terminal capabilities, mobility, energy consumption and available radio resources. The vertical handover decision mechanisms described in the previous subsections address different issues related to the radio access selection and consider different decision criteria. Table 2.2 summarizes these mechanisms and provides a global view on the considered decision parameters as wall as the main advantages and drawbacks.

In the following we provide a comparative study of the seven considered groups of vertical handover decision mechanisms regarding different issues that should be addressed while treating the vertical handover decision problem:

- *User consideration*
- *Multi-criteria*
- *Complexity*
- *Flexibility*
- *Reliability*
- *Multi-services consideration* (different services running on different interfaces at the same time)

Table 3.1 provides a comparison of the considered □HO decision groups concerning these

Table 2.2: Overview of existing vertical handover decision strategies

Heuristic	Input Parameter	Feature	Advantages	Disdvantages
Function based . Network based access selection in composite radio environment [20]	. RSS, Requested service, bit rate and delay tolerance, available bandwidth, delay at the queue, cost, trust, compatibility, capability	. An objective function (OF) is defined through parameters gathered by both users and networks, M[illegible]s are connected to the network that maximizes OF	. Minimum degradations in high load and congestion situations	. Time consuming if services and/or available access points increase
User centric . Network selection decision in wireless heterogeneous networks [21] . A user centric analyses of vertical handovers [22]	. Terminal capability, data transfer requirements, users budget, flexibility to delay . User preferences in terms of QoS and cost	. A user utility or benefit function is defined to represent the user's preference rating of desired network metrics or willingness-to-pay . Two VHO decision policies: 1) satisfy user's required QoS 2) satisfy user's willingness to pay $\Rightarrow$ a cost function is defined to find the optimum VHO decision policy	. maximizes users' utility . High user consideration and low implementation complexity	. non real time support, simple rate prediction method . No real time support
MADM .A Network Selection Mechanism for Next Generation Networks [26]	. Availability, delay, jitter, response time, BER, burst error, packet loss ratio, RSS, security, cost, reliability, average number of retransmission	. AHP is used to define the weight of each decision parameter then GRA is used to rank the available networks regarding these parameters	. Multi criteria consideration	. Medium implementation complexity
Markov based . A VHO decision algorithm for heterogeneous wireless networks [2[illegible]] . VHO decision in an enhanced media independent handover framework [30]	. Network ID, bandwidth, delay, application QoS requirements, processing load, signaling overhead . Total bandwidth, Allowed bandwidth, Cost per byte, Load, Delay, Jitter, Packet loss	. 1) A link reward function is defined based on the QoS requirements 2) A signaling cost function associated with the processing load and signaling overhead is defined. $\Rightarrow$ maximize the expected total discounted reward. . Definition of weighted Markov Chain and selection of the favorite network that Maximizes the S[illegible] vector.	. Adaptive and applicable to a wide rage of conditions, improvement over SAW and GRA . better delay performance than TOPSIS	. Implementation complexity . Implementation complexity
Fuzzy logic based . Neural networks for adaptive vertical handover decision [3]	. RSS, CPICH Ec/[illegible]0, velocity, load.	. A FLC based algorithm is proposed and enhanced by a multi-layer perceptron [illegible] that learns the relationship between the FLC parametrs and adapt them.	. makes decisions in an autonomic way, considers multi-criteria.	. complexity increases if additional input parameters are considered
Game theory based . A cooperative game for bandwidth allocation in 4G wireless networks [34] .A nashstackelberg fuzzy q-learning decision approach in heterogeneous cognitive networks [36]	. Bandwidth, cost. . Load information, throughput, acceptance ratio, file transfer time, average file download time.	. N-person cooperative game, networks cooperate to provide new and VHO connections with the required bandwidth and maximize their revenue. . Decision based on Aggregated load information, interaction and convergence are modeled using a Nash-Stackelbek fuzzy Q-learning framework, MTs aim to maximize their QoS and Networks aim to maximize their profit.	. Efficient resource management . improves the individual efficiency of mobile users	. Additional decision parameters are required in practice to ensure better quality of service

Table 2.3: Comparison between vertical handover decision strategies

□□□ strategy	Function based	UC	MADM	Markov	FL	Game Theory
User consideration	medium	strong	medium	low	medium	strong
Multi-criteria	yes	yes	yes	yes	yes	yes
Complexity	low	low	medium	medium	high	medium
Flexibility	high	high	high	medium	low	medium
Reliability	medium	medium	medium	high	high	high
Multi-services	no	no	no	no	no	no

different parameters

User consideration most of the analyzed algorithms consider user preference and user satisfaction but with different degrees. Bearing in mind this aspect, user centric mechanisms and some game theory based decision algorithms that aim to maximize the user utility are the most relevant ones.

It is also interesting to point out that *multi-criteria* solutions are essential in such heterogeneous environments. All above proposed mechanisms consider multi-criteria. However, MADM and Markov based decision algorithm are the most pertinent mechanisms regarding this feature. Generally, user centric and some game theory based algorithms consider few decision parameters that are tightly related to the monetary cost. Fuzzy logic based mechanisms also don't consider many decision criteria since complexity increases with the increase of the number of input parameters.

Indeed, regarding *complexity*, Fuzzy logic combined to neural networks based mechanisms are the most complex ones and are not suitable for nowadays multi-homed mobile terminal with limited resources. However, if we consider that some contextual information or decision criteria may be unavailable, nit up to date, or imprecise at the decision time, the fuzzy logic technique seams the most appropriate tool to deal with uncertainty.

The studied decision strategies are also compared regarding their *reliability* and *flexibility*. By flexibility, we mean the separation of the handover decision mechanism from the whole handover management process and its adaptation with additional parameters or functionalities [27]. and by reliability, we mean the fact of getting precise and efficient decision that ensure good vertical handover performances. MADM, user centric and function based decision algorithms seem to be the most flexible and fuzzy logic seems to be the least flexible. However, when it comes to real-time application, user centric and some function based strategies are less reliable compared to other mechanisms like fuzzy logic, game theory, Markov and multiple attribute decision based algorithms.

Concerning the *multi-services* support, we notice that the stated decision mechanisms deal with only one service at a time. This leaves the multi-decisions making for simultaneous multi-services support in a multi-homed environment as an open issue that needs to be addressed.

2.□ Multihomed mobility

Mobility management is one of the key issues to ensure seamless mobility. The most known mobility management protocols are Mobility for Internet Protocol v.4 (MIPv4) [37], Mobility for Internet Protocol v.6 (MIPv6) [3□] and NEMO [3□] which extends the mechanisms utilized in Mobile IPv6.
These protocols have widely addressed mobility issues in mono-homed environments. However, with the convergence of heterogeneous wireless access technologies and the emergence of more capable devices that support different RATs, mobility management protocols are also intended to handle multihoming issues. In the following, we describe different multihoming mobility management protocols that have been proposed in the literature.

2.□.□ Definition

Multihoming, defined as the simultaneous use of multiple network interfaces or IP addresses on a single mobile node, is intended to enhance the overall network connectivity and increase the network applications reliability.
As far as connectivity to the Internet is concerned, the fact of using one single address increases the risk of network failure, which means that if the corresponding interface link fails, there will be no other alternatives to preserve connectivity and the connection will shut down. However, when exploiting multihoming, users may smoothly switch from one interface to another, depending on link reliability and network connectivity. Thus, by establishing connections with multiple addresses, multihoming can help to enhance the overall stability of the connectivity associated with the host. Multihoming support has several benefits [40]:

- Permanent and Ubiquitous Access: The use of multiple interfaces that can be connected to different RATs may ensure a permanent connectivity at anytime and anywhere and provide seamless VHO by allowing soft handovers.
- Reliability: In some cases, a particular flow may be duplicated through different interfaces. Thus, in case of link failure, other interfaces may guarantee the connection continuity which reduces packet loss and minimizes delay of packet delivery caused by congestion.
- Load Sharing and load balancing: Traffic load may be shared over several interfaces either to achieve load balancing or to choose the most suitable connections according to some preferences.
- Preference Settings: Multihoming provides users, applications and operators with some flexibility on the choice of the preferred access network according to some criteria and policies.

Table 2.4: Comparison between multihoming protocols

Protocol	LIN6	Homeless MIPv6	HIP	[illegible]	M[illegible]	SIP
Protocol Layer	Network	Network	Network/Transport	Transport	Transport	Session
End point identifier	GI	Sets of IP addresses	HI	dual sequence number	sets of IP addresses	SIP-URI
Deployment	Mapping agent	No additional support	Rendevouz server	No additional support	No additional support	SIP server
Interface Selection	Implicit	Implicit	Not defined	Implicit	Not defined	Not defined

2.5.2 Multihoming Protocols

Multihoming has been addressed at different layers of the protocol stack. For instance, Stream Control Transmission Protocol (SCTP) [41] supports multiple IP addresses at the transport layer. Multihomed MIP (M-MIP) [42] provides multihoming at the network layer and is transparent to the transport protocol. In the following, we give an overview of the multihoming protocols that have been proposed in the literature.

2.5.2.1 Location Independent Network Architecture for IPv6 (LIN6)

The basic idea of this mobility protocol is that the LIN6 Generalized Identifier (GI) is divided into tow parts, a unique 64-bits identifier through which a node is recognized in the LIN6 architecture and a 64-bits locator that changes when the mobile node moves. The generalized ID is then stored into the DNS with the address of a Mapping Agent [43].
In [44], Matsumoto et al. extend the mobile network protocol LIN6 to support multihoming thanks to its addressing architecture and to the design a new Application Program Interface (API). In this scheme, a LIN6 mobile node may have multiple global locators and in case of link failure it is able to switch its connection to another link by using another locator. A fault-tolerant connection is then achieved.

2.5.2.2 Homeless mobile IPv6

Homeless Mobile IPv6 [45] is a variation of Mobile IPv6; it introduces a semantic change in the way the IPv6 addresses are used. In this scheme, the connections are no more bound to interfaces represented by IP addresses, but to hosts that are represented by some sets of IP addresses. Technically, Homeless MIPv6 eliminates the difference between the home address and the care-of-address (es) and tolerates the use of multiple care-of-addresses and multiple home addresses. It does not require home addresses or home agents any more, but allows them to be used as in Mobile IPv6. The main benefits of Homeless MIPv6 are the support of multihoming and seamless vertical handover.

2.□.2.3 Multipath TCP (MPTCP)

Multipath TCP is a modified version of the TCP protocol that allows the simultaneous use of multiple IP paths foe the same TCP connection. In [46] a single sequence number space is considered. This results in a huge reordering at the receiver and makes it very difficult to determine which path(s) delivered a segment if the segment was sent on more than one path. MPTCP considers a dual sequence number space with a sequence that identifies each subflow as if it is running alone and a connection level sequence that allows reordering at the aggregate connection level [47, 48]. Each segment carries both subflow and data sequence numbers which fixes the problems faced with a single sequence number space [46].

2.□.2.4 Stream Control Transmission Protocol (SCTP)

One core feature of SCTP is multihoming, which enables a single SCTP endpoint to support multiple IP addresses within a single association [41]. The motivation to use multihoming in SCTP is the potentially better reliability in case of network failures. With SCTP, a host has one primary address and may have zero or more alternative addresses. The use of SCTP is then adapted to mobile environments due to its prominent features such as multihoming. A recent method called Dynamic Address Reconfiguration drafted in [49] was added to SCTP. This gives birth to the so-called extension: mobile SCTP (mSCTP) that enables mobility support in the transport layer [50]. IP mobility is insured by forwarding the packets sent to a mobile node to the new IP address in the new location without disrupting the ongoing session. The main idea of this mechanism is to exploit the overlapping of the current and the new APs coverage.

2.□.2.5 Host Identity Protocol (HIP)

The Host Identity Protocol [51] is a key establishment and parameter negotiation protocol. Its primary applications are for authenticating host messages based on host identities, and establishing security associations (SAs) for the Encapsulating Security Payload (ESP) transport format. The HIP supports an architecture that decouples the transport layer (TCP, UDP, etc.) from the inter-networking layer (IPv4 and IPv6) by using public/private key pairs, instead of IP addresses, as Host Identities (HI). One consequence of such a decoupling between host identities and IP addresses is that new solutions to network-layer mobility and host multihoming are possible [52]. When a host is multihomed, it has multiple locators simultaneously (names that control how the packet is routed through the network and demultiplexed by the end host). A multihomed host is then able to inform its peers of locators at which it can be reached, and can declare a particular locator as a "preferred" locator.

2.□.2.□ Session Initiation Protocol (SIP)

SIP has been originally designed to manage multimedia sessions. A SIP user is identified by a logical SIP Uniform Resource Identifier (URI). As a user roams around, he is able to set up a connection using his SIP URI from different terminal devices.
However, once the connection is established, he is no more able to change his point of attachment without causing the connection to be broken. Thus, the mobility support provided by the primary use of SIP was restricted to one network once a session has been set up.
In [53], Chai Kiat Yeo et al. propose a SIP-based Multihomed Mobility Management (SM3) that allows to maintain session continuity during handover. In this scheme, both horizontal and vertical handovers are supported and the multihomed terminals can be connected to different access networks at the same time. Each mobile terminal's SIP URI is associated with its multiple Care-of-Addresses (CoAs) . The SIP server is responsible for the SIP URI-to-CoA resolution. When a Correspondent Node (CN) wants to communicate with an MT, it asks the SIP server using the MT's SIP URI. The SIP server replies with the list of CoAs of the MT. CN picks one or more CoAs from the list to establish new connections. When a MT notice that one of its running sessions is about to be switched to a different network, it sends a Binding Update (BU) to the CN to inform it of the CoA imminent change. CN adjusts its distribution policy and transfers the connection to other available CoAs.

2.6 Conclusion

This chapter provides a survey on vertical mobility management processes including information gathering, vertical handover decision making and execution in the context of heterogeneous wireless access networks coexistence.

After presenting the interworking schemes and the architectural approaches proposed by the standardization bodies, this chapter presents an overview and a comparative analysis on the most known vertical mobility management techniques and highlights some of the main technical challenges caused by the coexistence of heterogeneous wireless networks, mainly seamless vertical handover making, a fundamental feature to all future networking endeavors. The chapter also points out the importance of mobility protocols and mainly multihoming techniques in such heterogeneous environments. An overview and a comparative analysis of the most recent protocol proposals to support advanced mobility management and multihoming is provided. The analysis shows that multihoming may be used at different levels of the protocol stack.

Globally, this chapter shows that mobility management over heterogeneous wireless networks is still challenging at different levels including architectural, decision-making and protocol aspects. Additional effort is required before reaching a seamless wireless world in particular concerning network cooperation and protocols. At the architectural level, virtualization seems to be a promising approach to mask heterogeneity. For decision making, the main difficulties are caused by the lack of up to date information at the decision points. Considering uncertainty and cooperative decisions (game like) may be helpful to make better decisions.

Chapter 3

On the Use of network Reputation for VHO decision making

3.1 Introduction

To provide mobile users with seamless access and services over existing and upcoming heterogeneous wireless access technologies, enhanced inter-working and cooperation mechanisms are required. The Always Best Connected, anytime, anywhere paradigm calls for light and efficient mechanisms able to overcome the increasing systems' complexity. The main issue is to maintain a good quality of service while switching users' connections from one access network to another according to users' and networks' context. Provisioning vertical handover decisions that considers all available observations, measures, preferences and constraints is not only very costly in terms of latency and resource consumption but may also lead to non-optimal or flawed decisions. Within the standards, the IEEE 802.21 [15], the 3GPPP [14] and P1900.4 [1□] tackle mobility over heterogeneous wireless environments regarding context information and vertical handover decision making. In the literature, as described in chapter 2, a large set of criteria such as users' preferences as well as applications' requirements and networks' capabilities are considered. Unfortunately, most of existing solutions are centralized, based on global knowledge and require long processing time. Ideally, an efficient vertical handover decision mechanism would minimize the decision computation latency and overcome the necessity of the non-attainable continuous tracking of all instantaneous parameter variations. It should be able to make acceptable decisions even with partial knowledge of its environment.

In this chapter, we propose the use of Networks' reputation as a new subjective metric that relies on previous users' experience and observations in similar contexts to minimize vertical handover latency and provide good QoS. We introduce reputation as an already experienced satisfaction reflector and show that it can be a useful and relevant construct to integrate in vertical handover decision mechanisms within complex networking environments. To the best of our knowledge, and while reputation has already been used in social, security and business fields as a trust factor, this is the first study introducing it for network selection and handover decisions.

The remaining of this chapter is organized as follows: An introduction to the use of reputation in different fields is given in section 3.2. Section 3.3, describes the proposed reputation system. Section 3.4 presents the overall reputation based vertical handover decision mechanism. Section 3.5 provides the performances results and, finally, section 3.6 concludes the proposed work.

3.2 Reputation systems in the literature

Reputation systems have been studied and applied in diverse disciplines such as economics, sociology, psychology, management science as well as marketing and computer science.

3.2.1 Reputation within social and business fields

From the business field point of view, reputation is often seen as a key intangible asset of a firm that helps to create value. In [54], Weigelt et al. provide a survey on reputation based solutions using game theory. They highlight the effect of reputation in managerial applications as well as in consumers' behaviors towards products and services. For instance, reputation is considered as a screening mechanism in which informed players (firms/customers) use reputation-building behavior to credibly indicate information to uninformed players. Uninformed players can also use reputation as a screening strategy to determine (though often imperfectly) the true type of another player. Generally, such screening models are useful when moral hazard or adverse selection conditions exist, in credit market for example.
Reputation effect has also been studied in many other fields like in judicial decision making. In [55], Miceli et al. developed a judicial decision-making model based on a judge's concern for reputation and the interdependence of judges' decisions through precedent. The audience of judges plays a crucial role in the analysis. It shows that reputation can not only restrain judicial discretion, but also inspire it if future judges are expected to be convinced by a decision and follow it, thereby enhancing the authoring judge's reputation.

3.2.2 Reputation within computer science field

In computer science, the use of reputation is quite new. However, with the growing popularity of self-organized communication systems, reputation systems have received increasing interest over the last few years especially in the fields of artificial intelligence, Internet-based P2P and Mobile Ad-Hoc Networks. Probably, the most visible example of reputation based systems is the online auctioning eBay systems [56] where buyers and sellers rate each other after each transaction. The overall reputation of a participant is then the sum of these ratings over the last 6 months.

Correspondingly, current research is concerned with investigating the use of reputation systems in different areas of telecommunications and computer science. In the following we provide a short overview of reputation systems' use in these areas.

3.2.2.1 Reputation in P2P networks

In the P2P networking, reputation has been proposed as a means to obtain reliable information on the quality of resources peers are exchanging. In [57], Kamvar et al. proposed an algorithm based on reputation calculation to decrease the number of inauthentic file downloads in a peer-to-peer file-sharing network. This algorithm is called EigenTrust. It assigns each peer a unique trust value reflecting its reputation leading to the reduction of the inauthentic exchanged files amount, even under conditions where malicious peers collaborate attempting to intentionally destabilize the system. In EigenTrust, the reputation of each peer i is given by the local trust scores assigned by other peers $j(j \neq i)$ weighted by the reputations of the assigning peers. Each peer i stores two numbers: $sat(i,j)$ and $unsat(i,j)$ referring respectively to the number of satisfactory and unsatisfactory transactions it has had with other peers.
In [58], Aberer et al. suggest a mechanism for P-Grid, a P2P system that spreads negative information only. They address the problem of reputation-based trust management at both data management and semantic level. The proposed solution does not require any central control and allows assessing trust by calculating an agent's reputation from its previous interactions with other agents.

3.2.2.2 Reputation in sensor networks

In [59], Kim et al. formulated a fuzzy logic model to evaluate the trustworthiness of sensor nodes and insure safe communications between sources and destinations in sensor networks. They suggested a trust model to distinguish proper sensors and abnormal sensors that may attack and contaminate the wireless sensor network. A degree of trust for each sensor is calculated and based on this value, each sensor node decides whether to communicate or not.

In [60], Ganeriwal et al. proposed an approach that allows the sensor nodes to develop a community of trust by providing information about the exchanged data accuracy. They proposed a scheme where each node keeps reputation information by looking to both present and past behavior of other nodes and uses this information to predict the future behavior. They adopted a Bayesian formulation for the representation of the reputation algorithm steps including updates, integration and trust evolution.

3.2.2.3 Reputation in mobile Ad-Hoc networks

Several reputation systems have been studied in the mobile Ad hoc area. In [61], Buchegger et al. provide a survey of reputation systems suggested for Mobile Ad-Hoc Networks. They pointed out that reputation systems are based on four main considerations which are the following: a) representation of classification and information, b) use of second-hand information, c) trust and d) redemption and secondary response.

The COllaborative REputation mechanism is one of the most known reputation systems. It was introduced in [62] with a game theoretic analysis. In this scheme, each network entity keeps track of its neighbors' behavior regarding collaboration. The nodes' reputations are then calculated based on various types of information that takes into account subjective observations, indirect reports as well as functional reputation.

In [63], Buchegger et al. propose a protocol for making misbehavior unattractive. It is called the CONFIDANT protocol and is based on selective altruism and utilitarianism. The principle is to detect misbehaving nodes and isolate them to make it unattractive to deny cooperation. In this scheme, reputation is based on direct observations and second hand information from other nodes and is updated according to a Bayesian estimation. The robustness of this system against wrong accusations and the effect of using rumors with respect to the detection time of misbehaved nodes are addressed in [64].

3.3 Proposed Reputation system for fast VHO

3.3.1 Motivation behind the use of Reputation for VHO decisions

In the context of heterogeneous wireless access networks, the lack of complete knowledge about the user environment makes the use of traditional handover decision techniques inefficient. As seen in the previous sections, reputation based decision making seems strategically important in incomplete information systems. Indeed, most of the traditional VHO decision methods require the knowledge of a multitude of parameters and measurements that are so often missing or not immediately accessible resulting in a long decision response time. In this

context, reputation based decision making seems to be strategically suitable.
In addition, heterogeneous wireless networks provide new prospects and challenges for reputation systems. Indeed, multihoming features and the omnipresence of heterogeneous wireless access networks in the same physical space offers a higher choice when it comes to network selection. In this context, selecting a network each time a VHO is required may be facilitated by the introduction of reputation systems that inform users about the global properties of available networks.

3.3.2 Features that a Reputation system should consider

Many questions arise while addressing reputation system conception. What information is kept? About whom? Where? For how long? In which context? When information is added? How is it integrated? What does this information looks like over time? What has to happen to change this information?
The main consideration on which we focus in our proposed reputation system are the following:
● Getting Initial reputation values:
Building networks' reputations is a statistic process that requires multiple samples of users' experiences. At the initiation phase, these reputation statistics should not be available or not statistically significant. That is, the behavior of available networks and their corresponding offered QoS should be learned during an initiation phase to get accurate reputation values.
Indeed, the more users make observations by getting connected to different networks, the faster an estimation of network reputation can be obtained.
In order to manage that, user's observations should regularly be collected and translated into reputation ratings. Our proposed Reputation system addresses this consideration in section 3.3.4.
● Keeping track of past behavior:
The basic premise of a reputation system is that one can predict future behavior by looking at past behavior. To provide this basis, the reputation system has to keep track of past behavior.
● Discounting adds resilience:
As time passes, the relevance of parts of the collected reputation data can change. Indeed, a recent behavior is most likely a better predictor of a future behavior than a one observed a long time ago. On the other hand, considering only the most recent behavior can establish a deformed representation of past behaviors, because only one observed instance is not enough to determine a trend. In this vision, a discounting adds resilience is required. For instance, giving higher weights to recent behaviors and discounting past behavior along time is an interesting feature that a reputation system should consider. This feature allows a reputation

system to attains two main objectives: better consistence and correspondence to future behavior and nodes' reputation recovery. When past behavior is discounted, nodes cannot take advantage of past good behavior but have to continuously behave well to preserve a good reputation. In the other hand, node redemption gives a node the chance to at least regain a neutral reputation after a certain time during which it behaved well. This is essential to deal with nodes that previously presented some problems and that have been repaired. In general, this is useful to adjust reputation to behavior changes regardless of the reason. This consideration is addressed in the aggregation step (section 3.3.5) in our proposed Reputation system.

Another important consideration is the context. Indeed, the notion of context is of great importance when considering reputation. The sentence 'I trust my doctor for giving me advice on medical issues but not on financial ones' is an example that shows how important context can be.

It is the same when we come to networks' reputations. Indeed, reputation is a multidimensional criteria that strongly depends on the quality of the different considered samples of users and their context. It mainly depends on:

- Users' density in a given area.
- Users' distribution on a given network.
- Users' proximity to access points or base stations.
- Users' running applications' class of service.
- Users' velocity.

For instance, a network may have a good reputation for streaming applications and a bad reputation for interactive video applications, it may have a good reputation in a given area and a bad reputation in another one.

In this vision, networks may have a reputation value per class of service, per area and even per category of velocity.

In this manner, the reputation assessment of a network will allow a MT, by referring to the experience that other terminals made in a similar context, to choose the best reputated network for its running service.

In summary, a reputation system requires a way of keeping information about the entity of interest, of updating it and of incorporating the information about that entity obtained from others. This provides the basis of our decision making mechanism. Then the decision making itself has to take place to allow nodes to chose the network that best fits their requirements and to update the reputation.

In the following section, we detail the proposed reputation system on which a new VHO decision algorithm is built. The proposed approach is based on the analysis of previous connections between MTs and available access networks.

3.3.3 Proposed solution

As stated in the previous section, the basic premise of a reputation system is that one can predict future behavior by looking at past behavior. Hence, the reputation system has to keep track of the past observed behaviors by collecting information from different sources. A reputation system should also give more importance to both recent and negative behaviors. In other words, it should be able to efficiently update reputation over time and to rapidly react to sudden degradations in the system. To satisfy these requirements we propose to go through three main phases:

- Collection: collection of individual scores given by users expressing their past experiences.
- Aggregation: computation of a global rating expressing the network reputation.
- Sharing: making the computed values available for users.

3.3.4 Collection

Let N denotes the set of available networks and M_n the set of MNs that already connected to network n. The behavioral data B are rates $r(m,n)$ a mobile $m \in M_n$ gives when it interacts with network $n \in N$. The reputation of a network is built through the set of observations B_n that mobiles had made before handing over to other networks.

$B_n = \{r(m_i,n) | m_i \in M_n\}$

We propose the use of a binary trust referring to [57], i.e. a network is considered either trustworthy (if it offers a good QoS for the given application) or not.

A mobile node m connected to a network n, may rate the connection as follows:

- Positive ($r^+(m,n) = 1$) if the QoS it perceived is sufficient.
- Negative ($r^-(m,n) = -1$) otherwise.

The issue here is the definition of a satisfaction factor through which we can conclude that a communication was satisfying or not. It's obvious to mention that the satisfaction factor depends on the requirement of each class of service s_k.

Therefore, for each of these classes, we define a required quality threshold Q_{th} above which the perceived quality is considered to be satisfying.

Q_{th} is defined based on some QoS parameters, namely Bit Error Rate (ber), delay (d), Jitter (J) and bandwidth (Bwd). The importance of these parameters depends on the running application. It is expressed through weights which are calculated using the Analytic Hierarchy Process as explained in the following. The first step in AHP is to decide of the relative preference of the QoS parameters (Objectives) considering the different class of services. The importance of the objectives is expressed through priority scores between 1 and 9. Let a_{ij} denote the relative importance of Objective (O_i) in comparison with Objective (O_j). For ex-

Table 3.1: AHP matrix of each class of service

Class of Service	**BER**	**Delay**	**Jitter**	**Bwd**
BER	1	a_{12}	a_{13}	a_{14}
Delay	$1/a_{12}$	1	a_{23}	a_{24}
Jitter	$1/a_{13}$	$1/a_{23}$	1	a_{34}
Bwd	$1/a_{14}$	$1/a_{24}$	$1/a_{34}$	1

ample, let's consider the following values

- $a_{ij} = 1$ if the two objectives are equal in importance
- $a_{ij} = 3$ if O_i is weakly more important than O_j
- $a_{ij} = 5$ if O_i is strongly more important than O_j
- $a_{ij} = 7$ if O_i is very strongly more important than O_j
- $a_{ij} = 9$ if O_i is absolutely more important than O_j

The AHP matrix is then generated (Table 3.1) then normalized to get the b_{ij} values. b_{ij} are the result of the division of each element of the matrix by the sum of its column. The required QoS parameter weights are finally given by equation (3.1).

$$W_i = \frac{b_{i1} + b_{i2} + b_{i3} + b_{i4}}{4} \tag{3.1}$$

The required quality thresholds are then calculated in equation (3.2):

$$\begin{aligned} Q_{th}(s_k) = {} & W_{ber(s_k)}.ber_{th}(s_k) + W_{J(s_k)}.J_{th}(s_k) \\ & + W_{d(s_k)}.d_{th}(s_k) + W_{Bwd(s_k)}.Bwd_{th}(s_k) \end{aligned} \tag{3.2}$$

Where $ber_{th}(s_k)$, $J_{th}(s_k)$, $d_{th}(s_k)$and $Bwd_{th}(s_k)$ are, respectively, the required threshold of the bit error rate, the jitter, the delay and the bandwidth used to calculate the require overall quality threshold Q_{th}.

Each time a mobile terminal connects to a network n, and before handing off to another one, it computes its perceived quality using equation (3.3) and concludes whether the offered quality satisfied its requirements or not.

$$\begin{aligned} Q_n(s_k) = {} & W_{ber(s_k)}.ber_n + W_{J(s_k)}.J_n \\ & + W_{d(s_k)}.d_n + W_{Bwd(s_k)}.Bwd_n \end{aligned} \tag{3.3}$$

If the perceived quality is better than the required quality, the mobile terminal rates the network positively; otherwise, it rates it negatively. The Network Quality and threshold functions require a comparable scale for all QoS parameters. Thus, it is necessary to normalize them and to distinguish costs and benefits. Let X denote a raw measured or calculated parameter. The normalization X_{nor} is obtained using equation (3.4) for cost parameters (i.e. The higher, the worth, e.g. BER, delay, ...) and equation (3.5) for benefit parameters (i.e. The higher, the better, e.g. bandwidth).

$$X_{nor} = X_{min}/X \tag{3.4}$$

$$X_{nor} = X/X_{max} \tag{3.5}$$

□.□.□ Aggregation

Rates given by different users are then aggregated to represent the global network reputation. Reputation is then computed in two steps:

- *Step 1:*

$$r_n(t) = w^+ \sum r^+(m,n) + w^- \sum r^-(m,n) \tag{3.6}$$

Where w^+ (w^-, respectively) is a weight allocated to positive (negative, respectively) rates. The weights can take different values depending on the importance given to positive and negative rates. For instance, setting $w^+ = w^- = 0.5$ would grant the same importance to both rates. We propose here to give more importance to negative behaviors by setting $w^+ = 0.4$ and $w^- = 0.6$. This is motivated by the fact that negative rates are more important as they generally represent an effective or sudden observed degradation on the network quality.

- *Step 2:*

The objective is to gradually decrease the effect of old observations through time. This consideration provides the possibility of revising the behavior towards a network triggered by a particular reputation value. Thus, the final global reputation value is computed as follows:

$$R_n(t) = \begin{cases} r_n(t) & \text{if } t = 1 \\ (1-\gamma) \cdot R_n(t-1) + \gamma * r_n(t) & \text{if } t \geq 2 \end{cases} \tag{3.7}$$

Where $\gamma \in [0,1]$ is a discounting factor that makes old observation gradually less important.

□.□.□ Sharing

The resulting global reputation can be stored in a centralized or in a distributed way, it depends on the network overall architecture. These architectural and implementation issues will be addressed in details in chapter 5.

3.4 The Proposed VHO decision algorithm based on reputation

In the following, we consider two different networks nomenclatures: Home Networks (HNs) are networks to which MTs are currently connected, and Target Networks (TNs) to which mobile nodes are intending to hand to. The reputation system is built as a distributed overlay able to gather, update and communicate networks' reputation values and QoS statistics (figure 3.1). In the following, it is denoted by the Overlay Reputation Manager (ORM).(The reputation system deployment will be addressed in details in chapter 5).

The ORM is not only defined to manage reputation values, it may also be considered as a

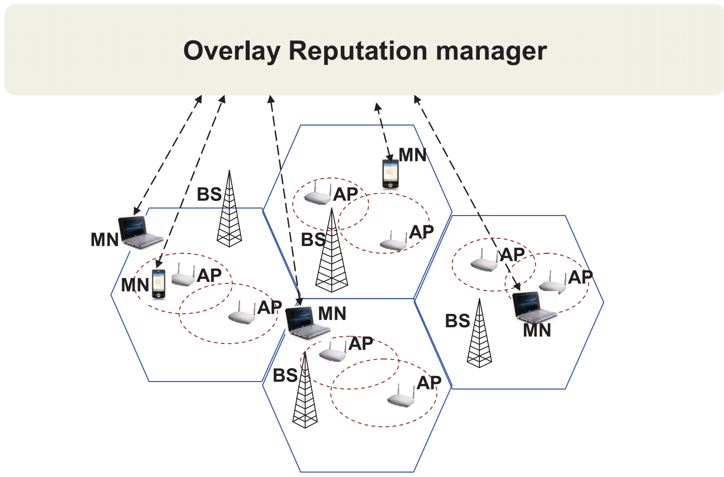


Figure 3.1: System model

control layer that makes reasoning on behalf of mobile nodes and networks. Indeed, the ORM carries different context information related to networks availability, to their offered QoS and to mobile nodes positions. Thus, mobile nodes report their positions and their perceived QoS parameters to the ORM that computes the global reputation values and makes reasoning on frequently changing contextual information. In this vision the ORM is responsible of:

• Making statistics on offered QoS and initiating VHO when an experienced QoS goes bellow a given threshold.

• Making a classification of available networks according to their reputation.

• Informing mobile nodes about networks' reputations and QoS when required.

The exportation of the reasoning activities to the ORM considerably reduces the processing on the mobile nodes side and thus allows their resource saving.

Each time a handover is imminent, the MN asks the ORM for available networks' reputations.

Available networks may be directly detected by the MT or may be deduced by the ORM, given the MT location.

The proposed algorithm (Fig. 3.2) considers both imperative and alternative VHOs as de-

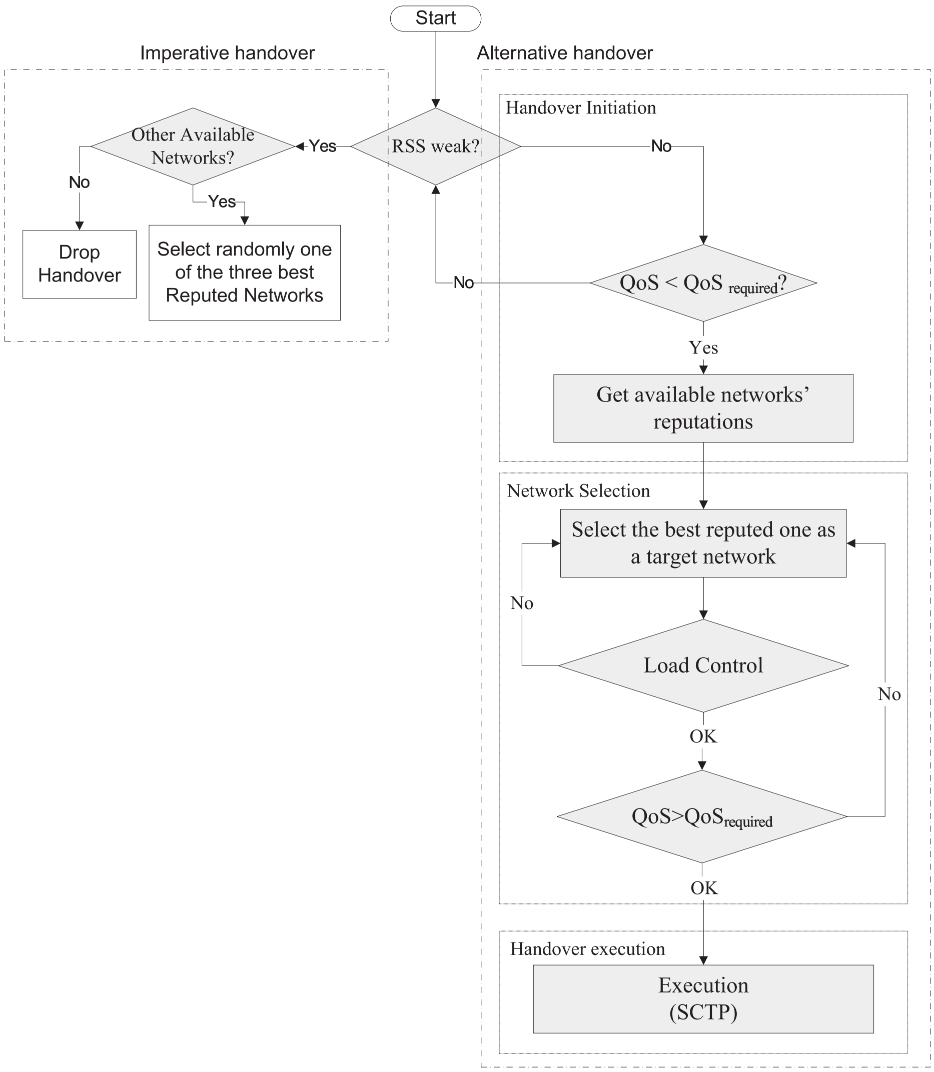


Figure 3.2: Proposed VHO decision algorithm

scribed in the following subsections. The Received Signal Strength is used as an Indicator that helps to decide which kind of these VHOs to trigger.

3.4.1 Imperative handover

The imperative handover is executed if the current connection can no longer be maintained on the Home Network. This is generally observed if the Home Network's RSS is suddenly lower than a minimum threshold $th_{min}(-115dbm)$ [65]. It may also be observed if the delay or any other QoS parameter is suddenly affected. Since existing VHO decision mechanisms

require high delay (a few seconds), the use of reputation system can be a good choice as it can increase the chance of handing over to a suitable QoS offering network within minimum delays (milliseconds).
Indeed, traditionally, when an imperative handover is required, the handover selection is only based on the received signal strength.
Let's consider a mobile node, connected to a WiFi network and running a streaming application, that has to perform an imperative handover. Traditionally, it hands over to the network that has the best signal quality. Let's assume that it is a GPRS network. In this case, the mobile node would experience a lower QoS and may even be forced to make another handover.
In such cases, using reputation increases the chance of handing over to an available network that offers comparable QoS to the one it was experiencing before making its imperative handover which avoids making useless handover and offers better QoS.

3.4.2 Alternative handover

If the Home Network RSS is higher than th_{min}, handover is not compulsory. The ORM periodically checks whether there are new available candidate networks with better reputations. In this case, the best reputed and not overloaded one is considered to be a target network. The next step is the network selection which is an important process before the handover execution. The proposed solution consists in three main phases: (a) Vertical handover initiation, (b) Network Selection and (c) Vertical handover execution as depicted in fig.3.2.
(a) Vertical handover initiation
The VHO may be initiated by both mobile nodes and the ORM.
• If the Received Signal Strength goes below a minimum threshold, the mobile terminal initiates a handover before it looses its current connection.
• If the ORM notices that a mobile node perceived QoS is lower than required, it initiates a VHO.
(b) Network Selection
During the selection process, the mobile node checks for available networks reputation values and selects the best reputed and not overloaded one as a target network. If this latter provides sufficient QoS, the mobile node hands over to it.

(c) Vertical handover execution
The vertical handover execution is an implementation issue. We propose the use of multihoming protocols such as SCTP (see section 2.5.2.4), at the network layer. In the standard SCTP mechanism, the change of primary address takes place only after the primary address is completely failed or inactive. The primary path is marked as inactive or failed after four

consecutive timeouts [66]. In our case, and thanks to the VHO anticipation capabilities of our reputation based decision mechanism, SCTP is adapted to perform "make before break" handover. Indeed, whenever a vertical handover is required, the mobile node establishes a new connection on the best reputed available interface while still communicating with the old one to ensure low latencies and losses.

3.5 Performance evaluation

In the first part of this section, the proposed reputation system is evaluated using matlab. The second part of the section deals with the VHO decision algorithm evaluation.

3.5.1 Reputation system evaluation

This section is devoted to evaluate the accuracy of the proposed reputation system. The Simple Additive Weighting algorithm (SAW) is used during the learning phase to compute the initial values of reputation. Simulations are conducted using Matlab. We considered mobile terminals evolving, according to the Gauss Markov mobility model [67], within an area covered by 4 UMTS base stations and 7WLAN access points as presented in Fig. 3.1. Two different sub-areas for each network are defined: a central zone and an edge zone. Four main traffic classes, as defined by the 3GPP in [68] are considered: conversational, streaming, interactive, and background. For the conversational class, we distinguish voice and video sub-classes. Each traffic class is associated with four QoS attributes: required bandwidth, end-to-end delay, jitter, and bit error rate. We used the same weighting as in [5] (see table 3.3).

The bandwidth varies between 32 and 2048 *kbps* for UMTS and between 1 and 11 *Mbps* for WLAN. For both technologies, delays vary between 1 and 180*ms*, jitter between 3 and 11 *ms* and BER between 10^{-6} and 10^{-2}. Reputations for each network area and for each class of service are computed as defined in section 3.3.4. We generate users running conversational voice sub-class or streaming class of service and we distributed the users in a manner to get different samples of users from different locations.

Fig. 3.3 depicts the evolution of the reputation in the central (zone 1) and the edge (zone 2) areas of a WLAN network. The reputation of the WLAN is better in zone 1. This may be explained by the fact that the QoS parameters and the received signal are generally better in the center. These results are obtained for the video streaming class of service.

Fig. 3.4 illustrates the evolution of reputation, in one of the available UMTS networks, considering the two applications (voice and streaming). The UMTS reputation is worse in the case of video streaming applications. This may be explained by the fact that the video streaming

Table 3.2: AHP matrix of each class of service [5]

□onversational	**□er**	**□ela□**	**□itter**	**□□d**
□er	1	1/□	1/□	1
□elay	□	1	1	□
□itter	□	1	1	□
□wd	1	1/□	1/□	1
□treaming	**□er**	**□ela□**	**□itter**	**□□d**
□er	1	1/5	1/□	1/□
□elay	5	1	1/5	1/5
□itter	□	5	1	1
□wd	□	5	1	1
□nteractive	**□er**	**□ela□**	**□itter**	**□□d**
□er	1	5	□	5
□elay	1/5	1	5	1
□itter	1/□	1/5	1	1/5
□wd	1/5	1	5	1
□ackgro□nd	**□er**	**□ela□**	**□itter**	**□□d**
□er	1	□	□	5
□elay	1/□	1	1	1/5
□itter	1/□	1	1	1/5
□wd	1/5	5	5	1

Table 3.3: Importance weights per class [5]

□lass o□service	**□er**	**□ela□**	**□itter**	**□□d**
conversatinal	0.04□□	0.45002	0.45002	0.04□□
Streaming	0.03737	0.113□0	0.42441	0.42441
Interactive	0.635□3	0.16051	0.04304	0.16051
□ackground	0.66□32	0.05546	0.05546	0.21□76

applications are much more □oS demanding. In fact, □MTS ensures good quality of service for voice applications as they require less bandwidth and are quite tolerant to □it error rate compared to video streaming.

□ig. 3.5 shows that WLA□ has a better reputation for video streaming applications. This may be due to its capability to offers higher □andwidth and generally ensures less delay which is very important for video streaming applications. In the following, a comparison between

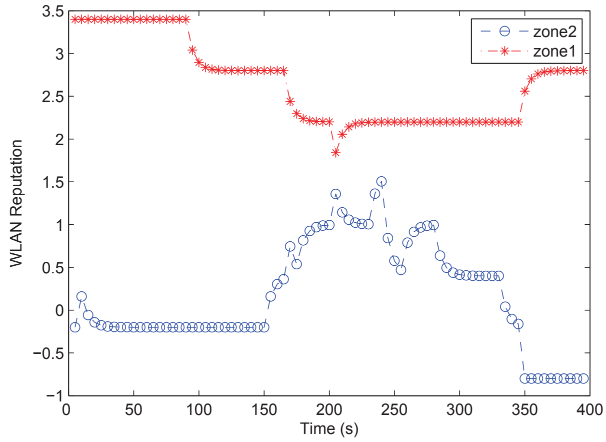


Figure 3.3: Reputation evolution in the central and the edge area of a WLAN

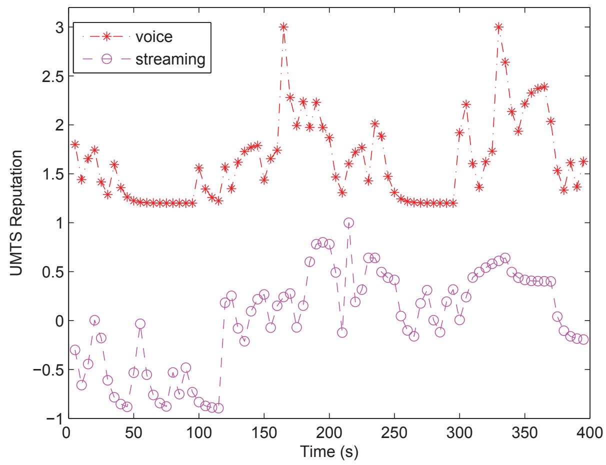


Figure 3.4: Reputation evolution for voice and video applications in UMTS

the decisions made by the SAW algorithm, used during the learning phase, and the decision made by referring to the built reputation is provided. Fig. 3.6 shows that, in similar QoS and mobility conditions, up to 7□percent of mobile terminals select the same network when using SAW's scores or reputation.

We also notice that the decision making is faster when using the reputation based proposed technique. Indeed, when using SAW (in its centralized or distributed forms) to make the VHO decision, a MN must either calculate the overall score of each available network to choose the best one or ask available networks for these scores that will be calculated on demand (each time a VHO is required). These calculations require high processing delay. Whereas, the proposed reputation based decision algorithm results in lower processing delay as it refers to

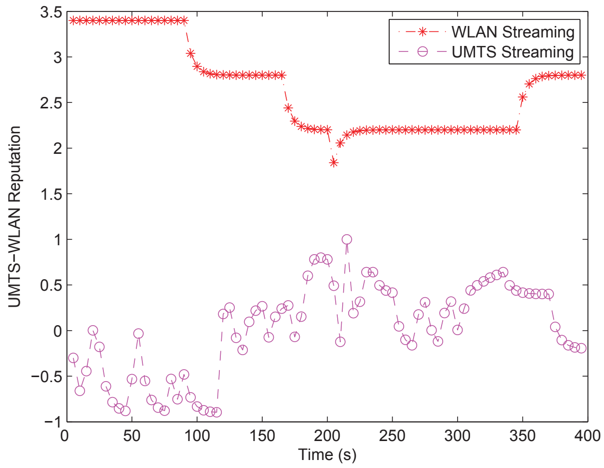


Figure 3.5: WLAN and UMTS reputations for video streaming application

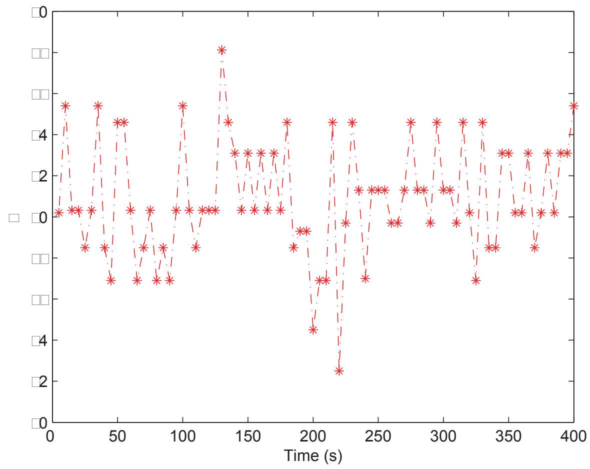
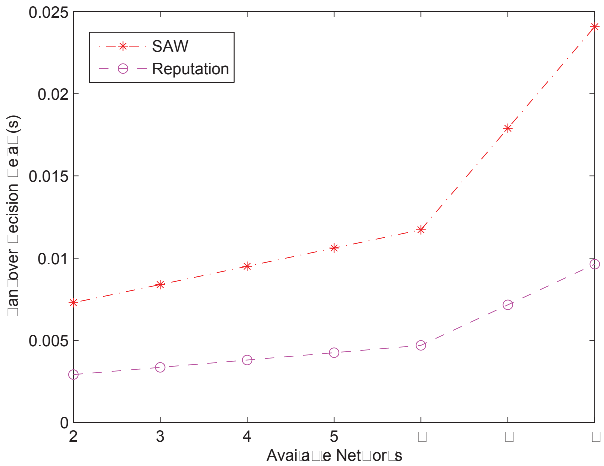


Figure 3.6: Percentage of similar decisions between SAW and the proposed solution

already built Reputations to make fast VHO decisions. In addition, the number of exchanged messages to make a decision is higher with SAW. Fig. 3.7 shows the impact of the number of available networks on the decision delay for both centralized SAW and our reputation based solution. In both solutions, the decision delay increases with the number of available networks. However, the proposed solution provides considerable enhancements.



□igure 3.7: Handover decision delay

□.□.2 □e□□tation based □□□ eval□ation

□im□lation to□olog□

The □HO decision algorithm evaluation is performed using □S 2. The solution is built on the SCTP protocol stack implemented in □S 2.
We consider the system topology defined in □igure 3.□. It consists of a correspondent node (C□), an Overlay Reputation Manager (ORM), a Wi□i access point (AP1), a WiMax base station (□S1) and an □MTS base station (□S2) connected to a router (R) through wired links. We consider a multihomed mobile node (three interfaces: Wi-fi, WiMax and □MTS) that moves across the coverage areas of the different APs and □Ss. We assume that the mobile node travels from the coverage area of AP1 to □S1 and to □S2. As it travels from different stations it passes through networks having different □oS parameters. Accordingly, the M□ has to select the best reputed networks and perform vertical handover as directed by the reputation manager. These available networks are characterized by their coverage area that are set according to the transmission power. An □TP traffic □ows from the correspondent node to the mobile node through wired and wireless links. The parameters used in the simulation are listed in tables 3.4, 3.5 and 3.6:

SCTP is used as a transport layer protocol that provides multi-homing to the mobile node. The different parameters used by SCTP are depicted in table 3.7.

Table 3.4: Simulation topology

□arameters	**□al□e**
Simulation environment	□S 2
Area size	□00 x □00 m2
Mobile node speed	10m□s
Maximum queue length	50

Table 3.5: Wired □odes properties

	□□□ro□ter	**□□M□ro□ter**	**□□□□ro□ter**	**□□□□ro□ter**	**□□2□ro□ter**
□andwidth	11Mb	11Mb	100Mb	100Mb	100Mb
□elay	5ms	5ms	2ms	2ms	2ms
□ueue	□roptail	□roptail	□roptail	□roptail	□roptail

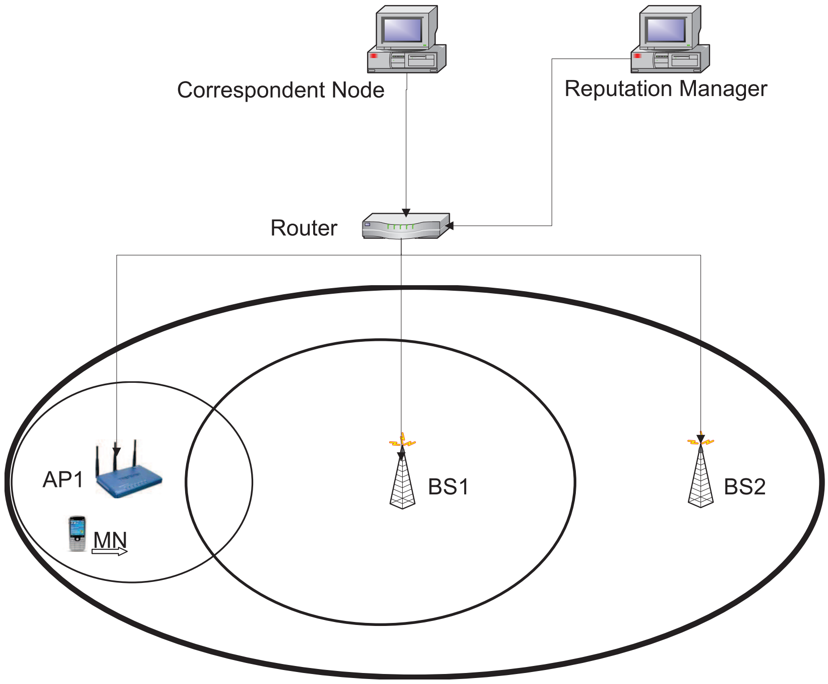
Table 3.6: Access Point and □ase station Properties

	□□□	**□□□**	**□□2**
Mac□□02.11 data rates	$11Mb$	$\square Mb$	$2Mb$
Transmission power Pt	0.2□1□	0.3□1□	4.□1□
Rx Threshold	$3.622x10^{-11}$	$3.622x10^{-11}$	$3.622x10^{-11}$
Cs Threshold	$1.55x10^{-11}$	$1.55x10^{-11}$	$1.552x10^{-11}$
□requency	$2.4x10^{\square}$	$3.5x10^{\square}$	$2.1x10^{\square}$
Location	□□100 □□2 □□0	□□400 □□2 □□0	□□500 □□2 □□0

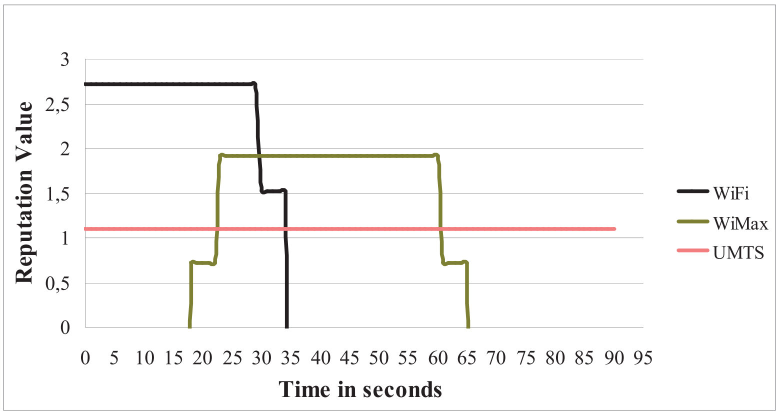
Table 3.7: SCTP Parameters

□arameters	**□al□e**
MT□	1040
□ata size	100□
Reliability	1 (retransmission occurs)
Retransmission to alternative	□isabled
Heartbeat Interval	30s

Reputation is calculated using two □oS parameters, namely, delay and bandwidth. Only the first aggregation step is considered for reputation calculation. The MT's experienced reputation values are shown in figure 3.□



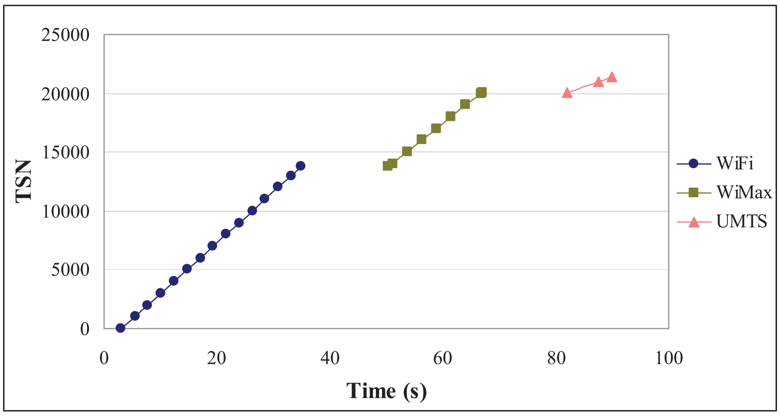
□igure 3.□: System model



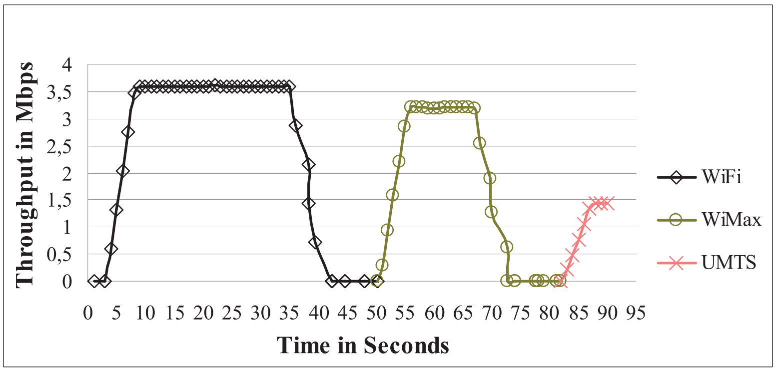
□igure 3.□: Reputation □alues

□ase□□□er□ormance o□m□ltihomed mobile node □itho□t re□□tation s□s□tem

When SCTP [41] is implemented without any □HO decision mechanism, a handover only occurs once the primary path has totally failed. This results in high handover delays and session discontinuities. Simulations show that the handover delay when the mobile travels from Wi□i to WiMax is 15.22 seconds and from WiMax to □MTS is 15.031 seconds. This is shown in figure 3.10 through the blackout periods. We also notice that the data rate is almost equal to zero, during these blackout periods, due to session discontinuities (□igure 3.11).



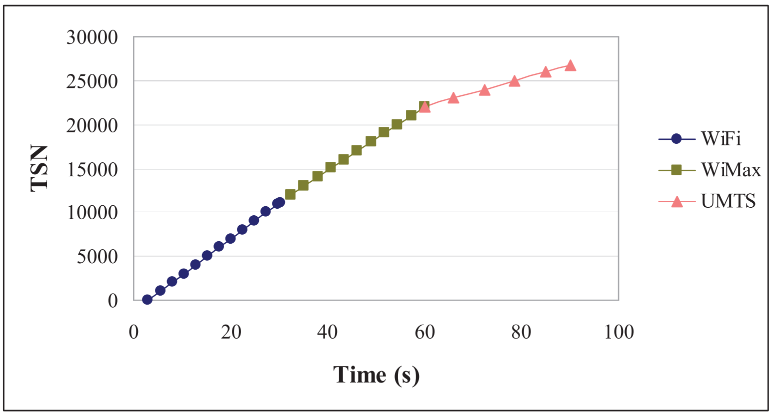
□igure 3.10: □HO delay without the Reputation System



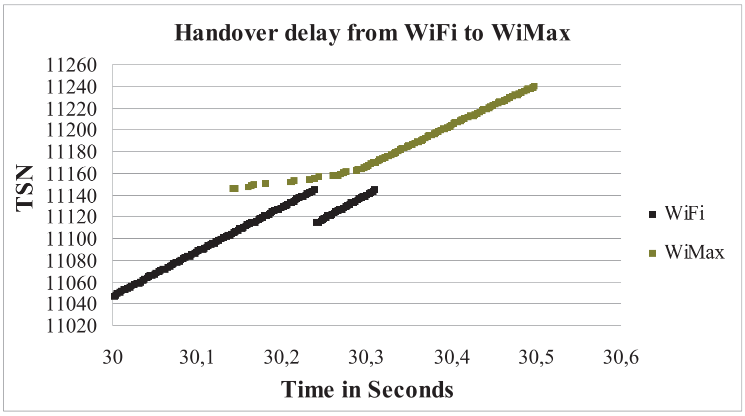
□igure 3.11: Experienced throughput without Reputation System

□ase 2□□er□ormance o□m□ltihomed mobile node □ith re□□tation s□stem

When the proposed reputation based □HO decision algorithm is implemented we notice that the □HO delay drastically decreases thanks to the ORM handover anticipation capability. It is about 141 ms from Wi□i to WiMax and 11□ms from WiMax to □MTS and almost no session discontinuity are noticed as depicted in figure 3.12. In this case, SCTP does not wait for the primary interface to get failed but consults the reputation system to get the best reputed network and anticipates the vertical handover. Therefore, the time the standard SCTP spends in declaring the primary network failure is saved and a seamless vertical handover is ensured as experienced delay is too small. The packet delivery ration was 100 percent with almost no session discontinuity. □igure 3.13 shows that, thanks to the multihoming feature of the SCTP protocol, transmission over WiMax starts early before the terminal gets disconnected from Wi□i.

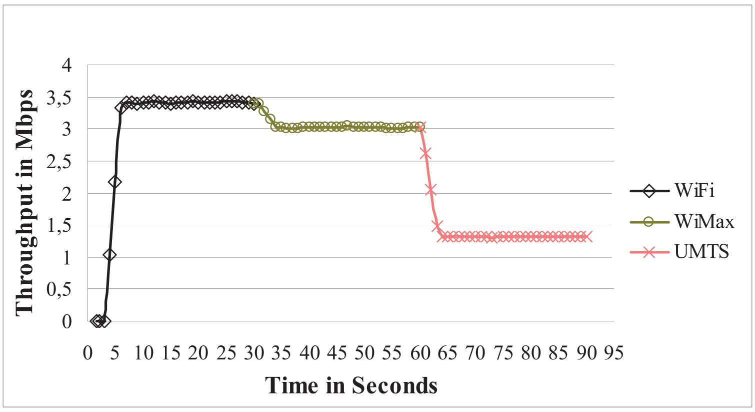


□igure 3.12: □HO delay with the Reputation System



□igure 3.13: Handover delay from Wi□i to WiMax

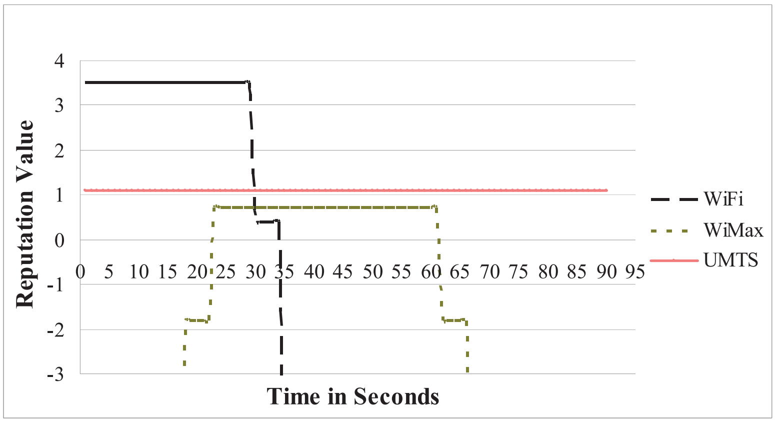
□igure 3.14 shows that the throughput experienced by the mobile node is continuous without any interruption, when the reputation system decision solution was employed. The blackout period is really reduced to milliseconds which confirms the better quality of service the user experiences with the reputation system decision solution.



□igure 3.14: Experienced throughput with Reputation System

case □□□er□ormance o□m□ltihomed mobile node □hen tra□□c increases in □ iMa□

If we consider a policy based □HO decision making as in [6□] where the most preferred available interface is generally used till the user moves out of its coverage, we get almost the same performances as in our reputation based scheme when the traffic is smooth in the preferred network. In the following, the impact of reputation is analyzed. The traffic in WiMax is increased and the performance of the proposed solution are compared with a policy based solution for which WiMax is always preferred over □MTS. When the traffic increases suddenly in WiMax, its reputation decreases rapidely and even goes bellow the □MTS reputation (figure 3.15).



□igure 3.15: Reputation □alues when traffic increases in WiMax

We can see from figure 3.16 that the total throughput experienced by the mobile node that uses a policy based □HO decision strategy decreases considerably in the WiMax coverage which is its preferred network. However, when the reputation solution is adopted, the mobile node directly connects to the □MTS that dispose of a better reputation and insures better throughput as shown in figure 3.17. In this simulation scenario, the handover takes place

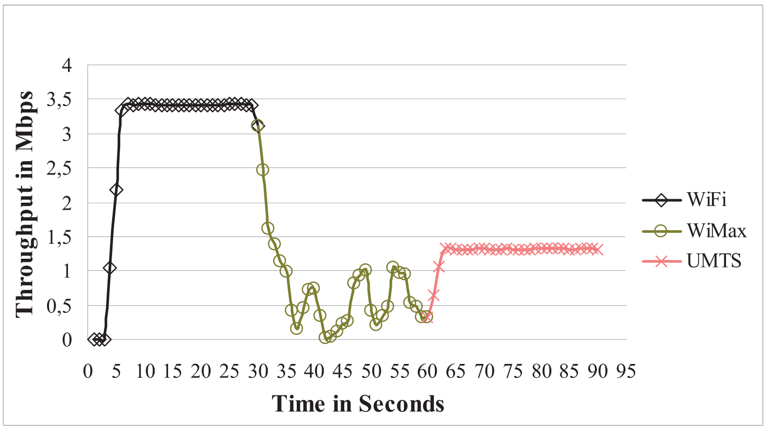


Figure 3.16: Experienced throughput with policies

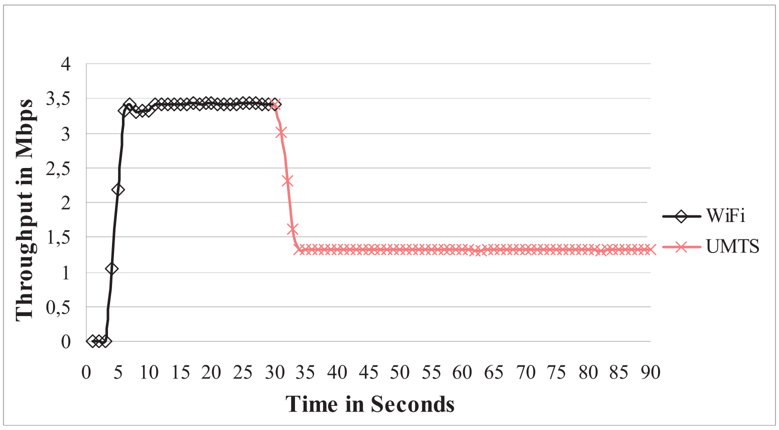


Figure 3.17: Experienced throughput with reputation based decision

between WiFi and UMTS only. The handover delay is about 147 milliseconds and no black-out periods are noticed in between. The throughput experienced by the mobile node in this scenario is also acceptable (figure 3.17) and improved compared to the one with the policy based strategy for which the WiMax is always preferred over UMTS.

Figures 3.1□ and 3.1□ compares the different simulation scenarios□it is shown that the overall throughput and number of received packets increase with the reputation based decision mechanism.

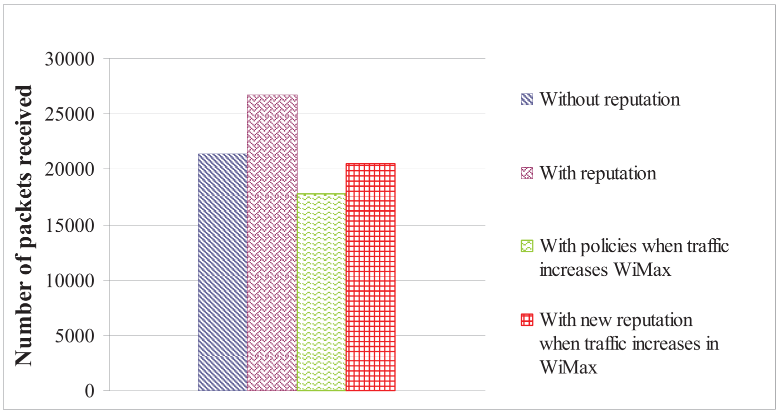


Figure 3.1□: Comparison between number of packets received

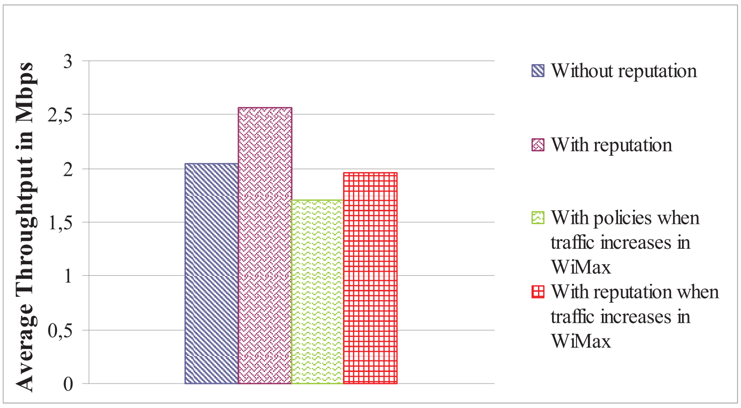


Figure 3.1□: Comparison between average throughput

□.□ Conclusion

In this Chapter, we proposed a reputation system to speed up wireless network selection and handover decisions. The Reputation System computes global reputation values based on past user experiences and allows mobile terminals to make faster VHO decisions. Building network reputations is a statistical process that requires multiple samples of users' experiences. At the initiation phase, these reputation statistics should not be available or not statistically significant.

Other decision mechanisms may be used during this learning phase to build up the reputation system.

Performance results show that the proposed solution provides up to 7□ percent of right decisions compared to the learning reference algorithm and reduces considerably the decision delay.

Performance results also show that the proposed solution provides better delay than SCTP without any decision mechanism, the handover delay decreased from 15 sec to almost 140 milliseconds, which helps to achieve seamlessness while vertical handover is performed. It is also shown that the reputation based VHO decision mechanism provides better throughput than a policy based VHO scheme when network conditions change suddenly.

Other issues should be addressed within this Reputation Systems and the proposed vertical handover decision making algorithm.

Some considerations regarding the robustness of our reputation system need to be addressed in our further works. First of all, the proposed reputation system needs to be normalized in an optimal manner to keep reputation significance. Second, fundamental questions regarding effectiveness and sustainability need to be addressed. Indeed, what is the impact of wrong observations? How to distinguish between deliberate packet dropping and congestion or loss of connectivity? How accurate and fair is the reputation system?

What is the impact of potential liars on the reputation values? What if the reputation values are falsified by a network to attract users? What strategies can an attacking node (user or network) employ to distort the reputation system, in addition to lying?

Regarding the decision mechanism, other decision parameters and methods may be introduced to enhance the proposed vertical handover mechanism. In the following chapter we propose a game theory based VHO decision algorithm that considers additional decision parameters and considers Fuzzy Logic for VHO initiation.

Chapter 4

A Nash Stackelberg approach for network pricing and □□□ decision making

4.1 Introduction

Radio resource and mobility managements are becoming more and more complex within nowadays rich and heterogeneous wireless access networking systems. Multiple requirements, challenges and constraints, at both technical and economical perspectives have to be considered. While the main objective remains guaranteeing the best Quality of Service and optimal radio resource utilization, economical aspects have also to be considered including cost minimization for users and revenue maximization for network providers.

In this chapter, we consider both technical and economical aspects to address vertical handover and pricing issues in heterogeneous wireless networks. This can be modeled as an interactive decision-making problem for involved actors with conflicting interests. Game theory seems a potential tool to study these interactions. We propose a game theoretic scheme where each available network plays a Stackelberg game with a finite set of users, while users are playing a Nash game among themselves to share the limited radio resources. A Nash equilibrium point is found and used for vertical handover decision making and admission control.

We also introduce in the proposed model: (a) user's requirements in terms of quality of service according to its running application and (b) the network reputation that is conducted from the users' quality of experience as explained in the previous chapter. The effect of these parameters on the network pricing and the revenue maximization problems is then studied.

The remainder of this chapter is organized as follows. In section 4.2, a basic introduction of the tool of game theory is given. In section 4.4 the motivation behind the use of game theory to model our problem is provided. Section 4.3 provides related work to game theory and pricing in the telecommunications field. Section 4.5 formulates the game and its resolution and analyses the networks' revenue. In section 4.6, a vertical handover decision algorithm with a selection process based on the obtained Nash equilibrium is proposed. Section 4.7 provides the performances results and, finally, section 4.8 concludes the proposed work.

4.2 Game theory

Game theory's roots are extremely old. It is a set of modeling tools that provide a mathematical basis for the understanding and the analysis of interactive decision-making problems for actors involved in situations with conflicting interests.

Game theory's greatest success was in the field of economics since many of the early game theorists were economists. It almost touched and analyzed every aspect of economics thought different game models and theories: utility theory, cooperative and team games, strategic use of information, auction theory, the problem of coordination between independent players, and implementation of incentive mechanisms. Game theory has also made important contributions to other fields, including political science, sociology, biology, and military strategy.

A game consists of three components:
- a set of rational players that interact to make decisions.
- a set of possible actions (strategies) A_i for each player i.
- a set of utilities u_i that are functions of action profiles ($a = (a_i, a_{-i})$) that determine the outcome of the game. In other words, the utility function assigns a value to each possible outcome: higher utilities represent more preferable outcomes.

a_i is the action of player i and a_{-i} is the vector of other players actions. This terminology does not mean that other players want to "beat" player i, it just means that each player aims to maximize his (her) utility function which may imply "helping" or "hearting" the other players.

In economics, the most familiar interpretation of strategies may be the choice of prices or output levels, which correspond to Bertrand and Cournot competition, respectively [70]. For political scientists, actions may be electoral platforms choices and votes.

A game model is generally appropriate only in scenarios where decisions of each actor impact the outcomes of other actors. In a system involving several players, we can distinguish between two types of games where players may be cooperative or competitive.

In a *cooperative game*, the problem may be reduced to an optimization problem for which a single player drives the system to a social equilibrium. A standard criterion used in game theory to express efficiency of such equilibrium is Pareto efficiency [71]. A strategy profile is called Pareto efficient if no other strategy exists such that:

1) all users do at least as well

2) at least one user does strictly better.

In a *non-cooperative game*, each player selfishly chooses his (her) strategy. In this case, if an equilibrium is reached, it is called a Nash equilibrium. It is the most well-known equilibrium concept in game theory and is defined as the point from which no player finds it beneficial to unilaterally deviate. In pure strategies, that means [70]:

An action $a \in A$ is a Nash equilibrium if $u_i(a) \geq u_i(a'_i, a_{-i}) \; \forall \; a'_i \in A_i, \; \forall \; i \in N$.

Where:

a is an action profile vector that contains the strategies of all players: $a = (a_i)_{i \in N} = (a_1, a_2, ..., a_N)$. a_{-i} is the collective actions of all players except player i. The joint action space (or the space of action profiles) is defined as the Cartesian product of the individual action spaces: $A = X_{i \in N} A_i$.

In a wireless system, the players may be mobile nodes, networks or services. Actions may include the choice of a modulation scheme, a flow control parameter, a power level, a bandwidth amount or any other factor that is controlled by the network, the node or the service. These actions may be constrained by technical capabilities or resource limitations or by rules or algorithms of a protocol.

However, each player in this context will dispose of some leeway to set the appropriate parameters to his (her) current situation or even to totally change his (her) mode of operation. These players are then autonomous agents that are able of making decisions about bandwidth allocation, transmit power, packet forwarding, backoff time, and so on.

As stated before, players may cooperate or not. In the context of wireless networks, nodes may look for the "greatest good" of the network as a whole, they may also behave selfishly, seeking their own interests or they may even behave maliciously, aiming to damage the network performance for other users.

In the context of our work we are subject to a non-cooperative scenario where users compete to share resources and maximize their utilities and networks compete to maximize their revenue. These entities will have to make different decisions in different situations, namely, when new users join a network, when a vertical handover is necessary, when the required QoS varies, when a network conditions change,...

4.□ Game theory and Pricing in telecommunications

Game theory has been applied in real games, economics, politics, commerce and recently in telecommunications and networking. For instance, intensive research effort has been devoted to game models in wireless networks. Some of the main studied issues are power control, pricing, security issues, access and flow control and auctions for resource reservation.

In [72], □iao et al. present a power control framework called □tility-□ased Power Control (□□PC) cost . This framework ameliorates system convergence and satisfies □oS requirements in term of delay and bit error rate for different service classes in Code □ivision Multiple Access (C□MA) cellular systems. The □□PC is represented as a non-cooperative □-person game where each user aims to maximize its satisfaction by increasing its □oS and minimizing its power consumption. There is also an extensive literature on game theoretic models of routing problems.
[73] presents an approach that formulated a multiple class routing problem based on game-theory as a □ash game and solved the routing problem for two classes of packets sharing two links. The first class may be queued at the link buffers and the second one is blocked when there is no space. The ob□ective is to minimize the delay for the first class and the blocking probability for the second.
[74] presents a routing problem in which non-cooperating agents wish to establish paths from sources to destinations to transport a fixed amount of traffic. The authors study the equilibrium that arise in networks of general-topology under some polynomial cost functions and obtain conditions for the uniqueness of the equilibrium. A promising potential application of game theory is also the area of network security. In [75], □odialam et al. resort to game theory to develop a network packet sampling strategy that detects network intrusions taking into consideration the constraint of not exceeding a given total sampling budget. They model the problem as a non-cooperative game between intruders and networks providers. The intruder in□ects malicious packets and picks paths to minimize chances of detection and the network operator chooses a sampling strategy to maximize the chances of detection. Another problem that is well studied using game theory is □ow control. [76] presents a game theoretic framework in which each user aims to maximize its performance measure expressed by a standard utility function. It demonstrates the existence and the uniqueness of □ash equilibrium and gives a proposal on how non-cooperative users can distribute their □ows among numerous links, by imposing a suitable pricing method that encourages load balancing.

□asar et al. in [77], propose a game theory based model for revenue maximization, pricing and capacity expansion in a Many-□sers regime. They consider a model where many users are accessing a single link and capacities are increased in proportion to the number of users. They show that, as the number of users increases, the service provider's revenue-per-unit-bandwidth increases for all values of the link capacity and the overall performance of each user improves.

The motivation behind using game theory to model our problem is explained in the following section.

4.4 Motivation

Nowadays, service providers are relying on different wireless access technologies to handle the increasing amount of subscribers' demands. These heterogeneous networks would be able to insure the "Always best connected" paradigm by providing different service classes with their corresponding required QoS. The considered wireless technologies have different characteristics including coverage, mobility management, security and capacity. To select the most appropriate access network, new solutions are required to meet both users' and networks' objectives. On the one hand, users seek the most suitable access network -for new arrivals and for VHO connections- regarding their needs and cost preferences. On the other hand, service providers aim to maximize their revenues that are proportional to the resource utilization while remaining competitive to attract users. Most of existing vertical handover decision mechanisms are mainly based on technical network aspects like RSS and QoS parameters and do not consider interactions that may exist between the actors concerned by the decision making (i.e. users, networks and service providers). These solutions are very interesting in the sense that different decision parameters related to different requirements are considered. However, other considerations related to the real interaction of all the actors involved in an heterogeneous environment (access networks, users, service providers,...) should be taken into account to make appropriate decisions.
Indeed, interactions across actors are non-negligible for VHO decision making because the choices of any one may influence the choices of the others.
In this context, it is also important to examine the economic concern by introducing the service provider and mobile users in a market like environment, allowing to jointly optimize both resource consumption and utilities of both users and providers.
Like any other market, the wireless network market will be made of services sold by service providers and bought by end users.
The determination of appropriate prices becomes a fundamental aspect for admission control and QoS provisioning. The traditional scheme of per service static pricing is no more applicable from service providers' perspective. We need a model where a service provider is able to continuously modify the price of a service according to its capacity and to users' requirements.
As a service provider, the first decision problem is to define different strategies for each class of service and choose a price that allows it to attract users and maximize profit. As a user, the decision problem is to select the best network for a given service according to his willingness to pay and his required QoS.
Note that, the prices applied by service providers should not be too high as that may repel users that are not willing to pay. At the same time, they shouldn't be too low in order to stay profitable.

It is also important to mention that a major limitation with most of the pricing schemes is that they do not consider the differentiated nature of QoS and networks' reputation perceived by users for different applications.
As stated in the previous section, game theory has shown to be a powerful tool for the analysis of interactive decision-making processes. It provides mathematical tools to predict what should happen when agents (or players) with conflicting interests interact.
In the following, the pricing and VHO decision problems are modeled as an hierarchical game among heterogeneous available networks and multiple users running various services and having different requirements. We propose a scheme where each available network plays a Stackelberg game with users to maximize the service provider revenue, while these latter are playing a Nash game among them selves to maximize their utilities.

4.5 A Two-Level hierarchical Game

4.5.1 Game Formulation

Let's assume that there is a single service provider that manages the available networks. Let's denote by:
- N^j the available networks ($j = \{1, ..., k\}$, and users by $I = \{1, ..., n\}$. Network N^j has a total available bandwidth denoted by C^j.
- $B_i^j \geq 0$ the bandwidth provided by N^j to a user i.
- $p_i^j \geq 0$ the charged price to user i by network N^j.
- $w_i > 0$ the user i ability to pay [7□].
- r^j the network N^j reputation, it represents the network reliability in terms of good QoS providing and depends on QoS parameters including delay, jitter, bit error rate, etc. r^j varies between 1 and 10: 1 for very bad reputation and 10 for excellent reputation.
- q_i the user i requirement in term of QoS according to its running application. q_i is between 1 and 5, 1 for low QoS requirements and 5 very high QoS requirements.

The problem is modeled as a two-level hierarchical game [7□], the choice of a hierarchic game is motivated by the fact that it allows to study both the network pricing problem and users' behaviors. Indeed, users' behaviors in the lower level (w_i, q_i,...) depend on their requirements and to networks prices set by the upper level.
Similarly, network pricing strategies defined at the upper level depend on users' behaviors defined at the lower level.
• The upper level is a Stackelberg game with the service provider (the networks) as a leader

and mobile users as followers. In this level each network predicts the response of the followers and adjusts its prices in order to maximize its total revenue when users respond with their bandwidth requests corresponding to their requirements. The network revenue is given by:

$$R^j = \sum_{i=1}^{n} p_i^j B_i^j$$

and the service provider total revenue is:

$$R = \sum_{j=1}^{k} R^j$$

• The lower level is an *I-players* non cooperative game where each user i objective is to maximize the following utility function:

$$U_i^j = w_i * log(1 + r^j q_i B_i^j) - p_i^j B_i^j$$

subject to the constraint

$$\sum_{l=1}^{n} B_l^j \leqslant C^j$$

Remark: The utility function chosen for user i is $w_i * log(1 + r^j q_i B_i^j)$. It is close to the utility function $w_i log x_i$ used in [□0] that leads to proportional fair resource allocation. However, in our case, if we use $w_i log r^j q_i B_i^j$, a user will be obliged to ask for a nonzero B_i^j to avoid the case where his utility becomes equal to $-\infty$ if his demand is equal to zero. In addition, if a user is obliged to ask for a nonzero bandwidth, the service provider may get profit of this situation by imposing high prices. Our utility function $w_i \log(1 + r^j q_i B_i^j)$ allows users to decide whether to join a network or not which ensures a nontrivial solution to the Stackelberg game.

In pursuing a solution to the Stackelberg game, our intention is to find the Nash Equilibrium (NE) point where neither networks nor users have any incentive to deviate unilaterally from that point. This (NE) point is formally defined as follows:

Definition: (Nash Equilibrium) Let p_i^{j*} be the network solution for the stackelberg problem and B_i^{j*} be a solution for the $i^t h$ user's Nash problem. The point (p_i^{j*}, B_i^{j*}) is a NE for the Stackelberg game if for any (p_i^j, B_i^j):

$$U_i^j(p_i^{j*}, B_i^{j*}) \geq U_i^j(p_i^{j*}, B_i^j) \forall i,j \quad and$$

$$R^j(p_i^{j*}, B_i^{j*}) \geq R^j(p_i^j, B_i^{j*})$$

4.5.2 Solution

Theorem I: (Existence of Unique Nash Equilibrium)
For each price p_i^j the n-player non cooperative game admits a unique Nash equilibrium solution.
Proof:

$$U_i^j(B,p^j) = w_i log(1+r^j q_i B_i^j) - p_i^j B_i^j \tag{4.1}$$

under the constraints given by

$$\sum_{i=1}^{n} B_i^j \leq C^j \tag{4.2}$$

Note that for all B_i^j, $i \in \{1,...,n\}$ and $j \in \{1,...,k\}$ such that $\sum_{i=1}^{n} B_i^j \leq C^j$

$$\frac{\partial U_i^j}{\partial B_i^j} = \frac{w_i r^j q_i}{1+r^j q_i B_i^j} - p_i^j$$

and

$$\frac{\partial^2 U_i^j}{\partial {B_i^j}^2} = -\frac{w_i (r^j q_i)^2}{(1+r^j q_i B_i^j)^2} < 0 \tag{4.3}$$

U_i^j is then a concave function of B_i^j and the second derivative given in (4.3) is negative. This leads to conclude the uniqueness of the Nash equilibrium point.

Resolution:
Using the Lagrangian approach, equations 4.1 and 4.2 can be reduced to optimize the new function (4.4):

$$L = w_i.log(1+r^j q_i B_i^j) - p_i^j B_i^j - \lambda \left[\sum_{l=1}^{n} B_l^j - C^j \right] \tag{4.4}$$

where $\lambda \geq 0$ is the Lagrangian multiplier.
$\forall i \in \{1,...,n\}$ and for a network j, we can write:

$$\frac{\partial L}{\partial B_i^j} = 0 \Longleftrightarrow \frac{w_i r^j q_i}{1+r^j q_i B_i^j} - p_i^j - \lambda = 0 \tag{4.5}$$

Letting

$$B_i^j = \frac{w_i}{p_i^j + \lambda} - \frac{1}{r^j q_i} \tag{4.6}$$

□n the other hand, we can write:

$$\frac{\partial L}{\partial \lambda} = 0 \Longleftrightarrow \sum_{l=1}^{n} B_l^j = C^j \tag{4.□}$$

□f $\lambda = 0$, equation (4.6) leads to

$$B_i^j(p^j) = \frac{w_i}{p_i^j} - \frac{1}{r^j q_i}, \qquad (p_i^j > 0) \tag{4.□}$$

□f $\lambda > 0$, equations (4.6) and (4.□) lead to

$$\sum_{i=1}^{n} B_i^j = \sum_{i=1}^{n} \frac{w_i}{p_i^j + \lambda} - \sum_{i=1}^{n} \frac{1}{r^j q_i} = C^j \tag{4.□}$$

$\Leftrightarrow$

$$\sum_{k \neq i}^{n} \frac{w_k}{p_k^j + \lambda} = \sum_{i=1}^{n} \frac{1}{r^j q_i} + C^j - \frac{w_i}{p_k^j + \lambda} \tag{4.10}$$

The e□pression $\sum_{k \neq i}^{n} \frac{w_k}{p_k^j + \lambda}$ can be written in this equivalent form:

$$\sum_{k \neq i}^{n} \frac{w_k}{p_k^j + \lambda} = \frac{\sum_{k \neq i}^{n} w_k \prod_{l \neq k,i}^{n} (p_l^j + \lambda)}{\prod_{m \neq i}^{n} (p_m^j + \lambda)} \tag{4.11}$$

□quations (4.10) and (4.11) lead to:

$$\frac{\sum_{k \neq i}^{n} w_k \prod_{l \neq k,i}^{n} (p_l^j + \lambda)}{\prod_{m \neq i}^{n} (p_m^j + \lambda)} = \sum_{i=1}^{n} \frac{1}{r^j q_i} + C^j - \frac{w_i}{p_k^j + \lambda} \tag{4.12}$$

□onsidering $\gamma = \sum_{i=1}^{n} \frac{1}{r^j q_i} + C^j - \frac{w_i}{p_k^j + \lambda}$, equation (4.12) leads to

$$\gamma \prod_{m \neq i}^{n} (p_m^j + \lambda) - \sum_{k \neq i}^{n} w_k \prod_{l \neq k,i}^{n} (p_l^j + \lambda) = 0 \tag{4.13}$$

$\Leftrightarrow$

$$\gamma (p_t^j + \lambda) \prod_{m \neq i,t}^{n} (p_m^j + \lambda) - \sum_{k \neq i}^{n} w_k \prod_{l \neq k,i}^{n} (p_l^j + \lambda) = 0 \tag{4.14}$$

□imple manipulations then lead to

$$\sum_{t \neq i}^{n} \gamma (p_t^j + \lambda) \prod_{m \neq i,t}^{n} (p_m^j + \lambda) - (n-1) \sum_{k \neq i}^{n} w_k \prod_{l \neq k,i}^{n} (p_l^j + \lambda) = 0 \tag{4.15}$$

Summing up terms with the same indices and taking the product as a common factor give:

$$\gamma(p_t^j+\lambda)=(n-1)w_t \tag{4.16}$$

$\Leftrightarrow$

$$\left[\sum_{i=1}^{n}\frac{1}{r^j q_i}+C^j-\frac{w_i}{p_k^j+\lambda}\right](p_t^j+\lambda)=(n-1)w_t \tag{4.17}$$

$\Leftrightarrow$

$$\sum_{i=1}^{n}\frac{1}{r^j q_i}+C^j-\frac{w_i}{p_k^j+\lambda}=(n-1)\frac{w_t}{(p_t^j+\lambda)} \tag{4.18}$$

$\Leftrightarrow$

$$\frac{w_i}{p_k^j+\lambda}=\sum_{i=1}^{n}\frac{1}{r^j q_i}+C^j-(n-1)\frac{w_t}{(p_t^j+\lambda)} \tag{4.19}$$

$\Leftrightarrow$

$$\sum_{i=1}^{n}\frac{w_i}{p_i^j+\lambda}=nC^j+n\sum_{i=1}^{n}\frac{1}{r^j q_i}-n(n-1)\frac{w_t}{(p_t^j+\lambda)} \tag{4.20}$$

Equations (4.[illegible]) and (4.20) lead to

$$\sum_{i=1}^{n}\frac{1}{r^j q_i}+C^j=nC^j+n\sum_{i=1}^{n}\frac{1}{r^j q_i}-n(n-1)\frac{w_t}{(p_t^j+\lambda)} \tag{4.21}$$

$\Leftrightarrow$

$$\frac{w_t}{p_t^j+\lambda}=\frac{C^j}{n}+\frac{1}{n}\sum_{i=1}^{n}\frac{1}{r^j q_i} \tag{4.22}$$

Equations (4.22) and (4.6) give:

$$B_i^{j*}=\frac{C^j}{n}+\frac{1}{n}\sum_{i=1}^{n}\frac{1}{r^j q_i}-\frac{1}{r^j q_i} \tag{4.23}$$

Finally:

$$p_i^{j*}=\frac{nw_i}{C^j+\sum_{i=1}^{n}\frac{1}{r^j q_i}} \tag{4.24}$$

From the above equations, we notice that, when a user requirements in terms of QoS increase, its demand in terms of bandwidth at the N[illegible] point increases ($\frac{\partial B_i^{j*}}{\partial q_i}$ is positive).
Similarly, the optimal prices increase when users' requirements increase. Indeed, (6.2) suggests charging more the users that are more exigent in terms of QoS, i.e. higher q_i, and who are more willing to pay for their utilities, i.e. higher w_i.
Deeper analysis are provides in the following section.

4.5.3 Revenue analyses

Considering the optimal prices given by (6.2) and the optimal bandwidth demands given by (6.1) we can calculate the optimal revenue of a network N^j:

$$R^{j*} = \sum_{i=1}^{n} R_i^{j*} \tag{4.25}$$

Where, $R_i^{j*} = B_i^{j*} p_i^{j*}$.

$$R^{j*} = \sum_{i=1}^{n} w_i - \frac{n}{C^j + \sum_{i=1}^{n} \frac{1}{r^j q_i}} \sum_{i=1}^{n} \frac{w_i}{r^j q_i} \tag{4.26}$$

R^{j*} depends on the user's ability to pay and his (her) requirement. It is interesting to study the behavior of R^{j*} according to these parameters. We note that:

$$R_i^{j*} = w_i - \frac{\frac{nw_i}{r^j q_i}}{C^j + \sum_{i=1}^{n} \frac{1}{r^j q_i}} \tag{4.27}$$

4.5.3.1 Behavior of R^{j*} with respect to q_i

In this paragraph we study the effect of users' requirements in terms of QoS on the networks' revenue.

$$\frac{\partial R^{j*}}{\partial q_i} = \sum_{i=1}^{n} \frac{\partial R_i^{j*}}{\partial q_i} = \sum_{i=1}^{n} \frac{nw_i[r^j(C^j + \sum_{l=1}^{n} \frac{1}{r^j q_l}) - \frac{1}{q_i}]}{[r^j q_i(C^j + \sum_{l=1}^{n} \frac{1}{r^j q_l})]^2} \tag{4.28}$$

We notice that:

$$r^j C^j + \sum_{l=1}^{n} \frac{1}{q_l} - \frac{1}{q_i} = r^j C^j + \sum_{l \neq i}^{n} \frac{1}{q_l} > 0 \ \forall i, j \tag{4.29}$$

$\frac{\partial R^{j*}}{\partial q_i}$ is strictly positive $\forall i \in \{1, ..., n\}$ *and* $\forall j \in \{1, ..., k\}$. This means that the revenue of a network N^j increases when users' requirements in terms of QoS increases. This can be explained by the fact that, when a user is more exigent in terms of QoS, the network can charge him with a higher price(see equation (6.2)).

4.5.3.2 Behavior of R^{j*} with respect to w_i

$$\frac{\partial R^{j*}}{\partial w_i} = \sum_{i=1}^{n} \frac{\partial R_i^{j*}}{\partial w_i} = \sum_{i=1}^{n} \frac{\partial B_i^{j*}}{\partial w_i} p_i^{j*} + \frac{\partial p_i^{j*}}{\partial w_i} B_i^{j*} = \sum_{i=1}^{n} \frac{\partial p_i^{j*}}{\partial w_i} B_i^{j*}. \tag{4.30}$$

$\frac{\partial R^{j*}}{\partial w_i}$ is positive as $\frac{\partial p_i^{j*}}{\partial w_i} > 0$ and B_i^{j*} is strictly positive for all $n \geqslant 1$.

Thus, R^{j*} increases when the user ability to pay increases. This means that the total revenue of a network N^j increases when the users are more willing to pay.

In the following, we propose a handover decision algorithm with a selection process based on the obtained Nash-Stackelberg equilibrium.

4.7 Vertical handover decision making and admission control

In this section we propose to use the above obtained results for vertical handover decision making and admission control.

4.7.1 Proposed vertical handover decision making based on NE

As explained in section 1.3.2, VHO process is composed of three phases: Vertical handover information gathering, Vertical handover decision making and vertical handover execution (see figure 4.1).

We consider that the VHO decision management engine is implemented on the mobile node side. In this section, we mainly focus on the handover decision making step. We propose a VHO decision mechanism based on the NE obtained in the previous section. The proposed vertical handover *Decision Making* consists in two steps which are *Vertical Handover Initiation* and *Network Selection* as presented in figure 1.4.

The proposed solution considers the network and terminal context (for handover initiation) as well as users preferences (for network selection) in terms of cost and QoS.

As illustrated in figure 4.1 the *Vertical Handover Initiator* block gets contexts information, namely, velocity, load and RSS from the *Context Information Gathering* block to evaluate whether a handover is required or not. The evaluation is performed using a Fuzzy Logic Controller.

Once a handover is required, the *Network Selection* block gets information, regarding available networks, their capacities, prices and the number of users in each available network, from the *Context Information Gathering* block. At the end of the network selection step, a VHO decision is made and the handover execution is lunched in the *Handover Execution* block.

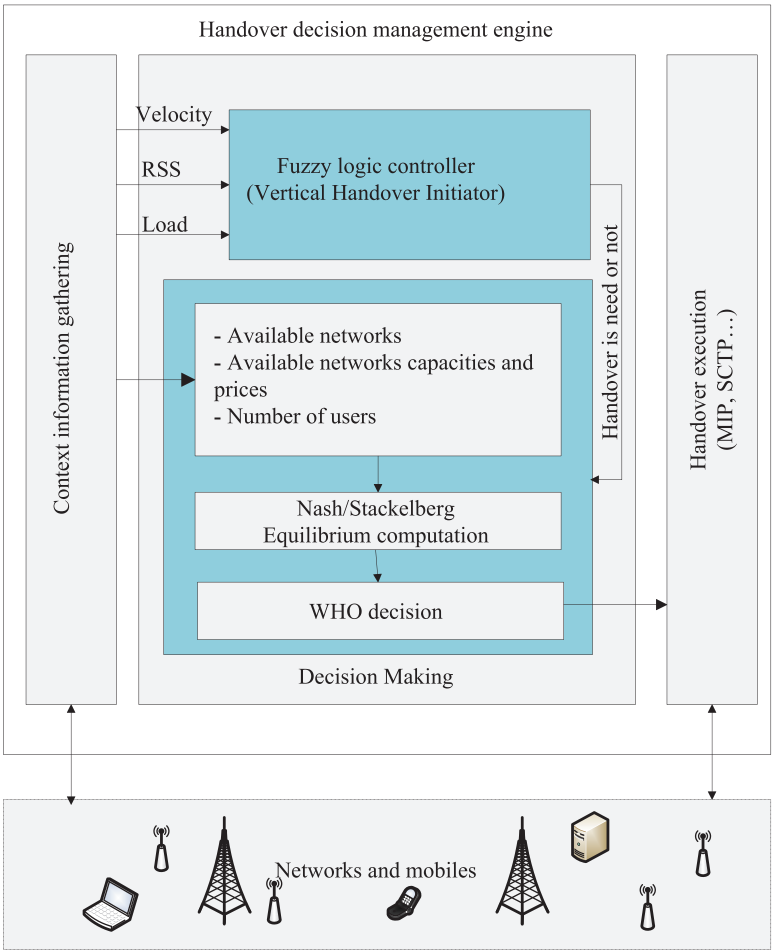


Figure 4.1: Proposed Vertical Handover Process

4.□.1.1 Handover initiation

The VHO initiation phase is crucial since it is triggered according to the user/network context. User context analysis may be a complex and a time demanding process and may be faced to uncertainty and/or unavailability of some measures and statistics. For that, we opt for the use of Fuzzy Logic that offers tools to address these aspects.
The proposed VHO decision making incorporates a Fuzzy Logic Controller (FLC) at the initiation phase, based on fuzzification/defuzzification mechanisms [□1] (see figure 4.2).
In our proposal, the FLC checks whether the current network is still able to handle a user

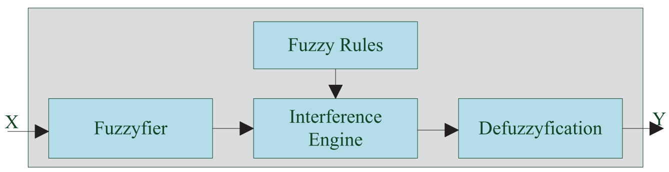
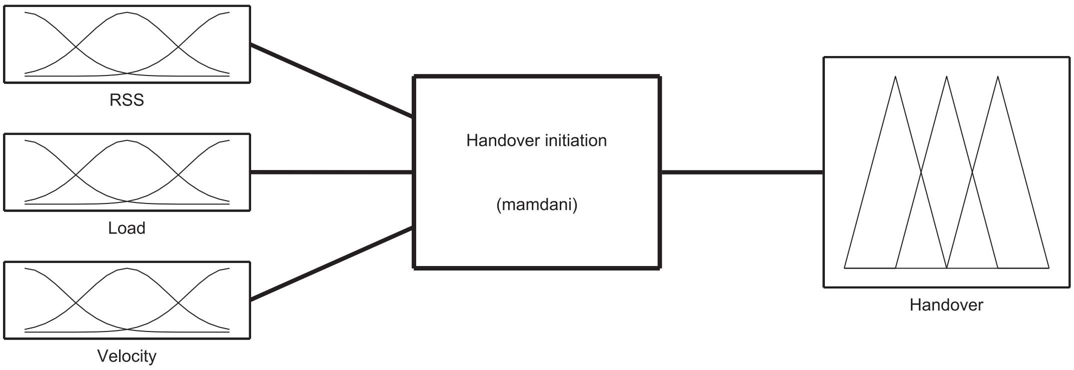


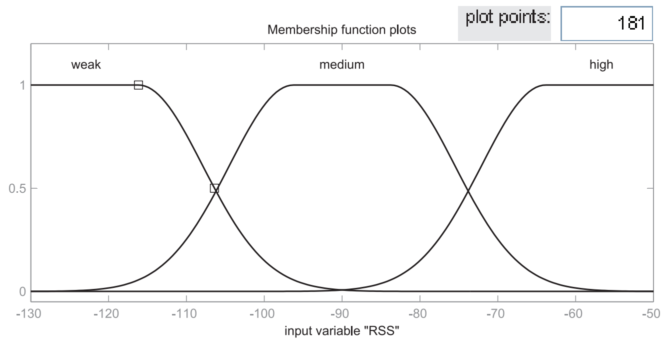
Figure 4.2: Fuzzification/defuzzification mechanism

connection. □t uses conte□tual information (□□□, load and velocit□) to detect whether a □□□ is required or not.
The consider □L□ is illustrated in □gure 4.3. The □L□ input parameters are fed into the fuzzi□



□igure 4.3: □uzz□Logic □ontroller illustration

□er where the□are transformed into fuzz□sets.
□s shown in □gure 4.3, we consider three input parameters: □□□, □elocit□and load. These parameters are transformed into fuzz□concepts that are described b□different sets.
To describe the concept □□□□□for e□ample we introduce 3 sets: Low □edium or □igh as illustrated in □gure 4.4.
The output of the □L□ is the handover (handoff) variable which membership sets are pre□



□igure 4.4: □□□ fuzz□sets

sented in □gure 4.5. The handover variable has two different sets: □es handover and No handover. □fter the defuzz□□cation process, if the output is smaller than 0.5, no handover is required. □therwise, a handover is initiated. The fuzz□sets are then fed into the inference engine, where a set of prede□ned fuzz□ □□T□□N rules are applied to indicate whether a han□dover is required. □n e□ample of the □□T□□N rules that can be applied is presented in □gure 4.6. The result of the □□T□□N rules application provides estimation on the output value (the

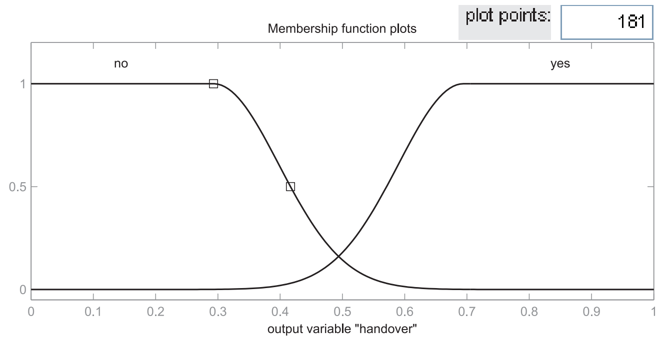


Figure 4.5: Handover decision fuzzy sets

1. If (RSS is weak) and (Load is high) and (Velocity is high) then (handover is yes) (1)
2. If (RSS is weak) and (Load is high) and (Velocity is medium) then (handover is yes) (1)
3. If (RSS is weak) and (Load is weak) and (Velocity is weak) then (handover is yes) (1)
4. If (RSS is weak) and (Load is medium) and (Velocity is medium) then (handover is yes) (1)
5. If (RSS is weak) and (Load is medium) and (Velocity is high) then (handover is yes) (1)
6. If (RSS is medium) and (Load is medium) and (Velocity is medium) then (handover is no) (1)
7. If (RSS is medium) and (Load is weak) and (Velocity is weak) then (handover is no) (1)
8. If (RSS is medium) and (Load is weak) and (Velocity is medium) then (handover is no) (1)
9. If (RSS is medium) and (Load is weak) and (Velocity is high) then (handover is yes) (1)
10. If (RSS is medium) and (Load is medium) and (Velocity is weak) then (handover is no) (1)
11. If (RSS is medium) and (Load is medium) and (Velocity is high) then (handover is yes) (1)
12. If (RSS is high) and (Load is weak) and (Velocity is weak) then (handover is no) (1)
13. If (RSS is high) and (Load is medium) and (Velocity is weak) then (handover is no) (1)
14. If (RSS is high) and (Load is high) and (Velocity is weak) then (handover is no) (1)
15. If (RSS is high) and (Load is weak) and (Velocity is medium) then (handover is no) (1)
16. If (RSS is high) and (Load is weak) and (Velocity is high) then (handover is yes) (1)
17. If (RSS is high) and (Load is weak) and (Velocity is medium) then (handover is no) (1)

Figure 4.6: A set of fuzzy IF-THEN rules

blue curves) as illustrated in the example shown in figure 4.7.

The final curve (the blue curve in the last line of figure 4.7) is the sum of all the other curves obtained by the application of the IF-THEN rules, in the inference engine. The final result (obtained by the deffuzzification block) is the abscissa of the center of gravity of the final curve. In this example, as shown in figure 4.7, no handover is required. Figure 4.8 illustrates an example where a VHO is required.

Figures 4.9, 4.10 and 4.11 show the behavior of the handover variable while varying, respectively, the velocity and load, the load and RSS and the velocity and RSS.

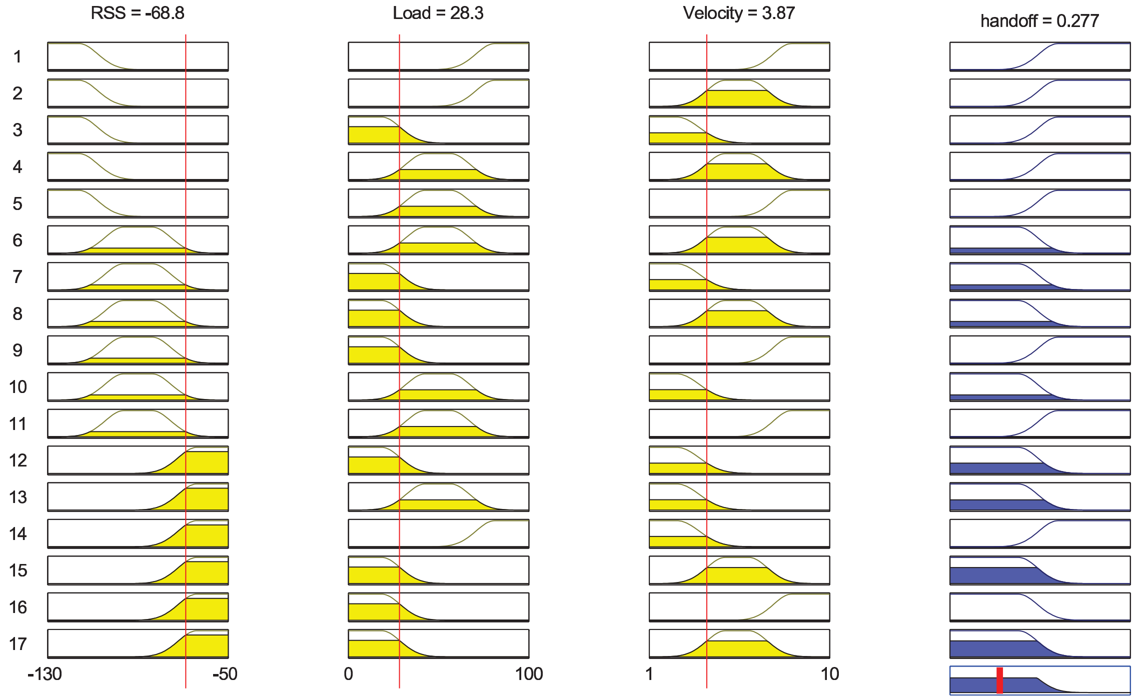


Figure 4.[illegible]: Example 1 of a handover decision

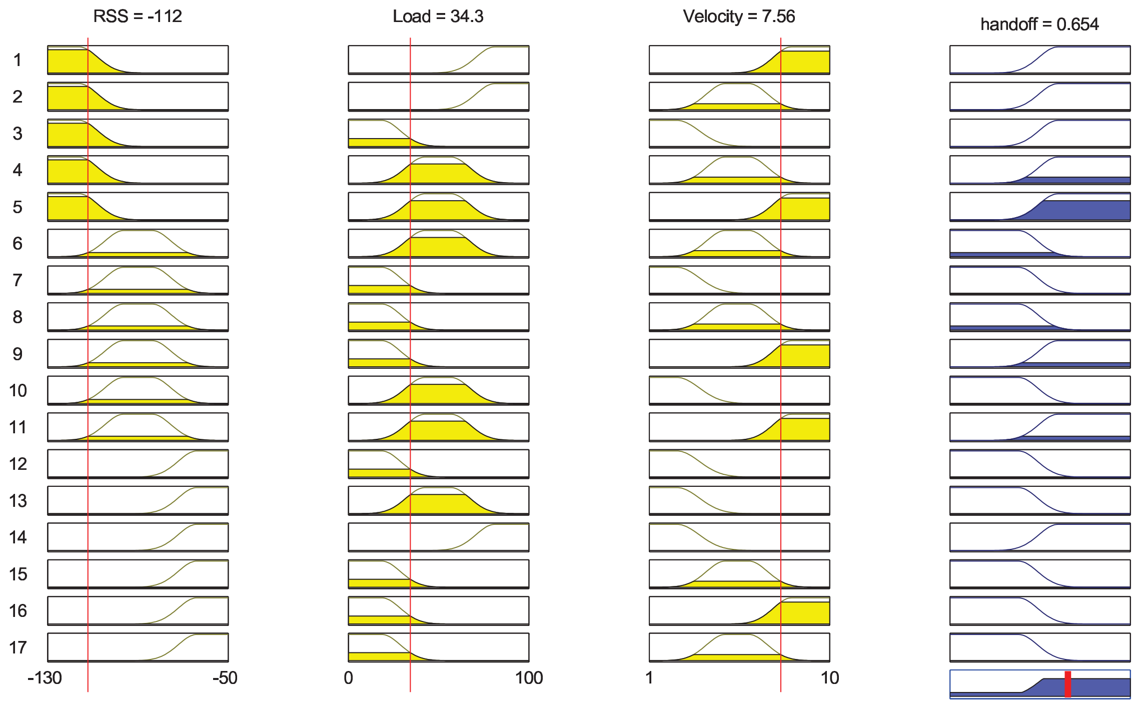


Figure 4.[illegible]: Example 2 of a handover decision

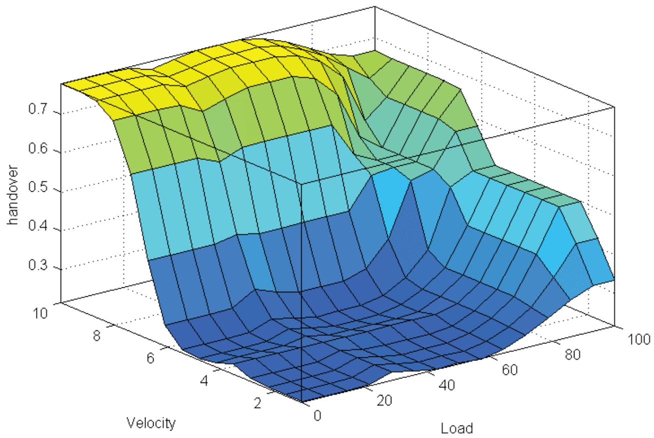


Figure 4.9: Handover variation with respect to velocity and load

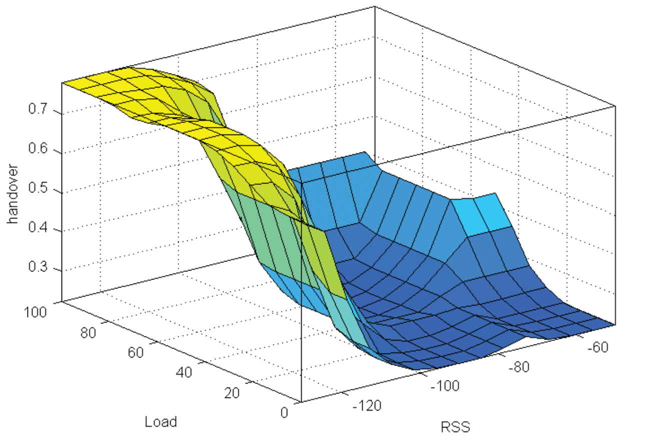


Figure 4.10: Handover variation with respect to load and RSS

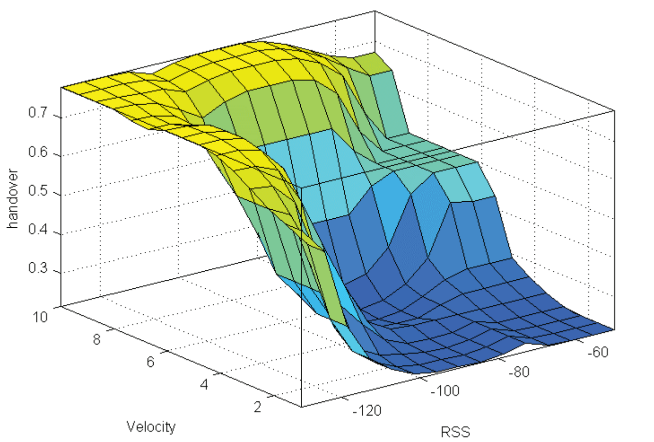


Figure 4.11: Handover variation with respect to velocity and RSS

4.6.1.2 Network selection

Once the decision to initiate a VHO is made, we have to select the most suitable network to which to hand over to. The network selection is performed according to the algorithm 1, provided in the following. We consider mobile users equipped by multihomed mobile terminals having a WLAN interface, a WMAN interface and a cellular network interface. A given interface may be connected to only one network at a time.

First, we classify the finite set of networks into three classes (WLAN, WMAN and cellular networks). Then, we order the three classes of networks according to the utility function $U_i^j(B_i^{j*}, p_i^{j*})$.

If we suppose that all the three classes are available, let this preference order be as follows: $Cl_{(1)} \succeq Cl_{(2)} \succeq Cl_{(3)}$. This means that for a user i the class $Cl_{(1)}$ is preferable to the class $Cl_{(2)}$ which is also preferable to $Cl_{(3)}$ with respect to the utility function $U_i^j(B_i^{j*}, p_i^{j*})$.

In the following, we denote by V the number of available classes($V \in \{1,2,3\}$) and by x_i^j be the variable of decision making. $x_i^j = 1$ if user i decides to connect to network j, and $x_i^j = 0$ otherwise. $Band_i$ is the total value of allocated bandwidth to a user i.

As illustrated in algorithm 1, when a new connection or a VHO is initiated by a user i, he (she) checks, by order of preference, whether the available networks can provide him (her) with the required bandwidth.

A user i can't be provided by more than B_i^{j*} from network j.

The algorithm supposes that: if the most preferred available network provides a user with his (her) required bandwidth, the user only connects to this network, otherwise, he (she) is provided with a part of his (her) required bandwidth from this network and requests the other part from the second preferred network and so on, till he (she) gets the required bandwidth. If all available preferred networks don't dispose of enough resources to serve this user connection, he (she) is rejected.

Algorithm 1 VHO decision making algorithm

$Band_i = 0$, $index = 1$;
while ($Band_i < B_i$) and ($index \leq V$) **do**
  $j_1^* = ArgMax_j\{U_i^j, j \in Cl_{(index)}\}$;
  $x_i^{j_1*} = 1$;
  $\triangle Band = B_i - Band_i$
  $Band_i += \min\{B_i^{j_1^*}, \triangle Band\}$
  $index++$;
end while
if $Band_i < B_i$ **then**
  Connection not admitted;
end if

4.□.2 □□□ission control

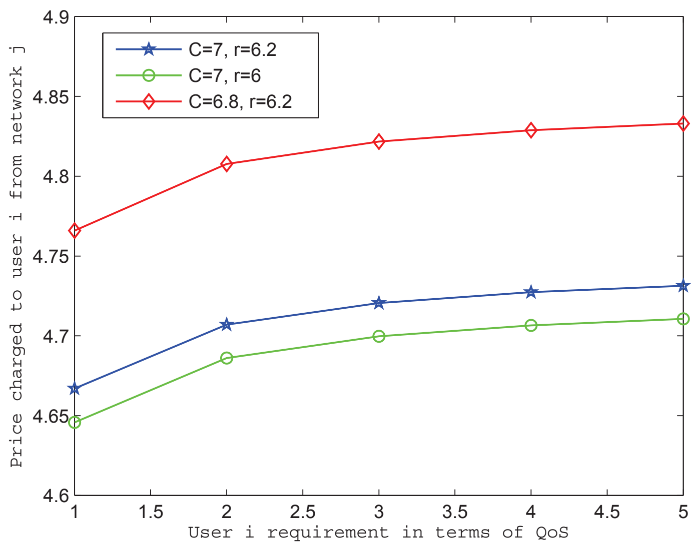
□hen a new connection or a □□□ is initiated b□a user i, the required bandwidth is compared to the total bandwidth $Band_i$ that user could be offered b□the available networks. $Band_i = (B_i^{Cl(1)})^* + \ldots + (B_i^{Cl(V)})^*$□□e consider $B_i^{j*} = 0$ if network j is not available in a service area. □f a connection required bandwidth is smaller than $Band_i$, we consider that the user can be offered the required bandwidth and the connection is admitted. □therwise, it is re□ected.

4.□ □u□erical results

□n this section, the behavior of proposed models are numericall□veri□ed and the algorithms are applied to a selected scenario to be evaluated.

4.□.1 Revenue □a□i□i□ation

□n this paragraph we numericall□verif□the results obtained in section 4.5.3 and we discuss the user□s utilit□evolution when the network parameters var□(r^j and C^j). To stud□the effect of the users□parameters (q_i and w_i) on the optimal prices and the network revenue, we calculate p_i^{j*} and R_i^{j*} while var□ing q_i. The case where w_i increases is trivial as p_i^{j*} and R_i^{j*} increase linearl□with respect to w_i. □igure 4.12 shows the variation of p_i^j when a user i requirement



□igure 4.12: □ptimum prices vs □o□, □apacit□and □eputation

in terms of □o□increases from 1 to 5 for different network capacities and reputations values.

We set the number of users to 30 and their requirements in terms of quality of service are randomly generated in the range of 1 to 5. The user i 's ability to pay is set to 3 ($w_i = 3$). One can remark in figure 4.12 that the charged prices increase when users requirements in QoS increase. It is also shown that for the same amount of available capacity and for different reputation values of a network, the prices charged to user i are higher for networks with better reputation. For the same value of reputation, the charged prices are lower for higher network capacity.

Figure 4.13 depicts the revenue variation when a user i requirements in QoS increase. When

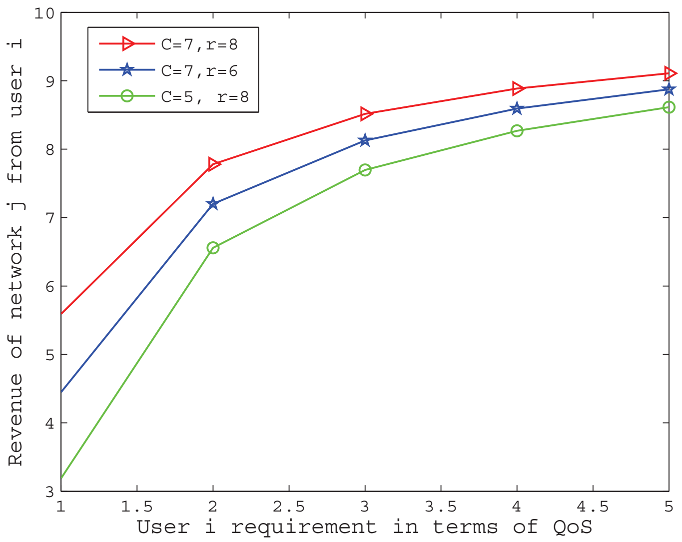


Figure 4.13: Optimum revenue vs QoS, Capacity and Reputation

a network reputation (respectively capacity) increases, the network revenue increases. In other words, our results show that to enhance networks revenue for a given available capacity, it is interesting to improve the reputation by providing good QoS parameters (delay, jitter, bit error rate...).

If we look to this problem from the user side, it is important to notice that the utility of users also increases when the network reputation is improved. Thus, even if the network price is increased, users will still be attracted by this network because this prices rise is compensated by the reputation enhancement. This is illustrated in figure 4.14. However, when a network capacity decreases, the network prices increase to improve the network revenue which strongly affects the user utility as depicted in figure 4.15. In this case, a network with scarce resource should expand his capacity to stay competitive with other networks and to keep attracting users.

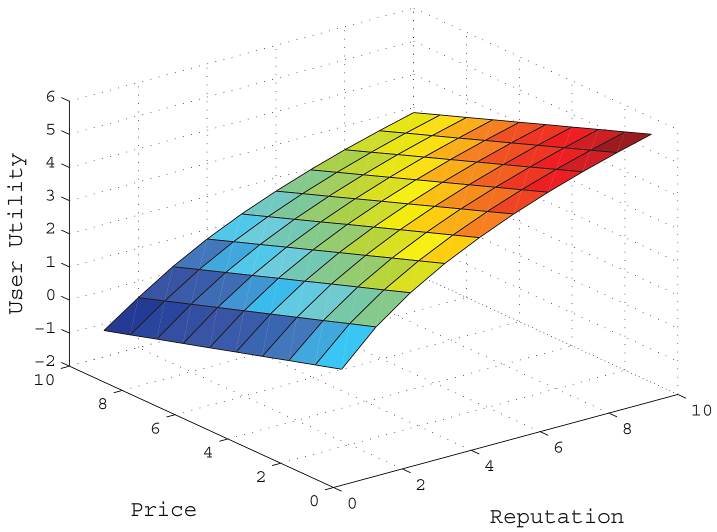


Figure 4.14: User utility vs reputation and prices

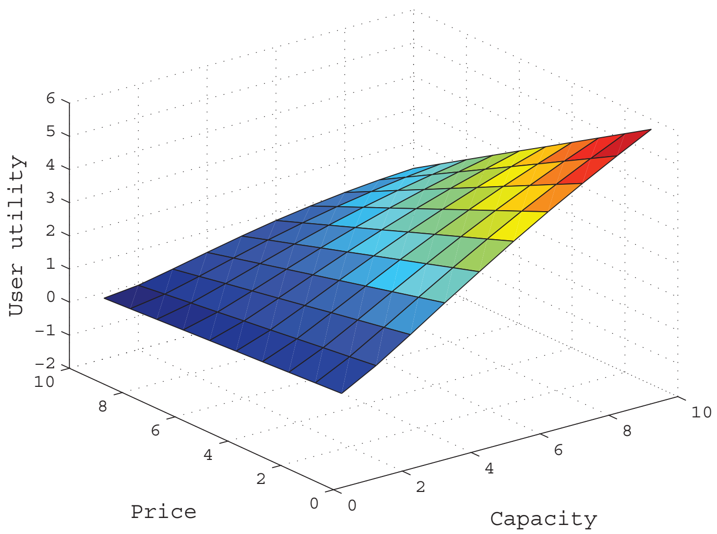
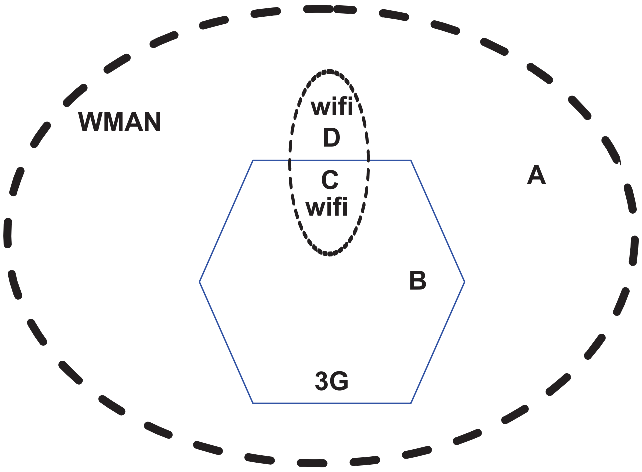


Figure 4.15: User utility vs capacities and prices

4.□.2 □□□ □ecision □a□in□

□n this section, we consider the s□stem model presented in the following (□gure 4.16and we consider uniform demands in terms of □o□ for all arriving users. □e consider an hetero□geneous wireless environment consisting of two □□□□ □02.11 □L□Ns, one U□T□ cellular network (3□) and one □□□□ □02.16 □ □ □N. □e consider different areas where a multihomed



□igure 4.16: □imulation □odel

mobile terminal ma□ connect to different access technologies. □n area □, onl□ the □ □ □N is available. □n area □, 3□ and □ □ □N are available. □n area □, a mobile terminal is able to connect to □ □ □N, □i□i and 3□. □inall□, in area □, □ □ □N and □i□i are available. The transmission rate is 2□ bps in the 3□ cell, 10□ bps in the □ □ □N, and 11□ bps in the □ L□N.

□igure 4.1□ illustrates the □□□ dropping probabilit□ in the areas □, □ and □. □hen the arrival rate of □□□ connections is low, the □□□ blocking rate in our scheme is almost equal to zero. □owever, when the number of simultaneous □□□ connection requests increases, the □□□ blocking rate increases to reach about 3□ percent in area □, for a high amount of arrivals (40 simultaneous □□□ arriving connections). Under the same conditions (same □□□ connections arrival rate and the same bandwidth requests), □g.4.1□ shows that the blocking rate in area □ is less important than in area □ which in turn is less important in area □. This ma□ be e□plained b□ the fact that users in area □ ma□ connect to three different networks and get higher bandwidth than users in the two other areas.

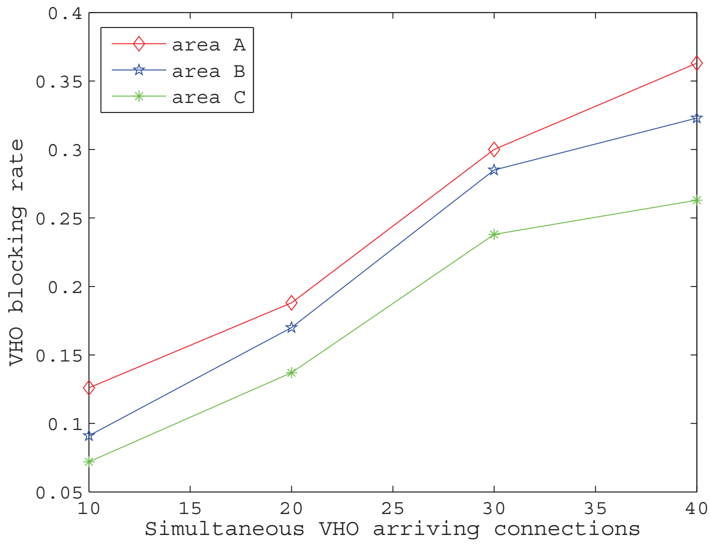


Figure 4.11: VHO blocking rate

4.6 Conclusion

Mobility and QoS over heterogeneous wireless access networks is a challenging feature that requires the consideration of a set of parameters from the network's and the user's point of view. Game theory is a promising tool to analyze and model interactions between cooperative and/or competitive actors. In this chapter, we propose a modeling tool based on game theory to study the revenue of a service provider managing heterogeneous wireless access networks and dealing with a finite set of users that aim to maximize their utilities. This tool is then used for vertical handover decision making. We formulate and model mathematically the problem as a Stackelberg-Nash game and present an optimal bandwidth-pricing policy for different players. Then we propose a handover decision algorithm with a selection process based on the obtained Nash-Stackelberg equilibrium. The analyses of the optimal bandwidth-prices and the revenue at the equilibrium point show that these latter increase when user's requirements increase in terms of QoS. We pointed out that networks having same capacities and different reputation values will charge users with different prices. Obviously, the one who has the best reputation is the most expensive. Nevertheless, users will still be attracted by good reputed networks as they provide them with better QoS which improve their utilities. In this vision, networks' reputations should be efficiently managed to avoid its falsification.

Chapter 5

Architectural and implementation solutions

5.1 Introduction

In heterogeneous networks, interworking and roaming can include various possible scenarios and network architecture configurations. In general, a roaming agreement that deals with technical and commercial aspects of the roaming procedure is required to allow subscribers of one operator to access to networks of other operators without interrupting users' on-going sessions.

In this context, there are still many challenges to solve. These are linked to the development of network architectures, to the mechanisms and protocols adopted for the vertical handover and to advanced management and pricing functionalities of the interconnected networks. In this chapter, we focus on the architectural and implementation issue and we provide and discuss two different solutions on which our vertical handover decision mechanism, provided in chapter 3, can be integrated.

The first proposed architecture is a centralized one. It is based on the IEEE 802.21 standard to which some extensions are proposed. The second proposed architecture is distributed. It is based on an overlay control level composed of two virtualization layers able to make reasoning on behalf of physical entities within the system. This architecture allows higher flexibility especially for loosely coupled interconnected networks.

Important issues, mainly trust and energy consumption considerations are discussed in both proposals.

5.2 □roposal 1□□ □□2.21 □ase□ architecture for □□□

□s stated in chapter 2, □□□□ □02.21 □15□has been basicall□designed to facilitate the handover between heterogeneous networks including □ □ □Ns and □ L□Ns. □□□□ □02.21 introduces a new logical entit□called □ □□ □unction. This entit□hides the speci□cities of different link la□er technologies from the upper la□er entities (see □gure 2.4). The upper la□ers entit□, known as □ □□ users (□ □□Us), communicate with the □ □□ framework to get information about the lower la□ers. □ □□ users can include mobilit□management protocols (□ro□□□ □□v6, □□T□,...) and vertical mobilit□decision algorithms.
Like man□standards, □□□□ □02.21 does not propose decision algorithms or engines. □n this section, we describe how we can integrate our □□□ decision mechanism into a □02.21 based framework. This solution applies to tight coupling, as well as loose coupling architectures. □n our proposal, we assume that the mobile terminal is responsible for □□□ decision making. □igure 5.1 shows the overall proposed architecture.
The □rst la□er is the □□□□□ □□ la□er. □bove, we have the □ □□□module and its three ma□or services, namel□, the media independent event service (□ □□□), the media independent com□mand service (□ □□□) and the media independent information service (□ □□□). □e propose to implement our proposed □ertical □andover □anagement □ngine (□□□ □) between the □ □□□ la□er and the upper la□ers as illustrated in □gure 5.1.
□n the following we describe the proposed architecture in more details:

□*The PHY/MAC layer*:
□n the mobile node side, the □□□□□ □□ la□er is responsible for effective interface switching and handover trigger generation through □ □□□, it gathers link qualit□information and pro□vides current data rate measurements.

□*The MIHF module*
This la□er is responsible for different tasks related to the □□□ initiation and links control. □t consists of the □ □□ three main services:
• The □edia □ndependent □vent □ervice (□ □□□) detects events and delivers triggers corre□sponding to d□namic changes in link characteristics, status and qualit□to the □□□ □ecision making block in the proposed □ertical □andover □anagement □ngine.
Trigger event are delivered through interface (a) as illustrated in □gure 5.1. The □ □□□com□municates with the lower la□ers through interface (l).
• The □edia □ndependent □ommand □ervice (□ □□□) provides a set of commands to control handover relevant link states. The □□□ □ is able to control the ph□sical and the link la□er through the □ □□□. □ndeed, the □□□ □ sends decision noti□cations to the □ □□□through in□

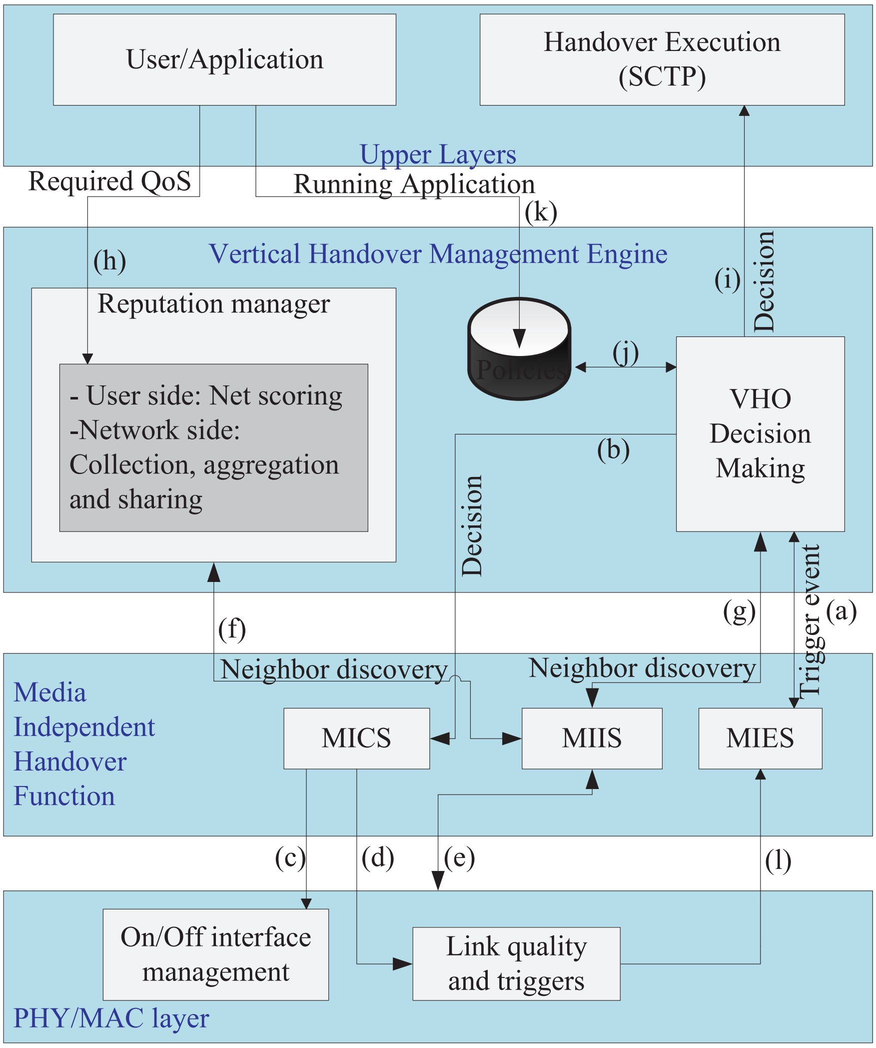


Figure 5.1: An 802.21 based architecture for VHO decision making

terface (b) and the MICS sends required commands to the lower layers through interfaces (c) and (d).

• The Media Independent Information Service (MIIS) provides the information model for query and response on network resources and capabilities. It allows the mobile terminal to discover and obtain network information within a neighboring area. The main goal of the MIIS is to get a global view of all heterogeneous networks in the area to optimize the handover when moving across these networks. The MIIS communicates with the lower layer through interface (e) and with the VHME through interfaces (f) and (g). In our proposal, the MIIS is also responsible for networks' reputation providing to the VHO decision making block.

- *The VHO management engine:*

This additional layer is responsible for both reputation management and VHO decision making. It is composed of two main blocks and a policies repository:

• The policies repository:

Stores rules and policies related to user's preferences and application's requirements. The policies repository communicates with the User/Application layer via interface (k).

• Reputation management block:

On the mobile node side, the reputation manager block is in charge of network scoring according to our proposed reputation system described in chapter □. The scores are calculated according to the current network QoS parameters (that the reputation manager block receives from the MIIS through interface (f)) and to the running application requirements in terms of QoS (that the reputation manager gets from the User/Application layer via interface (h)). The scores are then sent to the reputation manager on the network side through the MIIS. The reputation manager on the network side computes an aggregated reputation value, according to our proposed reputation system described in chapter □, and sends this reputation to the mobile nodes, when requested, via the MIIS.

• Decision making block:

This block is responsible for VHO decision making. Based on the trigger events provided by the MIES and on neighbor networks information provided by the MIIS, this block applies our reputation based VHO decision algorithm for network selection. It gets available networks' reputation and QoS information from the MIIS via interface (g) and communicates with the policies repository through interface (□) to get information on users and application requirements. When a VHO is required, the VHO decision making block sends decision notification to the MICS via interface (b) to activate the lower layers handover and a notification to the handover execution block via interface (i) to activate the IP handover.

- *Upper layers:*

When an application session is initiated, the user/application block informs the VHME about this application QoS requirements. When a handover is required the Handover execution block manages the IP mobility handover execution.

A discussion on the proposed architecture's main advantages and limitations is provided in the following.

Advantages and limitations of the proposed architecture

• Energy consumption:

The energy consumption is one of the major issues within the wireless mobile devices world. Thus, an efficient VHO decision mechanism should not only ensure good QoS but also consume the lowest possible amount of energy, especially, when implemented on the wireless device side.

The proposed architecture allows the minimization of the mobile node energy consumption. In the 802.21 based architecture, thanks to the MIIS, a multihomed mobile terminal is able to gather information regarding its neighbor networks through its current active interface. Indeed, MIIS provides to the mobile node a wide range of information concerning its neighboring: it may be related to the type of the network, QoS and bandwidth capability, data rates, transmission range, cost, etc. In this regard, the mobile terminal may always keep only one interface "on" instead of continuously scanning the different available networks and keeping all its interfaces "on" which is very wasteful in terms of energy consumption. In other words, the non active interfaces are turned off in the meanwhile and turned on only when needed to carry application data. Thus, the one single interface "on" feature may save a considerable amount of energy at the mobile node and allows it to keep operational much longer.

However, in this proposed architecture, the exchange of neighboring information through a single active interface only applies when there are agreements between operators or service providers managing the different available networks.

When no agreements are adopted the exchange of information between networks belonging to different operators is not possible even if users subscribed to these different networks.

Another issue regarding energy consumption in the proposed architecture is related to the fact that the decision making is performed in the mobile side. This may consume considerable amount of the mobile node's energy resources. This point will be addressed in the next section by the introduction of our decision algorithm into an existing overlay based architecture.

- Reputation trust issue:

The considered scheme assumes that the available networks may be managed by different operators or service providers. In this context, delegating the reputation calculation and sharing tasks to the networks may incite them to falsify the reputation values. In this case, the reputation values received by the mobile node to make the decision won't be significant and won't reflect the real network's condition. Indeed, getting falsified reputation and QoS values may cause multiple handover events that may increase the processing delay and degrade the experienced QoS. In this regard, the establishment of a trust relationship between the networks and the mobile nodes is very challenging. To address this issue, we may encrypt the reputation value in a way that prevents networks from its falsification as follows:

To address the trust problem in the 802.21 based architecture, we add an overlay entity: the Overlay Reputation Controller (ORC), as a trustworthy third party that will ensure the reputation computation and effectiveness. The mobile nodes' scores are then encrypted and sent to the Reputation Manager on the network side. This latter forwards the encrypted scores to the ORC that decrypts them and computes an aggregated reputation value for each network.

The aggregated values are then encrypted and sent to the mobile nodes through the networks' reputation managers when requested.
We opt for an asymmetric encryption/decryption scheme in which each node holds a public and a secret key. When a mobile node wants to send a rate to the ORC, it gives a Sequence Number (SN) to its rate and sends to the ORC the message $M = (score, (nodeID, SN))$ encrypted with the public key of the ORC that uses its secret key to decrypt it. When a mobile node "n" asks for the available networks reputation, the ORC sends the message

$$M' = (Reputation1, Reputation2, ..., Reputationn, SN_{ORC_n})$$

encrypted with the public key of node "n". SN_{ORC_n} is a sequence number corresponding to node n. In other words, each time a mobile node "i" asks for a Reputation, the ORC increments the SN_{ORC_i} of this node and integrates it into the encrypted message to prevent the networks of falsifying the reputation by forwarding old reputation messages.
- *Mobile side:*
Let's take an example of a mobile node "Bob" that already scored a network □□□ three times, in this case S□□□. If Bob has to rate this network again it will increment SN to have S□□□.
Let's suppose that Bob will rate this network positively. The encrypted message will then be the following:

$$M = (1, (Bob, □))_{pub_{ORC}}$$

The ORC collects the scores of all other users that rated □□□, checks that there are no messages having the same couple $(nodeID, SN)$ to be sure that the network did not duplicate scores. If it is the case, the ORC discards the duplicated messages and computes the reputation.
- *ORC side:*
Lets assume that Bob did not ask the ORC for Reputation values. In this case, $SN_{ORC_{Bob}} = 0$ at both mobile and ORC side. Once Bob asks the ORC for a reputation value, he will increment the $SN_{ORC_{Bob}}$ it becomes equals to $SN_{ORC_{Bob}} = 1$. When the ORC receives Bob' request, it increments $SN_{ORC_{Bob}}$ in its turn and sends Bob the message

$$M' = (reputation1, ..., reputationN, SN_{ORC_{Bob}})_{pub_{Bob}}$$

where reputation1 to reputationN are the available networks' reputations.

In the following section we describe the considered overlay based architecture that will address the above mentioned issues in a more efficient way.

5.3 Proposal 2: An overlay based framework for VHO

In this section, we propose the integration of our VHO solutions within the overlay framework proposed in [illegible].
The proposed framework is built on the top of a loose coupling architecture using SCTP. In the following, we present the adopted loose coupling scheme, we describe the architecture on which our proposed VHO management framework is based and we present the proposed VHO management framework.

5.3.1 Description of the adopted interworking scheme

The proposed framework is built on the top of a loose coupling architecture using SCTP. As stated in the second chapter the integration of WiMAX and 3G-UMTS is considered to be equivalent to that of WLAN and 3G-UMTS. Thus, we only describe the WLAN-3G-UMTS integration scheme. This choice of loose coupling using SCTP is motivated by the following two main reasons:

- Using the loose coupling architecture is advantageous because the networks remain independent and provide independent services, which is not the case in tightly coupled solutions that are highly specific to the UMTS technology and cause a larger impact in the form of extensive access interface standardization. In addition, loose coupling avoids any change on the UMTS core network and allows service providers and network operators to manage VHO between different networks through roaming agreements.
- The rationale behind the use of SCTP for UMTS and WLAN coupling is its multi-homing feature. Indeed, from an association point of view, SCTP doesn't matter whether the current and the target network in a VHO procedure belong to the same technology or not. As long as the establishment of an Internet connection is possible for a wireless interface, its IP address can be added to the current association [82]. This feature allows SCTP to provide an end-to-end soft handover solution for mobility management. Thus, introducing SCTP for UMTS and WLAN coupling allows their integration without additional entities. The basic assumption for the seamless VHO between UMTS and WLAN cells is that the mobile node is able to obtain a new IP address when it moves into a WLAN cell, via either DHCP or Stateless Address Auto-configuration in IPv6 network [82]. Figure.5.2 shows the architecture of UMTS-WLAN loose coupling using SCTP.

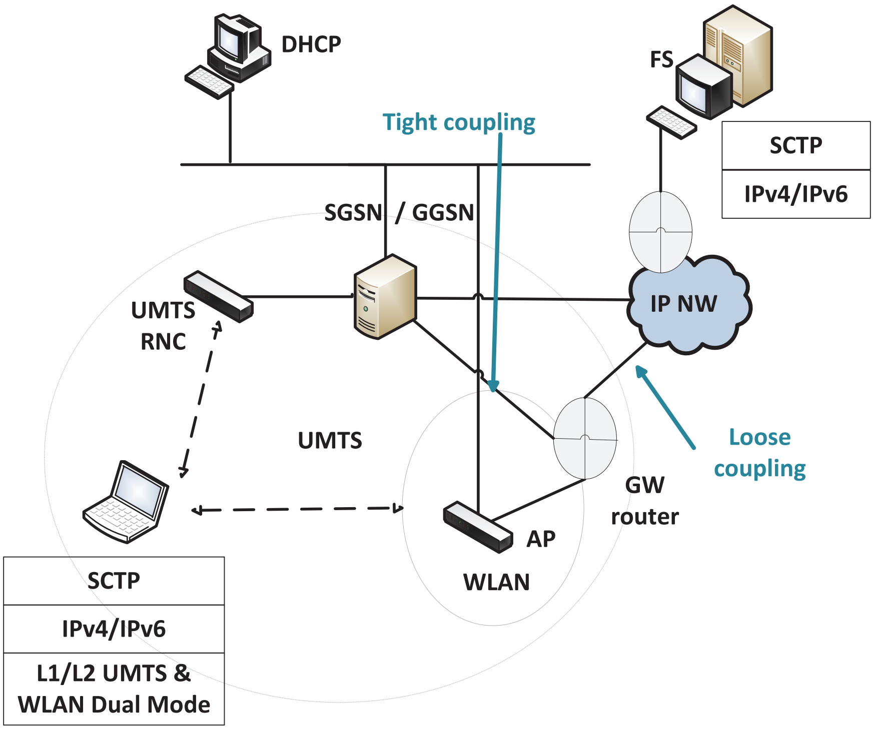


Figure 5.2: A loose coupling architecture using SCTP [82]

[illegible] A two layered virtualization overlay system using software avatars

The main purpose of the architecture proposed in [illegible] is to ease the management of different entities involved in an heterogeneous wireless environment including users, terminals, services, networks, service providers, etc. This architecture is built as a conceptual control level (see Figure 5.[illegible]), composed of two virtualization layers based on the use of Software Avatars. The first virtualization level is responsible of reasoning on dynamic contextual information and is composed of Avatars.
Avatars are software entities able to act on behalf of the physical entity they represent thanks to their communication and reasoning capabilities.
The second level is in charge of orchestrating the first one and makes reasoning on static contextual information.

[illegible] abstraction level

The first virtualization level consists of Avatars that are autonomous software components representing different entities like users, services, resources, mobile terminals, network devices, service providers, etc. The main principle is that each entity delegates its reasoning activities to its corresponding Avatar. Avatars rely on unified interfaces to exchange data and to con-

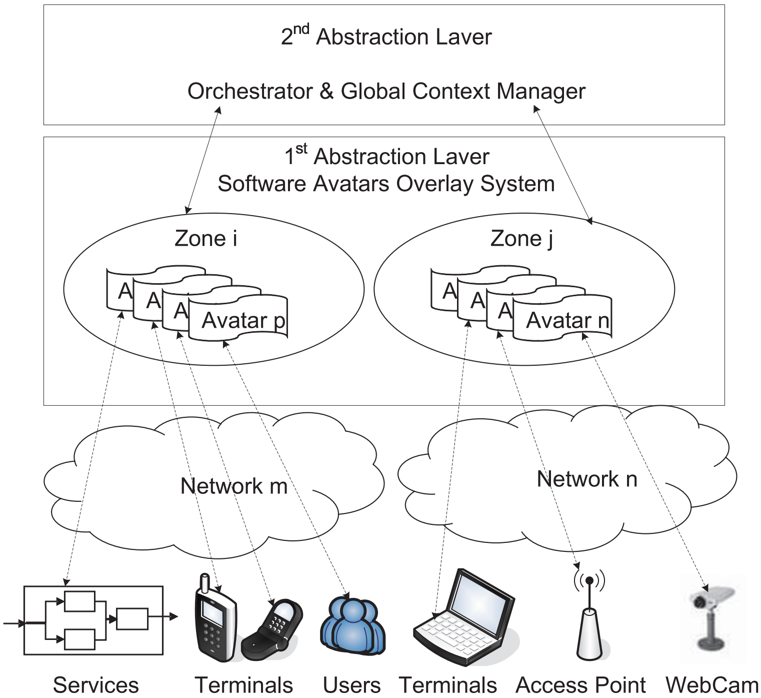


Figure 5.□: A two-layered virtualization overlay system □□□

tribute to proprietary or common decision making allowing heterogeneous entities to co-exist within the system. They generally share common context and cooperate to explore available resources in a given area. Avatars are also able to communicate with the second abstraction level, i.e. with the Orchestrator and the global Context Manager allowing them to provide, update and/or request context information, profiles, preferences, statistics. As stated before, an Avatar embeds and executes intelligence on behalf of the entity it represents, including processes for decision-making and adaptation. For instance, a mobile terminal avatar can run decision processes for network selection and vertical handover decision making. A video service avatar can run video adaptation according to the available throughput. In addition, different Avatars can share common context and can cooperate to explore available resources in a given zone. Avatars should also be able to communicate with the second abstraction level. The proposed architecture does also consider mobile Avatars that can move among different Active zones to make the Avatars as close as possible to the entities they represent. Thus, to enhance system performances, Avatars can be created and moved in to active zones according the contextual information of the represented entities.

Second abstraction level

The orchestrator and the global context manager in the second abstraction level have a global view of the system and offer a unified representation through ontologies allowing reasoning and inferring. Ontologies are considered here to enables automated reasoning and inferring modules and to automate communications between system components including the Avatars, the Orchestrator and the correspondent physical entities.

[illegible] Proposed VHO management framework

We propose in this paragraph a flexible and evolutionary mobility management framework that handles dynamic and static context information and allows mobile devices to be always connected to the most suitable access network by making VHO decisions based on networks' reputations.
Based on the proposed and developed platform described in [illegible], we propose a framework for vertical handover management that integrates our vertical handover scheme described in chapter [illegible]. The main purpose of this work is to evaluate our proposed VHO decision mechanism in an experimental setting using the in-house architecture described in [illegible]. The adoption of this kind of architecture eases the management of different entities implied in a heterogeneous wireless network environment, namely, users, terminals, services, networks, service provider, etc.

The idea consists in building a framework for VHO decision making on the first abstraction level of the architecture described in paragraph 5.[illegible]2. This framework is mainly based on software agents that are able to make reasoning on behalf of physical entities within the system. More specifically, agents act on behalf of MNs for VHO decision making and on behalf of networks for reputation computation and sharing. Figure 5.[illegible] presents the proposed mobility management framework.
In the following we focus on Agents' VHO decision making and reputation computation functions and we detail their main interactions that allow gathering, updating and sharing required information for reliable VHO decision making.

The mobile user's agent

The mobile user's agent has to keep track of the required information to make VHO decisions. Thus, it continuously discusses with the physical entity it represents (the mobile node) and the available networks' agents.

- Using interface (a1), the mobile user's agent exchanges with the mobile node dynamic information regarding 1) its current network, the delay, the jitter, the bandwidth and the bit error rate it perceives and 2) information regarding other available networks and their corresponding received signal strength.

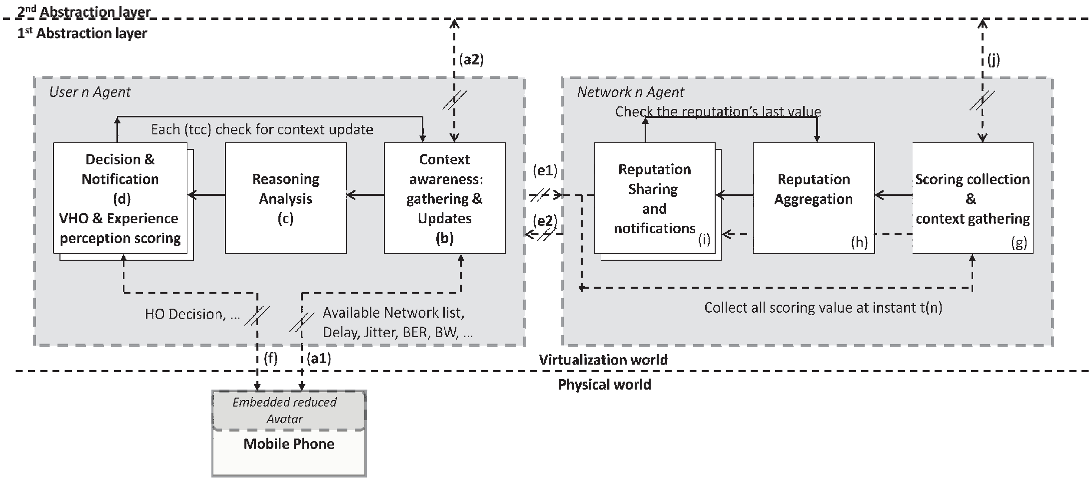


Figure 5.□: Proposed VHO management framework

The software user's agent also communicates with the second abstraction level of the architecture to exchange contextual static information through the interface (a2). The exchanged data at this level are mainly related to authentication information (at the beginning of each session), to the user profile (preferences, habits...), to mobile capabilities, to service requirements and to available networks' profiles.
After running the VHO algorithm, the VHO decisions are sent to the mobile node through interface (f).

• The mobile user's agent communicates with the network agent through interfaces (e1) and (e2). (e1) is used to exchange networks scores given by the users' agents and (e2) is used to exchange information about networks context and their reputations.

• The VHO decision making and the networks' QoS scoring are performed in block (d) of the proposed framework. This block is made up of different processes; each of them is responsible of a specific decision making. In the following we only focus on the VHO decision making and the scoring parts. Network selection notifications are sent to the mobile terminal through interface (f) for VHO and HHO execution. The current network scoring is performed according to the QoS it offered the mobile terminal and is sent to the agent of this network through interface (e1).
Indeed, each time a mobile terminal m connects to a network n, and before handing over to another one, it computes its perceived quality and concludes whether the offered quality satisfied its requirements or not. If the perceived quality is better than the required quality, the user's agent rates the network positively; otherwise, it rates it negatively:
$*$ Positive $(r^{+}(m,n) = 1)$ if its perceived QoS is satisfying.

$*$ Negative ($r^{-}(m,n) = -1$) otherwise. Details on the perceived QoS evaluation are provided in chapter □.

• The two other block (b) and (c) presented in figure 5.□ are respectively responsible of updating the dynamic context information and analyzing these information to provide each process in block (d) with the information it requires.

The network's agent

The main function of the network's agent is the computation and the sharing of the reputation. It communicates with the user's agent to get scores and to share the aggregated reputation values. To this matter, block (g) periodically receives the scores it is given by the users that are connected to the network represented by this agent. These scores are then forwarded, as a part of the network's agent work profile, to bloc (h) to be aggregated.
The aggregation is done in two steps through the following equations. Details about these equations are provided in chapter □.
- *Step 1:*

$$r_n(t) = w^{+} \sum r^{+}(m,n) + w^{-} \sum r^{-}(m,n) \tag{5.1}$$

- *Step 2:*

$$R_n(t) = \begin{cases} r_n(t) & \text{if } t = 1 \\ (1-\gamma) \cdot R_n(t-1) + \gamma * r_n(t) & \text{if } t \geq 2 \end{cases} \tag{2}$$

Block (g) also communicates with the second abstraction level, through interface (□), to get or to update static context information related to this network.
It also counts the number of users it is serving to gather load information. In case of overload, the network's agent generates notifications through bloc (i) and sends them to users' agents via interface (e2).
The global reputation value and the perceived QoS of the last user of this network are saved in block (i) that forwards this information, using interface (e2), to users' agents requesting them. These may be users connected to this network at this time or users in the range of this network and looking for VHO decision making.

Advantages of the proposed architecture

• Energy consumption:
The proposed scheme allows the minimization of the mobile node energy consumption as it exports all the processing to the software agents. In addition, the adoption of this context aware architecture allows a mobile terminal to get information about available networks through its representative agent which beneficial in terms of energy consumption. Indeed, a mobile terminal may use only its currently active interface to gather information on its neighboring access networks through the information exchange capabilities between users and networks agents. In this scheme, even when no agreements are performed between operators, a mobile user that subscribed to different networks can keep only one interface “on” to get information, when required, on the networks it subscribed to.
• Reputation Trust:
The considered overlay architecture assumes that all handover and reputation required processing are performed in the first abstraction layer. This layer is a kind of virtual level that hides the processing, the QoS and the reputation information from invoked networks and users. In this vision, networks won’t be able to affect or falsify their reputation values that are exchanged between their representative agents and users’ agents.

5.5 Performance evaluation

To evaluate the overlay based architecture for vertical handover decision making, the platform proposed in [illegible] was extended to integrate the reputation system and the VHO decision making based on this metric. A Multi-Agents sub-System (MAS) with JADE Environment [8[illegible]] is considered. This Multi-Agents technology allows the instantiation of the Agents within an initial Active Zone and to move them when required to another Active Zone as specified in [illegible]. One of the main advantages of JADE is the use of the ACL (Agent Communication Language) that allows unified communications between software Agents. Communications between the Agents and their corresponding physical entities is achieved through the generation of ACL-like messages.

The proposed architecture is tested for a video streaming application. Each mobile node and each wireless network is represented by his own agent within the overlay system. When the current network’s RSS or QoS (or both of them) goes below a given threshold, the user’s agent detects this degradation and asks his current network for available networks’ reputations to make a VHO decision. Once a decision is made, the user’s agent sends a notification to the mobile node it represents which executes the handover.

Figures 5.5 and 5.□ illustrate the variation of the average VHO decision delay for different numbers of users and available networks. The presented results are obtained for a con□dence interval with a con□dence level of □5□. This means that the average VHO decision decision delay has a probability equal to 0.□5 to be in the illustrated con□dence interval. This con□dence interval is based on the Monte Carlo method and is calculated using equation 5.2.

$$\frac{1,\square\square.Var(X)}{\sqrt{k-1}} \tag{5.2}$$

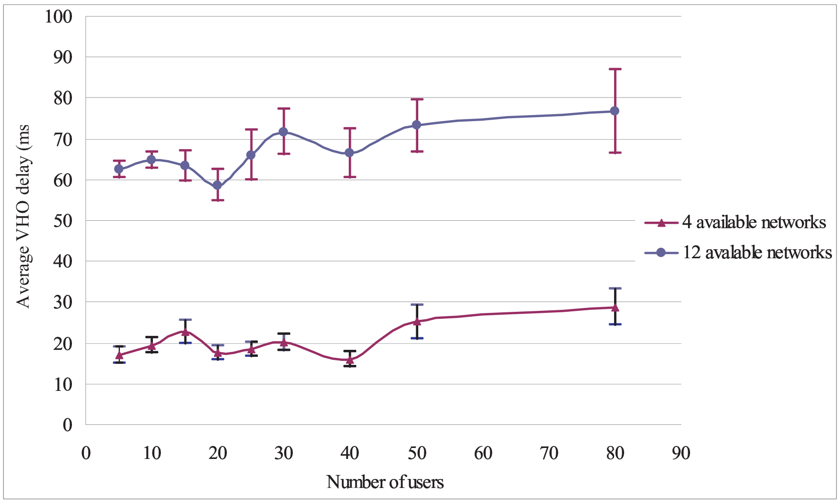


Figure 5.5: Average VHO delay for 12 available networks

Figure 5.5 illustrates the average vertical handover decision delay when the number of users simultaneously making a vertical handover increases. □e notice that, when the number of users varies between 5 and 80, the average VHO decision delay varies between 58 and □□ milliseconds for 12 available networks and between 15 and 2□ milliseconds for □ available networks. The VHO decision delay increase slightly with the increase of the number of users using the proposed overlay architecture. This may be e□plained by the fact that when the number of users making a VHO increases, the processing on the networks' agents side also increases which generates a little more delay. In spite of this variation, the e□perienced VHO delay is acceptable and is lower than the delay we got in chapter □ when using □S2.

Figure 5.□ illustrates the average vertical handover decision delay, for 20 users making a handover at the same time, when the number of available networks varies. This □gure shows that the VHO decision delay is lower than □0 milliseconds when the number of available networks is not very important (less than 8 available networks). □ hen the number of available networks goes above 8 the delay increases to reach 58 milliseconds for 12 available networks. This variation is e□plained by the increase of the processing on the users' agents side because

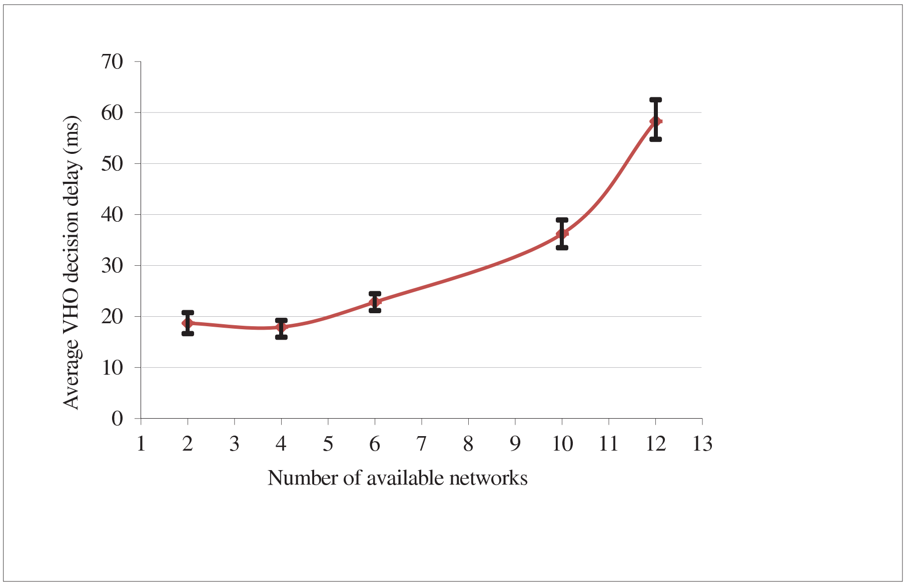


Figure 5.□: Average VHO delay for 20 users

of the increase of the exchanged messages and data with the available networks' agents. In addition, when the number of available networks increases, a user's agent, desiring to make a handover, sends messages to the available networks, waits for all these networks answers, classes them according to their reputations, checks the best reputed network's QoS and then makes a decision which affects the VHO delay.

In this considerations, we should point out that the VHO decision delays are obtained while using our personal computers in the lab, a more appropriate platform will considerably optimize the results and decrease the VHO decision delay. In this way, the proposed scheme can provide good performances if implemented in reel heterogeneous wireless networks platforms.

5.5 Conclusion

In heterogeneous wireless networks environments, architectural and implementation schemes are of prime importance to achieve ubiquitous access and seamless mobility. In this chapter, we provide and discuss two different architectural solutions on which our proposed vertical handover decision mechanisms can be integrated. The first proposed architecture is a centralized one. It is based on the IEEE 802.21 standard to which some extensions are proposed.

The proposed architecture allows the minimization of the mobile node energy consumption thanks to the MIIS that allows a multihomed mobile terminal to gather information regarding its neighbor networks through its current active interface.

We also propose an encryption/decryption mechanism that insures the reputation trustworthiness.

The second proposed architecture is distributed. It is based on an overlay control level composed of two virtualization layers able to make reasoning on behalf of physical entities within the system. This architecture allows higher flexibility especially for loosely coupled interconnected networks. This considered overlay architecture assumes that all handover and reputation required processing are performed in the first abstraction layer which is a kind of virtual level that hides the processing, the QoS and the reputation information from invoked networks and users. In this vision, networks won't be able to affect or falsify their reputation values that are exchanged between their representative agents and users' agents.

Performance evaluation show that the experienced VHO decision delay is not very important and is lower than the VHO delay experienced with the simulations performed using NS2 in chapter □

Chapter

Conclusion

With the evolution of heterogeneous wireless networks and the development of more capable mobile devices, mobile users are becoming more and more exigent in terms of QoS and mobility support. They would like to enjoy seamless mobility and ubiquitous access to services in an always best connected mode. In this context, the inter-system mobility management is an important and challenging technical issue to be solved. Inter-system mobility or vertical handover is performed between heterogeneous wireless access networks. It generally consists of three main tasks, namely, handover initiation, handover decision and handover execution. While appropriate decision processes should allow to determine the appropriate time and the appropriate wireless access network to handover to, the richness and the complexity of the parameters and measurements on which these decision processes should be built are challenging.
In the literature, different decisions approaches are proposed with different architectures and decision schemes. These consider different decision parameters regarding user preferences, available radio resources, application requirements and terminal capabilities. The complexity and the performances of these algorithms depend on the accessibility and the dynamicity of the used indicators, on the amount of exchanged data, on the required interworking architecture and on the complexity of the decision computations.
Ideally, an efficient vertical handover decision mechanism would minimize the decision computation latency and overcome the necessity of the non-attainable continuous tracking of all instantaneous parameter variations. It should be able to make acceptable decisions even with partial knowledge of its environment.

In this thesis, we mainly focus on the vertical handover decision making. We also addressed other important issues related to network pricing, architectural approaches, energy and trust. We proposed two vertical handover decision algorithms. The first one is based on reputation

and the second one is based on a Nash-Strackelberg game that maximizes both users and networks utilities. Then we proposed two architectures on which the VHO decision mechanisms can be integrated. The first architecture is an IEEE 802.21 based architecture and the second one is an overlay architecture composed of two virtualization layers.
In the first contribution, we proposed a reputation system to speed up wireless network selection and handover decisions. The Reputation System computes global reputation values based on past user experiences and allows mobile terminals to make faster VHO decisions.
Building network reputations is a statistical process that requires multiple samples of users' experiences. At the initiation phase, these reputation statistics should not be available or not statistically significant. Other decision mechanisms may be used during this learning phase to build up the reputation system. Performance results show that the proposed solution provides up to [illegible]8 percent of right decisions compared to the learning reference algorithm and reduces considerably the decision delay. Performance results also show that the proposed solution provides better delays than SCTP without any decision mechanism, the handover delay decreased from 15 seconds to almost 1[illegible]0 milliseconds, which helps to achieve seamless vertical handover. It is also shown that the reputation based VHO decision mechanism provides better throughput than a policy based VHO scheme when network conditions change suddenly. This reputation based VHO decision mechanism may be enhanced by the introduction of additional decision parameters and VHO initiation methods.
In the second contribution, we addressed this point to tackle both QoS and economical aspects in heterogeneous wireless networks. We proposed a model to study the revenue of a service provider managing heterogeneous wireless access networks and dealing with a finite set of users that aim to maximize their utilities. This model is then used within a decision tool for vertical handover decision making.
The problem is formulated and modeled as a Stackelberg-Nash game and present an optimal bandwidth-pricing policy for different players. A handover decision algorithm with a selection process based on the obtained Nash-Stackelberg equilibrium is then proposed.
The VHO decision mechanisms considers the current available bandwidth and the users requirements in terms of QoS as decision parameters and integrates a Fuzzy Logic inference engine, that has velocity, RSS and network coverage as input parameters, for VHO initiation. The analyses of the optimal bandwidth-prices and the revenue at the equilibrium point show that these latter increase when user's requirements increase in terms of QoS.
We pointed out that networks having same capacities and different reputation values should charge users with different prices. Obviously, the one who has the best reputation is the most expensive. Nevertheless, users will still be attracted by good reputed networks as they provide them with better QoS which improve their utilities. It is important to mention that network reputation should be efficiently managed to avoid its falsification.

Reputation management and sharing strongly depend on the architecture on which the reputation system is integrated.
In this sense, two possible architecture are proposed and discussed in the last chapter of our thesis. The first one is based on the 802.21 standard and the second one is an overlay based architecture.
The IEEE 802.21 based architecture allows the minimization of the mobile node energy consumption thanks to the MIIS that allows a multihomed mobile terminal to gather information regarding its neighbor networks through its current active interface.
We also proposed an encryption/decryption mechanism that insures the reputation trustworthiness.
The overlay based architecture is composed of two virtualization layers able to make reasoning on behalf of physical entities within the system. This architecture allows higher flexibility especially for loosely coupled interconnected networks. It exports all handover and reputation required processing to the first abstraction layer which is a kind of virtual level that hides the processing, the QoS and the reputation information management from invoked networks and users. In this vision, networks won't be able to affect or falsify their reputation values that are exchanged between their representative agents and users' agents.

Future Work

The work presented in this dissertation presents a first step for the adoption of a qualitative metric, namely, network's reputation which is as a significant criteria for VHO decision making.
Several issues still need to be addressed regarding reputation effectiveness and robustness. For instance, there is still a need for an accurate normalization approach that keeps enough precision to allow reputation comparison between different systems.
Among the other important open issues: How to distinguish between deliberate packet dropping and congestion or loss of connectivity? How accurate and fair is the reputation system? What is the impact of potential liars on the reputation values? What if the reputation values are falsified by a network to attract users? What is the impact of such wrong observations on the reputation system? What strategies can an attacking node (user or network) employ to distort the reputation system, in addition to lying, and how to counter this?
In chapter 5 the proposed solutions addressed this problem from the networks side. This issue should also be addressed from the users side.
Regarding the architectural aspects, the proposed solutions based on IEEE 802.21 based and the overlay virtualization architecture only deal with the reputation based VHO decision mechanism proposed in chapter [illegible]. Further evaluation for the Nash/Stackelberg based VHO

decision making algorithm are required. Although the simulations were useful in analyzing some performance metrics, a better evaluation can be obtained by the integration of this decision mechanism into the overlay architecture that we considered to evaluate the first proposed VHO decision algorithm. This will allow the study of the behavior of the proposed tool in real conditions.

The proposed Nash-Stackelberg game assumes that there is a single service provider that manages the available networks. Our future research will also address the non cooperative case in which different service providers are competing for resource charing while dealing with a finite set of users.

Résumé

L'évolution des technologies réseaux sans fil, des terminaux mobiles ainsi que des contenus et des services créent des environnements hétérogènes de plus en plus complexes. Dans ce contexte, un compromis entre la mobilité, la transparence et la performance apparaît.
Les utilisateurs mobiles, ayant différents profils et préférences, voudraient être toujours connectés au meilleur réseau à tout moment, sans avoir à se soucier des différentes transitions entre réseaux hétérogènes.
Face à cette complexité, il parait nécessaire de proposer de nouvelles approches afin de rendre ces systèmes plus autonomes et de rendre les décisions de handover vertical plus efficaces.
Cette thèse se concentre sur la gestion de mobilité verticale, plus précisément sur la prise de décision de handover vertical dans un environnements de réseaux hétérogènes sans fil.
Traditionnellement, le handover était étudié entre des points d'accès ou des réseaux utilisant la même technologie d'accès. Ce processus, désigné par handover vertical, est principalement basé sur la force du signal reçu.
Avec l'émergence d'une multitude de réseaux sans fil, les terminaux mobiles ont la possibilité de commuter leurs connexions entre différentes technologies d'accès offrant des capacités et des caractéristiques différentes.
Dans ce cas, le processus de transfert est plus complexe et est dénoté par handover vertical.
Pour atteindre un handover vertical efficace, de nombreux critères doivent être considérés. En effet, l'état du réseau, les exigences des applications et les ressources disponibles doivent être suivies en continu et de nombreux critères de décision VHO devraient être collectés.

État de l'art

Dans le chapitre de l'état de l'art de cette thèse nous identifions les différents critères de prise de décision et nous présentons les mécanismes de prise de décision les plus connus dans la littérature. Les critères de prise de décision peuvent être relatifs aux préférences de l'utilisateur, aux capacités du terminal mobile et des réseaux disponibles et aux exigences des services en

cours. Parmi les mécanismes de prise de décision les plus connus nous citons ceux qui sont :
- basés sur une fonction de décision,
- centrés sur l'utilisateur,
- à attributs multiples,
- basés sur la logique floue et les réseaux de neurones,
- basés sur les chaines de Markov,
- basés sur la théorie des jeux.

Une étude comparative de ces différents mécanismes de prise de décision est faite après la description de ces derniers.

Vers l'utilisation de la réputation des réseaux pour la prise de décision du handover vertical.

Dans le troisième chapitre, nous proposons l'utilisation de la réputation des réseaux comme une nouvelle métriques subjective qui repose sur l'expérience et les observations des utilisateurs précédents dans des contextes similaires. Dans la première partie du chapitre, nous décrivons le système de réputation. Ensuite nous proposant un mécanisme de prise de décision basé sur cette nouvelle métrique.

Le but d'introduire la réputation dans ce contexte est de minimiser la latence du handover vertical et de garantir une bonne qualité de service. La réputation des réseaux reflète le degré de satisfaction des anciens utilisateurs d'un réseau donné. Nous montrons que la réputation peut être une métrique utile et pertinente si on l'intègrer dans les mécanismes de prise de décision du handover vertical dans un environnements réseau complexes. Au meilleur de nos connaissances, et tandis que la réputation a déjà été utilisée dans les domaines sociaux, de sécurité et des affaires comme un facteur de confiance, c'est la première étude qui l'introduit pour la sélection de réseaux et la prise des décisions.

Nous proposons alors un système de réputation qui permet d'accélérer la sélection d'un réseau sans fil en cas de handover vertical imminent.

Le système calcule les valeurs de réputation en se basant sur les expériences passées. La construction des réputations des réseau est un processus statistique qui nécessite de multiples échantillons des expériences des utilisateurs. Lors de la phase d'initiation, ces statistiques peuvent ne pas être disponibles ou statistiquement non significatives.

Ainsi, d'autres mécanismes de décision peuvent être utilisés pendant cette phase d'apprentissage pour construire le système de réputation.

Afin de gérer cela, les observations des utilisateurs devrait être régulièrement collectées et traduites comme étant des notes de réputation.

Le système de réputation proposé répond aussi à différents critères indispensables pour garantir son efficacité. En effet, la pertinence de certaines données collectées concernant la réputation peuvent changer au cours du temps. D’une part, un comportement récent est généralement un meilleur prédicateur d’un comportement futur qu’un événement observé il y a longtemps. D’autre part, considérer que le comportement le plus récent, peut établir une représentation déformée des comportements passés, parce qu’une seule instance observée n’est pas suffisante pour déterminer une tendance.

Pour répondre a ces exigences, nous donnons plus de poids aux comportements récents tout en considérant les comportements passés.

Cette fonctionnalité permet à notre système de réputation d’atteindre deux objectifs principaux : une meilleure consistance par rapport au comportement futur et la possibilité de récupération de la réputation des nœuds qui étaient défectueux. Cela est essentiel pour faire face à des nœuds qui, auparavant, présentaient quelques problèmes et qui ont été réparés.

Une autre considération importante pour la construction du système de réputation est le contexte. En effet, la notion de contexte est d’une grande importance lorsque on parle de réputation. La phrase « J’ai confiance en mon médecin pour me donner des conseils sur des questions médicales, mais pas sur des questions financières » est un exemple qui montre comment le contexte peut être important.

C’est la même chose quand nous parlons de réputation des réseaux. Nous considérons que la réputation est un critère multidimensionnel qui dépend fortement de la qualité des différents échantillons d’utilisateurs considérés et de leurs contextes.

Par exemple, un réseau peut avoir une bonne réputation pour les applications de streaming et une mauvaise réputation pour les applications de vidéo interactive, il peut avoir une bonne réputation dans une zone donnée et une mauvaise réputation dans une autre.

Dans cette vision, les réseaux ont une valeur de réputation par classe de service et par zone.

Pour répondre à ces différents critères, le processus de construction et de la mise à jour de la réputation passe à travers trois phases qui sont les suivantes:

- La phase de collection.
- La phase d’agrégation.
- La phase de partage de la réputation.

Le système de réputation est construit comme un système overlay (O□M) distribué capable de collecter, mettre à jour et communiquer les valeurs de la réputation de chacun des réseaux.

Après la description du système de réputation et de ses différentes exigences, nous avons présenté un mécanisme de prise de décision basé sur la réputation. Le mécanisme de prise de décision proposé considère le handover vertical impératif et alternatif.

La force du signal reçu est utilisée comme indicateur qui permet de décider quel type de handover déclencher. Le handover impératif est exécuté si la connexion actuelle ne peut plus être maintenue sur le réseau courant. Ceci est généralement observé si la force du signal reçu du réseau courant est soudainement inférieure à un seuil minimum de $th_{min}(-115dbm)$. Il peut également être observé si le délai ou tout autre paramètre de QoS est soudainement affecté. Dans ce cas, l'utilisation de la réputation augmente les chances de faire un handover vers un réseau disponible qui offre une QoS comparables à celle qu'il avait avant de changer de réseau. Ceci évite les handovers inutiles et permet de garantir une meilleure qualité de service. Si la force du signal du réseau courant est plus élevée que th_{min}, le handover n'est pas obligatoire. L'O□M vérifie périodiquement s'il y a de nouveaux réseaux candidats disponibles qui ont une meilleure réputation. Dans ce cas, l'un des meilleurs réputés et pas surchargé est considéré comme un réseau cible. Dans le cas d'un handover alternatif, l'algorithme de prise de décision proposé consiste en trois phases principales: (a) initiation du handover, (b) sélection de réseau et (c) exécution du handover vertical (voir figure □1).

(a) Initiation du handover

Le handover peut être initié par les nœuds mobiles ou par l'O□M.

• Si la force du signal reçu passe en dessous d'un seuil minimum, le terminal mobile initie un handover avant qu'il perd sa connexion courante.

• Si l'O□M constate que la QoS perçue par un nœud mobile est inférieure à celle requise ou qu'un réseau disponible peut mieux servir l'application en cours, il lance un handover vertical.

(b) Sélection réseau

Pendant le processus de sélection, un nœud mobile vérifie la réputation des réseaux disponibles et sélectionne le réseau le mieux réputé s'il est pas surchargé. Si ce dernier fournit suffisamment de QoS, le nœud mobile fait un handover vers ce réseau.

(c) Exécution du handover vertical

L'exécution du handover vertical est un problème de mise en œuvre. Nous proposons l'utilisation de protocoles de multihoming tels que SCTP.

Dans le mécanisme standard du protocole SCTP, le changement d'adresse primaire a lieu seulement après que l'adresse principale échoue complètement. Dans notre cas, et grâce aux capacités d'anticipation de notre mécanisme de prise de décision basé sur la réputation, SCTP est adapté pour établir une nouvelle connexion avant de perdre complètement la première pour assurer faibles délais de prise de décision.

Les résultats de performance montrent que la solution proposée offre jusqu'à □8 pour cent de bonnes décisions par rapport à l'algorithme d'apprentissage de référence et réduit considérablement le délai de décision.

Les résultats de performance montrent également que l'adoption de la réputation comme paramètre de prise de décision et d'anticipation du handover vertical dans un framework qui utilise le protocole SCTP comme protocole de mobilité assurant le multihoming, offre de

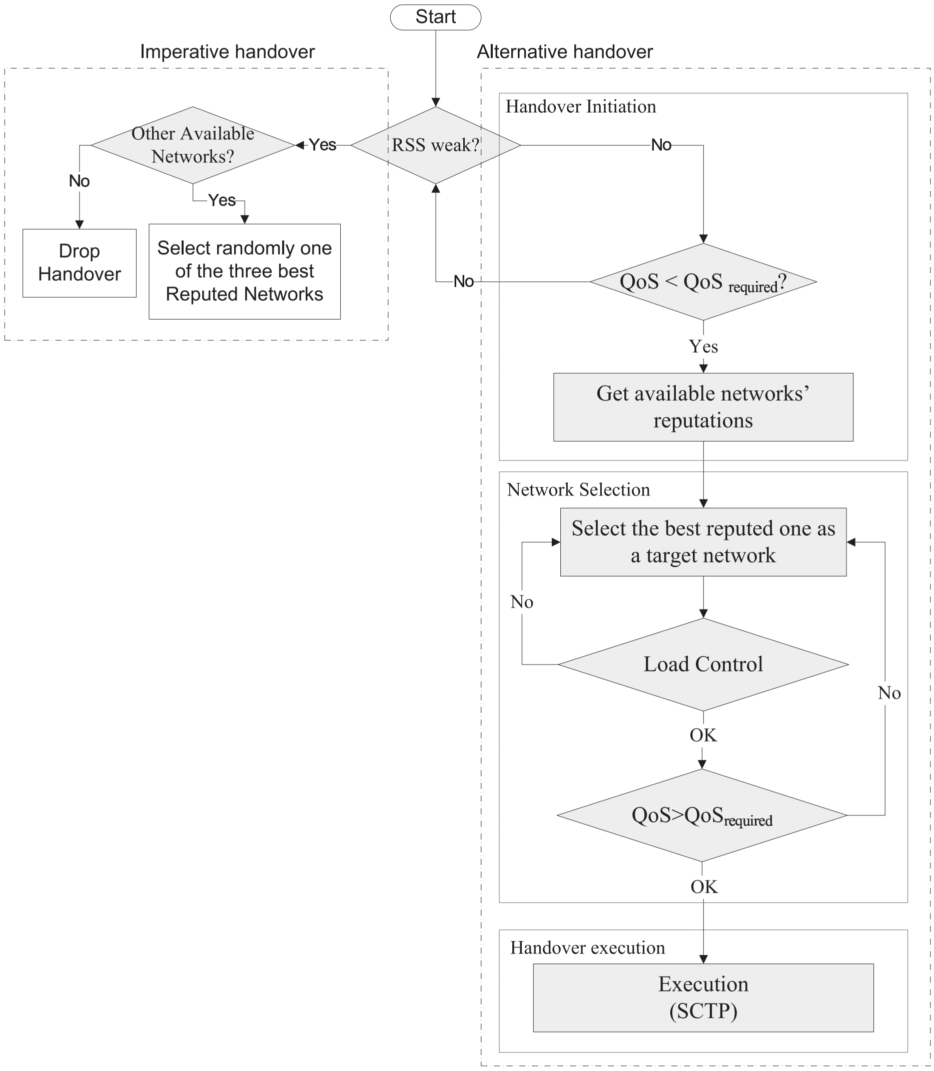


Figure [illegible].1: Mécanisme de prise de décision proposé

meilleurs performances que SCTP sans aucun mécanisme de décision. Le délai de handover vertical est diminué de 15 sec après de 1[illegible]0 millisecondes. Ceci permet d'assurer la transparence du passage de la connexion d'un réseau à l'un autre.

Nous avons également démontré que le mécanisme de prise de décision basé sur la réputation offre un meilleur débit qu'un mécanisme basé sur une politique de décision lorsque les conditions du réseau changent soudainement.

□ne approche □as□e sur un □eu de □ash □tac□el□erg pour la tari□cation des services et la prise de d□cision du handover vertical□

□ien que l'ob□ectif principal soit de garantir la meilleure qualit□de service et l'utilisation optimale des ressources radios, les aspects □conomiques doivent □galement □tre consid□r□s, y compris la minimisation des co□ts pour les utilisateurs et la ma□imisation des revenus pour les fournisseurs de services ou les operateurs.

□ous proposons alors, dans la deu□i□me partie de la th□se, un m□canisme de prise de d□cision bas□sur la th□orie des □eu□. Ce dernier permet la ma□imisation des utilit□s des r□seau□et des utilisateurs.

□ans cette solution, chaque r□seau disponible □oue un □eu de Stackelberg avec un ensemble d'utilisateurs, tandis que les utilisateurs □ouent un □eu de □ash entre eu□ pour partager les ressources radios limit□es.

En tant que fournisseur de services ou op□rateur, le probl□me consiste □d□□nir des strat□gies diff□rentes pour chaque classe de service et de choisir un pri□qui permet d'attirer les utilisateurs a□n de ma□imiser son pro□t.

En tant qu'utilisateur, le probl□me est de choisir le meilleur r□seau pour un service donn□ selon sa capacit□□payer et sa qualit□de service requise.

□ans cette vision, les pri□appliqu□s par les fournisseurs de services ne doivent pas □tre trop □lev□s pour ne pas repousser les utilisateurs qui ne sont pas dispos□s □payer. Au m□me temps, ils ne devraient pas □tre trop faibles pour rester rentable.

A□n de r□soudre le probl□me du cot□de l'utilisateur et du cot□du fournisseur de service, un point d'□quilibre de □ash, qui ma□imise l'utilit□de l'utilisateur et les revenus des fournisseurs de services, est trouv□et utilis□pour le contr□le d'admission et la prise de d□cision de handover vertical.

□ous introduisons □galement dans le mod□le propos□: (a) les e□igences de l'utilisateur en termes de qualit□de service en fonction de son application en cours et (b) la r□putation des r□seau□qui est conduite □partir de la qualit□d'e□p□rience des utilisateurs comme e□pliqu□ dans le chapitre pr□c□dent. □'effet de ces param□tres sur la tari□cation et sur le probl□me de ma□imisation des revenus est ensuite □tudi□.

□e probl□me est mod□lis□comme un □eu hi□rarchiques □deu□niveau□. □e choi□d'un □eu hi□rarchique est motiv□par le fait qu'il permet d'□tudier □la fois le probl□me des pri□des r□seau□et les comportements des utilisateurs. En effet, les comportements des utilisateurs dans le niveau inf□rieur d□pendent de leurs besoins en terme de □oS et des pri□□□□s par les r□seau□au niveau sup□rieur.

De même, les stratégies de tarification du réseau définies au niveau supérieur dépendent des comportements des utilisateurs définis au niveau inférieur.

• Le niveau supérieur est un jeu de Stackelberg où les fournisseurs de services (les réseaux) jouent le rôle du leader et les utilisateurs mobiles jouent le rôle de disciples.

Dans ce niveau chaque réseau prédit la réponse des disciples et ajuste ses prix afin de maximiser ses revenus lorsque les utilisateurs demandent une certaine bande passante correspondant à leurs besoins et à leurs capacités de payer. Le revenu d'un réseau est donné par:

$$R^j = \sum_{i=1}^{n} p_i^j B_i^j$$

et le revenu total du fournisseur de services est donné par l'equation suivante:

$$R = \sum_{j=1}^{k} R^j$$

• Le niveau inférieur est représenté par un jeu de Nash non coopératif, où chaque utilisateur a pour objectif de maximiser la fonction d'utilité suivante:

$$U_i^j = w_i * log(1 + r^j q_i B_i^j) - p_i^j B_i^j$$

soumise à la contrainte:

$$\sum_{l=1}^{n} B_l^j \leqslant C^j$$

Après avoir prouvé l'existence et l'unicité de l'équilibre de Nash-Stakelberg, la résolution des fonctions d'utilité a mené aux résultats suivants:

$$B_i^{j*} = \frac{C^j}{n} + \frac{1}{n}\sum_{i=1}^{n}\frac{1}{r^j q_i} - \frac{1}{r^j q_i} \qquad (□1)$$

Et:

$$p_i^{j*} = \frac{n w_i}{C^j + \sum_{i=1}^{n}\frac{1}{r^j q_i}} \qquad (□2)$$

Où B_i^{j*} et p_i^{j*} représentent, respectivement, la bande passante et le prix à l'équilibre.

Cet équilibre est ensuite analysé et utilisé pour la prise de décision du handover vertical. Le mécanisme de prise de décision proposé consiste en deux étapes qui sont: l'initiation du handover vertical et la sélection du réseau tel que présenté dans la figure □2.

La solution proposée tient compte du contexte du réseau courant et du terminal (pour l'initiation du handover), ainsi que des préférences des utilisateurs en termes de coût et de QoS (pour la sélection de réseau).

Comme illustré dans la figure □2, le bloc d'initiation du handover reçoit les informations de

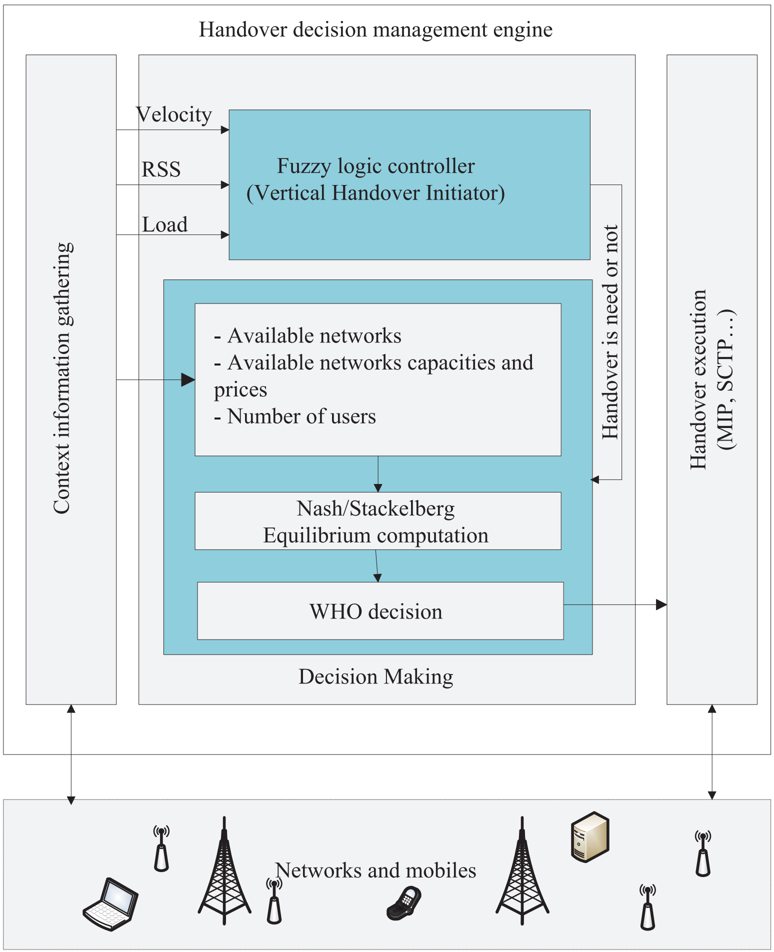


Figure □2: M□canisme de handover vertical propos□

conte□te, □savoir, la vitesse de l'utilisateur, la charge du r□seau et la force du signal re□u pour □valuer si un handover est n□cessaire ou non. □'□valuation est r□alis□e en utilisant un contr□leur de logique □oue.

□ne fois qu'un handover est n□cessaire, le bloc de s□lection de r□seau obtient les informations, concernant les r□seau□disponibles, leurs capacit□s, les pri□et le nombre d'utilisateurs dans chaque r□seau disponible, □partir du bloc de collecte d'information de conte□te.

A la □n de l'□tape de s□lection du r□seau, une d□cision de handover vertical est faite et l'e□□cution du handover est lanc□e.

□a s□lection du r□seau est r□alis□e selon l'algorithme 2, illustr□ci-dessous. □ous consid□rons des utilisateurs mobiles □quip□s par des mobiles multihom□s disposant d'une interface □ □A□, une interface □ MA□ et une interface r□seau cellulaire. □ne interface donn□e peut □tre connect□e □un seul r□seau □la fois.

Tout d'abord, nous cat□gorisons l'ensemble des r□seau□en trois classes (□ □A□, □ MA□ et r□seau□cellulaires). Ensuite, nous classons les trois cat□gories de r□seau□par ordre de pr□f□rence en fonction de $U_i^j(B_i^{j*}, p_i^{j*})$.

Si nous supposons que toutes les trois classes sont disponibles, et que l'ordre de préférence est le suivant:

$$Cl_{(1)} \succeq Cl_{(2)} \succeq Cl_{(3)}$$

ce qui signifie que pour un utilisateur i, la classe $Cl_{(1)}$ est préférable à la classe $Cl_{(2)}$ qui est aussi préférable à la classe $Cl_{(3)}$ par rapport à la fonction d'utilité $U_i^j(B_i^{j*}, p_i^{j*})$.
Dans la suite, nous noterons par V le nombre de classes disponibles ($V \in \{1,2,3\}$) et par x_i^j la variable de la prise de décision. $x_i^j = 1$ si l'utilisateur i décide de se connecter au réseau de j et $x_i^j = 0$ autrement. $Band_i$ est la valeur totale de bande passante allouée à un utilisateur i.
Comme illustré dans l'algorithme 2, quand une nouvelle connexion ou un handover est initié par un utilisateur i, il vérifie, par ordre de préférence, si les réseaux peuvent lui fournir la bande passante nécessaire.
Si tous les réseaux préférés disponibles ne disposent pas de suffisamment de ressources pour une connexion, elle est rejetée.

Algorithm 2 Algorithme de prise de décision

$Band_i = 0, index = 1;$
while ($Band_i < B_i$) and ($index \leq V$) **do**
  $j_1^* = ArgMax_j\{U_i^j, j \in Cl_{(index)}\};$
  $x_i^{j_1*} = 1;$
  $\triangle Band = B_i - Band_i$
  $Band_i + = \min\{B_i^{j_1^*}, \triangle Band\}$
  $index + +;$
end while
if $Band_i < B_i$ **then**
  Connection not admitted;
end if

Ces analyses de la bande passante optimale et des revenus au point d'équilibre montrent que ces derniers augmentent lorsque les exigences de l'utilisateur en termes de QoS augmentent. Nous avons souligné que les réseaux ayant les mêmes capacités et des valeurs de réputation différentes factureront les utilisateurs avec des prix différents. Évidemment, celui qui a la meilleure réputation est le plus chère. Néanmoins, les utilisateurs seront toujours attirés par les réseaux les mieux réputés puisqu'ils leur offriront une meilleure qualité de service qui améliore leurs utilités.

□olutions architecturales et de mise en □uvre□

□ans ce chapitre, nous proposons et discutons deu□ diff□rentes solutions architecturales sur lesquelles nos m□canismes de prise de d□cision propos□s peuvent □tre int□gr□s.
□a premi□re architecture propos□e est bas□e sur la norme IEEE 802.21 □laquelle nous proposons certaines e□tensions.
□a seconde architecture propos□e est bas□e sur un niveau de contr□le compos□de deu□couches de virtualisation. □a virtualisation est assur□e via des agents capables de faire un raisonnement et de prendre des d□cisions pour le compte d'entit□s physiques qu'ils repr□sentent au sein du syst□me. Cette architecture permet une plus grande □e□ibili□.
□es questions importantes concernant la con□ance et la consommation d'□nergie sont discut□es dans les deu□propositions.

- Architecture bas□e sur la norme 802.21:

Comme beaucoup de normes, l'IEEE 802.21 ne propose pas d'algorithmes de prise de d□cision. □ans la suite, nous d□crivons comment nous pouvons int□grer notre m□canisme de prise de d□cision de handover vertical dans une architecture bas□e sur la norme 802.21. □ans notre proposition, nous supposons que le terminal mobile est responsable de la prise de d□cision du handover vertical. □a □gure □.□illustre l'architecture globale propos□e.
□a premi□re couche est la couche □H□□MAC. □essus, nous avons le module MIHF et ses trois principau□services, □savoir, les services MIES, les services MICS et les services MIIS. □ous proposons d'int□grer notre m□canisme de prise de d□cision entre la couche MIHF et les couches sup□rieures, comme illustr□dans la □gure □.□.
Cette couche suppl□mentaire est responsable de la gestion de la r□putation et de la prise de d□cision du handover vertical. Elle est compos□e de deu□blocs principau□et d'un r□f□rentiel de politiques de d□cision:

- □e r□f□rentiel de politiques de d□cision:

Ce r□f□rentiel emmagasine les r□gles et les politiques relatives au□pr□f□rences des utilisateurs et des e□igences de l'application. □e r□f□rentiel de politiques communique avec la couche utilisateur□Application via l'interface (k).

- □e bloc de gestion de la r□putation:

□u c□t□du n□ud mobile, le bloc de gestion de la r□putation est en charge de la notation des r□seau□selon le syst□me de r□putation propos□dans le chapitre III. □es scores sont calcul□s en fonction des param□tres de □oS (que le bloc de gestion de la r□putation re□oit du MIIS via l'interface (f)) et des e□igences de l'application en termes de qualit□de service (que le bloc gestion de la r□putation re□oit de la couche utilisateur□Application via l'interface (h)). □es scores sont ensuite envoy□s au bloc de gestion de la r□putation du c□t□r□seau □travers

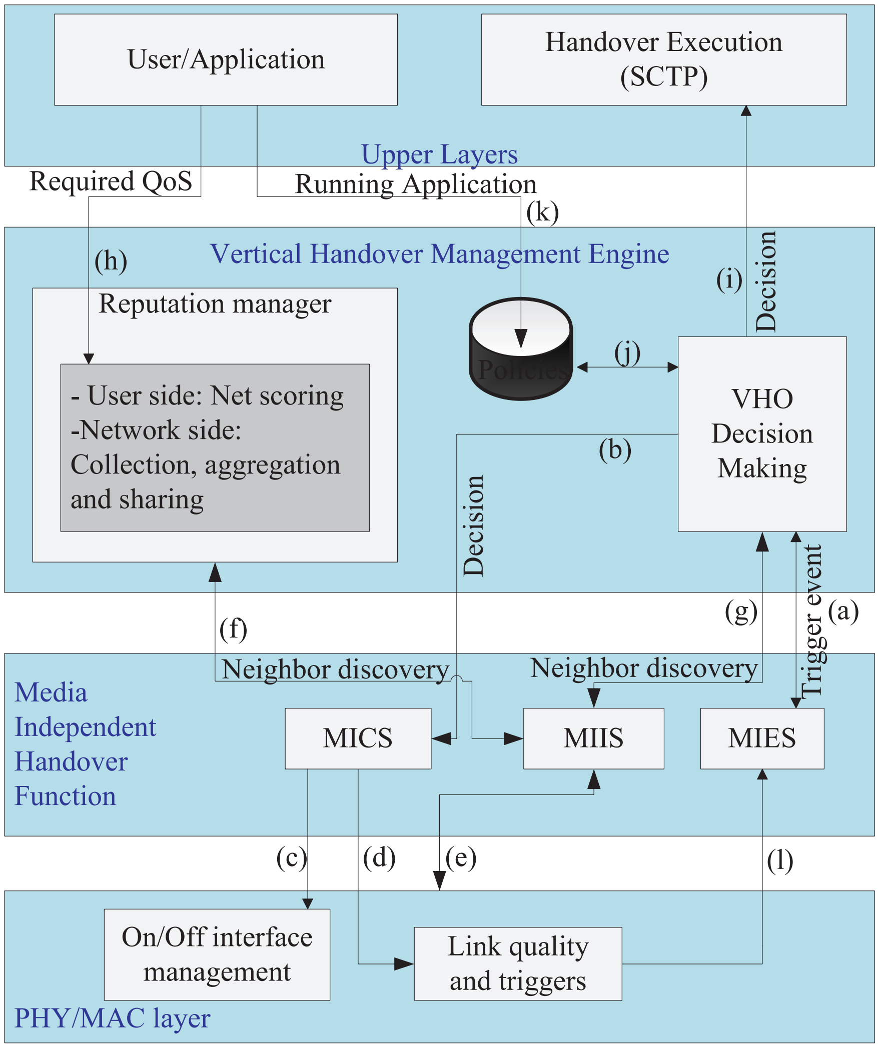


Figure [illegible].[illegible] : Une architecture basée sur la norme 802.21

le MIIS. Le gestionnaire de la réputation du côté réseau calcule une valeur de réputation agrégées, selon notre système de réputation, et envoie cette réputation aux nœuds mobiles, sur demande, via le MIIS.

- Le bloc de la prise de décision:

Ce bloc est responsable de la prise de décision du handover. Sur la base des événements déclencheurs fournis par la MIES et des informations sur les réseaux voisins fournies par le MIIS. Ce bloc obtient la réputation des réseaux disponibles et les informations de QoS à partir de la MIIS via l'interface (g) et communique avec le référentiel des politiques grâce à l'interface (j) pour obtenir des informations sur les exigences des utilisateurs et des applications. Quand un handover vertical est requis, le bloc de décision envoie une notification de décision à la MICS via l'interface (b) pour lancer le handover au niveau inférieures et une notification au bloc d'exécution via l'interface (i) pour activer le handover au niveau IP. La consommation d'énergie est l'un des enjeux majeurs dans le monde des terminaux mobiles.

Ainsi, un mécanisme de décision de handover efficace ne devraient pas seulement assurer une bonne qualité de service mais aussi assurer la consommation la plus faible possible d'énergie (batterie).
L'architecture proposée permet la minimisation de la consommation de l'énergie des nœuds mobiles.
En effet, dans l'architecture 802.21 de base, grâce à la MIIS, un terminal multihomé mobile est capable de recueillir des informations concernant ses réseaux voisins via son interface active. En effet, la MIIS fournit au nœud mobile un large éventail d'informations concernant ses voisins.
À cet égard, le terminal mobile peut toujours garder une seule interface active au lieu de scanner sans cesse les différents réseaux disponibles. En d'autres termes, les autres interfaces sont désactivées en attendant et ne sont activées que lorsque cela est nécessaire pour transporter des données d'application.
Ainsi, nous économisons une quantité considérable d'énergie au niveau du nœud mobile ce qui permet de le garder opérationnel beaucoup plus longtemps.
L'architecture proposée suppose que les réseaux disponibles peuvent être gérés par des opérateurs différents. Dans ce contexte, la délégation des tâches de calcul et de partage de la réputation aux réseaux peut les inciter à falsifier les valeurs de réputation. Dans ce cas, les réputations reçues par un nœud mobile pour prendre une décision peut ne pas être significatives et ne pas refléter les conditions réelles sur un réseau. À cet égard, l'établissement d'une relation de confiance entre les réseaux et les nœuds mobiles est très délicate. Pour résoudre ce problème, nous avons proposé de chiffrer la valeur de la réputation de façon à ce qu'elle soit transparente aux réseaux.

Pour ceci nous avons ajouté une entité de confiance qui est une entité overlay qui assure le calcul et la fiabilité des valeurs de la réputation. Les scores données par les nœuds mobiles sont alors cryptés et envoyés au gestionnaire de réputation du côté réseau. Ce dernier transmet les scores chiffrés à l'entité de confiance qui les décrypte et calcule la valeur agrégée de la réputation pour chaque réseau. Les valeurs agrégées sont ensuite cryptées et envoyées à la demande au nœuds mobiles via le gestionnaire de réputation du coté des réseaux. Nous avons opté pour un schéma de cryptage/décryptage asymétrique dans lequel chaque nœud est titulaire d'une clé publique et d'une clé secrète. Quand un nœud mobile veut envoyer un message à l'entité de confiance, il donne un numéro de séquence (SN) a son message et envoie à l'entité le message $M = (score, (nodeID, SN))$ chiffré avec la clé publique de l'entité de confiance qui utilise sa clé secrète pour le décrypter.
Quand un nœud mobile n_i demande la réputation des réseaux disponibles, l'entité de confi-

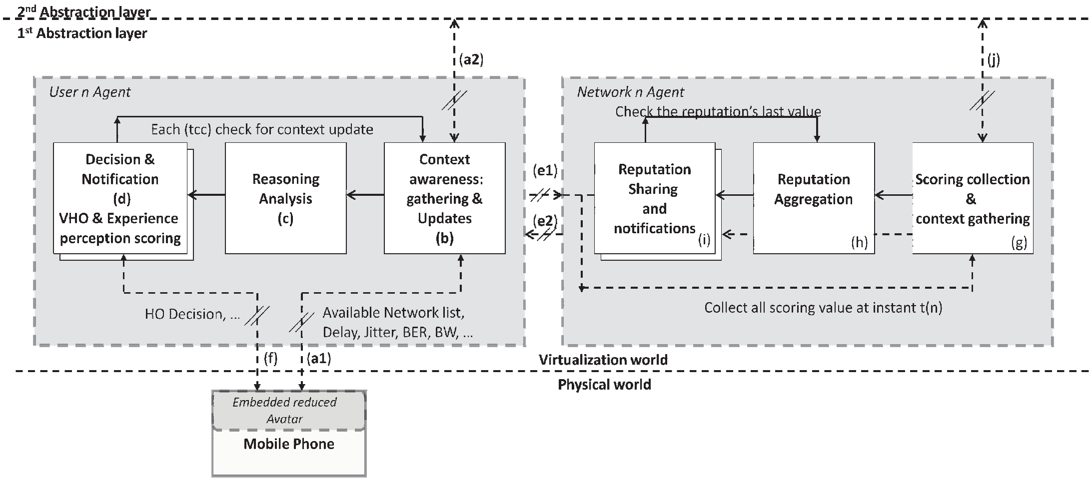


Figure □.□: Framework de gestion de mobilité proposé

ance lui envoie le message

$$M' = (Reputation1, Reputation2, ..., Reputationn, SN_{ORC_n})$$

cryptée avec la clé publique du nœud « n ». SN_{ORC_n} est un numéro de séquence correspondant au nœud n. En d'autres termes, chaque fois qu'un nœud mobile « i » demande une réputation, il incrémente SN_{ORC_i} et l'intègre dans le message chiffré pour empêcher la falsification de la réputation par l'envoi d'ancienne réputation par le réseau.

- Architecture overlay basée sur un système multi-agent:

Nous avons proposé un framework de gestion de mobilité flexible et évolutif qui gère les informations de contexte dynamiques et statiques et permet aux terminaux mobiles d'être toujours connectés au réseau d'accès le plus approprié en prenant des décisions de handover basées sur la réputation des réseaux.

Ce framework intègre notre mécanisme de prise de décision présenté dans le chapitre III. L'adoption de ce type d'architecture facilite la gestion des différentes entités impliquées dans un environnement réseau sans fil hétérogène, à savoir les utilisateurs, les terminaux, les services, les réseaux, les fournisseurs de services, etc. La solution proposée est essentiellement basée sur des agents logiciels qui sont capables de faire un raisonnement pour le compte d'entités physiques au sein du système. Plus précisément, les agents agissent au nom des terminaux mobiles pour la prise de décision et pour le compte de réseaux pour le calcul et le partage de la réputation. La figure □.□ présente le framework de gestion de mobilité proposé. Les principales interactions qui permettent le collecte, l'actualisation et le partage des informations nécessaires pour prendre une décision fiable sont détaillées ci-dessous.

L'agent de l'utilisateur mobile doit discuter en permanence avec l'entité physique qu'il

représente (le nœud mobile) et les agents des réseaux disponibles afin de collecter les informations de contexte nécessaires à la prise de décision.
• L'agent utilisateur communique avec le terminal qu'il représente via l'interface (a1). Ils échangent des informations de contexte dynamique tel que le réseau courant, les réseaux voisins, le délai, la gigue, la bande passante et le taux d'erreur binaire que le terminal perçoit. L'agent utilisateur communique également avec le second niveau d'abstraction de l'architecture pour échanger des informations contextuelles statiques grâce à l'interface (a2). Les données échangées à ce niveau sont principalement liés aux informations d'authentification (au début de chaque session), au profil de l'utilisateur (préférences, habitudes ...), aux capacités du mobiles, aux exigences des services et aux caractéristiques des réseaux disponibles.
Après l'exécution de l'algorithme de prise de décision, les décisions de handver sont envoyés au nœud mobile grâce à une interface (f).

- L'agent utilisateur communique avec l'agent de réseau grâce aux interfaces (e1) et (e2).
- La prise de décision du handover et la notation des réseaux sont effectuées dans le bloc (d) du framework proposé. Ce bloc est composé de différents processus, chacun d'eux est responsable d'une prise de décision spécifique.

Les notifications de sélection du réseau sont envoyées vers le terminal mobile via l'interface (f) pour l'exécution du handover.
• Les bloc (b) et (c) présentés dans la figure [illegible] sont respectivement responsables de la mise à jour des informations de contexte dynamique et de l'analyse de ces informations pour fournir à chaque processus du bloc (d) les informations requises.
La fonction principale de l'agent du réseau est le calcul et le partage de la réputation. Il communique avec l'agent de l'utilisateur afin d'obtenir les scores et de partager les valeurs agrégées de réputation. Le bloc (g) reçoit périodiquement les scores donnés par les utilisateurs qui sont connectés au réseau représenté par cet agent. L'agrégation se fait en deux étapes tel que décrit dans le chapitre III. [illegible]lock (g) communique également avec le second niveau d'abstraction via l'interface ([illegible]), pour obtenir ou mettre à jour les informations liées à un contexte statique de ce réseau.
En cas de surcharge, l'agent du réseau génère des notifications par le biais du bloc (i) et les envoie aux agents utilisateurs via l'interface (e2).
Les valeurs de réputation et de la QoS perçue sont enregistrées dans le bloc (i) qui transmet cette information à la demande aux agents utilisateurs.

Cette architecture suppose que tous les transferts et les traitements de réputation sont effectués dans le premier niveau d'abstraction qui est une sorte de niveau virtuel qui cache le traitement, la QoS et les informations de réputation aux réseaux et aux utilisateurs. Dans cette

vision, les réseaux ne seront pas en mesure d'affecter ou de falsifier leurs valeurs de réputation qui sont échangés entre leurs agents et les agents représentatifs des utilisateurs.
L'évaluation des performances montre que le délai de décision expériment n'est pas très important et est inférieur au délai obtenu par les simulations réalisées à l'aide de NS2 dans le chapitre III.

Le travail présenté dans cette thèse présente une première étape pour l'adoption d'une nouvelle métrique de prise de décision qualitative, à savoir, la réputation des réseaux.
Plusieurs questions doivent encore être abordés concernant l'efficacité et la robustesse de la réputation. Par exemple, il y a encore besoin de préciser une approche de normalisation qui assure suffisamment de précision pour permettre une comparaison entre différents systèmes de réputation.
Parmi les autres questions importantes: Comment distinguer entre l'abandon de paquets délibérés et la perte de connectivité à cause d'une congestion ? Quel est l'impact des menteurs potentiels sur la réputation ? Et si les valeurs de réputation sont falsifiées par un réseau pour attirer les utilisateurs ? Quel est l'impact d'une telle observation sur le système de réputation ? Dans le chapitre V les solutions proposées abordent ce problème du côté des réseaux. Cette question devrait également être abordée du côté des utilisateurs.
D'autre part, une évaluation plus poussée du mécanisme de prise de décision basé sur l'équilibre de Nash-Stackelberg est nécessaire. Bien que les simulations ont été utiles dans l'analyse des performances, une meilleure évaluation peut être obtenue par l'intégration de ce mécanisme de décision dans l'architecture overlay que nous avons considéré pour évaluer le premier algorithme de décision proposé.

□ist of □u□lications

□ournal

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