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A Multi Criteria Real Time Network Selection Framework in Heterogeneous Wireless Environment for 5G systems: Application for Mobile and Vehicular Heterogeneous Networks

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Research is creating new knowledge.

Neil Armstrong

Dedications

To my dear parents, whose words of encouragement and push for tenacity ring in my ears

...

To my dear sisters: Safae, Imane and Yousra

...

To my nieces: Tkito Hajar, Zineb and Sarah as well as Belhachemi Israe

...

To my late Grandmother: Bendahmane Zahra

...

To all my Family

...

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... ...

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Abstract

Network selection receives considerable attention from communication networks researchers. This remarkable interest is motivated by the variety of the existing technologies and the offered services. The widespread use of these services leads to growth in the expectations and requirements of mobile users in terms of efficiency. This thesis focuses on proposing and evaluating new network selection models for heterogeneous wireless networks, and providing a real-time selection of always best connected network while maintaining the QoS for different multimedia services. The main contribution consists of the proposal of a model of multi-criteria network selection. This model is open in the sense that it can accommodate the implementation of different parameters in the decision of the network that may be selected, considering the type of application used by the mobile user. This thesis is developed from two aspects: Network selection algorithms proposition and performance study.

In the first part, three complementary solutions were proposed to enable a fair and thoughtful allocation of resources and serve a maximum number of users. First, we study the problem of network selection using the decision-making strategy MADM (Multi-Criteria Decision Making). It consists of choosing the best network according to several criteria using a batch of weights generated with the AHP method. We propose, therefore, a weight improvement based on fuzzy logic, FAHP. In order to take into account the speed of mobile users, we propose a context-aware network selection based on a new utility function that takes into account the user's preferences and the quality of service requirements in a high mobility scenario. We also improve the latter solution by proposing a network selection algorithm that provides a load balancing technique based on matching game theory to overcome network overload conditions in high-speed scenarios. In the second part, the performance study has been evaluated for two scenario types: Cellular and Vehicular. The proposed algorithms were evaluated and validated in both mobile and vehicular environments using the NS3 simulator.

Keywords: Heterogeneous Networks; Vertical Handover; Network Selection; Multi-Criteria Decision; Matching Theory; Cellular Networks; Vehicular Networks.

Résumé

La sélection du réseau reçoit une attention considérable des chercheurs en réseaux de communication. Cet intérêt remarquable est motivé par la variété des technologies existantes et des services offerts. L'utilisation généralisée de ces services entraîne une croissance des attentes et des exigences des utilisateurs mobiles en termes d'efficacité. Cette thèse se concentre sur la proposition et l'évaluation de nouveaux modèles de sélection de réseau pour des réseaux sans fil hétérogènes. Elle fournit une sélection en temps réel du réseau toujours mieux connecté tout en maintenant la qualité de service pour différents services multimédias. La principale contribution consiste à proposer un modèle de sélection multicritères de réseaux. Ce modèle est ouvert dans le sens où il peut accueillir la mise en œuvre de différents paramètres dans la décision du réseau sélectionné, en considérant le type d'application utilisée par l'utilisateur mobile. Cette thèse est développée à partir de deux aspects: proposition d'algorithmes de sélection de réseau et étude de performance.

Dans la première partie, trois solutions complémentaires ont été proposées pour permettre une répartition équitable et réfléchie des ressources et servir un nombre maximal d'utilisateurs. En premier lieu, nous étudions le problème de la sélection du réseau en utilisant la stratégie de prise de décision MADM (L'aide à la décision multicritère). Il s'agit de choisir le meilleur réseau selon plusieurs critères à l'aide d'un lot de poids générés avec la méthode AHP. Nous proposons, ainsi, une amélioration de poids basée sur la logique floue FAHP. Afin de tenir compte de la vitesse des utilisateurs mobiles, nous proposons une sélection de réseau d'accès contextuelle basée sur une nouvelle fonction d'utilité qui prend en compte les préférences de l'utilisateur et les conditions requises en termes de qualité de service dans un scénario à mobilité élevée. En outre, nous améliorons cette dernière solution en proposant un algorithme de sélection de réseau qui fournit une technique d'équilibrage de charge basée sur la théorie des jeux de correspondance pour remédier aux conditions de surcharge du réseau dans les scénarios à grande vitesse. Dans la deuxième partie, l'étude de performance a été évaluée pour deux types de scénarios: cellulaire et véhiculaire. Les algorithmes proposés ont été évalués et validés dans des environnements mobiles et véhiculaires en utilisant le simulateur NS3.

Mots-clés: Réseaux Hétérogènes; Handover Vertical; Séléction de Réseau; Décision Multi-Critères; Théorie de Correspendance; Réseaux Cellulaires; Réseaux Véhiculaires.

Résumé détaillé

La sélection du réseau reçoit une attention considérable des chercheurs en réseaux de communication. Cet intérêt remarquable est motivé par la variété des technologies existantes et des services offerts. L'utilisation généralisée de ces services entraîne une croissance des attentes et des exigences des utilisateurs mobiles en termes d'efficacité.

Cette thèse se concentre sur la proposition et l'évaluation de nouveaux modèles de sélection de réseau pour des réseaux sans fil hétérogènes et en fournissant une sélection en temps réel du réseau toujours mieux connecté tout en maintenant la qualité de service pour différents services multimédias. Cette thèse est développée à partir de deux aspects: proposition d'algorithmes de sélection de réseau et étude de performance. Dans la première partie, trois solutions complémentaires ont été proposées pour permettre une répartition équitable et réfléchie des ressources et servir un nombre maximal d'utilisateurs. La principale contribution consiste à proposer un modèle de sélection multicritères de réseaux. Ce modèle est ouvert dans le sens où il peut accueillir la mise en œuvre de différents paramètres dans la décision du réseau qui peut être sélectionnée, en considérant le type d'application utilisée par l'utilisateur mobile. Dans la deuxième partie, l'étude de performance a été évaluée pour deux types de scénarios: cellulaire et véhiculaire. Les algorithmes proposés ont été évalués dans des environnements mobiles et véhiculaires. Ce mémoire est constitué de six chapitres, en plus de l'introduction et la conclusion qui peuvent être résumés comme suit :

Le premier chapitre donne des informations de base sur des réseaux hétérogènes ainsi qu'un aperçu des schémas de sélection de réseau. Nous présentons l'évolution des réseaux sans fils mobiles en termes d'exigences derrière chaque génération et discutons des solutions pour faire face à la croissance exponentielle d'utilisation. Enfin, nous détaillons le problème de Handover. Le Simulateur NS3 est présenté en annexe, étant l'outil que nous avons utilisé dans toutes nos campagnes de simulations.

Dans le chapitre suivant, nous donnons un etat d'art sur la littérature et discutons les differentes stratégies de sélection de réseau existantes. Nous résumons les schémas classiques basés sur MADM, Logique floue, Fonction d'Utilité et théorie de correspondance. Ils sont introduits comme les algorithmes de référence du travail principal de la thèse. en plus de quelques travaux récents concernant les scénarios véhiculaires dans les systèmes 5G.

Les chapitres suivants sont subdivisés en deux parties. Dans la première partie, nous présentons le modèle système des contributions. Dans la deuxième partie, les algorithmes proposés sont évalués dans des environnements mobiles et véhicules en temps réel.

Dans le troisième chapitre, nous étudions le problème de la sélection du réseau en utilisant une stratégie de prise de décision appelée MADM (L'aide à la décision multicritère), l'une des meilleures stratégies de sélection de réseau utilisées pour le handover vertical dans des réseaux sans fil hétérogènes. Les méthodes MADM consistent à choisir le meilleur réseau à partir de ceux disponibles selon plusieurs critères. Dans ce premier ensemble de contributions, nous proposons un système de sélection multicritères de réseau dans lequel nous comparons les algorithmes de décision: VIKOR, SAW, MEW et TOPSIS à l'aide d'un lot de poids générés avec la méthode AHP. Sur cette base, nous proposons une amélioration de poids basée sur la logique floue qui, en termes de qualité de service, améliorera la sélection du réseau dans un environnement hétérogène.

Dans l'algorithme précédent, le handover vertical est traité sans tenir compte de la vitesse des utilisateurs mobiles ni des conditions de surcharge du réseau, ce qui pourrait se produire dans le cas rare d'un grand nombre de terminaux et d'applications utilisant le cadre proposé et en compétition sur le même réseau. Ces limites sont confrontées par le deuxième et troisième algorithmes proposés, presentées dans le quatrième chapitre, où une nouvelle sélection de réseau basée sur l'utilité est proposée et ensuite améliorée à l'aide de la théorie des jeux de correspondance dans le but d'équilibrer la charge sur la topologie disponible. Nous étudions donc le problème de la sélection du réseau à partir de la satisfaction qu'un réseau fournit aux utilisateurs mobiles. Différents réseaux disponibles avec différentes préférences d'utilisateur auront différentes valeurs d'utilité. Nous proposons une sélection de réseau d'accès contextuelle basée sur une nouvelle fonction d'utilité qui prend en compte les préférences de l'utilisateur et les conditions requises en termes de qualité de service. Elle vise à maximiser la satisfaction de l'utilisateur tout en rencontrant les exigences de qualité de service des applications lors de la connexion au réseau cible dans un scénario à mobilité élevée. En outre, nous améliorons cette dernière solution en proposant un algorithme de sélection de réseau qui fournit une technique d'équilibrage de charge basée sur la théorie de correspondance. Ce schéma se concentre sur la possibilité d'invocation simultanée d'applications avec différentes caractéristiques de trafic et de qualité de service. Nous formulons, par conséquent, notre problème en tant que jeu de correspondance, visant à répondre aux besoins des utilisateurs cellulaires en termes de qualité de service requise, ces derniers distribués de manière aléatoire dans la couverture des réseaux hétérogènes. Nous proposons un algorithme qui calcule la correspondance stable optimale impliquant l'affectation de tous les utilisateurs au réseau le plus approprié en considérant le type de service dont chaque utilisateur a besoin dans les scénarios à grande vitesse.

Dans le cinquième chapitre, les évaluations de performance, les solutions proposées sont évaluées. Dans un environnement hétérogène, composé de réseaux LTE-WiFi, nous présentons les détails des simulations et discutons les résultats. Les algorithmes proposés ont été évalués et validés dans des environnements mobiles et véhiculaires en utilisant le simulateur NS3. Les trois algorithmes sont évalués dans le but de prouver leur applicabilité dans un environnement mobile en considérant les applications cellulaires, à savoir, Conversationnelle, Streaming, Interactive et Background.

En outre, dans les scénarios à grande vitesse, tels que véhiculaire, la sélection du réseau dédiée aux systèmes 5G est plus critique. Ainsi, dans le dernier chapitre, nous avons appliqué, par conséquent, l'algorithme proposé précédemment qui calcule l'appariement stable optimal pour impliquer l'affectation de tous les véhicules dans une topologie à grande échelle au réseau le plus approprié en considérant le type de service requis par chaque véhicule, notamment: Conduite avancée, conduite à distance, Platooning et capteur étendu. cet algorithme a été appliqué au réseau de véhicules hétérogène basé sur LTE dédié aux systèmes 5G dans les scénarios véhiculaires. Les résultats montrent que l'algorithme proposé est plus précis par rapport aux algorithmes de référence pour les applications cellulaires et véhiculaires.

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Introduction

1 Context

Wireless networks have gained tremendous popularity in the communication industry and have become one of the most significant technological breakthroughs in the past few decades. In the past, it was difficult to assume the telecommunication service can be provided to people regardless of their geographical location and while they are moving around. But, it is very difficult now for many people to imagine life without continuous availability of wireless communication. Telecommunication technology has indeed completed its biggest improvement in just a few years and in the example of wireless communication, its growth has far exceeded the most optimistic expectations.

In recent years, various types of wireless access technologies have been deployed including 802.11 Wireless Fidelity (Wi-Fi), 802.16 Worldwide Interoperability for Microwave Access (WiMAX) Wang et al. (2008), long-Term Evolution (LTE) Heath Jr et al. (2016) and Light Fidelity (Li-Fi)Bao et al. (2015). The most promising Next Generation Networks (NGN) are the heterogeneous networks. They are based on the coexistence and interoperability of the different types of Radio Access Technologies (RAT), and support existing and emerging networks. Indeed, Mobile terminals are equipped with multiple interfaces can handover seamlessly between heterogeneous networks to guarantee the continuity of an ongoing application session such as Voice over IP (VoIP) and on-line gaming, adopting by that the concept of Always Best Connected (ABC) Concept. Authors (Gustafsson and Jonsson, 2003) assert that a terminal supports the ABC features means that it is not only always connected, but also connected through the best available network and access technology at all times. The ABC concept achieves a win-win partnership because it considers user's and operator's benefits since it includes basically all types of access technologies. Meanwhile, the heterogeneous wireless networks require an intelligent network selection algorithm to establish seamless communication in order to provide high Quality of Service (QoS) for different multimedia applications. The major issue for the heterogeneous networks is Network Selection, i.e., a smooth and efficient handover scheme that allows the roaming of mobile devices from one wireless system to another.

To provide pervasive wireless access for users, it is important to choose the best network among the available ones. Being the key for resource management in a wireless heterogeneous network, dynamic network selection process intend to provide users with the required QoS in terms of metrics and user's preferences since both are acknowledged during the process of network selection. Hence, this technology is a hot research topic in the field of wireless communication. Indeed, Heterogeneous networks involve development of diverse paradigms of the concerned technologies, such as context-awareness of mobile devices and QoS awareness. Communication in such environment has to cope with many provider's constraints (e.g., strong fluctuations of Real-time traffic and dynamic network topology) and also it has to meet user's application requirements. In addition to ABC functionalities, heterogeneous systems bring many promising paradigms aiming to deliver significantly higher capacity to meet the huge growth of mobile data traffic.

Whereas the previous generations of cellular systems have been primarily designed towards increased spectral efficiencies to enable bandwidth greedy applications for users, the development of a 5G radio access attended to the conclusion that the latest and next generation of cellular communication systems will be driven by newly arisen use cases Alliance (2015). The 5G radio access will have to acknowledge a number of requirements advanced by a large collection of different new services, such as those from the context of massive Machine-Type Communication (mMTC) and ultra-reliable MTC (urMTC). As the name suggests, mMTC is about massive access by a large number of devices, i.e., about providing wireless connectivity to tens of billions of often low-complexity low-power machine-type devices. On the other hand, urMTC is about providing adequate wireless links for network services with rather stringent requirements on availability, latency and reliability. For the concept of urMTC, an important technology is Vehicle-to-Everything (V2X) communications Bockelmann et al. (2016). V2X communication has the ability to efficiently improve the application like road safety and traffic efficiency services, as well as highly autonomous driving. As a consequence, a "One-Network" solution for the air interface as prevailing in today's radio systems would no longer be the suitable solution in the future, as it can barely provide an inadequate compromise. Instead, the system should provide more flexibility and scalability to enable tailoring the system configurations to the service types and their demands Dohler and Nakamura (2016). Moreover, as the data rates to be provided by mobile radio systems are always increasing, technologies need to take advantage of the last bit from the limited spectrum resources.

2 Motivation for this thesis

Next generation wireless networks entangle a disparate number of technologies. For the next three years, CiscoCisco Visual Networking (2015) expected that the mobile data traffic increases of nearly eightfold and reaches 30.6 exabytes (1018) by 2020. This exponential increase in throughput demand must be accompanied with an increase, at the same speed, in network capacity. Due to resources limitations, coverage issues and mobile user's swollen demands, a single communication is definitely not qualified to deliver continuous mobile services and cannot afford the recommended QoS while bestowing all connected user's demanding applications.

Furthermore, The widespread use of mobile and high definition video devices is changing internet traffic, with a significant increase in multimedia content, especially Video on Demand (VoD). A crucial challenge is that heterogeneous networks require strict QoS including better latency, reliability, higher spectral and energy efficiency, but also need an improved Quality of Experience (QoE) for users of wireless services in 4G and beyond networks. Nevertheless, the coexistence of other networks with different access technologies overlapping each other's, and the mobility of the users in the coverage areas of the available networks is the opportune solution in such heterogeneous environment.

In V2X use cases, traditional wireless communication technologies such as 2G/3G/LTE cannot satisfy the demand of aforementioned high reliability and low latency, together, in the V2X communication scenarios. Thus, there is a need of new communication technologies to support the V2X communication. Vehicular ad hoc networks (VANETs) is deemed to be a feasible solutions for the V2X communication Ye et al. (2016). Indeed, VANETs is one of the effective technologies to enhance traffic safety, in-which vehicles are connected in a form of network so that every vehicle can be aware of others' state information, such as velocity and direction. Although VANETs seems to be among the future V2X communication technologies, fast moving speed of vehicles is a challenging condition, difficult to be handled by VANETs, and already managed by LTE. In addition, and to the best of our knowledge, the majority of researches are working on the development of this technologies under "one-network" and ignore the situation of heterogeneous environment which is well-handled by LTE network through the handover procedure.

However, the heterogeneity of access technologies involves four major problems to which we will be interested in this thesis:

- How to transfer a communication from a network (source network) to a another network (target network) without discontinuity and with better quality of service?
- When the mobile user must change its source network to attach to another target network?
- How is the decision made to choose the best available network in terms of quality of service?
- What is the unit responsible for decision-making (network, user, etc.)?

The potent network selection algorithm is foreseen to grant the users with the recommended QoS per applications in terms of networks link state and user's pre-requisites. Hence, both QoS requirements and user's preferences are approved during the network selection process. To meet these requirements, mobile terminals have to select the suitable access network that fit for their QoS requirements of applications; escape a network with high traffic load for avoiding congestion and also minimize costs by handling an intelligent network selection allowing mobile devices to make appropriate and timely decisions on behalf of users. Therein, real time access point selection is the key for a flawless resource management strategy to an efficient exploit of coexistence in heterogeneous networks.

Several technical challenges arise, such as, Seamless Handover; where the transfer of a mobile user happens without service discontinuity; the assurance of good QoS, mobility management, network resource management, and ensuring a balance to satisfy both the needs of the users and operators. There are also other factors to consider (security, authentication, etc.) that play an important role during the handover process. All these hypotheses open the door wide open to the research and the design of decision-making solutions based on several parameters that manage a transparent transfer of the mobile node between the networks (imperceptibly by the user). The handover procedure within 3GPP LTE defined in LTE (2011), has three main phases: Handover initiation, handover preparation (Network Selection) and handover execution. The first two phases are highly important that in the literature claims that the first two phases provide 90% of the handover delay Khan et al. (2017); Lee and Cho (2011).

Wherefore, this feature is a trendy research matter in the area of wireless communication.

3 Author's contribution

This thesis focus on proposing and evaluating network selection models for heterogeneous wireless networks, and providing a real-time selection of always best connected network while maintaining QoS for different multimedia services. The objective of this thesis is mainly to implement three complementary solutions enabling networks a fair and thoughtful allocation of resources to serve the most possible users. The main contribution consists of the proposal of a model of multi-criteria selection of networks. This model is open in the sense that it can accommodate the implementation of different parameters in the decision of the network that may be selected, regarding the type of application used by the mobile user. Two approaches are proposed and studied in both mobile and vehicular environments, based on nine original publications, including four journal papers, two book chapters and three conference papers.

3.1 A Multi-Criteria Approach for Network Selection in Heterogeneous Environment using MADM:

The first approach is a novel strategy called Multiple Attribute Decision Making (MADM), one of the best network selection methods used for Vertical Handover Decision (VHD) in heterogeneous wireless networks. MADM consist in choosing the best network from available ones.

3.1.1 Evaluation of Multi-Criteria Vertical Handover for Heterogeneous Wireless Networks

Drissi and Oumsis (2015b) In this paper we studied the use of MADM used to choose the best network from available networks. We compared handover decision algorithms: Simple Additive Weighting (SAW), Multiplicative Exponential Weighting (MEW) and Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) in terms of end-to-end delay and packet loss using two available networks Wi-Fi and WiMAX. All algorithms allow different attributes (e.g., bandwidth, delay, Jitter and Bite Error rate) to be included in the decision.

3.1.2 Multi-Criteria Vertical Handover Comparison Between WiMAX and WiFi

Drissi and Oumsis (2015a) We studied, in this paper, the benefit of MADM methods for network selection. We compared three of these methods naming SAW, MEW and TOPSIS in a real-time. In which

Analytic Hierarchy Process (AHP) method provides the weights of attributes which allow the comparison in different types of applications. We proposed a set of weights contributing to improved delay and packet loss in different types of applications.

3.1.3 VIKOR for multi-criteria network selection in heterogeneous wireless networks

Drissi et al. (2016a) We proposed an automatic and real-time selection of the next handed network in heterogeneous environment consisting of Wi-Fi and WiMAX networks, while maintaining the best QoS. We propose, thereby, a network selection scheme based on VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method. VIKOR belongs to MADM family, which consider multiple attributes for the decision of the best available alternatives. We compared and approved the proposed scheme with other MADM methods as baseline schemes, namely, SAW, MEW and TOPSIS from the previous work.

3.1.4 A Fuzzy AHP Approach to Network Selection Improvement in Heterogeneous Wireless Networks

Drissi et al. (2016b) In this paper, we proposed an algorithm for network selection based on Fuzzy Analytic Hierarchy Process (FAHP), applied to determine the relative weights of the evaluation criteria. The contribution consists of a fuzzy optimization model to solve Multi-Criteria Vertical Handover based on a FAHP. To deal with the imprecise judgements of decision makers involved by classical AHP, a FAHPdecision-making model aim is to determine the weights of certain QoS indicators that act as the criteria impacting the decision process.

3.1.5 A Multi-Criteria Decision Framework for Network Selection over LTE and WLAN

Drissi et al. (2017d) The aim of this paper is to select the appropriate network for a certain type of traffic considering a number of QoS metrics. Network selection problem is solved using a combination of MADM methods. Due to the interaction between the criteria, AHP is applied to determine the weight of the criterion (QoSmetrics) for each alternative (type of traffic). Since FAHP decision model confirmed its efficiency to ascertain the weights of QoS metrics that impact the decision process without prejudice, we led the FAHP scheme further in proving its performance with the other well reputed methods, MEW, TOPSIS and VIKOR in order to sort the accessible networks. The empirical results showed that FAHP schemes, compared with classical AHP ones, achieve a momentous refinement in terms of delay and Packet Loss Rate. Furthermore, in pursuance of minimizing delay and packet loss, the most suitable schemes are suggested for each type of traffic.

3.2 Matching Game for Access Point Selection in Heterogeneous Wireless Networks:

The second approach is the utility function. For network selection decision, utility function assigned to the satisfaction that a network provides to mobile users. Different available networks with different user preferences will have different utility values.

3.2.1 A Context-Aware Access Network Selection Based on Utility-Function for Handover in WLAN-LTE Environment

Drissi et al. (2017a) In this paper we proposed a context-aware access network selection based on utility function that takes into consideration user's and QoS preferences. It aims at maximizing the user satisfaction while meeting application QoS when connecting to a target network. The proposed approach prioritizes networks with higher relevance to different types of applications and enables seamless connectivity to mobile user and applications. Thus, network resources are conveniently managed to support diverse services that might be considered by mobile users. Results are provided to evaluate the performance of the proposed approach in low, medium and high mobility scenarios consisting in WLAN-LTE networks compared with the existing baseline scheme.

3.2.2 User-Driven Handover Scheme in Long-Term Evolution (LTE) Macro/Femto Cells for High Speed Scenarios

Drissi et al. (2016c) Ubiquitous communication depends upon an expanded capacity and suitable QoS. To meet these requirements, LTE mobile network providers deploy small cells in shadow zones and next to base station to increase the network capacity and coverage for Mobile users. An optimal cell selection scheme in such scenario allows User Equipment (UE) to reconnect to the most convenient cell while maintaining its QoS requirements. To this end, this paper presents an UE triggered handover where cell selection is performed by mobile terminal instead of classical cell selection where the process is launched and controlled by Evolved Node B (eNB). A comprehensive analysis of the proposed scheme is presented, compared with classical handover triggered by (eNB) at varying speeds to demonstrate its robustness.

This approach is enhanced using the matching game theory, a winning the 2012 Nobel Prize, which provides a mathematically tractable method for personnel assignment problem in two distinct sets. In wireless networks, the matching is applied for mobile users and access points.

3.2.3 A Load Balanced Network Selection Algorithm in Heterogeneous Networks using Matching Game

Drissi et al. (2017c) Through this paper, we proposed a solution that provides a context-aware access point selection and association of UE, which considers the type of application used, to available networks in the LTE and Wi-Fi environment. This scheme focuses on enabling simultaneous invocation of applications with different traffic and QoS characteristics by the UEs. This solution considers also various link parameters that provide the best solution in terms of QoS which makes it a QoS-aware solution as well. The real time context-aware and QoS-aware access point selection method is based on matching theory. We formulated, thereby, our problem as a matching game, aiming to meet the required QoS of cellular users, randomly distributed in LTE and Wi-Fi networks, then we proposed an algorithm that computes the optimal stable matching entailing the assignment of all users to the most suitable network regarding the type of the service each user need.

3.3 Application for Mobile and Vehicular Heterogeneous Networks:

In high-speed scenarios, such as vehicular, the selection of the network dedicated to 5G systems is more critical. Thus, in the last contribution, we have applied the matching algorithm proposed above, in a large scale topology considering vehicular applications.

3.3.1 Enabling Use Case Aware Handover in LTE-Based Heterogeneous Vehicular Network for 5G V2X Scenarios

Drissi et al. (2017b) V2X technology is one of the key technologies in Fifth Generation (5G) network. In V2X scenarios, being one of the 5G network slices, when safety-related applications are concerned, it should be ascertained that other use cases (non-safety) does not negatively affect the QoS of such critical V2X applications. As vehicles can be driven without human intervention, and safety is been taken care of, human inside the vehicle will engage in other activities such as media consumption (e.g. browsing, or VoD). However, enabling seamless handover and always-best-connected services in such environment is a difficult and challenging task. To address this issue, this paper proposes a use case aware network selection algorithm based on utility function that considers V2X applications requirements, for LTE-Based heterogeneous vehicular networks. A novel framework which uses the eNodeBs of the LTE network as an access point for V2X Scenarios. It aims at maximizing the satisfaction of the required service when connecting to a target network. We used, thereby, the previously proposed algorithm that computes the optimal stable matching entailing the assignment of all vehicles to the most suitable network regarding the type of the service each vehicle requires. The proposed approach prioritizes networks with higher relevance to different use cases and enables seamless connectivity to vehicles. Simulations results are provided to evaluate the performance of the proposed approach in high mobility V2X scenarios compared with the existing baseline scheme.

4 Outline of the thesis

This thesis consists of six chapters, in addition to the introduction and conclusion.

Chapter 1 gives background information of heterogeneous networks along with an overview of network selection schemes. We present the evolution of mobile wireless networks in terms of requirements and technologies behind each generation, and discuss solutions to face with this exponential growth and we detail the handover issue. Also the Network Simulator 3 (NS3) is presented as an annex, being the tool we used in all our simulations campaigns.

Chapter 2 gives a literature survey and discusses several existing network selection strategies. We summarize the classical MADM-based, Fuzzy-Logic-based, Utility-Function-based and Matching-Theory-based schemes in addition to some recent works dealing with the V2X scenarios in the 5G systems. They are introduced as the reference algorithms of the thesis's main work.

The next chapters are subdivided in two parts. In the first part, we present the system model of the contributions. In the second part, the proposed algorithms are evaluated in real time Mobile and Vehicular environments.

In Chapter 3, we detail the contributions made using MADM approach. First, we present an architecture of our selection algorithm, which has been implemented in two variants of weighting distribution algorithms AHP and FAHP and we present the mathematical modelling of different network selection strategies considered in this approach. We explain the functioning of each variant and present some limitation of the contribution.

In Chapter 4, the process of selecting the always best connected network in real-time is detailed, while maintaining the required QoS for multimedia services such as: Conversational, Streaming, Interactive and Background traffic. Using utility-function based approach, we captured the satisfaction level of mobile user with this scheme in the purpose of enhancing vertical handover decision. In addition, we present its improvement using the fuzzy weights proposed in the previous chapter. This algorithm is enhanced using Matching Theory Game. We detail the proposed system model being a context-aware and QoS-aware access point selection method in real time based on matching theory, aiming to meet the required QoS of cellular users in an heterogeneous wireless networks and show how it is effective for avoiding the severe congestion of one network, ensuring load balancing, improving access point selection and user admission to another available network.

In chapter 5, performance evaluations the proposed solutions are assessed. In an heterogeneous environment, consisting of LTE-Wi-Fi networks, we present the details of the simulations and discuss the outcomes.

In chapter 6, the matching algorithm is applied to LTE-Based heterogeneous vehicular network dedicated to 5G systems in V2X Scenarios.

In the conclusion, we summarize the main results of this thesis and look into the perspectives of future researches.

Chapter

1

Network Selection for Multi-homed Users in Heterogeneous Networks: An overview

Contents

1.1 Introduction

Wireless networks have revolutionized the world of telephony since they have allowed users to communicate even when they are mobile. Today, mobile networks are victims of their own success. In recent years, the revolution in mobile terminals, notably with the appearance of smart phones, has led operators to offer several services that are more bandwidth intensive and have more stringent real-time constraints. In addition, the diversity of services offered has led to an explosion in the number of subscribers. The mobile network must provide sufficient capacity to serve all network clients and ensure faster processing services used. Faced with these constraints, operators must ensure the development of mobile networks while guaranteeing a certain QoS adapted to the services offered. In fact, they have to find the right compromise between, on the one hand, this QoS, and on the other hand the limited capacity and the cost of deploying such a network (energy cost, development cost, maintenance cost, etc.). In this chapter, we lay out the background of heterogeneous wireless networks and detail the wireless network evolution by outlining requirements and techniques used in each wireless network. Then, we outline the main problem of Network Selection. Finally, we introduce some solutions made to manage this latter.

1.2 Background: Heterogeneous Wireless Networks

Before wireless networks come to the stage they reached today, they went through several states of specification and standardization processes. In this section, we examine the evolution of mobile networks.

Wireless technologies can be categorized into four classes, characterized by the size of their coverage area and the throughput offered by the network. The first class concerns Wireless Personal Area Networks (WPAN) characterized by a low range (order of a few tens of meters), and a low throughput.. The second class concerns Wireless Local Area Networks (WLAN) characterized by a range of about one hundred meters. The WLAN class contains several competing technologies such as IEEE 802.11. Wireless Metropolitan Area Networks (WMAN) represents the third class. These networks were originally intended to interconnect geographical areas with difficult access. They have a range of some tens of kilometers like the WiMAX network. Finally, the fourth class concerns Wireless Wide Area Networks (WWAN). This category is also known as mobile Cellular Networks. These are the most widely used wireless networks in the field of telecommunications.

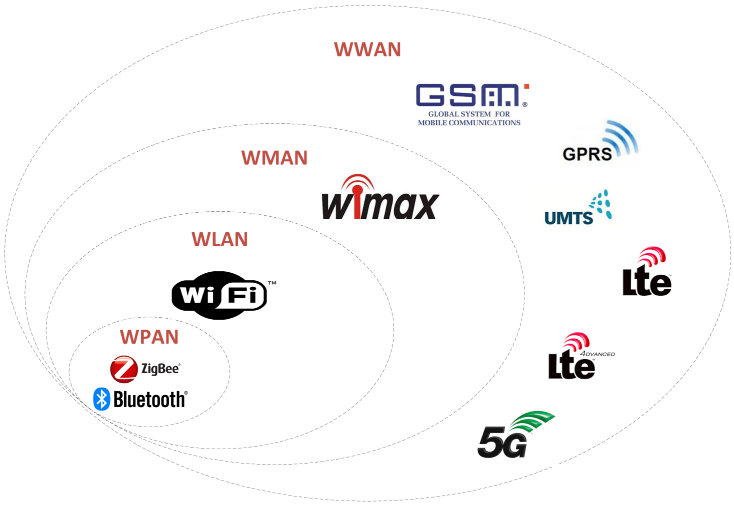


Figure 1.1: Evolution of Mobile Technologies.

1.2.1 Scope of Wireless Networks

Wireless Personal Area Networks (WPAN)

The range of a WPAN network does not exceed a few tens of meters. This type of network is typically used to connect peripherals such as a printer, a cell phone, a Personal Digital Assistant (PDA), connect a remote control to a television set, and so on. The main technology used with this category of wireless networks is the IEEE 802.15.1 (Bluetooth) standard launched by Ericsson in 1994 with a bit rate of 1 Mbps and with a coverage of no more than 30 meters. It is known for its high energy consumption. The IEEE 802.15.4 standard (ZigBee) with low power consumption and infrared links represent other examples of wireless networks that can transmit data over a few tens of meters.

Wireless Local Area Networks (WLAN)

The range of a WLAN network is a few hundred meters (300 meters) and is often used in companies to connect computers and printers. A well-known example of this type of network is the well-known Wi-Fi with a throughput of up to 54 Mbps and a range of several hundred meters. Another example of WLAN is HiperLAN2 which is a European standard offering a bit rate equivalent to Wi-Fi(with 54 Mbps and a range of 300 meters).

IEEE 802.11 Standard: Wi-Fi It is one of the standards that enables a wireless network to be deployed by communicating a plurality of devices (computer, PDA, cell, etc.) together, across the radio wave and to a high-speed link over a nearly equal coverage radius A few tens of meters. Wi-Fi is used in airports, cafes, etc. The IEEE 802.11 standard offered a throughput of between 1 and 2 Mbps. For reasons of performance improvement (range, throughput, etc.), this standard has undergone several evolutions through the appearance of different versions.

IEEE 802.11p Standard: VANETs VANETs is an emerging new technology integrating ad-hoc network and WLAN to achieve intelligent inter-vehicle communications and improve road traffic safety and efficiency. VANETs are distinguished from other kinds of ad-hoc networks by their node movement characteristics, and new application scenarios. Therefore, VANETs pose many unique networking research challenges, and the design of an efficient routing protocol for VANETs is very crucial.

Wireless Metropolitan Area Networks (WMAN)

This type of network aims to provide a wider coverage than its predecessors while offering a throughput of 1 to 10 Mbps and a range of 4 to 10 km. With this type of network, the radio wave allows several companies to be Interconnected or connecting different buildings in the same neighborhood, etc. An example of this network is IEEE 802.16, WiMAX)

IEEE 802.16 Standard: WiMAX It is a technology mainly used for WMANthat aim to provide a broadband internet connection over a coverage area several kilometers radius. The theoretical rate of WiMAX is of the order of 70 Mbps with a range of 50 kilometers. WiMAX technology proposes to introduce mobility features into its network: a WiMAX terminal can move while maintaining reliable access to the network. This feature is introduced by the IEEE 802.16e standard which can be classified in WMAN. WiMAX works in point-to-point mode, that is to say the infrastructure mode known for WiWi-Fi, or the same functioning as the 2G, 3G technologies of mobile telephony. Thus, as in 2G, a base station called Base Transceiver Station (BTS) or Base Station (BS) transmits to the clients and receives their requests and then transmits them to the provider's network. Several variants of standard have been proposed, modified and ratified as summarized in Barja et al. (2012).

Wireless Wide Area Networks (WWAN)

This type of network is used by Telecommunication. Several well-known systems today use this type of network: the Global System For Mobile Communication (GSM) Tantani (2010), the General Packet Radio Service (GPRS) ETSI (1998), the Universal Mobile Telecommunication System (UMTS) Evolved Universal Terrestrial Radio (2008), LTEEvolved Universal Terrestrial Radio (2010a) and LTE Advanced (LTE-A) Evolved Universal Terrestrial Radio (2010b).

First Generation (1G) Mobile Networks The so-called First Generation (1G) is the network of the 1980*s*. The first cellular network to use the same frequency channels for remote cells. Various standards existed throughout the world: Advanced Mobile Phone Service (AMPS), Total Access Coverage System (TACS), RADIOCOM2000 (France), etc. This generation of network enabled the mobility of users and the use Of the first SIM cards. Technically, this type of network is totally based on the analog signal and that is what characterizes it. The transmission rate is 10 Kbit/s and the communications are frequency modulated Frequency Division Multiple Access (FDMA). A channel is reserved exclusively for each call during the entire call. It is circuit-switched Akoka and Collectif (2006).

Second Generation (2G) Mobile Networks

GSM Network The Second Generation (2G) of mobile phone systems is characterized by the use of the digital signal, which allowed the transmission of small data and the appearance of text messages exchanged between clients. A multitude of standards have been considered throughout the world. Examples include iDEN (USA), PDC (Japan) and GSM (developed in Europe and used worldwide) Akoka and Collectif (2006). The GSM network, in particular, has enjoyed great success with more than one billion subscribers to its communication services in more than two hundred countries (82%) of mobile phones). It is a mobile phone system launched by the GSM in the 1990*s*. This network operates a wider range of Hertzian frequencies than previous networks. It is based on a Time Division Multiple Access (TDMA) resource sharing system; The resources of a base station are shared in time between the connected mobiles Tantani (2010) Akoka and Collectif (2006).

GPRS Network Originally, the GSM network is a system dedicated to voice. With the aim of increasing the transmission rate, the switching of the packets during the transmission of data was necessary. This led to a revision of the standards and the birth of the GPRS network. The latter is an advanced version of the GSM network and offers a throughput of up to 80 Kbps. It allows the sharing of time and frequency resources Frequency Division Time Division Multiple Access (FD-TDMA), a hybrid mode between TDMAand FDMA. Data is transmitted in packets using the TCP/ IP protocol mainly. Transmission Control Protocol (TCP) and Internet Protocol (IP) protocols are used to transfer data over the Internet and wired connections Fall and Stevens (2011). This protocol is used for the Internet, which allows customers to enjoy multimedia services. As for the voice, it is always transmitted by circuit switching. Most European countries adopted this standard in the summer of 2001 Akoka and Collectif (2006), Al Agha et al. (2001).

Enhanced Data Rates over GSM Evolution (EDGE) Network The continued need to increase transmission throughput and clients' greed in terms of throughput has led the standardization groups to push the boundaries of networks and evolve the GPRS network. This gave birth to the EDGE . This new network allows clients to reach a speed three times faster (240 Kbps) thanks to new modulation and coding schemes. The EDGE standard is called the 2.75 generation Akoka and Collectif (2006).

Third Generation (3G) Mobile Networks

UMTS Network Until this generation, communication systems have been very successful and allow communication between mobiles with a suitable QoS. However, in order to generalize the multimedia services and prepare the networks of the future, a new generation had to be defined. It is the Third Generation (3G) mobile networks. This generation allows to offer with more flexibility services more gourmand in bandwidth Akoka and Collectif (2006). It is based on the two types of switching circuits and packets; Circuits for voice and packets for other types of data (file transfers, web browsing ...). The 3rd Generation Partnership Project (3GPP) has defined the UMTS along with the appearance of 2.5 and 2.75 generations. The implementation of this technology UMTS took place gradually and lasted a few years since several equipment had to be replaced. UMTS allows a bit rate up to 2Mbits/s under certain conditions. Indeed, this network has turned to multimedia services and user mobility using Wideband Code Division Multiple Access (W-CDMA) broadband code share. This enabled mobile customers to gain broadband access to the Internet without video conferencing and videoconferencing, as well as the reception of television on the telephone Al Agha et al. (2001). The technologies chosen by the International Telecommunication Union (ITU), in the framework of 3G have been named IMT-2000 (International Mobile Telecommunication 2000). ITU manages radio frequency spectra globally, as well as satellite orbits in order to avoid interference between countries. It sets standards for communication systems to ensure the proper use of the spectrum. IMT-2000 is the result of a global collaboration between the various ITU standardization bodies.

High Speed Packet Access (HSPA) Network The evolution of UMTS technology, the so-called advanced third generation, was launched in 2000 with the introduction of HSPA standards. An even more advanced version then appeared, called HSPA+. These standards are called 3G + and 3G ++ networks.

This generation of networks is more oriented towards packet logic and offers more capacity with higher throughput (up to 21Mbits s). This favors the development of new applications, in particular in the field of multimedia (video telephony, broadcasting of video and audio content, MMS video or audio, etc.). Compared to previous generation networks, an advanced 3G network ensures that mobile clients can access web and e-mail data even when moving at a higher speed Al Agha et al. (2001).

Fourth Generation (4G) Mobile Networks With the evolution of the mobile terminal market (smart phones, tablets, notebooks, ...), telecommunication technologies have evolved towards an architecture known as all-IP. They are based only on packet switching. Indeed, let us recall that the previous generation 3G transmitted the text data (file, navigation, ...) by switching packets while the voice data was transmitted by circuit switching. In this generation of telecommunication Fourth Generation (4G), no distinction is made between voice and other data types. Packet switching is done through the TCP/IP protocol. This generation uses the coding and frequency multiplexing technique over time. This is a combination of the FDMA and TDMA modes used separately by previous generations. This mode of resource sharing is called Orthogonal Frequency Division Multiple Access (OFDMA). Efforts are continuously being made to respond to the changing needs of users in terms of mobile applications. LTE and WiMAX networks are among the emerging all-IP technologies recognized in this generation.

Cellular WiMAX The WiMAX network is a collection of IEEE 802.16 standards developed by the Institute of Electrical and Electronics Engineers (IEEE). WiMAX was designed in 2001 for point-to-point communications for high-speed wireless networks such as Wi-Fi. Since then, several versions have been developed to offer more bandwidth Ergen (2009). The IEEE 802.16e variant targets the mobile communication market. The cellular network of this technology provides wireless Internet access and offers mobile services with high bit rates (up to 70Mbits/s). The transmission and modulation techniques used in WiMAX networks facilitate deployment in urban areas and in large urban centers Etemad and Lai (2011)Ergen (2009).

LTE Network LTE technology is the result of the natural evolution of the mobile communication networks developed by the 3GPP standardization group. As it was presented at the beginning by 3GPP, the LTE standard was not recognized as a 4th generation of mobile networks since it did not satisfy the conditions imposed by the ITU. For this, 3GPP has introduced improvements to LTE technology to make it a new generation 4G network Etemad and Lai (2011). The LTE network is designed to last and is based primarily on GSM/EDGE and UMTS/HSPA technologies. The architecture of this network is distinguished by the separation of the control entity from the network entity that handles the user plane. This allows better management of the network equipment and facilitates the operations of intervention and maintenance of mobile operators on these equipment. This separation offers a lower latency time (estimated at an average of 5ms) compared to that of other networks (estimated at 300ms for UMTS)

Etemad and Lai (2011) Akoka and Collectif (2006).The spectral efficiency of LTE networks provides additional capacity to the cells. This is reflected in the number of mobiles served simultaneously by the same cell and the flow rate that is offered to them even when moving at a high speed. Indeed, the architecture of the LTE network remains functional up to a speed of 350kmh.

LTE Advanced Network The 3GPP group proposed the advanced version of LTE that allows auto-configuration and self-organization of base stations. That is, the parameters of the latter can be adapted to the various changes that can occur in the network (deployment of a neighboring cell, variation in spectral allocation, etc.). The advanced LTE network also allows the deployment of small cells by the mobile operator itself or by its customers. This type of cells comes to complement locally the regular coverage of the network and it o ers an additional capacity. Thus, the network is said to be heterogeneous Etemad and Lai (2011)Akoka and Collectif (2006).

Fifth Generation (5G) Mobile Networks The ITU has developed a global road map for the development of 5G mobile systems, which it named IMT-2020 on June 19, 2015. ITU attention is now focused on the possibility of creating a continuously connected society by 2020 and beyond. A society in which people as well as objects, data, applications, transportation systems and cities would be grouped together in an environment under the sign of intelligent networked communications. The ITU will continue to work in partnership with the global mobile systems industry and with government agencies to ensure the practical implementation of IMT-2020. The goals of this generation include improvements in customer experience, privacy and data security. This will provide a wide range of emerging services. Improvements in the network architecture also aim at its ease of use and its energy and operational efficiency. In this thesis, the challenges of handover management were studied with different mobile network standards and wireless such as Wi-Fi, WiMAX and LTE. In the next section, we introduce the handover process.

Wireless Networks: Synthesis and Comparison

The variety of existing wireless communications standards raises the problem of the choice of the technology to be adopted to meet the needs of mobile users. To facilitate this choice, a comparative analysis between different mobile technologies remains necessary in order to choose the best technology. Table 1.1 presents the key elements of this comparative analysis. In this comparison, we focus on a set of relevant parameters such as throughput, coverage, cost of service, mobility speed, energy consumption, etc. We note that the two technologies of the 4G: WIMAX and LTE allow to improve the performances of a radio-mobile communication compared to the 3G or the 2G, in particular in terms of rate, coverage and cost.

Table 1.1: Summary of the various Wireless Network Technologies.

Parameters	**Wi-Fi (WLAN)**	**GPRS (2G)**	**UMTS (3G)**	**LTE (4G)**	**WiMAX (4G)**
Frequency band	2.4 or 5 GHZ	900 or 1800 MHz	1920 – 1980, 2110 – 2170 Mhz	2.4 GHZ	2.3 – 2.4, 2.496 – 2.69, 3.3 – 3.8 GHz
Max Throughput (Downlink, Uplink)	540Mbps	80Kbps, 20Kbps	2Mbps	326Mbps, 86Mbps	75Mbps, 25Mbps
Cell Coverage	300 m	70-140 Km	70-140 Km	5 Km	2-7 Km
Cell Capacity (Users Number)	32	64	1000	200-400	100-200
Supported Mobility	4 Kmph	500 Kmph	500 Kmph	350 Kmph	120 Kmph
Cost	Low	Medium	Medium	High	High
Energy Consumption	Medium	Medium	Medium	High	High
Security	Medium	Medium	Medium	High	High
QoS	Yes	No	Yes	Yes	Yes

1.2.2 Heterogeneous Networks

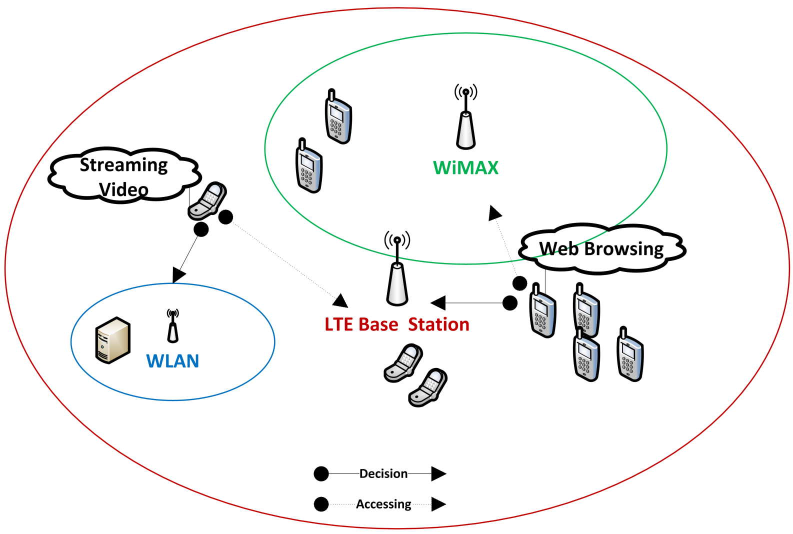


Figure 1.2: An illustration of Heterogeneous Network Topology.

The notion of heterogeneity in a network can have different aspects. On one hand, the network can be considered heterogeneous from the point of view of users who require different types of services with a different pricing mode. The heterogeneity can also be compared to the services provided to users via each technology. Since the different communication standards do not belong to the same generation, networks do not, eventually, support the same classes of services. On the other hand, a heterogeneous network environment is characterized by a complementarity between the available access technologies. For example, as shown in figure 1.2, Wi-Fi provides better bandwidth quality with limited coverage and low cost of service, as opposed to LTE, which offers low bandwidth with a high cost of service and better coverage. Problems in the heterogeneous network environment consist mainly in the interconnection and the mobility management. Interconnection is a set of mechanisms that allow the access nodes of different technologies to be interconnected in order to share services and resources while maintaining an independence between the different elementary networks.

1.2.2.1 Mobility management and Handover

Mobility is the operation of changing the point of connection in a wireless access network to another one while maintaining the continuity of services. The main objective of mobility management is to maintain information on the position of the mobile terminals and to manage their connections when they move within the coverage areas. Mobility management includes two procedures Sun and Sauvola (2002) :

- Location management: This functionality provides the network with information on the current position of a mobile terminal. It contains two steps, first the registration process of the location, where the mobile terminal is authenticated and its position is updated. Then the paging, where the position of the mobile terminals searched during the initialization of a new session.
- Handovers: Handover is the process by which the mobile terminal can maintain communication when it moves from an attachment point (base station) to another attachment point.

Indeed, handover is the process that allows a mobile node to change its attachment point. A mobile node connected to a network can, in order to improve the quality of service, have the need to leave it to connect to another cell, either of the same network or of a new network.

Handover Necessity: Among the causes which are at the origin of a need of Handover we can quote:

- The mobile node leaves the coverage area of the current cell and communicates through a new cell.
- The mobile node is highly interfered with on the current cell, hence the need to switch to another cell (of the same network or a different network), where there is less interference.
- The number of mobile nodes in a cell is very large so that the bandwidth is insufficient causing a deterioration in the quality of the service. The mobile can choose to go into neighbouring cells that are less congested.

Handover can take place between two cells of the same technology and will be called Handover Horizontal, or between two cells using different technologies, in this case a Vertical Handover. Finally, the combination of these two versions of Handover is called Handover Diagonal to transfer traffic from an access point that reaches a connection limit to a different technology network

Handover Procedure

Phase I: Handover initiation and information gathering Handover process must begin when a mobile node needs to leave its point of attachment to the current network to connect to another network where the quality of service will be better. Generally, the reason may be a low power of the signal or a value of one or more quality of service parameters that fall below a certain threshold. During this phase, the mobile node continuously scans the networks in its surroundings by collecting the necessary information from each. This information is essential for the network selection phase. Among these, we find those that are connected to the network such as network coverage radius, packet loss rate, bandwidth, Bit Error Ratio (BER), Signal to Interference Ratio (SINR), and so on. Other information is related to the mobile, such as signal strength, battery life, and mobile speed.

Phase II: Destination Network Selection During this phase the information that has been collected from the previous phase will be compiled to arrive at a decision and choose one of several networks available in the environment of the mobile node. The mechanism for selecting a new network is the main subject of this thesis. Classical approaches implements an algorithm based on a single parameter such as : signal strength, , throughput or position (See section 1.2.2.2).

Phase III: Execution of the Handover In the previous phase, we chose the network to which the mobile node must connect. During this phase, the execution of the disconnection of the links with the old network and the connection with the new network is carried out. This can be done in one of the following four cases:

- Network Controlled Handover Decision (NCHO), usually used by operators to distribute network loads.
- Mobile Controlled Handover Decision (MCHO).
- Mobile Assisted Handover (MAHO)
- Network Assisted Handover (NAHO).

1.2.2.2 Conventional Cell Selection Techniques

Handover decision helps to determine which access network should be chosen and the handover decision policy represents the influence of the network on when and where the handover occurs. The traditional handover decision policy is based only on Received Signal Strength (RSS) Kassar et al. (2008) Pahlavan et al. (2000). Conventional algorithms dealing with Network Selection introduce a single decisive parameter, either to trigger the initiation of the handover, or to determine the best interface. These algorithms include algorithms based on bandwidth, algorithms based on terminal speed, algorithms based on the direction of the terminal and algorithms based on energy consumption Pahlavan et al. (2000). It is important to note that the RSS-based algorithms cause the "ping-pong effect" phenomenon due to signal degradation. This phenomenon engenders unnecessary handovers. Thus, RSS should not be the priority criterion in relation to the other criteria for network selection. Given the heterogeneous environment in 4G mobility networks, the handover decision algorithm must combine the RSS parameter and other parameters such as the bandwidth where the network availability time to deliver a given service Zahran and Liang (2005). Bandwidth based vertical handover algorithms consider the bandwidth available to serve the mobile terminal as a primary parameter when selecting the best network interface. The set of approaches proposed in this framework are presented in detail in Yan et al. (2010). In order to have a better decision in the network selection phase, the bandwidth-based vertical handover algorithms generally use the signal strength as a second selection criterion in parallel Liu (2008) Zahran et al. (2006). Different techniques Evolved Universal Terrestrial Radio (2010a) Kim et al. (1996) have been proposed in the literature to optimize vertical handover by using the speed of the mobile terminal as the main criterion in the decision phase. When the mobile terminal moves at high speed, the probability of blocking users to enter a new cell becomes high. For this reason, speed-based techniques must take into account the different speed threshold values at the time of decision. Handover strategies based on the direction of movement of a mobile terminal are useful when the latter moves at high speed. The direction criterion makes it easy to select the best network interface. The strategies that use this criterion make it possible to improve the performance of handover in terms of minimization of number of handovers and also minimization of handover delay. Details of these strategies are provided in Austin and Stuber (1994) Zheng et al. (2004) Tripathi et al. (1998).

1.2.2.3 Vertical handover performance evaluation

The performance of different vertical handover algorithms can be evaluated and compared based on the measurement of the following parameters:

- Handover Delay: This parameter represents the elapsed time between the handover initiation phase and the end of the handover execution phase. Moreover, this metric directly influences the complexity of a handover algorithm. Indeed, a simple decision algorithm can produce a minimum value of this parameter. Generally, real-time applications require a very sensitive value of this metric in order to satisfy user requirements;
- Number of handovers: an effective handover algorithm must avoid unnecessary handovers to maximize network resources and minimize power consumption at the mobile terminal;
- Number of failed handovers: handover failure occurs when the mobile terminal switches to a new target network that does not guarantee sufficient resources for the terminal. This failure is also

possible when the terminal moves outside the coverage of the target network before the vertical handover process is completed. This parameter directly influences the QoS of the current session;

- Quality of service: it is important that the handover algorithm optimizes the performance of QoS parameters such as throughput, delay, jitter, loss rate, etc.

1.3 Conclusion

Wireless network technologies are applied in different fields such as industry and science. In this chapter we have presented the different mobile communications standards with their heterogeneous performance and capabilities. We have also found that these different standards constitute a heterogeneous environment for the user. The integration of various wireless networking technologies has become necessary to provide seamless interoperability for users. Vertical handover has been proposed as an effective solution to integrate existing technologies in next-generation networks while ensuring the ABC paradigm. We have also described the process of vertical handover, the different phases that constitute this process, as well as the parameters involved in the decision-making phase of the handover. Seamless Network Selection is a very complex problem, since it must take account of several factors such as the mobility of the mobile terminal, the selection criteria and the type of services. To address this problem, several algorithms are proposed in the literature in recent years. According to the criteria used and the mathematical models that exploit these criteria, there are four main propositions in the literature. We chose to optimize the network selection phase, which represents the most important phase in the handover process.

The literature review of the most reputed schemes are outlined in the next chapter.

Chapter

2 Literature Review

Contents

2.1 Introduction

In the previous chapter, (section 1.2.2.2), we have come to the conclusion that single-parameter approaches do not follow the evolution of wireless networks. Thus, in this chapter, we present the state of the art of the main approaches that are developed and proposed to optimize vertical handover using multi criteria concept.

2.2 Related Works on Multi Criteria Network Selection Approaches

2.2.1 Network Selection

2.2.1.1 Network Selection Based On MADM Strategy

The selection of the next handed network is a crucial step in the process of Vertical Handover (VH) to enact a ubiquitous handover and achieve the best Quality of Service in an heterogeneous environment. it's a matter of choice comparison of the available networks and making decision by amassing informations about the behaviours of the candidate networks, and sorting them in order to select the best available alternative. It is an outstanding revolution in the world of mobile communication, by providing an enhanced QoE for mobile users of wireless technologies.

In the framework of VH, Ahuja et al. (2014a) suggested an algorithm for vertical handover depend on "averaged received signal strength, outage probability and distance". Not to mention that authors improved their work in Ahuja et al. (2014b), in the way of proposing a new scheme using "signal strength, available bit rate, signal to noise ratio, achievable throughput, bit error rate and outage probability metrics" as metrics of comparison. Authors mixed excerpt metrics with "Particle Swarm Optimization (PSO)" for a dynamic weight computation. In the context of type of metrics used, a vertical handover decision that relies on "coverage area" of the network and "the velocity" of the mobile user was proposed by Jain and Tokekar (2015). Moreover, Yang and Tseng (2013) proposed a handover that considers two actions: "attributes rating and network ranking". Authors related their scheme to the classical "signal based handover model" and certainly proved a lowest packet drop ratio and higher average throughput. In Jaraiz-Simon et al. (2015), authors explained that a determined set of weights produces certain quality or merit degree for each network; these merit values change if we consider another set of weights. The goal is to obtain the best merit value, which will correspond to the selected network for the VH decision phase. Accordingly, the more combinations of weights, the more possibilities to get better merit values we will have.

Recent scientific researches Dealt with Multi Criteria problems in different domains. Authors of Moghaddam (2015) developed a fuzzy multi-objective mathematical model to identify and rank the candidate suppliers. Whereas, the authors of Memon et al. (2015) applied the combination of grey system theory and uncertainty theory which neither requires any probability distribution nor fuzzy membership function to solve Supplier selection problem. In Abdollahi et al. (2015), Authors presented a framework for supplier selection based on product-related and organization-related characteristics of the suppliers to be more competitive in the market and flexible to overcome probable changes in demands, supplies etc. Supplier selection problem was solved by the authors using a combination of multi-criteria decision making (MCDM) methods. A model for ranking the suppliers for the automotive industry in Pakistan was proposed in Dweiri et al. (2016), the weights affecting supplier selection could be qualitative or quantitative. There are many qualitative concerns when assessing the factors critical to supplier selection. Some of the factors can be difficult to quantify. Therefore, an hybrid techniques such as fuzzy AHP can be used to address this gap.

Accordingly, "Multiple Criteria Decision Making (MCDM)" is one of the best network selection methods that can used for Vertical Handover Decision (VHD) in heterogeneous wireless networks. It presents many assets, conspicuously, its simplicity of implementation, however, the growing number of users make it incompetent considering the time of the decision when is more significant particularly for real-time applications. Another omission of such decision is the human interference at the moment of initiation of the performance indicators. As an example, AHP lacks of objectivity of judgement. In Goyal and Kaushal

(2016), authors explain that a defined set of weights yields a specific merits for candidate networks; these merit estimations vary with the use of another collection of weights. The goal is to acquire the best merit that fit the best elected network during the vertical handover decision phase.

2.2.1.2 Network Selection Based On Utility Function and Matching Game

One of the challenges involved in the context of next generation networks is the development of solutions that consider several requirements in order to select the best network whenever it is needed to evaluate the transition of the mobile device between different networks.

There have been many works dealing with the Network Selection problem in different ways. Kassar et al. (2008) compared traditional handover decision strategies (RSSbased), and concluded that they are not good enough to make a vertical handover decision. They do not take into account the current context or user preferences. Therefore, vertical handover decision strategy involves complicated considerations and compromises. Authors of Wang and Kuo (2013) studied the most important mathematical theories used for modelling the network selection problem in the literature. Authors compared the schemes of various mathematical theories in an unified scenario and discuss the ways to benefit from combining multiple algorithms together. As a matter of fact, Lopez-Benitez and Gozalvez (2011) proposed and optimized a common radio resource management techniques designed to efficiently distribute traffic among the available radio access technologies while providing adequate quality of service levels under heterogeneous traffic scenarios. Ma and Ma (2009) also investigated in vertical handover in heterogeneous wireless networks. authors proposed a QoS-based vertical handover scheme for WLAN and WiMAX networks in order to provide always best service to users. Furthermore, authors of Mansouri et al. (2015) proposed a scheduling algorithm for the same cited goals, they proposed solution for scheduling packets while maintaining performance in wireless networks. The scheduling scheme is based on transmission link's condition from the media independent handover (MIH) protocol, type of call and classes of service. In a similar context, Some researchers have been using utility function to select the best candidate network. Utility function refers to the satisfaction that a good or service provides to the decision maker. Indeed, Kosmides et al. (2014) allocated terminals to the most appropriate network by jointly examining both user's and provider's preferences. Authors introduced three utility-based optimization functions based on the type of application that users request. In the same way, Chamodrakas and Martakos (2011) presented a method that takes into account user preferences, network conditions, QoS and energy consumption requirements in order to select the optimal network which achieves the best balance between performance and energy consumption. The proposed network selection method incorporates the use of parametrized utility functions in order to model diverse QoS elasticities of different applications. Pirmez et al. (2010) presented a selection mechanism that prioritizes networks with higher relevance to the application and lower energy consumption based on utility function. Wu and Du (2015) proposed a network selection scheme based on a utility function that take user's QoS demands, preferences and channel state information (CSI) into account.

A tremendous endeavours have been achieved recently in the field of wireless networks to improve QoS and QoE while meeting the growing demand for high data rates and coverage of mobile users.

For bringing in the benefits of wireless networks coexistence, numerous approaches have been addressed such as resource management, user association and access point selection Anpalagan (2015), Lopez-Perez et al. (2011), De La Roche et al. (2010), Ashraf et al. (2016) and Beltran et al. (2016) using matching game theory, a winning the 2012 Nobel Prize, which provides a mathematically tractable method for personnel assignment problem in two distinct sets. Moghaddam and Nof (2017) defined Best Matching as the process of finding the best match between the elements of two or more sets, considering certain conditions and criteria. In wireless communications context, it is essentially based on the link of user equipments (UEs) with different available Access Points (AP). These links, in turn, define their predilection or preferences to one another under peculiar criteria. There are some surveys in the literature that introduce matching theory applied to wireless communications Xu and Li (2011),Gu et al. (2015). Gu et al. (2015) introduced general concepts of matching theory and an efficient algorithm, known as the Deferred Acceptance (DA) algorithm, which was developed by Gale and Shapley (1962), to find a matching between mobile users and access points. DA is an iterative procedure, in which players in one set make proposals to the other set, whose players, in turn, decide to accept or reject these proposals, respecting their quota. This algorithm has been used differently in more than one work to solve network selection problem Kazmi et al. (2016),Shao et al. (2016) and Zeng et al. (2016). Matching theory has loomed as an up-and-coming approach for wireless resource management which can subdue some drawbacks of previous approaches such as such as Utility Function, Multiple Attribute Decision Making (MADM) and Fuzzy logic Gu et al. (2015). In the same context, authors in Bayat et al. (2016) described wireless networks as a diverse interacting selfish and rational agents with a natural propensity to solicit their maximum benefit from the network without caring about other agents, claiming that, Game theory which has been widely used in open literature to facilitate autonomous network management and dynamic resource allocation can not deal with complex networks, in which, different types of agents with various characteristics and requirements want to interact with each other, and conventional game theoretical models can hardly be utilized. In Gu et al. (2016), authors claimed that the matching approach can be applied to multiple wireless resource allocation problems in the sense that it has a convenient models for characterizing interactions between the heterogeneous players. In addition, it is able to describe properly the "preferences" that can interpret the complex system constraints. It offers achievable solutions that reflect different system objectives, such as stability and finally, it provides efficient algorithms for distributed implementations. The theory of games is a mathematical tool developed mainly for the study of the interactions between several agents (individuals, groups, companies, etc.) Fudenberg and Tirole (1991). Game theory provides mathematical approaches to structuring, analyzing and understanding problems that require decision-making. The field of application of gaming theory has invaded several fields such as war, biology, engineering, transport, networks / telecommunications, etc. In the context of heterogeneous networks, several works are proposed in the literature to optimize the decision of handover Trestian et al. (2012b). Authors Trestian et al. (2012b) presented an overview of the work that is published to overcome the problems and challenges of network selection in 4G. The authors aim to familiarize the researchers with the concept of the selection of the network and also with the different algorithms of the theory of games that are used in the literature to model the problem of the network selection. For the same reason, the authors propose a complete classification concerning the different approaches based on the theory of games as well as their uses to attack the problem of network selection. This classification regroups the algorithms of the handover in three categories according to the interactions of the actors intervening in the game: users vs. Users, networks vs. Networks and users vs. Networks. Finally, the authors gave a comparison and an analysis between the different solutions developed to solve the problem of network selection based on the theory of games.

2.2.2 Network Selection Schemes: Synthesis and Comparison

This section provides a comparison and synthesis of the handover algorithms that are discussed in this chapter. Because network selection is the most important phase during vertical handover, the evaluation and comparison between the different vertical handover approaches focus mainly on this phase. Network performance, user satisfaction, user preferences, efficiency, complexity, flexibility and reliability for all handover algorithms should be considered to compare and evaluate approaches to vertical handover. Thus, table 2.1 presents comparison is based on evaluation parameters such as: multi-criteria choice, user preferences, efficiency, flexibility, complexity and type of services supported.

Table 2.1: Comparison of Different Network Selection Approaches. Yan et al. (2010)

	Multi-Criteria	User Preferences	Eefficiency	Flexibility	Complexity	Multi-Service
RSS	No	No	Low	Low	Low	No
MADM	Yes	Medium	High	Medium	Medium	Yes
Utility Function	Yes	High	High	Medium	Medium	Yes
Fuzzy Logic	Yes	Medium-High	High	High	High	Yes
Matching Theory	Yes	High	High	Medium	High	Yes

According to this comparison, the network selection algorithms which are proposed despite their developed aspects present some disadvantages and certain limits. In terms of complexity, conventional algorithms are generally the simplest to implement among all categories since they mainly use a single criterion such as RSS, bandwidth, and so on. The complexity increases with the MADM methods which require not only a set of criteria but also the fact that the latter must be standardized.

Moreover, the use of artificial intelligence and hybrid algorithms have the disadvantage of being too complex to implement. In terms of reliability, handover algorithms that are based on artificial intelligence and the MADM approach are considered to be the most reliable algorithms among all existing handover approaches. They can provide precise solutions by taking into account several decision factors in the network selection process. In terms of services, conventional algorithms are not applicable for real-time transmission. On the other hand, methods based on Artificial Intelligence and the MADM approach can support all classes of services.

2.3 Related works on 5G V2X scenarios

2.3.1 Heterogeneous Networking in 5G for V2X Scenarios

The evolution towards future Intelligent Transportation Systems (ITS) is significantly influenced by enabling telematics services for vehicular applications. Under this premise, numerous research and development projects dealing with the topic of V2X mobile communication have been conducted from both industry and academia within the past decade Stübing et al. (2010). Most of the previous work in this field aims at understanding the effects of mobility on communication processes taking place on the physical layer as well as on system level for the dedicated IEEE 802.11p standard.

In order to overcome the known issues in an adequate manner,the incorporation of LTE as a 4G cellular network into the communication is considered. Due to its inherent characteristics, e.g. low achievable end-to-end latency between users and wide area coverage, the use of LTE for V2X communication can be especially beneficial in certain situations where IEEE 802.11p suffers from low signal to noise ratio (SNR), e.g. in urban intersections with obstructed line-of-sight Möller et al. (2014). Taking this approach one step further, also combining IEEE 802.11p and LTE to a hybrid communication system is possible. This would enable to use either only one radio access technology (RAT) or both simultaneously to achieve the reliable dissemination of information between vehicles and traffic infrastructure, depending on the individual street- and telephone traffic as well as propagation conditions. The design of such a hybrid system architecture requires the detailed evaluation of individual system performances in specific situations with respect to both vehicular applications and their requirements as well as boundary conditions such as network load and radio propagation. Sensible metrics need to be derived as input for involved protocols, e.g. to trigger inter-system handovers Mir and Filali (2014b), Mir and Filali (2014a). Seo et al. (2016) discussed how LTE systems are evolving in order to support V2X services. Basic safety services such as collision warning as well as convenience services such as traffic flow optimization are identified as the first step of LTE-based V2X services. Those services can be provided in multiple operation scenarios using the D2D interface, the cellular interface, or their combination. The main challenges identified in supporting V2X services are high mobility and dense population of UEs, and LTE systems need to be enhanced so that the service requirements can be fulfilled in such a vehicular communication environment. Levering the spectrally efficient air interface, cost-effective network deployment, and the versatile nature of supporting different communication types, LTE systems along with proper enhancements can be a cost-effective enabler of V2X services. Furthermore, 3GPP has also started to discuss more advanced services of connected cars as the second step, and the related specification work is expected to continue for further LTE evolution and the new air interface design for 5G communications.

V2X communications concern the communication of information between fast moving vehicles with relative velocities that can exceed 300 km/h in some cases (or moving in opposite directions). The V2X applications in the present specification of the 3GPP 3rd Generation Partnership Project (2017b), as for LTE V2X, the essential use cases identified are as follows 3rd Generation Partnership Project (2015):

- Vehicle-to-Vehicle (V2V): expect UEs that are in proximity of each other to exchange V2V application information. The UE supporting V2V applications transmits messages containing V2V application information (e.g. location, dynamics, and attributes).
- Vehicle-to-Infrastructure (V2I): The UE supporting V2I applications transmits messages containing V2I application information to a relevant application server. This latter transmits messages containing V2I application information to one or more UEs supporting V2I applications in a particular geographic area. There can be multiple application servers serving overlapping areas, providing the same or different applications. It covers communication between a vehicle and a roadside unit.
- Vehicle-to-Pedestrian (V2P): Expect UEs that are in proximity of each other to exchange V2P application information. It is expected also that V2P application information can be transmitted either by a UE supporting V2X application in a vehicle (e.g., warning to pedestrian), or by a UE supporting V2X application associated with a vulnerable road user (e.g., warning to vehicle). It covers communication between a vehicle and a device carried by an individual (e.g. hand-held terminal carried by a pedestrian, cyclist, driver or passenger).

V2X applications have stringent requirements on high reliability and low latency. In the road safety and traffic efficiency applications, information is exchanged between traffic actors using V2V, V2P or V2I communications.

The 3GPP also identified different use cases and potential service requirements to enhance support for V2X service. Different V2X scenarios require the transport of V2X messages with different performance requirements for the 3GPP system. This Technical Specification specifies service requirements to enhance 3GPP support for V2X scenarios in the following areas, Vehicle Platooning, Advanced Driving, Extended Sensors and Remote Driving 3rd Generation Partnership Project (2017a) 3rd Generation Partnership Project (2016):

- Vehicles Platooning enables the vehicles to dynamically form a platoon travelling together. All the UEs in the platoon obtain information from the leading vehicle to manage this platoon. These information allow the vehicles to drive closer (short time or distance inter-vehicle gap) than normal in a coordinated manner, going to the same direction and travelling together. These are expected to be a set of sophisticated application.

- Extended Sensors enables the exchange of raw or processed data gathered through local sensors or live video images among vehicles, road site units, devices' of pedestrian and V2X application servers. The vehicles can increase the perception of their environment beyond of what their own sensors can detect and have have a more broad and holistic view of the local situation. High data rate is one of the key characteristics.

- Advanced driving enables semi-automated or full-automated driving. Longer inter-vehicle distance is assumed. Each vehicle and/or Road Side Unit (RSU) shares its own perception data obtained from its local sensors with vehicles in proximity and that allows vehicles to synchronize and coordinate their trajectories or manoeuvres. Each vehicle shares its driving intention with vehicles in proximity, too. The benefits of this use case group are safer travelling, collision avoidance, and improved traffic efficiency.

- Remote Driving enables a remote driver or a V2X application to operate a remote vehicle for those passengers who cannot drive by themselves or remote vehicles located in dangerous environments. For a case where variation is limited and routes are predictable, such as public transportation, driving based on cloud computing can be used. Also, access to cloud-based back-end service platform can be considered for this use case group. High reliability and short low latency are the main requirements.

It should be noted that there are various use case related variables involved in these scenarios (e.g. maximum tolerable latency, minimum application layer message reception reliability). These parameters need to be managed as designing the system in such a way as to meet all of the most stringent criteria places an unnecessary burden on the system. Some of these parameters are as follow:

- End-to-end latency: Time it takes to transfer a given piece of information from a source to a destination, measured at the application level, from the moment it is transmitted by the source to the moment it is received at the destination.

- Reliability (%): The success probability of transmitting X bytes within a certain delay.

- Data rate: The speed at which data is transferred from source to destination.

Discussion on the evolution of LTE-Advanced in Rel-14 is already occurring. It is expected that Rel-14 would introduce technologies for latency reduction, which is one of the most important aspects for improving the user experience but has not been improved much since the introduction of LTE. Technologies for V2X such as Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), and Vehicle-to-Pedestrian (V2P) have recently attracted significant attention from the cellular industry as another opportunity for LTE-Advanced technologies to be extended to support vertical industries, and are expected to be specified in Rel-14. As a technology for further improving spectral efficiency by allowing non-orthogonal downlink transmissions within a cell, the enhancement for downlink multi-user transmission using superposition coding was studied during Rel-13 for potential specification work in Rel-14 Lee et al. (2016).

The main factor contributing to the delay increase, in such environment is the network handover decision which increase drastically the time and latency of the interface between source and target cell. Consequently, for high-mobility vehicles, The shorter the handover time, the better. Moreover, various issues are present in the current vertical handover management schemes such as inappropriate handover triggering, high handover delay, wrong network selection, etc.

2.4 Conclusion

These works have brought us, as first contribution, to investigate in the framework of multi criteria prominent MADM methods, namely, MEW, SAW, TOPSIS, VIKOR and AHP and examine the impact of their combination as vertical handover schemes in environment with recent technologies. Matching game theory works have exhorted us to use a matching theoretic approach to find the most suitable network to mobile users regarding the type of application they use. Although gaming theory is widely used for load distribution, it does not prove to be appropriate for the ABC paradigm. Indeed, with the theory of games, networks (players in a game) select their appropriate services. For the "ABC" concept, the services must select their best network. Therefore, as a contribution, we used matching theory to ensure load balancing in our system model. Finally, in order to address the aforementioned issues related to vehicular environments, we applied the handover management schemes that provide a cooperative awareness of different use cases in heterogeneous vehicular networks in furtherance of enabling more intelligent services for end-users in V2X scenarios.

Chapter

3

A Multi-Criteria Network Selection Approach in Heterogeneous Environment using MADM

Contents

3.1 Introduction

In this chapter, we tackle the network selection issue levering a combination of Multi-Criteria Decision Making (MCDM) methods to ensure that appropriate network is selected for a certain type of traffic and considering a number of QoS metrics that due to their interdependency, a weight distribution phase is required. To ascertain thoroughly the weights of QoS metrics impacting the decision for each application, AHP is generally applied. But its classical form comes with biased rules that are dealt with through an enhanced version FAHP (Fuzzy AHP) that has proven its performance when combined with the other well reputed ranking methods, namely: MEW,SAW,TOPSIS and VIKOR.

3.2 MADM-based Network Selection Schemes

We present in this section the mathematical modelling of MADM-based Network selection strategies.

3.2.1 Principle of MADM

For Network Selection, classical MADM approach consists in choosing the best network from available networks considering multiple attributes. The vertical handover decision problem can be formulated as a matrix form Q, where each row i corresponds to the candidate network and each column j corresponds to an attribute. The matrix of N alternative networks is settled conforming to M attributes.

$$Q_{N,M} = \begin{array}{c c} & \begin{array}{cccc} Attribute_1 & Attribute_2 & \ldots & Attribute_M \end{array} \\ \begin{array}{c} Network_1 \\ Network_2 \\ \vdots \\ Network_N \end{array} & \begin{pmatrix} q_{11} & q_{12} & \cdots & q_{1M} \\ q_{21} & q_{22} & \cdots & q_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ q_{N1} & q_{N2} & \cdots & q_{NM} \end{pmatrix} \end{array}$$

3.2.2 Normalization Methods

As all MADM methods grant the evaluated criteria to be expressed in different measurement units, it is necessary to convert them into normalized values.

3.2.2.1 The Euclidean Normalization Technique

This technique has the advantage of normalizing the attributes on different units in a very simple way Yoon and Hwang (1995). Thus, considering the matrix above, the normalized values using the Euclidean normalization technique are:

$$n_{ij} = \frac{q_{ij}}{\sqrt{\sum_{i=1}^{i=N} q_{ij}^2}}, j = 1, ..., M \tag{3.1}$$

3.2.2.2 The Normalization by Sum Technique

This procedure consists in dividing the value q_{ij} of the attribute for each alternative by the sum of the values of all the alternatives corresponding to this attribute. The normalized value n_{ij} is obtained as follows:

$$n_{ij} = \frac{q_{ij}}{\sum_{i=1}^{i=N} q_{ij}}, j = 1, ..., M \tag{3.2}$$

Finally, the choice of the proper technique of normalization to be used for such a MADM Method remains open. Or, there is no specification made for response in light of the diversity of MADM methods in the literature.

3.2.3 MADM Methods

This section presents the different algorithms that can be used as the core of network selection. In order to guarantee continuity and quality of service during the transfer of a communication, the design and modelling of an intelligent solution for the vertical handover decision is required. This solution allows users to select the optimal network while maintaining the ABC principle. Several algorithms, based on the MADM approach have been proposed to solve the problem of network selection. These algorithms are applied mainly to classify network alternatives. In the remainder of this section, we present a detailed description of the main steps of each MADM methods AHP, FAHP, TOPSIS, VIKOR, MEW and SAW.

3.2.3.1 Analytical Hierarchy Process: AHP

AHP was proposed by Saaty (1987) for "decision-making in multi-criteria problems, they introduced it as a method of measurement with ratio scales, AHP allows comparison and a choice of pre-set options. It is based on the comparison of pairs of options and criteria". A AHP problem is organized in a tiered form; the different rows have different items. The significance of an item (or "scores of alternatives") is calculated eventually under the aegis of a succession of comparative statements. Indeed, we have to specify the predilections by contrasting all items in each row with respect to above row items. The calculation of the importance of an item requires deal with to a series of comparisons of two elements (or metrics). Generally, the comparison's purpose is to ascertain which item answers the more the option's requirements. If quantitative data is not available, a qualitative judgement can be used for a pair wise comparison. This qualitative pairwise comparison follows the importance scale suggested by Saaty (1987) as shown in table 3.1.

Table 3.1: Criteria importance scale in pairwise comparison.

Importance scale	**Importance description**
1	Equal importance of metric i and metric j
3	Weak importance of metric i over metric j
5	Strong importance of metric i over metric j
7	Demonstrated importance of metric i over metric j
9	Absolute importance of metric i over metric j

Note: 2, 4, 6 and 8 are intermediate values.

According to Kubler et al. (2016), if A is a pairwise comparison matrix as formalized in Eq. 3.3, where $a_{ij} \mid (i, j \in N)$ is supposed to reflect how many more times item/criterion i is preferred to item/criterion

j in a certain case.

$$\mathbf{A_{nxn}} = \begin{array}{c c} \begin{array}{cccc} metric_1 & metric_2 & \dots & metric_n \end{array} & \\ \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} & \begin{array}{c} metric_1 \\ metric_2 \\ \vdots \\ metric_n \end{array} \end{array} \tag{3.3}$$

AHP generates weights w that express the significance of the quality of service metrics regarding a criterion. As a deduction, vectors $w_j > 0$ serves as the significance of the j^{th} metric as $\sum_{j=1}^{j=M} w_j = 1$. The next step is to derive the weights, by solving the eigenvector method (EM) proposed by Saaty (1977) and then normalizing the result. EM derives the priorities w_1, w_2, $\dots$, w_n of comparable metrics: $metric_1$, $metric_2$, $\dots$, $metric_n$ as the solution of the right eigenvector problem for the corresponding pairwise comparison matrix $\mathbf{A_{nxn}}$ with λ_{max} as the maximal eigenvalue.

$$\mathbf{A_{nxn}} \cdot \begin{pmatrix} w_1 \\ w_2 \\ \dots \\ w_n \end{pmatrix} = \lambda_{max} \cdot \begin{pmatrix} w_1 \\ w_2 \\ \dots \\ w_n \end{pmatrix} \tag{3.4}$$

Thereby, the weights are produced based upon certain criterion. The result weights are used for the decision.

3.2.3.2 Fuzzy Analytical Hierarchy Process: FAHP

Fuzzy set approach purpose is to cut off the hazy analogy assessments by the use of fuzzy numbers. FAHP engenders the fuzzy significance of a combination of two items in the same row. The fuzzy extension is required because the basic AHP misses the important aspect of tackling the high degree in vagueness of personal subjective judgements and preferences Tyagi et al. (2017), as authors claimed, FAHP is relevant to solve the problem at hand considering multi-criteria structure and vagueness in real environment. This systematic approach basically integrates two fundamentally distinct concepts, the fuzzy set theory and the AHP. The advantage of fuzzy set theory is in dealing with the ambiguity intrinsic to the decision-making problems and the ability to define vague data using classes and grouping with boundaries Nguyen and Gordon-Brown (2012).

Fuzzy Set Theory and Fuzzy Numbers : Zadeh (1965) explained that the focal point of the fuzzy sets theory is its facility to represent an ambiguous data in a innate form. It has been worn for modelling complex systems that can be controlled by humans but are severe to determine fairly and without bias which is the case of AHP. The fundamental feature of fuzziness is the grouping of criteria into a set of collections without sharply define the outer limits. The reason for the success of fuzzy logic in many applications is its capacity to accredit degree of membership between 0 and 1 using ”Linguistic terms”, expressed by membership functions and valued in ”the real unit interval”, which convert the ambiguity of human conclusions in a particular problem.

In the existing researches, the triangular fuzzy numbers (TFN) are commonly exploited to define the ambiguity of the metric studied all along the investigation. A TFN is a particular category of fuzzy numbers, its membership is defined by (l, m, u) three crisp numbers as: $(l \leq m \leq u)$, where l is ”the lower limit value”, m is ”the most propitious value” and u is ”the upper limit value” presented in figure 3.1. When $l = m = u$, fuzzy number become a real number. A TFN can be defined as:

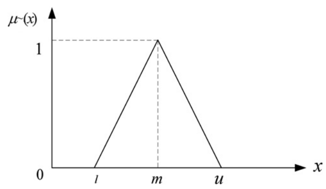


Figure 3.1: A Triangular Fuzzy Number Representation.

$$\mu_{A(x)} = \begin{cases} \frac{x-l}{m-l}, & l < x < m \\ \frac{u-l}{u-m}, & m < x < u \\ 0, & Otherwise \end{cases} \tag{3.5}$$

$$\overline{\mathbf{A}}_{n*n} = (\overline{a_{i,j}})_{n*n} = \begin{array}{c} \begin{array}{cccc} metric_1 & metric_2 & \dots & metric_n \end{array} \\ \begin{bmatrix} \overline{a}_{11} & \overline{a}_{12} & \dots & \overline{a}_{1n} \\ \overline{a}_{21} & \overline{a}_{22} & \dots & \overline{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \overline{a}_{n1} & \overline{a}_{n2} & \dots & \overline{a}_{nn} \end{bmatrix} \end{array} \begin{array}{l} \\ metric_1 \\ metric_2 \\ \vdots \\ metric_n \end{array} \tag{3.6}$$

Hence, fuzzy pairwise comparison matrices can be built up (Eq. 3.6) as the case of AHP pairwise comparison model, in a fuzzy form by using TFNs as instead of crisp numbers:

$$\overline{a}_{i,j} = (l_{i,j}, m_{i,j}, u_{i,j}) \text{ and } \overline{a}_{i,j}^{-1} = (1/u_{i,j}, 1/m_{i,j}, 1/l_{i,j}).$$

$\overline{a}_{i,j}, i, j \in 1, 2, \dots, n$ is supposed to reveal how many more times criterion i is preferred to criterion j with a certain level of ambiguity and/or equivocalness in each type of traffic. The fuzzy pairwise comparison matrices follow the importance scale suggested by Büyüközkan et al. (2008) and recapped in table 3.2.

Table 3.2: Importance scale of factors in fuzzy pairwise comparison.

Triangular Fuzzy Importance scale	**Triangular fuzzy reciprocal scale**	**Importance description**
(1, 1, 1)	(1, 1, 1)	Equal importance of metric i and metric j
(1, 3/2, 2)	(1/2, 2/3, 1)	Weak importance of metric i over metric j
(3/2, 2, 5/2)	(2/5, 1/2, 2/3)	Strong importance of metric i over metric j
(2, 5/2, 3)	(1/3, 2/5, 1/2)	Demonstrated importance of metric i over metric j
(5/2, 3, 7/2)	(2/7, 1/3, 2/5)	Absolute importance of metric i over metric j

Resultantly, the fuzzy weight vectors are computed for all alternatives by applying the "Extent Analysis Method" Chang (1996) which derives crisp weights from a fuzzy pairwise comparison matrices.

3.2.3.3 Technique for Order of Preference by Similarity to Ideal Solution: TOPSIS

The selected network is the one that is abutting to the positive ideal network and distant from the negative ideal solution. These networks are determined as networks with the maximum and minimum values for each QoS metrics. It should be mentioned that for a metric of performance the best value is the largest and for a cost metric the best value is the lowest. The steps of TOPSIS process are cited in Vega et al. (2014):

Step 1 Compute the weighted decision matrix:

$$v_{ij} = w_{ij} \cdot n_{ij} \tag{3.7}$$

Step 2 Define the "positive ideal" and "negative ideal" networks given by:

$$A^{+} = \{v_1^{+}, v_2^{+}, ...\}, v_j^{+} = \max_i(v_{ij}) \tag{3.8}$$

$$A^{-} = \{v_1^{-}, v_2^{-}, ...\}, v_j^{-} = \min_i(v_{ij})$$

Step 3 Compute the distances: The gap of network A^i from the ideal solution A^+ and the ant-ideal solution A^- are d_i^+ and d_i^- respectively:

$$d_i^{+} = \sqrt{\sum_{j=1}^{M} |v_i^{+} - v_{ij}|} \tag{3.9}$$

$$d_i^- = \sqrt{\sum_{j=1}^{M} |v_i^- - v_{ij}|}$$

Step 4 Compute the ratio closeness R_i of network i to the ideal and anti-ideal solutions by:

$$R_i = \frac{d_i^+}{d_i^+ + d_i^-} \tag{3.10}$$

Such as R_i is better when converging 0; $R_i \in [0, 1]$.

3.2.3.4 VlseKriterijumska Optimizacija I Kompromisno Resenje: VIKOR

The VlseKriterijumska Optimizacija I Kompromisno Resenje "(VIKOR; that means multi-criteria optimization and compromise solution)". It was elaborated for multi-criteria optimization of intricate systems Opricovic (1998) and Tzeng and Huang (2011). VIKOR is based on listing and choosing from a batch of available networks in consideration of an inconsistent metrics. It proposes the multi-criteria ranking key based on the specific measure of "closeness" to the "ideal" solution. The concept of VIKOR is hinged on figuring out the compromise solution from ranking the alternatives regarding the weight coherence intervals which depend on the preference of the compromise solution provided with the original weights. The following steps are mandatory for VIKOR:

Step 1 For each metric $j = 1, 2, ..., M$, define the best and worst values given by:

$$f_j^+ = \{(\max_{i=1,2,...,N}(n_{ij}) \mid j \subset M_p), (\min_{i=1,2,...,N}(n_{ij}) \mid j \subset M_c)\} \tag{3.11}$$

and

$$f_j^- = \{(\min_{i=1,2,...,N}(n_{ij}) \mid j \subset M_p), (\max_{i=1,2,...,N}(n_{ij}) \mid j \subset M_c)\} \tag{3.12}$$

Where M_p and M_c are the collections of performance and cost parameters respectively.

Step 2 Compute the of S_i and R_i for N_i networks as $i = 1, 2, ..., N$:

$$S_i = \sum_{j=1}^{M} w_j \frac{(f_j^+ - n_{ij})}{(f_j^+ - f_j^-)} \tag{3.13}$$

and

$$R_i = \max_{j=1,...,M} \left[w_j \frac{(f_j^+ - n_{ij})}{(f_j^+ - f_j^-)} \right] \tag{3.14}$$

Where w_j is the weight of metric j.

Step 3 Afterwards, the values of Q_i for $i = 1, 2, ..., N$ are calculated as:

$$Q_i = \beta \left(\frac{S_i - S^+}{S_i - S^-} \right) + (1 - \beta) \left(\frac{R_i - R^+}{R_i - R^-} \right) \tag{3.15}$$

Where:

$$S^+ = \min_{i=1,2,\dots,N} S_i, \quad S^- = \max_{i=1,2,\dots,N} S_i$$

$$R^+ = \min_{i=1,2,\dots,N} R_i, \quad R^- = \max_{i=1,2,\dots,N} R_i$$

The coefficient β , $0 \leq \beta \leq 1$ is called the weight of the approach defined as ”the majority of criteria” (or ”the maximum group utility”). Here, we set $\beta = 0.5$ since we consider the batch of metrics for all networks.

Step 4 Given the values for Q, for all $i = 1, 2, ..., N$, the available networks can be sorted in ascending order. The selected network $VIKOR$ is :

$$VIKOR = arg(\min_{i=1,2,\dots,N} Q_i) \tag{3.16}$$

3.2.3.5 Multiplicative Exponent Weighting: MEW

The tally S_{MEW} of a candidate network i is defined by the compromised product of the multiplication of the metrics:

$$S_{MEW} = \prod_{j=1}^{M} n_{ij}^{w_j} \tag{3.17}$$

It should be noted that in the previous equation, w_j is a positive exponent $n_{ij}^{w_j}$ for metrics of performance , and a negative exponent $n_{ij}^{-w_j}$ for metrics of cost. Whereas the overall score of a network produced by MEW bounded above, it is suitable to compare each network vector with the score of a positive ideal network A^+ which is defined by the first part of equation (4.7). The proportion R_i of network i regarding the positive ideal network is computed by:

$$R_i = \frac{\prod_{j=1}^{M} n_{ij}^{w_j}}{\prod_{j=1}^{M} (n_{ij}^{*})^{w_j}} \tag{3.18}$$

Such as$R_i \in [0, 1]$. Duly, the elected network according to MEW is : $A_{MEW} = \max_i(R_i)$

3.2.3.6 Simple Additive Weighting: SAW

SAW is also noted as ”the weighted sum method” and it is the most commonly used MADM method Hwang and Yoon (1981). The main purpose of SAW is to bring in a weighted worth of the performances of the candidate networks. Thusly, the outright tally of a candidate network S_{SAW} is defined by the weighted sum of all metrics. It is obtained by summing the performances n_{ij} the normalized metric multiplied by the importance w_j of the metric Q_j as follow:

$$S_{SAW} = \sum_{j=1}^{M} w_j \cdot n_{ij} \tag{3.19}$$

Such as:
w_j is the weight vector. n_{ij} is the value of normalized metric j of network i. N and M are respectively the number of alternatives and the number of criterion of each alternative.

3.3 Proposed Network Selection Framework System Model

The purview of our work is primarily in handover decision phase, as mentioned in the previous section. The contribution, in this chapter, consists of a handover decision phase, where Users must choose the best network from available networks regarding the decision metrics. Multifarious MADM methods have been suggested in the literature for vertical handover decision, methods such as SAW, VIKOR, MEW, TOPSIS or AHP.

We modelled the decision into two phases namely, the weighting and the ranking of available networks. Thus, the algorithms, in the MADM approach, are used in two ways:

- The weighting algorithms that are used to assign weights for criteria such as AHP, FAHP, etc.
- The ranking algorithms that are applied to classify the alternatives according to their performance as SAW, VIKOR, MEW and TOPSIS.

The goal of this contribution is to compare the impact of different multi-criteria vertical handover schemes on the QoS in different traffic scenarios. As disclosed in figure 3.2, QoS metric measurement can be provided to the system by simulation or the real network in real time. Afterwards, the pairwise comparison processes related to AHP method are applied according to each QoS class: Conversational ”Conv”, Streaming ”Strea”, Interactive ”Inter” and Background ”Back”. The Weight Distribution Algorithm (AHP or FAHP) is used eventually to compute the weight vectors in order to obtain the relative importance of each metric considering Bit Error Rate ”Ber”, Jitter ”J”, Delay ”D” and Throughput ”T” of the participating access networks to make the handover decisions. Thereupon, SAW, VIKOR, MEW and TOPSIS are applied to the weighted matrices (or fuzzy weighted matrices) to attain the outright decision for each method. Each handover decision is made in real-time and repeatedly, in our case the process is repeated every 5 seconds.

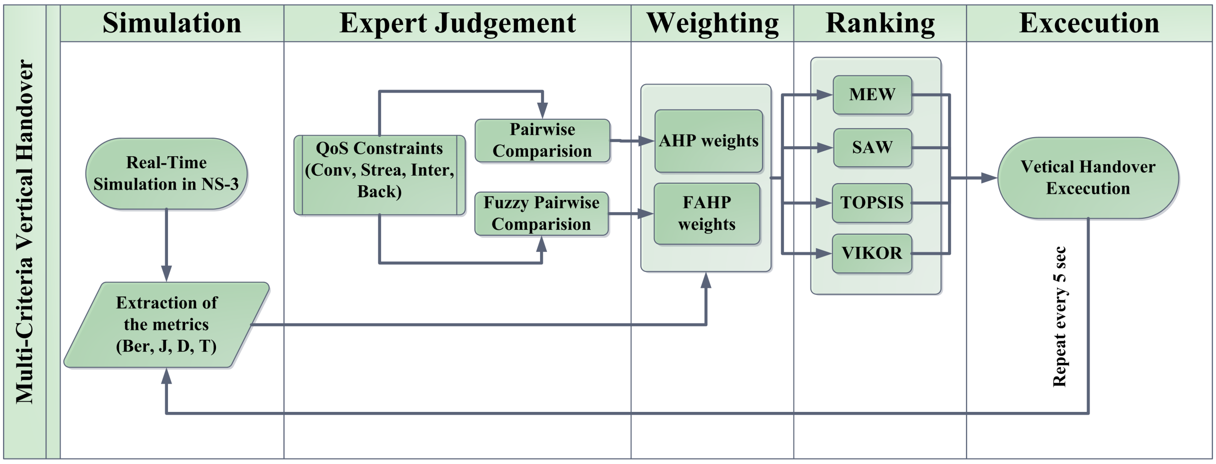


Figure 3.2: MADM-based Algorithm Block

3.3.1 Weighting Distribution Phase

The weighting of the criteria is an important step in the decision-making process. In this phase, decision makers express their preferences between the criteria by weighting or the relative weight they attribute to each criterion. Weight therefore expresses the importance given by a decision-maker to a criterion. There are different weighting methods to calculate the weight of each criterion. These methods can be categorized into two categories. The first category represents subjective weighting methods. The subjective determination of weights leads to several sets of weights that reflect different scales of values and opinions that may be divergent. Among the methods of this category, we cite AHP and FAHP. The second category represents the objective weighting in which decision makers do not intervene to assign weights. The degree of importance of each criterion is calculated according to the numerical measures of the set of criteria. This category contains methods such as entropy, random weighting, and genetic algorithms.

3.3.1.1 Weighting Distribution by AHP (Drissi and Oumsis, 2015a)

Algorithm steps Weight computing requires answering to a sequence of comparisons between a pair metrics. The common way to ask a question is to consider two elements, and find out which one satisfies the criterion more. The answers are given by using the fundamental 1-9 AHP scale Saaty (1987) in Table 3.1 presented in section 3.2.3.1. Table 3.3 presents the answers of the questions asked about the relative importance between each pair of metric Bit Error Rate (BER), Jitter (J), Delay (D) and Throughput (T) , for example, in Conversational Class, the first comparison is (BER, Jitter), the question is : How much more is BER preferred over Jitter in conversational Class? Indeed, Jitter is 7 times more important than BER, so the value in matrix is 1/7, and accordingly 7 is put in the opposite side (symmetrical to the diagonal).

Table 3.3: Judgement AHP Matrices for each Traffic Class.

Conv	Ber	J	D	T
Ber	1	1/7	1/7	3
J	7	1	3	7
D	7	1/3	1	7
T	1/3	1/7	1/7	1

Inter	Ber	J	D	T
Ber	1	3	7	3
J	1/3	1	5	3
D	1/7	1/5	1	1/7
T	1/3	1/3	7	1

Strea	Ber	J	D	T
Ber	1	1/3	1/7	1/7
J	3	1	1/3	1/3
D	7	3	1	1/3
T	7	3	3	1

Back	Ber	J	D	T
Ber	1	7	7	9
J	1/7	1	3	5
D	1/7	1/3	1	5
T	1/9	1/5	1/5	1

In Stevens-Navarro and Wong (2006) , authors explained that if C is defined as an AHP comparison matrix as in Table 3.11, then by solving the system : $U.w = n_{max}$ (where n_{max} is the largest eigenvalue of U), the priority or importance vector w can be obtained. Thus, the weights rely on the QoS prerequisite of the traffic classes. We use the eigenvector method used by the AHP to figure out the weights presented in Table 3.4.

Table 3.4: Importance Weights Per Class by AHP Drissi and Oumsis (2015a).

Traffic Class	**Ber**	**Jitter**	**Delay**	**Throughput**
Conversational	0.07968	0.55464	0.31956	0.04610
Streaming	0.05104	0.13444	0.29493	0.51957
Interactive	0.50385	0.27509	0.04608	0.17496
Background	0.68037	0.17644	0.10390	0.03926

AHP critics AHP is easy to implement. Moreover, it has the advantage of modelling the problem of decision by a hierarchical structure. Moreover, it uses a semantic scale to express the preferences of the decision-maker. However, AHP has been the subject of several criticisms:

- It requires dependency between elements of the same hierarchical level.
- A large number of elements in the decision problem increases the number of paired comparisons.
- The problem of reversal of rank or what is also called an anomaly of the ranking (two actions may have their order of priority reversed following a modification (addition or deletion of one or more actions) of all the actions
- The association of a numerical scale with the semantic scale is restrictive, it introduces imprecise numerical values

In order to avoid these various limitations, AHP method has to be the subject of several extensions to be considered in the expression of judgements and adapted to network selection.

3.3.1.2 Weighting Distribution by Fuzzy AHP (Drissi et al., 2016b)

Algorithm steps To compare the FAHP with our previous work Drissi and Oumsis (2015a), we translated the weights of the previous work regarding the Triangular Fuzzy Conversion Scale of Büyüközkan et al. (2008), shown in Table 3.2 presented in section 3.2.3.2. Hence we generated the fuzzy relative importance for each class of traffic namely: Conversational (Conv), Streaming (Strea), Interactive (Inter) and Background (Back) and for each metric (BER), Jitter (J), Delay (D) and Throughput (T) presented in Table 3.5.

Table 3.5: Judgment FAHP Matrices for each Traffic Class.

Conv	Ber	J	D	T
Ber	$(1,1,1)$	$(\frac{1}{3},\frac{2}{5},\frac{1}{2})$	$(\frac{1}{3},\frac{2}{5},\frac{1}{2})$	$(1,\frac{3}{2},2)$
J	$(2,\frac{5}{2},3)$	$(1,1,1)$	$(1,\frac{3}{2},2)$	$(2,\frac{5}{2},3)$
D	$(2,\frac{5}{2},3)$	$(\frac{1}{2},\frac{2}{3},1)$	$(1,1,1)$	$(2,\frac{5}{2},3)$
T	$(\frac{1}{2},\frac{2}{3},1)$	$(\frac{1}{5},\frac{2}{5},\frac{1}{2})$	$(\frac{1}{5},\frac{2}{5},\frac{1}{2})$	$(1,1,1)$

Inter	Ber	J	D	T
Ber	$(1,1,1)$	$(1,\frac{3}{2},2)$	$(2,\frac{5}{2},3)$	$(1,\frac{3}{2},2)$
J	$(\frac{1}{2},\frac{2}{3},1)$	$(1,1,1)$	$(\frac{2}{5},\frac{1}{2},\frac{2}{3})$	$(1,\frac{3}{2},2)$
D	$(\frac{1}{3},\frac{2}{5},\frac{1}{2})$	$(\frac{3}{2},2,\frac{5}{2})$	$(1,1,1)$	$(\frac{1}{3},\frac{2}{5},\frac{1}{2})$
T	$(\frac{1}{2},\frac{2}{3},1)$	$(\frac{1}{2},\frac{2}{3},1)$	$(2,\frac{5}{2},3)$	$(1,1,1)$

Strea	Ber	J	D	T
Ber	$(1,1,1)$	$(\frac{1}{2},\frac{2}{3},1)$	$(\frac{1}{3},\frac{2}{5},\frac{1}{2})$	$(\frac{1}{3},\frac{2}{5},\frac{1}{2})$
J	$(1,\frac{3}{2},2)$	$(1,1,1)$	$(\frac{1}{2},\frac{2}{3},1)$	$(\frac{1}{2},\frac{2}{3},1)$
D	$(2,\frac{5}{2},3)$	$(1,\frac{3}{2},2)$	$(1,1,1)$	$(\frac{1}{2},\frac{2}{3},1)$
T	$(2,\frac{5}{2},3)$	$(1,\frac{3}{2},2)$	$(1,\frac{3}{2},2)$	$(1,1,1)$

Back	Ber	J	D	T
Ber	$(1,1,1)$	$(2,\frac{5}{2},3)$	$(2,\frac{5}{2},3)$	$(\frac{5}{2},3,\frac{7}{2})$
J	$(\frac{1}{3},\frac{2}{5},\frac{1}{2})$	$(1,1,1)$	$(1,\frac{3}{2},2)$	$(\frac{3}{2},2,\frac{5}{2})$
D	$(\frac{1}{3},\frac{2}{5},\frac{1}{2})$	$(\frac{1}{2},\frac{2}{3},1)$	$(1,1,1)$	$(\frac{3}{2},2,\frac{5}{2})$
T	$(\frac{2}{7},\frac{1}{3},\frac{2}{5})$	$(\frac{2}{5},\frac{1}{2},\frac{2}{3})$	$(\frac{2}{5},\frac{1}{2},\frac{2}{3})$	$(1,1,1)$

We reviewed the mathematical logic of fuzzy AHP of Chang Chang (1996) since it has a wide influence on the theories and applications of fuzzy AHP used in many recent researches. Accordingly, we calculated the fuzzy weighted importance of each class of traffic using the Extent Analysis Method, the value of fuzzy synthetic extent with respect to the i_{th} object is defined in eq.3.20:

$$S_i = \sum_{j=1}^{m} q_{ij} \odot \left[\sum_{i=1}^{n} \sum_{j=1}^{m} q_{ij} \right]^{-1} \tag{3.20}$$

The possibility of $S_i \geq S_j$ is defined as $V(S_i \geq S_j) = SUP_{x \geq y} \left[min(S_i(x), S_j(y)) \right]$, x and y are the values on the axis of the membership function of each criterion as shown in figure 3.3. This expression can be equivalently written as:

$$V(S_i \geq S_j) = \begin{cases} 1, & m_i \geq m_j \\ 0, & l_j \geq u_i \\ \frac{l_j - u_i}{(m_i - u_i)(m_j - l_j)}, & Otherwise \end{cases} \tag{3.21}$$

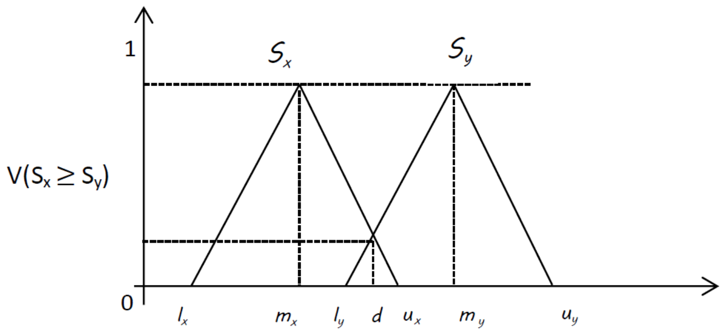


Figure 3.3: Membership Function of Criterion x and y.

The degree possibility for a convex fuzzy number to be greater than k convex fuzzy numbers $S_i(i = 1, 2.....k)$ defined in Chang (1996) by :

$$\begin{aligned} V(S \geqslant S_1, S_2.....S_k) &= V[(S \geqslant S_1,) \cap (S \geqslant S_2) \cap .. \cap (S \geqslant S_k)] \\ &= min(V(S \geqslant S_i)), i = 1, 2, ..., k. \end{aligned} \tag{3.22}$$

In this case the weight vector is given by : $W' = (w'(A_1), w'(A_2)...w'(A_m)$ where $A_i(i = 1, 2, ..., m)$ are m attributes. Via normalization, we get the normalized weight vectors, where W is a non-fuzzy number.

$$W = (w(A_1), w(A_2)...w(A_m))^T \tag{3.23}$$

Finally, the Fuzzy AHP method is applied for the four classes of QoS and the weights are correspondingly generated given in table 3.6.

Table 3.6: Importance Weights Per Class by FAHP Drissi et al. (2016b)

Traffic Class	**Ber**	**Jitter**	**Delay**	**Throughput**
Conversational	0.00006	0.45702	0.54286	0.00006
Streaming	0.00005	0.41146	0.17703	0.41146
Interactive	0.41277	0.15101	0.15846	0.27776
Background	0.83725	0.00010	0.16257	0.00008

Using AHP and FAHP weights, the available networks are ranked by SAW, VIKOR, MEW and TOPSIS.

FAHP critics Similar to AHP, FAHP has the same limitations as AHP except that it is able to associate a numeric scale with that semantic in an efficient and more neutral way. The inaccuracy caused by the decisions of the decision maker on the preferences between the alternative networks in AHP is avoided if it is combined with fuzzy logic.

3.3.2 Algorithm of the Proposed Framework (Drissi et al., 2017d)

Algorithm 3.1 MADM-based UE Real time Selection Algorithm

Data : UE' Application preferences.
Result: Best Network.

while The application is running **do**
  loop
    Every 5 seconds
    for all Available Network: $a_i/i = 1, 2, ..., N$ **do**

- weighting phase: AHP or FAHP
- Extract real-time QoS measurements
- Ranking Phase: SAW, MEW, TOPSIS or VIKOR (Section 3.2.3)
- Select the best Network N according to each method

    end for
    Handover to Network N
  end loop
end while

3.4 Conclusion

In order to reach the required QoS for all types of traffic and avoid service discontinuity in heterogeneous networks, we implemented, in this chapter, a Multi-Criteria Decision Framework for Network Selection for an ubiquitous and real time network selection based on AHP and FAHP methods coupled with four ranking Methods, i.e. TOPSIS, VIKOR, MEW and SAW to prove the effectiveness of the fuzzy enhancement. FAHP is used to produce the fuzzy weights in favour of ranking the candidate networks regarding the multi criteria concept. The fuzzy improvement enables to raise the QoS in all types of traffic, comparing with the use of classical AHP weights. It is due to the fact that the choice of the selected network is not distorted by the human intervention.

Chapter

4 Load Balanced Network Selection Algorithm in Heterogeneous Networks using Matching Game

Contents

4.1 Introduction

In this chapter, we focus on the real time selection of the always best connected network in heterogeneous environment using utility function, while maintaining QoS for multimedia services (Conversational, Streaming, Interactive and Background). We adopt, thereby, a utility-function based approach to enhance vertical handover decision; it enables a seamless real-time handover decision according to the network parameters and user's preferences. We give a detailed description of the utility-function based algorithm proposed in two versions. The first approach is concerned with the heterogeneous networks of different generations and the second one is particular developed for LTE Cells.

Through this chapter, we propose a solution that provides a context-aware Access Point (AP) selection and association of UEs, which considers the type of application used, to available networks in heterogeneous environment. This scheme focuses on enabling simultaneous invocation of applications with different traffic and QoS characteristics by the UEs. This solution considers also various link parameters that provide the best solution in terms of QoS which makes it a QoS-aware solution as well. The real time context-aware and QoS-aware access point selection method is based on matching theory. We formulate, thereby, our problem as a matching game, aiming to meet the required QoS of cellular users, randomly distributed heterogeneous networks, then we propose an algorithm that computes the optimal stable matching entailing the assignment of all users to the most suitable network regarding the type of the service each user need. To our best knowledge, a few numbers of works have been published to address user network selection based on QoS-Aware and Context-Aware as well, by putting to use multi Multiple Criteria Decision Making, Fuzzy Logic, Utility Function and Matching Game. The difference between our proposed scheme and the existing schemes mentioned above lies in the followings: (1). We propose a novel access point selection approach for maximizing performance QoS metrics and minimizing cost QoS metrics regarding the type of traffic asked by users. (2). We formulate the problem as a many-to-one matching game in which each user is assigned to one network. (3). We propose a new version of DA which corresponds to our UEs -APs matching goals, in which UEs and APs make their decisions based on their individual preferences (e.g., Type of traffic and QoS metrics).

4.2 Matching Game Theory-based Schemes

4.2.1 Utility Function Formulation

The VHD is a measure of the performance of a particular network. It is evaluated for each network that covers a user's service area. It is a sum of weighted functions of specific parameters. The utility function is used, in network selection, to evaluate the reachable wireless networks discovered (bandwidth and movement speed as factors) and to quantify the QoS provided by the wireless network.

4.2.1.1 Estimating Network Conditions

To capture the satisfaction level of mobile user when served by some network, utility function is used to measure the normalized satisfaction of mobile user by taking into account different criterion. The utility function represents how mobile user satisfaction is varying from low to high values with respect to user's needs in certain situation. The situation can be a type of application used by the user, the network link state, user's preferences or a predefined QoS level as in Trestian et al. (2012a).

4.2.1.2 Mathematical Model

The utility function is a mathematical model that describes the level of satisfaction of a decision maker or a specific objective in terms of several variables. This function is often used in the fields of economics and finance. It allows to measure in a subjective way the degree of satisfaction of the customer. For the network selection process, the utility function represents the degree of satisfaction of the mobile terminal with respect to a set of services offered by the target network. This function is defined as follows:

$$U_i = \sum_{j=1}^{M} w_j \cdot f_j(n_{ij}) \tag{4.1}$$

w_j is the weight vector. n_{ij} is the value of normalized metric j of network i. M is the number of criterion of each alternative. $f()$ represents the normalization function.

4.2.2 Game Theory

The imbalance between the growing demands of users and limited radio resources poses an imminent challenge in the effective selection of the network. In this context, an efficient dynamic network selection faces several challenges: a) user mobility and network topology is dynamic, b) different network infrastructures are likely to interact in the future ; C) users can have different behaviors when accessing the available networks (according to their needs); and d) the optimization of network sharing in a centralized approach is generally a problem of multi-objective optimization, very Difficult to analyze and solve. Therefore, Game Theory (GT) Fudenberg and Tirole (1991) is seen as a natural paradigm for studying a network where terminals compete with each other for a common goal of access to the best network. Game theory is a mathematical tool that analyses strategic interactions between rational decision-makers. The simplest representation of a game is the normal form defined as follows:

Definition 1. Normal Form Game Fudenberg and Tirole (1991)

A game in normal form is denoted by $\{K, S, u_k \forall k \in K\}$ and is composed of three elements:

- a set of players: $K = \{1, 2, \ldots, K\}$
- a set of strategy profiles:$S = S_1 \times \ldots \times S_K$ where S_k is the strategy set of the k^{th} player
- a set of utility functions: The k^{th} player's utility function is $u_k : S \longrightarrow R_+$ and is denoted by $u_k(s_k, s_{-k})$ where $s_k \in S_K$ and $s_{-k} = (s_1, \ldots, s_{k-1}, s_{k+1}, \ldots, s_K) \in S_1 \times \ldots \times S_{k-1} \times S_{k+1} \times \ldots \times S_K$.

The set of players is a finite set $K \subset N$ of which each element represents a player. The strategy set Sk contains the set of actions player k might take in the game. The utility function $u_k(sk, s_{-k})$ allows a player to evaluate the convenience of its strategy s_k with respect to the other players' strategies s_{-k}

4.2.3 Matching Theory

Wireless networks can be described as a diverse interacting selfish and rational agents with a natural propensity to solicit their maximum benefit from the network without caring about other agents, Game theory which has been widely used in open literature to facilitate autonomous network management and dynamic resource allocation cannot deal with complex networks, in which, different types of agents with various characteristics and requirements want to interact with each other, and conventional game theoretical models can hardly be utilized Bayat et al. (2016).

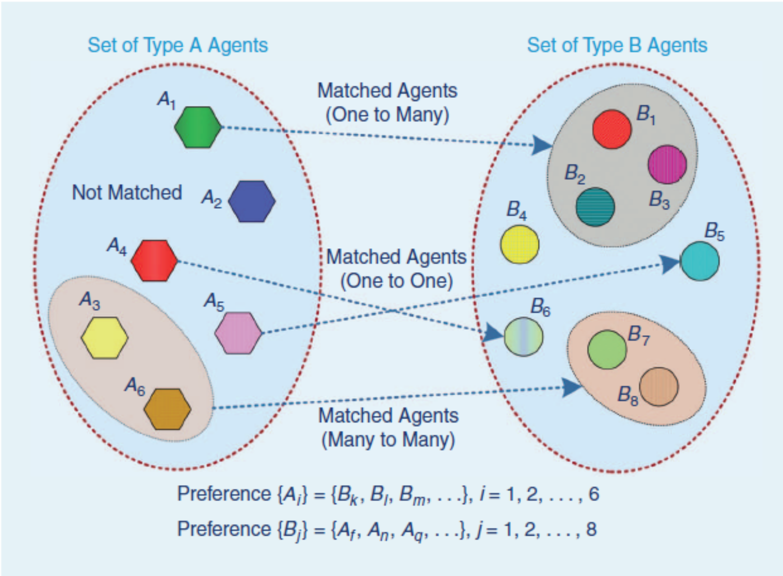


Figure 4.1: The general configuration of the matching structure Bayat et al. (2016).

Recently, matching theory has emerged as a promising technique for wireless resource allocation which can overcome some limitations of game theory and optimization. Matching theory is a Nobel-prize winning framework that provides mathematically tractable solutions for the combinatorial problem of matching players in two distinct sets , depending on the individual information and preference of each player. The advantages of matching theory for wireless resource management include: 1) suitable models for characterizing interactions between heterogeneous nodes, each of which has its own type, objective, and information, 2) ability to define general "preferences" that can handle heterogeneous and complex considerations related to wireless QoS, 3) suitable solutions, in terms of stability and optimality, that accurately reflect different system objectives, and 4) efficient algorithmic implementations that are inherently self-organizing and amenable to fast implementation Irving et al. (1987), Roth and Sotomayor (1992), Naparstek et al. (2014).

In game theory, utility is a measure of motivation of a player over a set of actions and evaluate the overall satisfaction of a player in matching games. It combines all the multiple related parameters to a single number to represent the net losses and gainsHossain et al. (2009). These parameters can be of different types. Utility functions have been widely used in wireless literature to model various radio resource management problems Liu et al. (2006),Jiang et al. (2005).

4.2.3.1 Preference list

The main goal of matching is to optimally match two sets of agents together, given their individual utilities. [Although the main matching models in the literature are between the two sets of agents, it should be noted that there are matching models that are among the agents in one set only (that are basic cooperative game models), and matching models among three sets of agents Eriksson et al. (2006). known as three-dimensional matching. It is notable that three-dimensional matchings are still under study and are beyond the scope of this tutorial.]

4.2.3.2 Basic Matching Definitions

The basic wireless resource management problem can be posed as a matching problem between resources and users. Depending on the scenario, the resources can be of different abstraction levels, representing base stations, time-frequency chunks, power, or others. Users can be devices, stations, or smartphone applications. Each user and resource has a quota that defines the maximum number of players with which it can be matched. The main goal of matching is to optimally match resources and users, given their individual, often different objectives and learned information. Each user (resource) builds a ranking of the resources (users) using a preference relation. The concept of a preference represents the individual view that each resource or user has on the other set, based on local information. In its basic form, a preference can simply be defined in terms of an objective utility function that quantifies the QoS achieved by a certain resource-user matching. However, a preference is more generic than a utility function in that it can incorporate additional qualitative measures extracted from the information available to users and resources Gu et al. (2015). A matching is essentially an allocation between resources and users. The basic solution concept for a matching problem is the so-called two-sided stable matching. A matching is said to be two-sided stable, if and only if there is no blocking pair (BP). A BP for a stable marriage case is defined as a pair of user and resource (u, r), where u prefers r to its currently matched user j, and r prefers u to its currently matched resource k. Thus, u will leave i to be matched to r and r would prefer being matched to user u than user k.

4.2.3.3 Conventional Classification

The classical classification of matching problems is based on the values of the player quotas as follows :

- One-to-one matching: Each player can be matched to at most one member of the opposite set. The most prominent example is the stable marriage problem in which men and women need to be matched for marriage.

- Many-to-one matching: Here, in one of the sets, at least one player can be matched to multiple players of the opposing set, while in the other set, every player has exactly one match. One example is the college admissions problem in which one student can be matched to one university while a university can recruit multiple students.
- Many-to-many matching: At least one player within each of the two sets could be matched to more than one member in the other set. Many-to-many matching is the most general type of problems and it admits many examples such as creating partnerships in peer-to-peer networks.

There exists other classifications for matching problems, such as based on the partitioning of players, and the preference requirement for players. However, such classes can be often derived as special cases of the above matching problems.

4.2.3.4 Basic Algorithmic Solution: Deferred Acceptance

The seminal result in matching theory shows that at least one stable matching exists for general preferences in conventional one-to-one and one-to-many gamesGale and Shapley (1962). This work also introduced an efficient algorithm, known as the Deferred Algorithm (DA) algorithm (polynomial time for one-to-one and empirically very fast for one-to-many) which can find such a matching. DA is an iterative procedure, shown in figure 4.2, in which players in one set make proposals to the other set, whose players, in turn, decide to accept or reject these proposals, respecting their quota. Users and resources make their decisions based on their individual preferences (e.g., available information or QoS metric). This process admits many distributed implementations which do not require the players to know each other's preferences Gale and Shapley (1962)

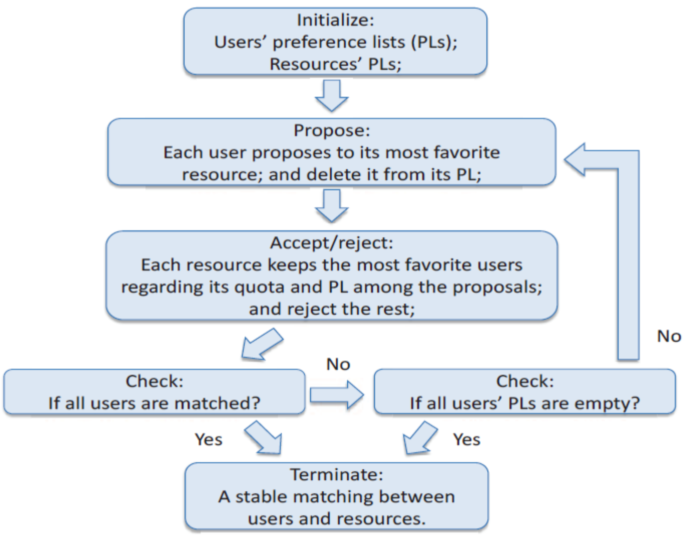


Figure 4.2: Deferred Acceptance (DA) Algorithm Gu et al. (2015).

4.3 Proposed Utility-based Multi-Criteria Selection for Heterogeneous Networks

4.3.1 System Model

For network selection decision, utility function assigned to the satisfaction that a network provides to mobile users. Different available networks with different user preferences will have different utility values. Thus, in this chapter, we propose a context-aware scheme of network selection based on utility function and considers both mobile user's awareness and provider's constraints. The selection decision function is defined as a utility function consisting of four parameters Bandwidth, Delay, Jitter and Bit Error Rate. During the network selection procedure, we consider multiple attributes together, so the utilities of multiple attributes are combined as a total utility. We consider four real time applications.

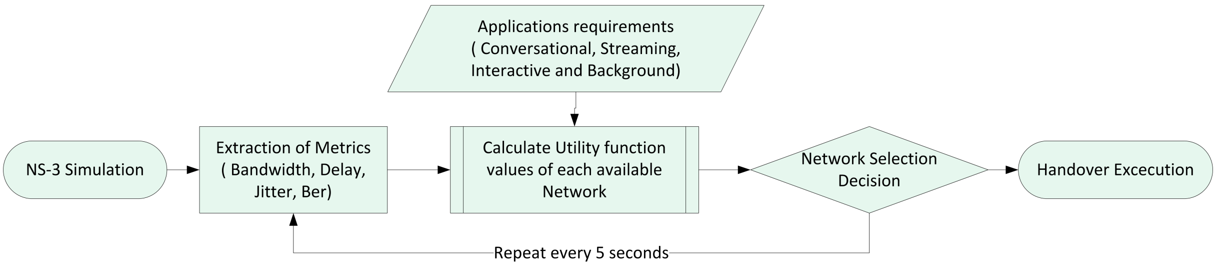


Figure 4.3: Utility-based Algorithm Block.

As reported in the algorithm block in figure 4.3, simulation provides the system with the metrics in real time and a the utility function is applied according to each QoS application: Conversational, Streaming, Interactive and Background involving by that the context awareness of the users.

4.3.2 Utility Computation for Heterogeneous Access Points (Drissi et al., 2017a)

To capture the satisfaction level of mobile user when served by some network, we use utility function, which measures the normalized satisfaction of mobile user by taking into account Bandwidth, Delay, Jitter and Bit Error Rate of each available network. Hence, the utility should be high and the decision is made accordingly. The utility function represents how mobile user satisfaction is varying from low to high values with respect to user's needs in terms of application. The applications that we study in this paper are Conversational, Streaming, Interactive and Background.

Network Selection Decision Network selection QoS metrics can be divided into two categories: Cost metrics and metric of performance. For metric of performance, the best utility value is the largest, like bandwidth, RSS, throughput, reliability degree, etc. Conversely, for a cost metric, the best utility value is the lowest, like delay, jitter, bit error rate, etc. However, in order to define a utility function that considers mobile user's needs, the network metrics are not enough. Thus, another important factor that has been considered is the type of applications in terms of QoS requirements. Indeed, applications are classified as inelastic, partially elastic and perfectly elastic based on their sensitivity to QoS parameters. For example, real-time voice (Conversational) and video applications (Streaming) are inelastic in their demand for bandwidth and their delay requirements, whereas data transfer, e-mail or web browsing (Interactive and Background) applications are considered perfectly elastic, i.e. tolerant to variations in bandwidth and delay Shenker (1995). The equations below define the mathematical models of utility-function for both performance and cost metrics.

For a metric of performance, the utility is calculated as follow:

$$f_{Performance}(x) = \frac{min(x, x_{max}) - x_{min}}{x_{max} - x_{min}} \tag{4.2}$$

For a cost metric, the utility is:

$$f_{Cost}(x) = \frac{x_{max} - max(x, x_{min})}{x_{max} - x_{min}} \tag{4.3}$$

x_{max} et x_{min} are the minimum and the maximum requirements of a metric in a specific type of application, the values of are provided in table 4.1.

Table 4.1: Application QoS requirements and utility function parameters.

	Bandwidth (kbps)		**Delay** (ms)		**Jitter** (ms)		**Bit Error Rate** (%)	
	x_{min}	x_{max}	x_{min}	x_{max}	x_{min}	x_{max}	x_{min}	x_{max}
Conversational	512	1024	5	100	2	30	0	2
Streaming	1024	2048	5	50	2	20	0	1
Interactive	512	1048	5	20	2	10	0	3
Background	256	512	5	120	2	40	0	5

Finally, in order to determine the relevance R_{ij} of network i for an application j (Eq. (4.10)), we combine the utility values of all metrics using three calibration coefficients as following:

$$R_{ij} = \alpha \cdot f_{Bandwidth} + \beta \cdot f_{Delay} + \gamma \cdot f_{Jitter} + \delta \cdot f_{BitErrorRate} \tag{4.4}$$

Where $\alpha + \beta + \gamma + \delta = 1$. Eq. (4.4) $0 \leq R_{ij} \leq 1$ the closer R_{ij} is to 1, the more relevant network i is to application j.

In a scenario where bandwidth, delay, jitter and bit error rate are evenly set up, we take $\alpha = \beta = \gamma = \delta = 1/4$. However, many conceivable scenarios can be patterned by conveniently assessing α, β, γ and δ.

4.3.3 Customized Utility Computation for LTE Heterogeneous cells (Drissi et al., 2016c)

LTE networks consist of deploying heterogeneous cells with different access in terms of Quality of Service (QoS) metrics such as: Bandwidth, latency, coverage range... etc. One of the critical issues that affect the QoS of connection is the choice of next handed network during the Handover. Handover is a system by which mobile node keeps its connection active even when it wanders from the coverage area of one cell to another's. In LTE the X2-Handover procedure is used for the inter-eNB handover which is the subject of our paper. It is crucial because the participating cells are heterogeneous and have different characteristics. In this case the signal strength sometimes is not sufficient to handle the handover and therefore dynamic parameters like velocity and delay should be considered.

LTE macrocells support multimedia services over a wide range of coverage whereas femtocells cover a limited area both with high bandwidth, they are complementary to each other in terms of coverage, thus the integration of such small cells overcome limitations of coverage and the user can move easily. In such overlapped coverage, appropriate handover decision reduces the number of unnecessary handover. In 3GPP LTE, handover depends on properties such as UE-assisted, where the UE provides measurement report to the network. And Network-controlled property where the network (i.e. source and target eNBs communicate) makes a decision when to trigger the handover and launch its execution. Such scheme decreases the QoS of application. It need an enhancement in terms of number of handovers, satisfaction of QoS required by users and execution of a seamless switching from one network to another with minimum loss rate. To this end, we propose a simple handover algorithm that confronts these challenges in Macrocell / Femtocell high speed scenario.

4.3.3.1 Background of LTE Handover Procedure

In this section, we present some backgrounds on the classical handover procedure in LTE 3GPP. LTE handover procedure within 3GPP LTE defined in LTE (2009) has three main phases: Handover initiation, handover preparation and handover completion.

Handover Initiation The HO procedure starts with the measurement reporting of a handover event by the UE to the serving eNB. The UE periodically performs downlink radio channel measurements based on the reference symbols (RS); namely, the UE can measure the reference symbols received power (RSRP) and the reference symbols received quality (RSRQ). If certain network configured conditions are satisfied, the UE sends the corresponding measurement report indicating the triggered event. In addition, the measurement report indicates the cell to which the UE has to be handed over, which is called target cell. This process is detailed in section 4.3.3.2

Handover Preparation Based on these measurement reports, the serving eNB starts handover preparation. The HO preparation involves exchanging of signalling between serving and target eNB and admission control of the UE in the target cell. The communication interface between the serving and the target eNB is called X2. Upon successful HO preparation, the HO decision is made and consequently the HO Command will be sent to the UE.

The connection between UE and the serving cell will be released. Then, the UE attempts to synchronize and access the target eNB, by using the random access channel (RACH). To speed up the handover procedure, the target cell can allocate a dedicated RACH preamble-included in HO command to the UE. Upon successful synchronization at the target eNB, this last one transmits an uplink scheduling grant to the UE.

Handover Completion The UE responds with a HO Confirm message, which notifies the completion of the HO procedure at the radio access network part. It is noted that the described signalling messages belong to the Radio Resource Control (RRC) protocol.

4.3.3.2 Cell Selection Handover Driven by UE

UE Measurements and Decision Basically, source eNB arranges how UEs report their proximities. When the UE sends approximation indication, source eNB configures the UE with the most recent measurement controls. These measurements include a list of all neighbouring cells which helps the UE in operating a faster and less battery consuming browsing.

If this list is not given, the UE will just detect those cells with a Reference Signal Received Power (RSRP) exceeding the UE's receiver sensitivity. These measurement configurations also include the assignments by which the UE start taking or not any further measurements. Usually, these measurements can be triggered by an event or periodically triggered.

UE Cell Selection One of the critical issues that affect the QoS of a certain connection is the choice of next handed cell during the handover in LTE networks. The network controlled handover where the network (i.e. source and target eNBs) makes a decision when to trigger the handover or not is not suitable for user's preferences considerations. Our cell selection scheme can be processed in Two phases:

- Information collection phase by UE.
- Cell Selection Decision by UE.

Information Collection Phase As a first stage of handover scheme, the information collected by UE will be reported to eNB. It has a decisive impact on the success of the overall handover process.

Indeed, the network must be well controlled to handle a seamless handover with no disruption of the current connection. Thus, information collection process is called regarding the application requirements, network conditions and user preference variations.

Network selection QoS metrics can be divided into two categories: Cost metrics and metric of performance. For metric of performance, the best utility value is the largest, like bandwidth, RSS, throughput, reliability degree, etc. Conversely, for a cost metric, the best utility value is the lowest, like delay, jitter, bit error rate, etc. In our approach handover triggering is based on throughput, delay, jitter and bit error rate with the nearest cell. those metrics are repeatedly reported to the network.

Consequently, the next phase is applied.

Cell Selection Decision The main goal of this phase is to determine, among the available LTE cells, the optimal one for an UE. The selected network must provide the best available QoS and network stability according to the metrics reported in information collection phase by each user. In eNBs sides, Each cell is scored according to the metrics, provided in UE reports in the previous phase, by minimizing the cost metrics and maximizing the performance metrics. The handover decision problem can be formulated as a vector form, where vector elements correspond to the metrics: Throughput, Delay, Jitter and Bit Error Rate. As all evaluated metrics are expressed in different measurement units, it is necessary to convert them into normalized values before attributing scores to the cells. For a metric of performance, the score is calculated as follow:

$$S_{Performance} = \sum_{j=1}^{4} max(n_{ij}) \tag{4.5}$$

For a cost metric, the score is :

$$S_{Cost}(x) == \sum_{j=1}^{4} min(n_{ij}) \tag{4.6}$$

Where n_{ij} is the value of normalized metric i reported by j UE. Finally, in order to determine the overall score C of a cell we combine the score values of all metrics:

$$C = \alpha \times S_{Throughput} + \beta \times S_{Delay} + \gamma \times S_{Jitter} + \delta \times S_{Ber} \tag{4.7}$$

In a scenario where bandwidth, delay, jitter and bit error rate are evenly set up, we take $\alpha = \beta = \gamma = \delta = 1/4$. However, many conceivable scenarios can be patterned by conveniently assessing α, β, γ and δ.

At this step, each cell is scored and in UE side, while roaming between cells, the selection can be made by choosing the nearest cell with minimum score.

4.3.4 Algorithm of the Proposed Utility Scheme

Algorithm 4.1 Utility-based Real time Network Selection Algorithm

Data: UE application preferences.
Result: Best next handed Network.

while The application is running **do**
  loop
    Every 5 seconds
    for all Available Network: $a_i/i = 1, 2, ..., N$ **do**

- Extract Network link state
- Compute utilities of QoS metrics $m_j/j = 1, 2, ..., M$ (Eqs. (4.2) and (4.3))
- Calculate R_{ij} (Eq. (4.4))
- Select Network N, where $R_N = \max_i(R_{ij})$

    end for
    Handover to Network i
  end loop
end while

4.4 Load Balanced Network Selection Algorithm in Heterogeneous Networks using Matching Game

4.4.1 Matching Game Formulartion

4.4.1.1 Network Model

We consider the transmission in a topology consisting of ν access point cells and χ users. Let $\nu = 1, 2, ..., N$ denotes the AP networks set. $\chi = 1, 2, ..., M$ denotes the user set located in the available networks coverage. Each user has a set of available APs i.e., the available APs set of user m denoted by $A_m \subseteq \nu$. Based on each APs condition of loading and UEs preferences, each user (m) can only access one AP (ap) at same time. Explicitly, on one hand, a user's association is not only about link's state, but also about the load on the associated network and resource allocation arrangement used by the network side and on the other hand, the UE has its part of decision since the choice include user's context. For resource allocation arrangement in network side, we use a QoS awareness policy that express the proportional fairness based on a QoS metrics of the links. With these considerations in mind, we propose, also, that APs Selection decision is based on the UE's context, more exactly, the context of different types of service adopted by the UEs.

4.4.1.2 QoS Awareness: Utility Function

To seizure the contentment extent, of an UE when served by an AP, varying from low to high values regarding the QoS requirements, we abstracted the idea of system model 4.3.1, where a scheme of network selection that considers QoS awareness based on utility function consisting of four parameters Bandwidth, Delay, Jitter and Bit Error Rate. According to authors, QoS metrics can be segregated into two groups: Cost metrics and metric of performance. For metric of performance, the best utility value is the largest, such as bandwidth, RSS, throughput, reliability degree, etc. Conversely, for a cost metric, the best utility value is the lowest, as delay, jitter, bit error rate, etc. The equations (Eq. (4.8)) and (Eq. (4.9)) define the utility functions for both performance and cost metrics:

$$u_{Performance}(x) = \frac{min(x, x_{max}) - x_{min}}{x_{max} - x_{min}} \tag{4.8}$$

For a cost metric, the utility is :

$$u_{Cost}(x) = \frac{x_{max} - max(x, x_{min})}{x_{max} - x_{min}} \tag{4.9}$$

x_{max} et x_{min} are the minimum and the maximum requirements of a QoS metric.

Finally, the utility $U_{ap\in\nu}(m)$ of an AP is defined (Eq. (4.10)), as a combination of the utility values of all metrics using calibration coefficients of a value of $w_q = 1/4$ as following:

$$U_{m\in\chi}(ap \in A_m) = \sum_{q\subset Q} w_q \cdot u_q \tag{4.10}$$

Where Q is a set of QoS metrics, namely: Throughput, Delay, Jitter and Bit Error Rate, and $0 \leq U \leq 1$ in which the closer $U_{m\in\chi}(ap \in A_m)$ is to 1, the more relevant the access point ap is to the user m.

In a scenario where throughput, delay, jitter and bit error rate are equally arranged, a calibration of 1/4 is used. Nonetheless, a countless possible sketches can be designed by efficiently gauging the calibration. The most convenient scenario is to express the type of application asked by the UE.

4.4.1.3 Context Awareness: Weight Distribution Algorithm

The concept of context awareness has been widely studied in pervasive computer science, and it is relatively novel in wireless networks. In this section, we used the context awareness as complementary to QoS awareness, defined by the user's context that designates the type of application, i.e, Conversational, Streaming, Interactive and Background. For this purpose, we calibrate the weights w_q in equation (Eq. (4.10)) instead of 1/4 to reveal the importance of a QoS metric in a certain type of application. In furtherance of apprehending such context awareness, we used FAHP proposed in section 3 to calculate the weights w_q of the QoS metric used in the previous section, i.e., Throughput, Delay, Jitter and Bit

Error Rate, for each application used by UE. Pursuant to the authors, FAHP calculates the weight vector w_q which represents the importance of each QoS metric in a certain application. It provides as results $w_q^m > 0$ the weight of the q_{th} metric by UE m. Given that $\sum_{q \subset Q} w_q^m = 1$. The major step of FAHP is to generate the relative fuzzy importance ratio of each pair of QoS metrics as a fuzzy evaluation matrix. Using Triangular Fuzzy Numbers (TFNs) and via pairwise comparison, the fuzzy evaluation matrix $R = (r_{i,j})_{q*q}; q \subset Q$ is modelled for each type of application as : $r_{i,j} = (x_{i,j}, y_{i,j}, z_{i,j})$ and $r_{i,j}^{-1} = (1/z_{i,j}, 1/y_{i,j}, 1/x_{i,j})$ such as $x \leq y \leq z$. Accordingly, the fuzzy weighted importance for all types of applications are calculated using the Extent Analysis Method Chang (1996). The weight vectors are correspondingly generated for each type of application. Upon that, the context awareness is highlighted and the AP selection considers the type of application used by the UE.

4.4.2 Proposed Solution (Drissi et al., 2017c)

4.4.2.1 Problem Formulation

Through the modelling in section 4.4, we are adept to establish the QoS-Aware and Context-Aware AP selection by associating a set of UEs to most suitable AP, for which it can meet the respective QoS requirements. In order to formalize the UE-AP matching problem, we define a suitable QoS-Aware and Context-aware utility function for a UE as follows:

$$U_{m \in \chi}(ap \in A_m) = \sum_{q \subset Q} w_q^m \cdot u_q^m \tag{4.11}$$

Where $\sum_{q \subset Q} w_q(m) = 1$ for each user m. Note that this utility captures QoS awareness that an AP can convey by taking into consideration a set Q of QoS metrics, i.e., Throughput, delay, jitter and bit error rate. Furthermore, the utility in equation (Eq. (4.11)) accordingly reckons for the UE's predilection and context awareness in terms of applications through w_q^m.

Having prescribed such utility in equation (Eq. (4.11)), we plan to solve the problem of matching each UE ($m \in \chi$) in the topology to the most suitable AP ($ap \in A_m$) among available APs set $A_m \subseteq \nu$ through a matching $\rho : \chi \longrightarrow \nu$. Basically, this leads us to the following maximization problem:

$$\max_{\rho:(m,ap)\in\rho} \sum_{m \in \chi} U_{ap \in \nu}(m) = \max_{\rho:(m,ap)\in\rho} \sum_{m \in \chi} \sum_{q \subset Q} w_q^m \cdot u_q^m \tag{5.5}$$

Subject to:

$$\rho(ap, m) \in \{0, 1\}, ap \in A_m, m \in \chi. \tag{5.5.a}$$

Constraint 5.5.a ensures that an available AP ap in our system can be: relevant or irrelevant if accessed by an UE m. $\rho(ap, m)$ stands for the matching index (such as: $\rho(x) = y \Leftrightarrow \rho(x, y) = 1$). It guarantees, also, that user can only access to one AP. We note that the UE-AP association (ap, m) in equation (Eq. (4.11)) is a integer programming problem, which is NP hard program. The complexity will depends on the number of APs and users in the network and significantly increase with the network size Shao et al. (2016).

One advisable strategy for evolving such a self-organizing UE-AP association approach which can solve equation (Eq. (5.5)) is disposed by the framework of matching games detailed in section below.

4.4.2.2 Matching Game Formulation

To determine the best AP for a certain UE regarding the network link state and the UE preferences, we formulate the problem as association scheme that can be solved by the theory of many-to-one matching game where each player can be adapted to several players of the other set. A well-known cases of this problem have been mentioned in Bodine-Baron et al. (2011) such as: matching medical interns to hospitals for residencies, students college admissions, the workers market and classic firms.

In view of this, one UE is matched to only one AP, while one AP can match to many UEs, but has a maximum allowance limit (quota) λ_{max} to not exceed (an AP can service only a maximum number of UEs). The definition is given below. For better perception of the matching game, we assume that $A_m = \nu$ which means that the UEs roam in the coverage of all the APs in the system. Hence, as we defined in section 4.4.1.1, $\nu = \{ap_1, ap_2, ..., ap_N\}$ and $\chi = \{m_1, m_2, ..., m_M\}$ two separate and finite sets, denoting AP networks set and UEs set located in the available networks coverage, respectively. For each AP, there exists a positive integer λ_{max} which indicates the maximum allowance number of positions an AP can afford. The solution of this game is a matching between APs and UE satisfying their predilections and prerequisites is given by the theory of matching games Roth and Sotomayor (1992).

Definition 2. Concept of Matching

A matching is a subset $\rho \in \varrho \subseteq \chi \otimes \nu$ such that:

$$\begin{cases} |\rho(m)| & = 1 \\ |\rho(ap)| & = \lambda_{max} \end{cases} \tag{4.13}$$

Where:

$$\rho(m) = \{ap \in \nu : (m, ap) \in \varrho\}. \tag{5.6.a}$$

And:

$$\rho(ap) = \{m \in \chi : (m, ap) \in \varrho\}. \tag{5.6.b}$$

Definition 3. Concept of Matching Stability

A matching ρ is said to be two-sided stable if and only if there is no blocking pair.

Definition 4. Concept of Matching Blocking

The matching $\rho(m, ap)$ is blocked by a player if this latter choose to be unmatched instead of being matched at $\rho(m, ap)$.

According to Hamidouche et al. (2016) stability refers to the state in which a player would not have the incentive to leave its group of players given that the other players have selected their partners or group mates. Thus, the stability is the goal of the matching game.

At this point, each UE can define its preferences over available APs implicitly by the weights in the utility function in equation (Eq. (5.5)) considering that an AP is either relevant or irrelevant to the UE according to the constraint 5.5.a. Whereas an AP must respect a quota while defining its preferences over UEs. Here, we define an Ap preference relation over UEs.

Definition 5. Preference Relation

Preference relation $\succ$ is defined as a complete, reflexive, and transitive binary relation over a list of APs, allowing each player UE $Um \in \chi$ to build a list of preferences over APs, i.e., to rank, the players in ν.

Correspondingly, for any UE m a preference relation $\succ$ over the set of APs ν is labelled as follow: For any two APs $ap, ap^* \in \nu$, $ap \neq ap^*$, and two matching $\rho, \rho^* \in \varrho \subseteq \chi \otimes \nu$. Where $ap = \rho(m), ap^* = \rho^*(m)$:

$$\rho(m, ap) \succ \rho^*(m, ap^*) \Leftrightarrow U_{ap \in \nu}(m) \succ U_{ap^* \in \nu}(m) \tag{5.7}$$

Accordingly, By observing the preference relation in equation (Eq. (5.7)), we can affirm that the choice of an Access Point do depend on the other decisions made by the UEs in the network. Thus, the preferences of UEs and APs consider the existing matching in the topology.

4.4.3 Proposed Algorithm

Heretofore, we have modelled the problem stated in (Eq. (5.5)) as a many-to-one matching game where the players are the access points APs and users UEs. Each user is able to choose and apply to the most suitable APs regarding the type of traffic used. Conversely, the AP can enlist one or more users respecting the maximum number of allowance λ_{max}. As a distributed algorithm, we propose that the APs and UEs define individual preferences over one another, based on weights computation in equation (Eq. (4.11)) for the UEs and the preference relations in equation (Eq. (5.7)) for the APs.

To identify a stable matching for UE-AP association, we propose Algorithm 4.2, composed of two main fragments: Context-Awareness and QoS-Awareness utility formulation and Matching Assessment. At the first beginning, the UEs are formerly assigned to a certain AP. The first fragment consists of exchanging context data and network performance metrics between UEs and APs. Every UE $m \in \chi$ pinpoints the set of APs ν in its neighbourhood and the utilities are accordingly calculated. The second fragment covers the matching evaluation. Using the preference relations (Eq. (5.7)), each AP creates and ranks a waiting lists and rejects the rest users. The UEs enrolled to a certain AP cancel the proposals to the other APs and the rejected ones reapply to other APs. This process is repeated until convergence to stability of matching.

Algorithm 4.2 QoS aware and Context Aware Matching AP Selection Algorithm

Data: UEs former assignment to APs
Result: A stable matching $\{\rho(m, ap) | \forall m \in \chi, \forall ap \in \nu\}$

Fragment I: Context-Awareness and QoS-Awareness formulation.
UEs weights Computation:
for all $m \in \chi$ **do**
- UEs ascertain the weights $w_q, \forall q \in Q$
- UEs communicate the weights w_q to the APs $\forall ap \in \nu$ in their neighbourhoods.

end for
APs Utility Computation:
for all $ap \in \nu$ **do**
- QoS metrics collection in real time
- Calculate $U_{ap \in \nu}(m \in \chi) = \sum_{q \subset Q} w_q^m \cdot u_q^m$, $\forall m \in \chi$, (Eq. (4.11))

end for

Fragment II: Matching Assessment
repeat
  for all $m \in \chi$, $ap \in \nu$ **do**
  - APs acknowledge $U_{ap \in \nu}(m \in \chi)$ to UEs
  - UEs rank APs regarding preference relation $\succ$ in (Eq. (5.7)).
  - UEs select most matched AP and cancel requests to other APs.
  - APs admit λ_{max}^{ap} UEs and reject the rest
  - The rejected UEs re-apply to the next AP in their lists.

  end for
until All UEs are enlisted at APs $\Rightarrow$ Reach a stable matching ρ.

4.4.3.1 Numerical Example

Let us discern algorithm 4.2 in a small size example. Figure 4.4 presents An example of the problem of matching solved in this chapter, in a topology consisting of three UEs trying to select the best AP among two APs. $\chi = \{ue1, ue2, ue3\}$ and $\nu = \{ap1, ap2\}$. Let's suppose that each AP admits two UE, $\lambda_{max} = 2$. UEs supply the computed weights to the APs. Each AP calculates and ranks the utilities according to the user's needs and considering $q \subset Q$ QoS metrics and choose $\lambda_{max} = 2$ UEs.

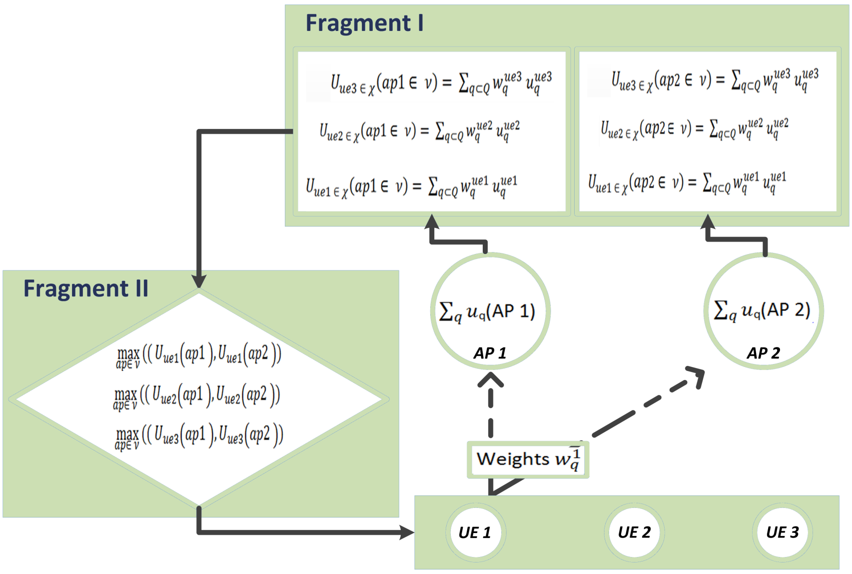


Figure 4.4: A matching example of three UEs and two APs.

Tables 4.2 and 4.3 depicts, respectively, the UEs weights supplied to the APs and the real time link measurements of the available APs. According to equation (Eq. (4.11)), the first fragment of algorithm 4.2 is executed and the calculated utilities are presented in table 4.4. By running the second fragment of the algorithm, the utilities are acknowledged to the UEs and the ranking lists are generated. The UEs select the most matched AP, hence, $ue2$ chooses to connect to $ap2$. In the second iteration, $ue3$ has to make a decision between $ap1$ and $ap2$, it selects $ap2$ in consideration of the maximal utility and since $\lambda_{max} = 2$, $ue1$ is rejected from the $ap2$ list. $ue2$ and $ue3$ cancel requests to $ap2$. Finally, $ue1$ is admitted to $ap2$ as the list is empty and still can afford users. Thereby, a stable matching is reached shown in table 4.5.

Table 4.2: UEs Weights calculated by FAHP (table 3.6).

UEs	Ber	Jitter	Delay	Throughput
UE 1	0.08	0.55	0.32	0.05
UE 2	0.05	0.14	0.29	0.52
UE 3	0.50	0.28	0.05	0.17

Table 4.3: Real time Link Measurements of APs.

APs	Ber [%]	Jitter [ms]	Delay [ms]	Throughput[$kbps$]
AP 1	1	15	50	1024
AP 2	3	10	30	512

Table 4.4: Normalized Utilities Computation and UEs ranking Lists.

APs	$UE1$	$UE2$	$UE3$	UE Lists
AP 1	0.09	0.68	0.23	$\{ue2; ue3; ue1\}$
AP 2	0.10	0.67	0.23	$\{ue2; ue3; ue1\}$
AP Lists	$\{ap1; ap2\}$	$\{ap1; ap2\}$	$\{ap1; ap2\}$	

Table 4.5: The stable matching.

λ_{max}	APs	UEs
2	$ap1$	$ue2$,$ue3$
2	$ap2$	$ue1$

4.4.3.2 Summary of Proposed Scheme with Baseline Schemes

Obviously, the access point selection based on matching users and access points based on QoS and the user's context yields a significant performance gains. Table 4.6 shows a comparison of the conspicuous features of different existing network selection strategies compared with the proposed scheme.

Table 4.6: Comparison of the Proposed Scheme with Baseline Schemes Aryafar et al. (2013)Drissi and Oumsis (2015a)Drissi et al. (2016b)Drissi et al. (2017a).

AP Selection Schemes	Context preferences	Multi-attribute	Autonomy	Complexity
Max-SINR	No	No	High	Low
Max-Throughput	No	No	High	Low
Simple Weighting	No	Yes	Low	Medium
Fuzzy Weighting	No	Yes	Medium	High
QoS-based Function	No	Yes	Low	Low
Proposed Scheme	Yes	Yes	High	Medium

4.5 Conclusion

In heterogeneous networks, the required QoS can be achieved through an efficient VHD that combines the requirements of mobile users and networks. In this chapter, we proposed a context-aware scheme of network selection based on utility function and considers both mobile user's needs and provider's constraints. On one hand, The selection decision function is defined as a utility function consisting of four parameters bandwidth, delay, jitter and bit error rate. We have considered four distinct real time applications in the process of selection. On the other hand we implemented two versions of the scheme. The first one is applicable to heterogeneous of different types and the second one is dedicated to LTE cells.

In wireless heterogeneous networks, the compulsory QoS perceived by users and affordable from operators can be attained through an ubiquitous vertical handover that fuses the mobile users prerequisite and networks capacities. In this chapter, we proposed a QoS -aware and context-aware scheme of network selection based on matching theory which considers both mobile user's needs and provider's hindrances. The decision operation inflicts the agreement of both sides. Indeed, the matching of UEs to APs considers preferences lists based on utility function on the network side, consisting of four QoS metrics, i.e., throughput, delay, jitter and bit error rate. Whilst, on the user side, a set of weights are generated to express the context awareness of the type of application used by each user.

Chapter 5

Application for Heterogeneous Network in Mobile Scenarios

Contents

5.1 Introduction

Performance assessment is one of the most challenging challenges often faced by proposed solutions in the context of network selection. Indeed, to judge that such a solution of the handover is better compared to another, it is essential to compare the performances of these solutions. To make this comparison, two points must be taken into account, the first being the choice of the platform, the evaluation model and the identification of the evaluation parameters. Given the usefulness of the evaluation as a very important step in the design phase and the development of a handover algorithm, several evaluation models are proposed in the literature. However, not all of these models take into account the degree of importance of each evaluation parameter. For this reason, we have developed a scalable evaluation model for algorithms for network selection. In simulation section, we aim to analyse and evaluate the performance of the proposed algorithms. We ran a set of NS3 simulations experiments operating the proposed algorithms for the two main contributions, the obtained results are compared.

5.2 Proposed Algorithms Simulation Campaigns

5.2.1 Network Configuration et Simulation Parameters

5.2.1.1 Network Topology

To assess the presented schemes, on the network side, we consider two available networks (Wi-Fi and LTE). Both are ideal partners for operators to deliver convenient and affordable services, they are wireless standards built from scratch for IP-based applications. We used the same scenario for all the proposed network selection schemes.
The entire simulated area is covered under one LTE cell of radius 500 m with its eNB located at the center of the region and one Wi-Fi access point range of 100 m overlapped with LTE cell in $500 - By - 500$ area, where 10 mobile nodes randomly distributed are deployed. The behaviours of QoS metrics considered by the schemes are calculated, in this paper, using the built-in FlowMonitor NS-3 tool that tracks per-flow statistics at the IP layer including throughput and latency and reliability.

As for the mobility model, all the nodes are mobile and follow the built-in Constant Velocity Mobility Model of NS3 while meandering betwixt WiFi and LTE in simulated area.

5.2.1.2 Application Scenarios

On the user side, we consider four scenarios with different types of application were generated in Network Simulator NS3, namely Conversational, Streaming, Interactive and Background traffics. Those services are a Client-Server based applications with different requirements implemented on top of IP and using either UDP or TCP. The applications are designed as:

- Conversational: A CBR voice traffic is designed to perform the conversational class traffic. The client mobile terminal engender traffic in 84 Kbits/sec. The voice call duration is equal to the duration of the simulation.
- Streaming: A CBR traffic designed as a video streaming between the client mobile terminal to server. The data rate simulated is steadily 1 Mbits/sec. The duration of a CBR video streaming is equal to the duration of the simulation as well.
- Interactive: The web browsing traffic is designed for the interactive application. The retrieved web page sizes randomly vary between $100 - 500$ Kilobytes. The duration of the web browsing application is also equal to the duration of the simulation.
- Background: E-mailing traffic is designed for the background traffic, in-which each mail size randomly vary between $25 - 100$ Kilobytes. E-mailing traffic' duration is equal to the duration of the

simulation.

Each traffic class is combined with four different QoS parameters or attributes: Throughput, Delay, Jitter, and BER. The four traffic classes have different QoS requirements presented in table 5.1.

Table 5.1: Standardized QoS characteristics Alasti et al. (2010)

Resource Type	Packet Delay budget	Packet Error Loss Rate	Example Services	QoS Classes
Guaranteed Bit Rate (GBR)	up to 100 ms	$\leq 10^{-2}$	Conversational Voice	Conversational
	up to 300 ms	$\leq 10^{-6}$	live streaming	Streaming
Non-GBR	up to 100 ms	$\leq 10^{-3}$	Interactive gaming	Interactive
	up to 300 ms	$\leq 10^{-6}$	e-mail, chat, ftp	Background

5.2.1.3 Simulation Parameters Summary

Many handover triggers can be adopted. However, the handover process is launched in real time regularly every 5 seconds in order to get the potential out of the schemes. All the simulations last 600 seconds. Simulations details and results are presented below.

Table 5.2: Simulation Parameters and Settings.

Simulation parameters and settings	
Hotspot Size (L)	500
Number of Nodes	10
Available Networks	Wi-Fi and LTE
WLAN Range (m)	100
Channel Bandwidth of Wi-Fi (MHz)	3
LTE Range (m)	500
Channel Bandwidth of LTE (MHz)	10
Mobility model	Adapted Constant Velocity Mobility Model
Application Traffic	Conversational (Voice) Streaming (Streaming Video) Interactive (Web Browsing) Background (E-mailing)
Simulation Time (s)	650

5.2.2 Evaluation Criteria

The objective of the experiments is to analyse and compare the effectiveness of proposed selection. To this end, we analyse the QoS metrics, delay and packet loss, inasmuch as those QoS metrics translate the satisfaction of greedy mobile users. In addition, delay and packet loss change constantly over the simulation each time the selection process is called. On one hand, delay is concerned by the time taken by the algorithm to converge which involves the time from the sending and receiving a packet by the source to the destination. On the other hand, a certain number of packets are lost during the vertical handover execution which has an influence on the Packet Loss Rate. All results are obtained by averaging over a large number of independent simulation runs.

- **Delay**: is the time elapsing from the sending of a packet by the source until it is received by the destination.
- **Packet Loss Rate**: is ratio of the number of non delivered packet by transmitted ones.
- **Throughput**: is the number of messages successfully delivered per unit time.
- **Number of Handovers**: is the average number of handovers per second.

The following section details the development of the network throughout the simulation.

5.3 Evaluation Results

5.3.1 MADM Scheme Performance Evaluation

With the constraints applied in our simulations, the high speed and the regular handover triggering, it is hard to achieve, every-time, seamless handover and preserve a stable connectivity. The QoS parameters of the available networks vary dynamically over time in terms of reliability and availability (i.e. throughput, delay, jitter and bit error rate), which are the parameters considered in all the decision schemes. In addition, user mobility results in a continuous change in environmental conditions, including the network operator and the service provider, as well as access network technology. In particular, the transfer is a main source of network variations in terms of packet delay and packet loss. Therefore, the handover delay and the packet loss rate are measured to evaluate the performance of the proposed framework.

5.3.1.1 Delay Measurements

Figures 6.5a, 6.5b, 5.3 and 5.4, exhibit, over time, the development of delay in the four scenarios. The contrast of the performances using FAHP against AHP weights, coupled with the ranking methods TOPSIS, VIKOR, MEW and SAW, is noticeable. A common observation is that the schemes that use fuzzy weights provide the lowest end-to-end delay in all types of traffic except for the SAW scheme, where, at a certain time, the AHP-SAW outperforms the fuzzy version FAHP-SAW. This shift is due to a shift of the type of technology used. This shoddy network choice of FAHP-SAW - based on the addition of the product of the fuzzy weight and real time link state of different QoS metrics - influences the system delay in a bad way. In long terms, the scheme' performances start to drop and elects the network with the best throughput and bit error rate, but ignored the latency (delay and jitter) of the network.

In conversational traffic shown in figure 6.5a, the delay produced by all methods tends to be constant during the simulation, however, it can be seen that the difference between AHP schemes and FAHP ones differs. For example, MEW introduces relatively higher delay for conversational calls when using AHP weights and improved with the fuzzy achievement. Also, an increasing of gap between AHP and FAHP is noticed in VIKOR scheme; this latter is due to the drop of the performance of the AHP-VIKOR. Yet, VIKOR provides better delays in AHP and FAHP schemes comparing with the other methods.

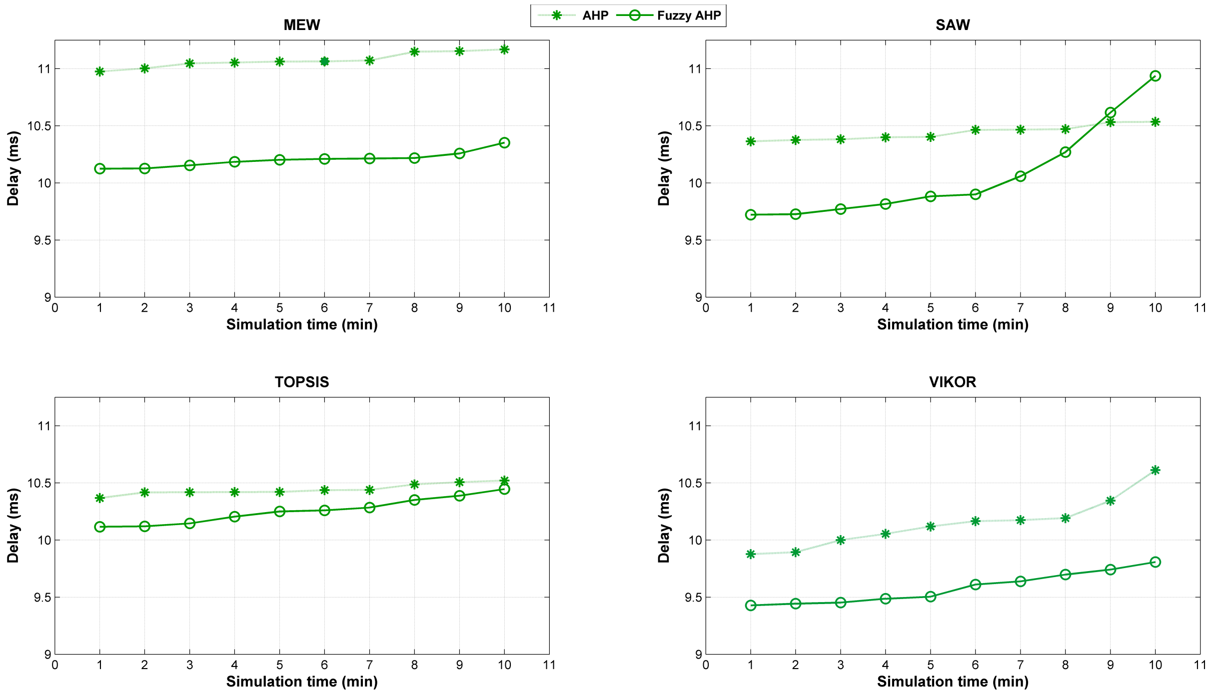


Figure 5.1: AHP and FAHP Performances of Delay over Time in Conversational Traffic.

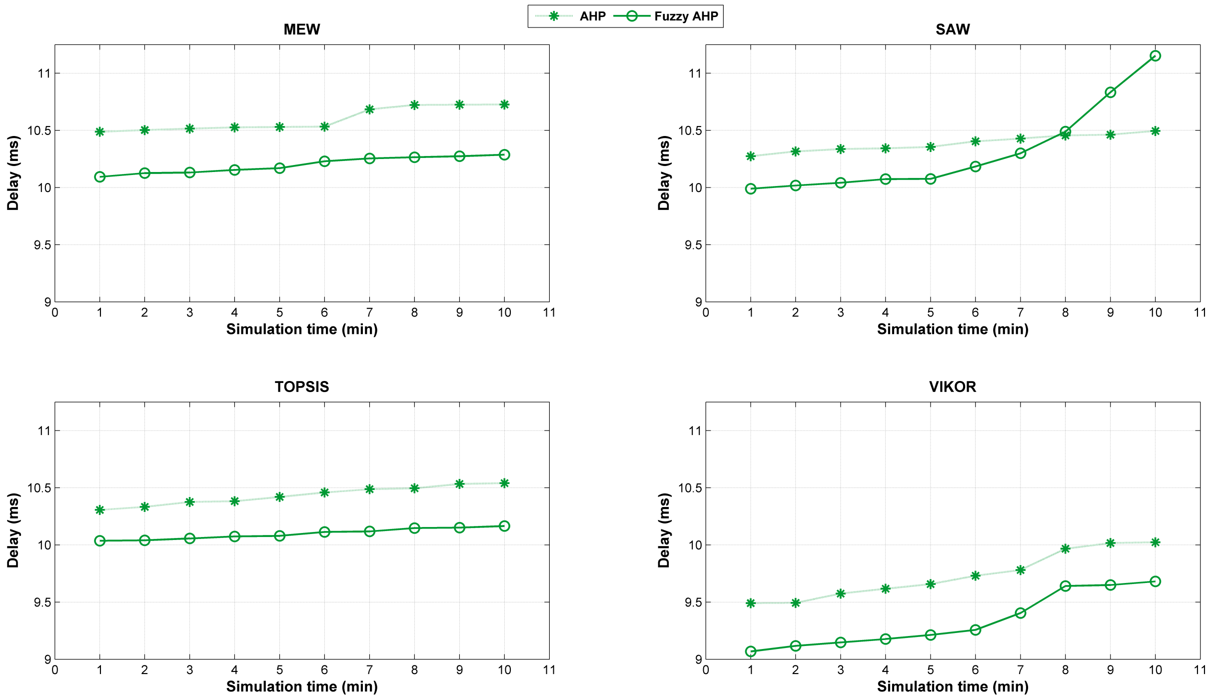


Figure 5.2: AHP and FAHP Performances of Delay over Time in Streamig Traffic.

The delay in Streaming traffic is shown in figure 6.5b. The worst delay performance is produced, almost evenly, by MEW and TOPSIS. Whereas VIKOR scheme provide the best delay when combined with AHP weights and even better delay with the fuzzy improvement.

In Interactive traffic presented in figure 5.3, the lowest delays is noticed in VIKOR scheme as well, even-though the fuzzy weights provided by FAHP did not improve greatly the delay, the average delays all along the simulation in FAHP-VIKOR is not much higher than AHP-VIKOR. However, FAHP surprisingly improved MEW performance with the lowest delay.

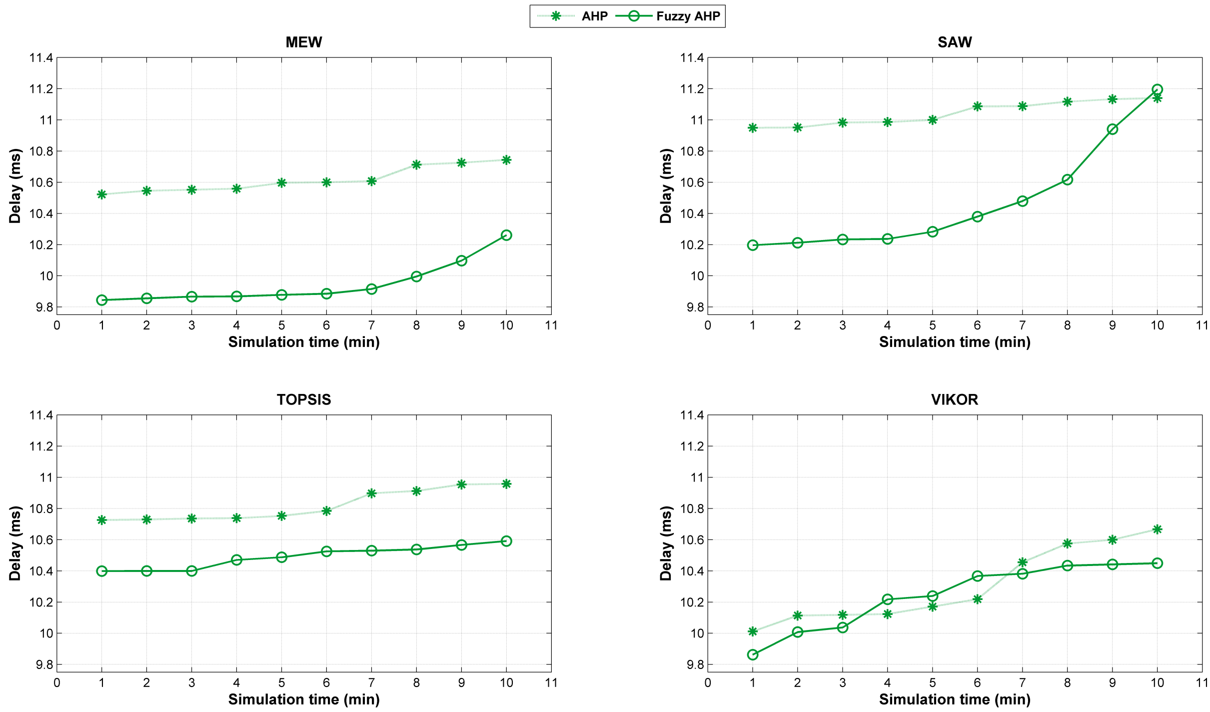


Figure 5.3: AHP and FAHP Performances of Delay over Time in Interactive Traffic.

The delay in background traffic is displayed in figure 5.4. Clearly, VIKOR introduces the least delays in both AHP and FAHP versions. MEW and TOPSIS Schemes induce relatively the same delays with a narrow improvement when using FAHP, while the delay in SAW algorithm declines considerably and provides the highest delay.

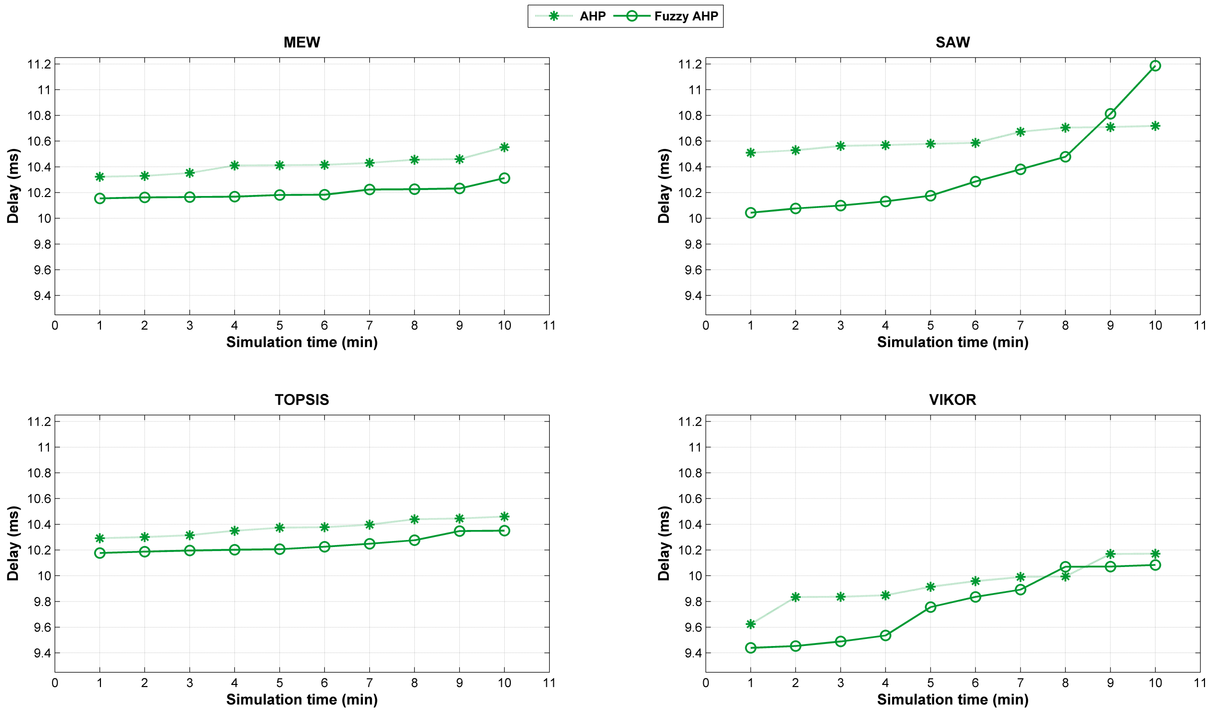


Figure 5.4: AHP and FAHP Performances of Delay over Time in Background Traffic.

5.3.1.2 Packet Loss Rate Measurements

Concerning Packet Loss Rate, it is defined as the total number of lost data packets divided by the total number of transmitted data packets. The packet loss rate of the four types of traffic is computed. Figures 5.5, 5.6, 5.7 and 5.8 evince, over time, the development of packet loss rate in the four scenarios. With time, the packet loss rate in AHP and FAHP schemes increase in all types of traffic, however, the distinction of the performances of AHP and FAHP when coupled with the ranking methods cited above is put in evidence. The rapidity of the decisions made using fuzzy enhancement impacts also on the number of packets discarded throughout the simulation.

From figure 5.5, which represents the Conversational traffic, it can be seen that the packet loss rate in MEW and TOPSIS is more than the one in SAW, whereas VIKOR provide the best packet loss rates in both AHP and FAHP in voice call application.

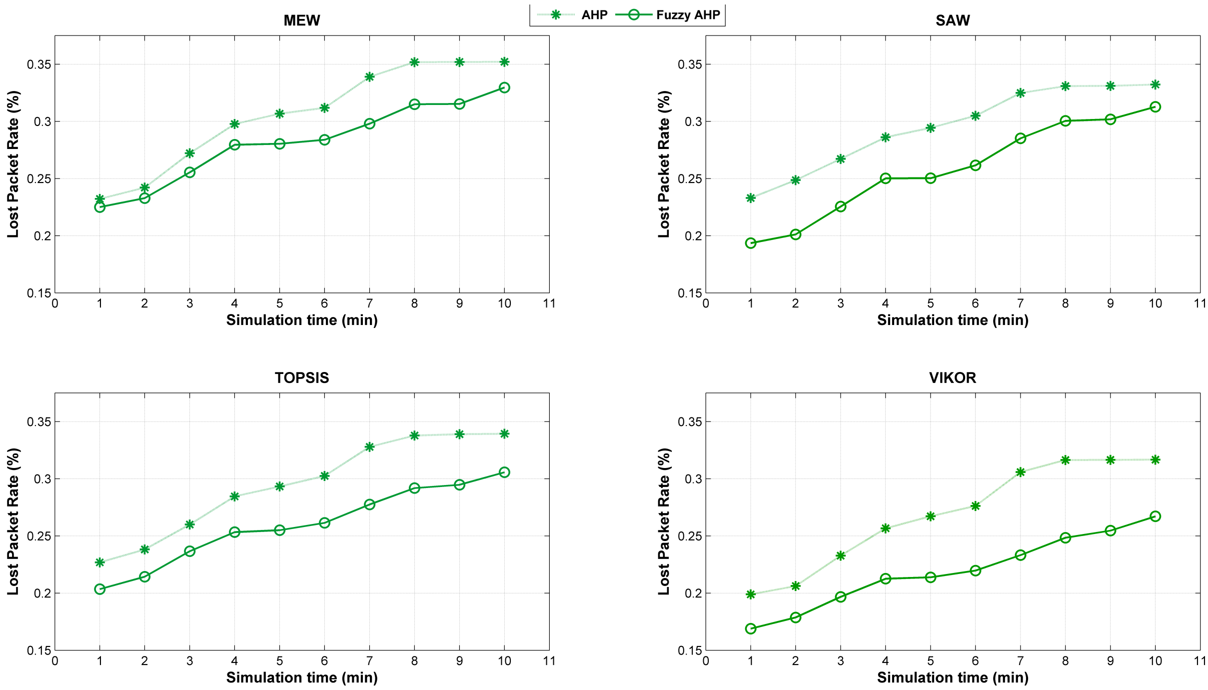


Figure 5.5: AHP and FAHP Performances of Packet Loss over Time in Conversational Traffic.

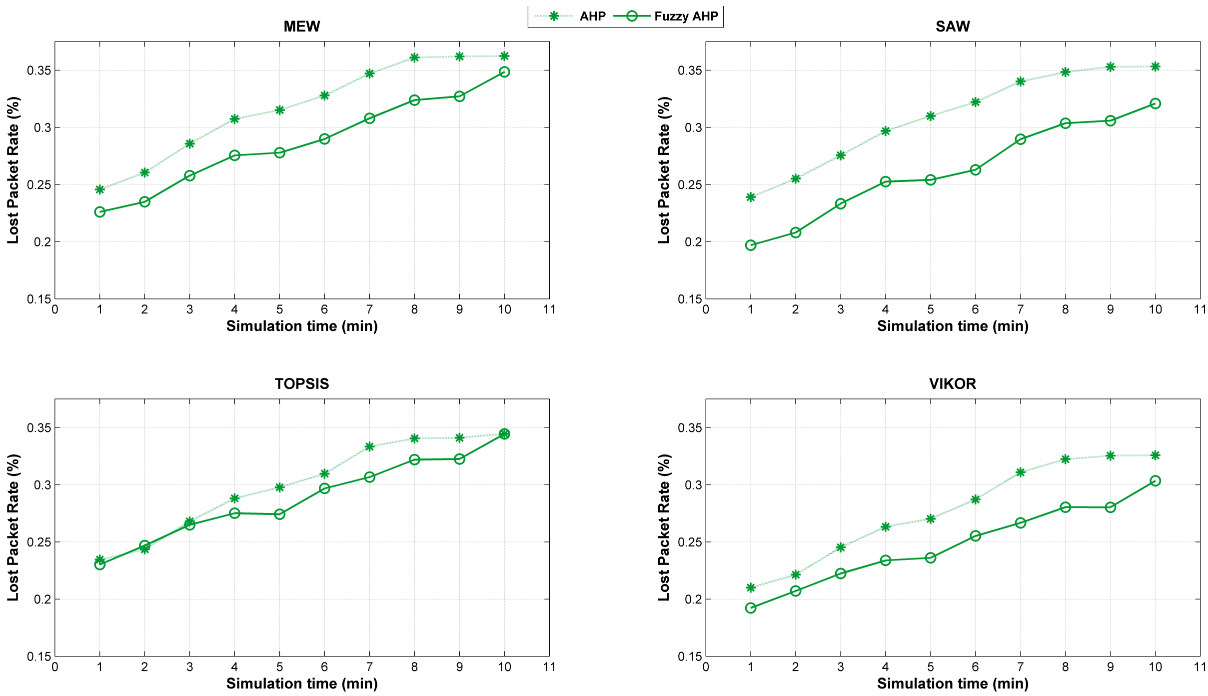


Figure 5.6: AHP and FAHP Performances of Packet Loss Rate over Time in Streaming Traffic.

In Streaming traffic presented in figure 5.6, MEW and TOPSIS achieve relatively higher packet loss rates than SAW and VIKOR. Moreover, the gaps between AHP and FAHP in MEW and TOPSIS are not quite high, which means the fuzzy weights have not a strong impact on the decision made by either MEW or TOPSIS in video streaming application. Nonetheless, VIKOR scheme provides the best performance in terms of packet loss as well.

Figure 5.7 displays the development of the packet loss rate, in the Interactive traffic, for all the schemes. Similarly to the Streaming traffic, the fuzzy weights did not impact notably the packet loss rate in MEW scheme; nevertheless, the improvement is obvious for TOPSIS scheme. In VIKOR scheme, a slight enhancement was produced. Nonetheless, the gap between AHP-SAW and FAHP-SAW schemes is the largest. FAHP-SAW provided thereby the largest packet loss rate improvement in web browsing traffic.

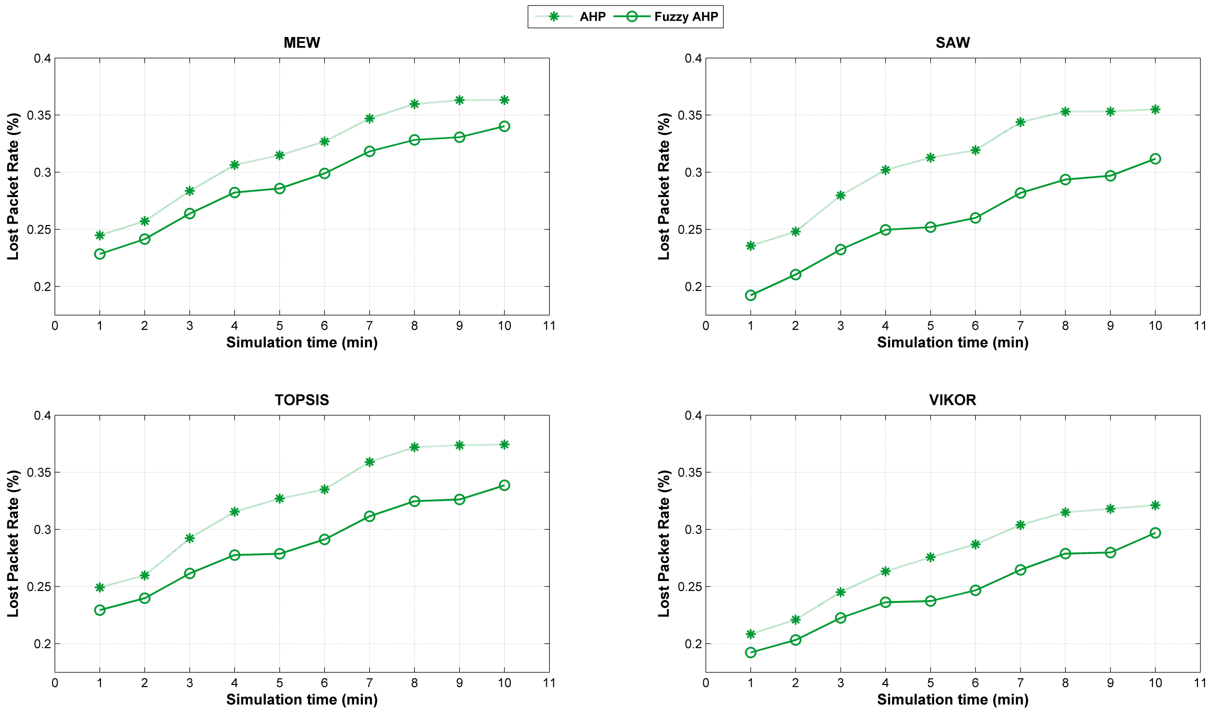


Figure 5.7: AHP and FAHP Performances of Packet Loss over Time in Interactive Traffic.

In background traffic depicted in figure 5.8, the packet loss rate improvement made by FAHP is irrefutable in MEW, SAW and TOPSIS schemes. However, in VIKOR scheme, the fuzzy weights had not impact on the packet loss rate, yet, FAHP-VIKOR provided the least packet loss rate in emailing application.

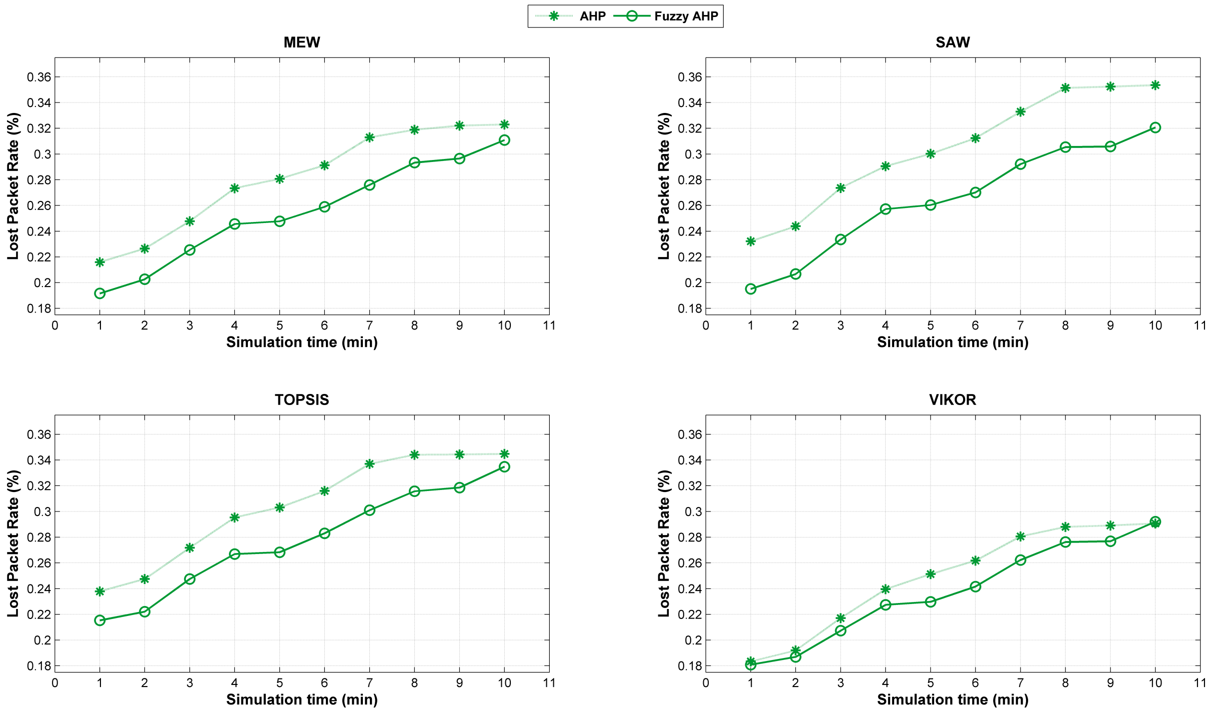


Figure 5.8: AHP and FAHP Performances of Packet Loss over Time in Background Traffic.

5.3.1.3 Applications Assessment

Table 5.3 below presents the delay improvement of the schemes when coupled with FAHP under the four types of traffic. The FAHP weights improved, for certain, the delay for all schemes as it minimizes the delay up to 10%.

Table 5.3: Improvement of DELAY by FAHP for all traffics

Traffic Class	**Conversational**	**Streaming**	**Interactive**	**Background**
MEW	10% ↓	5% ↓	8% ↓	3% ↓
SAW	7% ↓	7% ↓	8% ↓	5% ↓
TOPSIS	3% ↓	4% ↓	4% ↓	2% ↓
VIKOR	9% ↓	6% ↓	3% ↓	5% ↓

In table 5.4 below the packet loss rate improvement of the schemes when combined with FAHP under the four types of traffic is disclosed. The FAHP weights decreased the packet loss rate for all schemes comparing with the use of AHP weights, since it drops up to 32%.

Table 5.4: Improvement of Packet Loss by FAHP for all traffics

Traffic Class	**Conversational**	**Streaming**	**Interactive**	**Background**
MEW	14% ↓	14% ↓	11% ↓	14% ↓
SAW	24% ↓	23% ↓	25% ↓	20% ↓
TOPSIS	19% ↓	9% ↓	19% ↓	13% ↓
VIKOR	32% ↓	17% ↓	17% ↓	10% ↓

However, even if the delay improvement, in the conversational traffic, is more significant for FAHP-MEW scheme (see table 5.3), the best delay was actually provided by FAHP-VIKOR (see figure 6.5a). Further, in background traffic, although the best lowering of packet loss was produced by FAHP-SAW (see table 5.4), the best scheme that minimized the packet loss rate was in fact FAHP-VIKOR (see figure 5.8).

Accordingly, in order to choose the most suitable method minimizing delay time and packet loss, in a certain type of traffic, a comparison from an application point of view is conducted.

Conversational Traffic: The applications belonging to this class are characterized by the fact that the transfer time should be low due to the conversational nature of the traffic and at the same time the variation of the time between the information entities in the stream should be preserved In the same way as for real-time streams 3GPP (2017). Thus, there is no room for the cases of packet loss that generate the retransmission process. Figures 5.9 and 5.10, display the performances of fuzzy versions of the schemes in Conversational traffic.

In figures 5.9, a functional difference between the delay depiction in a voice call application for all schemes is highlighted. From the color scale, it is clear that the schemes producing the least delays are SAW and VIKOR, albeit, performances of SAW drop at the end of the simulation.

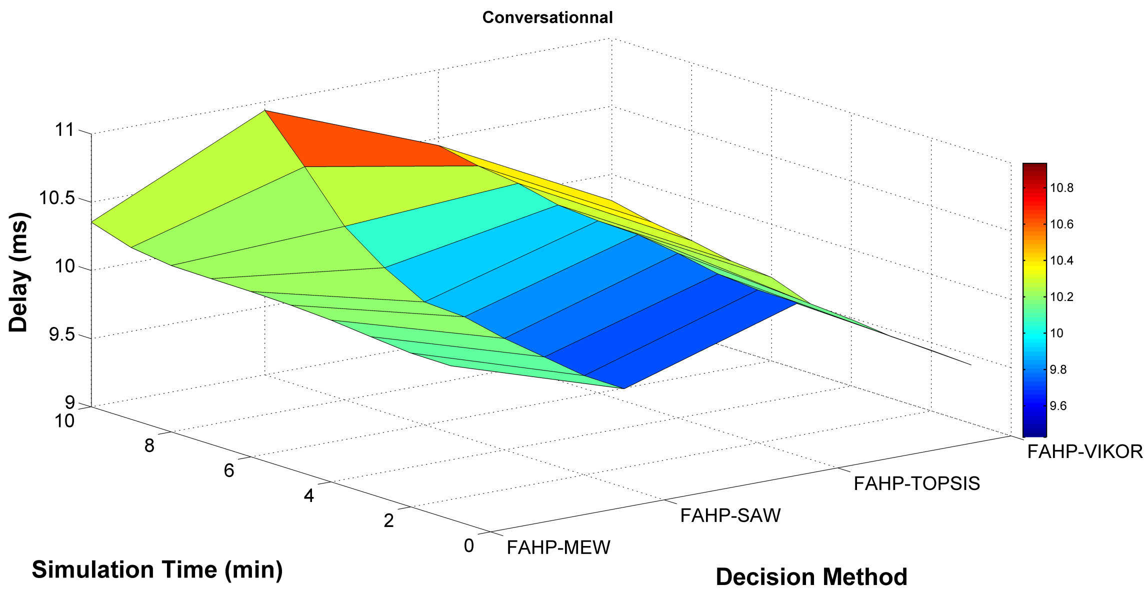


Figure 5.9: Delay Performance over Time in Conversational Traffic using FAHP.

Figure 5.10, exhibits the contrast between the representation of the total packet loss rates in a voice call application for all the schemes. Plainly, the scheme delivering the lowest packet loss rate is VIKOR.

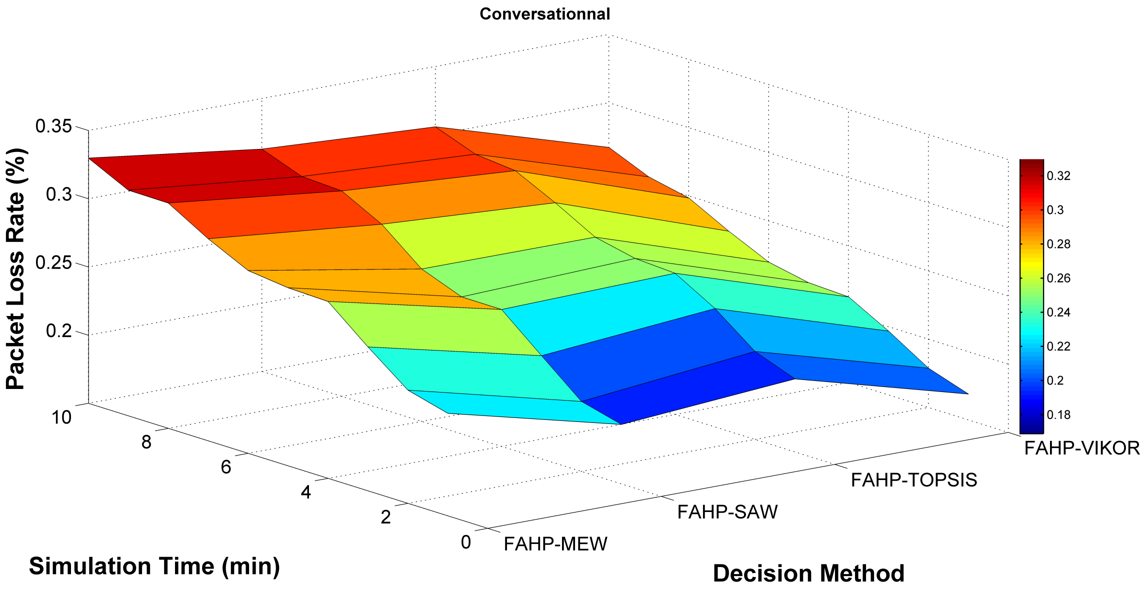


Figure 5.10: Packet Loss Performance over Time in Conversational Traffic using FAHP.

Streaming Traffic: When the user is looking at real time video streaming, the constraints of real time insight applies. This concept is one of the newcomers to data communication, which raises a number of new requirements in telecommunication and data communication systems. It is characterized in that the temporal relationships (variation) between the information entities (ie the samples, the packets) in a stream must be preserved 3GPP (2017) Figures 5.11 and 5.12, feature the performances of fuzzy versions of the schemes in Streaming traffic.

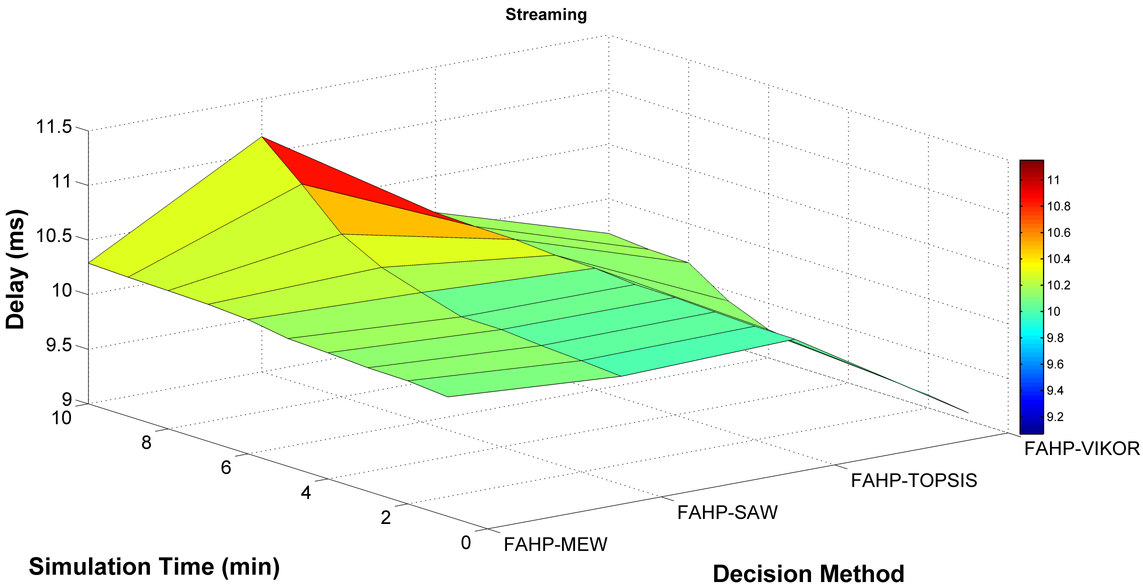


Figure 5.11: Delay Performance over Time in Streaming Traffic using FAHP.

Figure 5.11 spotlights the relationship between the behaviour of the delay of a streaming video for the four schemes. The only method reaching the lowest delay, as exposed by the color bar, is VIKOR.

Likewise, in figure 5.12, the packet loss rates of the four schemes are put on display. Even-though SAW reaches the low-most packet loss at the beginning of the simulation, but the total packet loss rate of VIKOR scheme is the lowest.

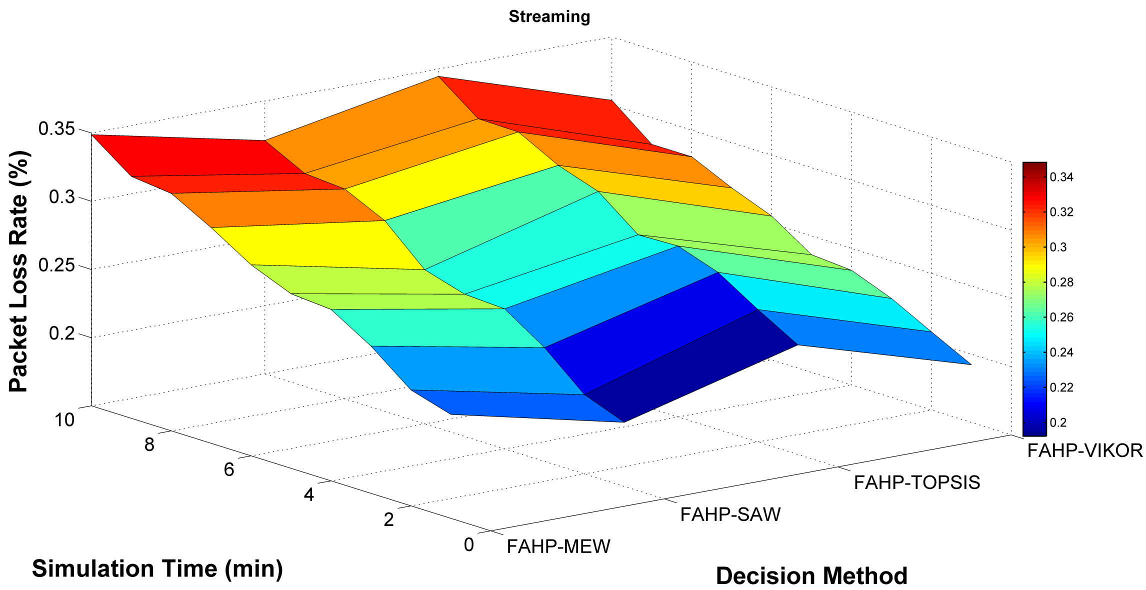


Figure 5.12: Packet Loss Performance over Time in Streaming Traffic using FAHP.

Interactive Traffic: Interactive traffic is a communication flow that is defined by the end-user request response model. The round trip delay is the most important attribute for this class. Another important attribute is that the error rate should be very low in the data transfer 3GPP (2017). Figures 5.13 and 5.14, exhibit the performances of fuzzy versions of the schemes in Interactive traffic.

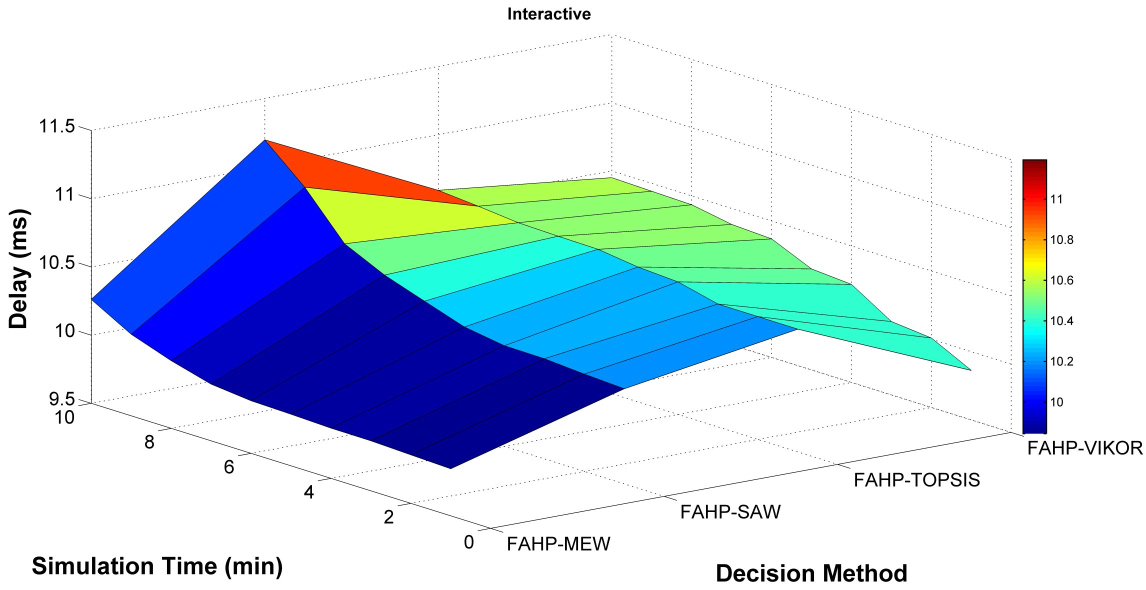


Figure 5.13: Delay Performance over Time in Interactive Traffic using FAHP.

Figure 5.13 emphasizes the delay performances of the fuzzy schemes of a web browsing application. Uncommonly to the other applications, MEW scheme settled the under-most delay all along the simulation time, as established by the color bar.

In figure 5.14, the packet loss rates of the fuzzy schemes are paraded. SAW scored a narrow packet loss during the time of simulation.

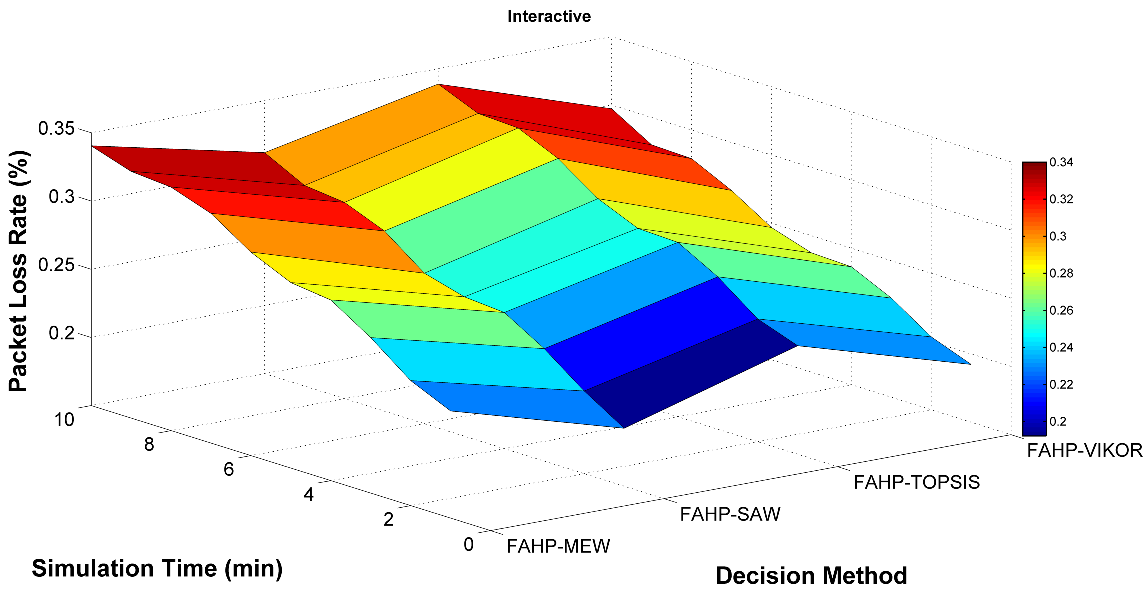


Figure 5.14: Packet Loss Performance over Time in Interactive Traffic using FAHP.

Background Traffic: In this class where applications run in the background, communication sleeps and wakes up when an email arrives. It is defined by the fact that the destination does not expect data in a certain time however it compels that the content must be delivered with a low error rate. Figures 5.15 and 5.16, emphasize the performances of fuzzy versions of the schemes in Background traffic.

Figure 5.15 underlines the delay performances of the fuzzy schemes of a emailing application. All the schemes hold the same delay level during the time of the simulation, apart from SAW which stretches to the utmost of background delays. However VIKOR provides the least delay comparing with the other schemes.

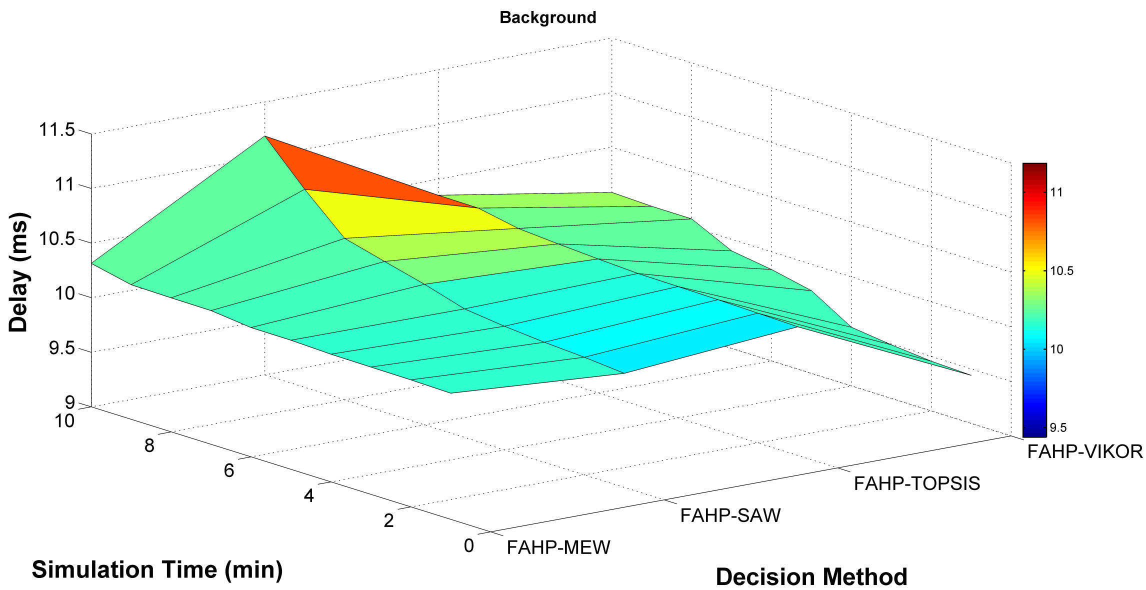


Figure 5.15: Delay Performance over Time in Background Traffic using FAHP.

In figure 5.16, the packet loss rates of the fuzzy schemes are exposed. Admitting that MEW exhibits the lowest packet loss at the beginning of the simulation, the sum packet loss rate of VIKOR scheme during the time of the simulation is the lowest of all the schemes.

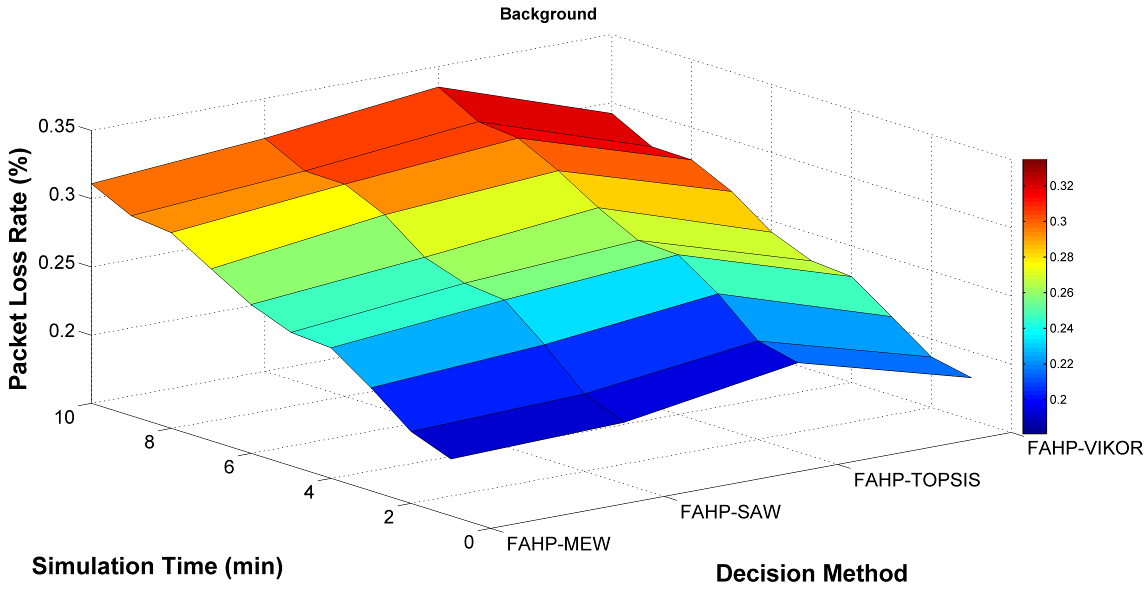


Figure 5.16: Packet Loss Performance over Time in Background Traffic using FAHP.

Table 5.5: MADM Best Scheme for all traffics

Traffic Class	**Delay**	**Packet Loss rate**
Conversational	*FAHP-VIKOR*	*FAHP-VIKOR*
Streaming	*FAHP-VIKOR*	*FAHP-VIKOR*
Interactive	*FAHP-MEW*	*FAHP-SAW*
Background	*FAHP-VIKOR*	*FAHP-VIKOR*

As a summary, table 5.5 rehashes the most suitable MADM handover scheme for each type of traffic.

5.3.2 Utility Function Scheme Performance Evaluation

5.3.2.1 Utility-based Scheme in Heterogeneous Networks

We handle the experiments, in this section, to validate the approach using utility-function, by analysing the impact of speed velocity on QoS. We analyse thereby the velocity speed by varying it: 20 m/s, 30 m/s and 40 m/s.

Figure 5.17 illustrates the behaviour of delay over time, it compares the performance of our scheme while varying the velocity speed. in terms of delay, its shows that the proposed scheme produces very good results at low 20 m/sec, medium 30 m/sec mobile user speed and allowable performance for high speed of 40 m/sec still better by 7% than the baseline scheme simulated with only 10 m/sec (see table below 5.6).

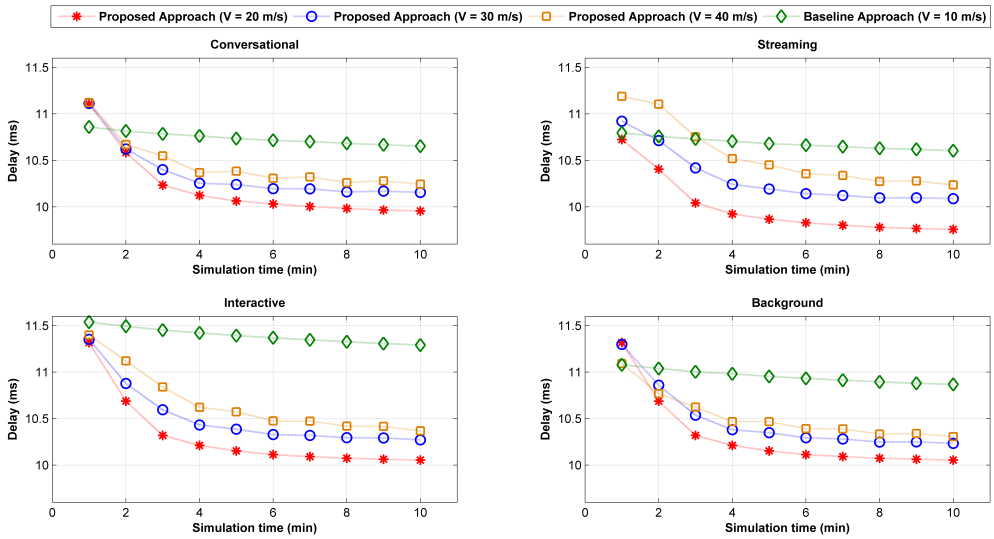


Figure 5.17: Behaviour of Delay over Time using Utility-based scheme in different speed scenarios for all traffics.

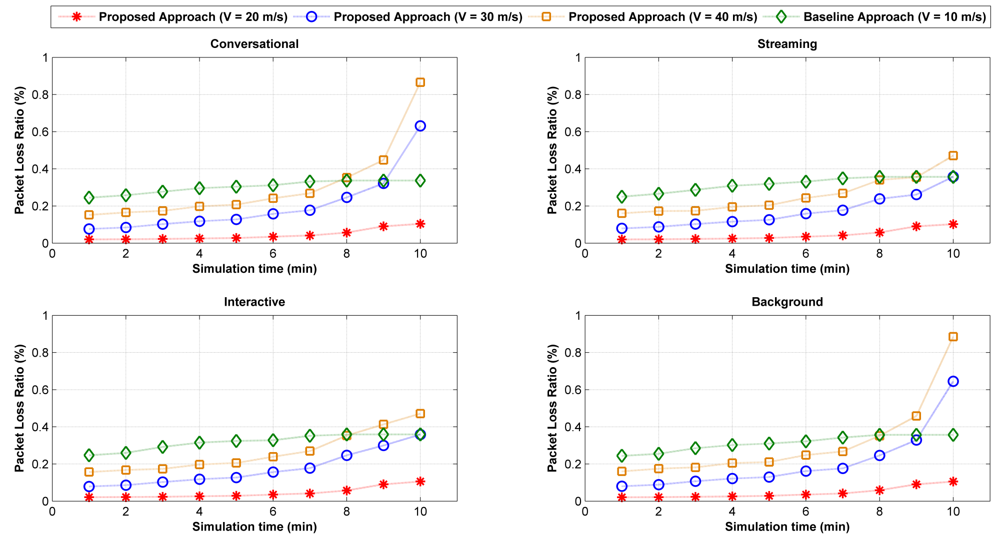


Figure 5.18: Behaviour of Packet Loss over Time using Utility-based scheme in different speed scenarios for all traffics.

In a similar way, Figure 5.18 exposes the behaviour of packet loss over time, it contrasts the performance of our scheme while varying the velocity speed. The swiftness of the decisions made by the terminal to utility values influences also on the number of packets dropped all along the simulation. For packet loss, the proposed scheme provides an acceptable packet loss for all types of application. Compared to the baseline, our proposed scheme reduces the packet by 40%.

Table 5.6: Improvement of Delay and Loss Packet by the proposed Utility Scheme

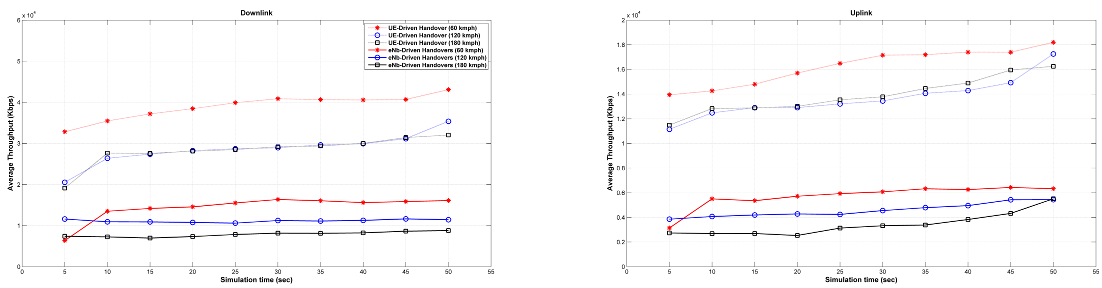
Traffic Class	DELAY	PACKET LOSS RATIO
Conversational	$3,66\% \downarrow$	$33,97\% \downarrow$
Streaming	$3,64\% \downarrow$	$39,41\% \downarrow$
Interactive	$7,19\% \downarrow$	$40,51\% \downarrow$
Background	$4,68\% \downarrow$	$36,24\% \downarrow$

5.3.2.2 Utility-based Scheme in Heterogeneous LTE

To evaluate our proposed scheme, we conducted simulation experiments for both UE driven handover and eNB triggered one, the obtained results are compared. Table 5.7 presents the detailed parameters considered in the scenario inspired from RAN (2009). In this scenario, UEs are randomly dispersed around the sites and attached to the network automatically. Simulations last 50 seconds, so UEs would have travelled far enough to trigger some handovers. In all simulations, we use a network consisting of Macrocells and Femtocells. UE nodes follow the same mobility model we managed to make users roam randomly between different cells as presented in table 5.7.

Table 5.7: Simulation Parameters and Settings of Utility-based Scheme in Heterogeneous LTE Scenario.

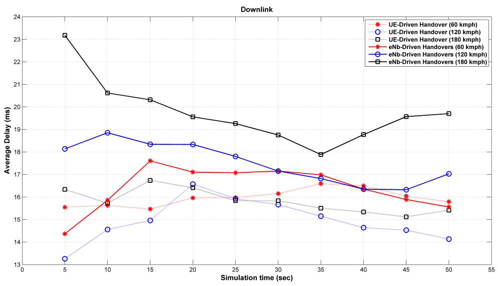
Simulation parameters and settings	
Size of The Area $(m * m)$	$1500 * 1400$
Inter-Site Distance (m)	500
Number of Nodes	53
Number of Macro eNBs	7
Number of Femto eNBs	5
eNBs Bandwidth (MHz)	5
eNBs Transmission Power (dBm)	46
Nodes Speed $(kmph)$	60 - 120 - 180
Mobility model	Steady State Random Waypoint
LTE Bearer	Non Guaranteed Bit Rate / Video Streaming
Simulation Time (s)	50
Simulation Number	6



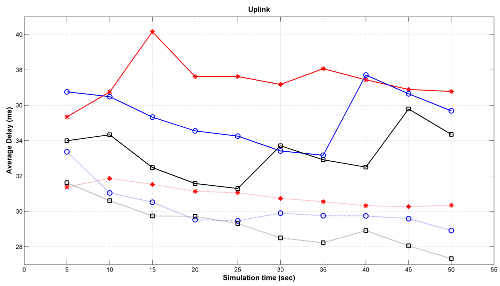
(a) Downlink (b) Uplink

Figure 5.19: Behaviour of Throughput over Time using User-Driven Handover Scheme in LTE Macro/Femto Cells in Streaming traffic.

DL and UL Throughputs An adequate handover scheme is that which establishes high throughput although UEs are in high speed mobility. Thereby, we consider the throughput for the three velocities all along the simulation time. Figure 5.19 shows the downlink and uplink throughputs over the simulation time. the downlink throughput of our proposed scheme is almost equal in medium and high speed. The uplink throughput in low speed scenario is highest. In addition, the proposed cell selection scheme performs better downlink and uplink throughputs higher than that of the cell selection triggered by eNB for all speed scenarios.



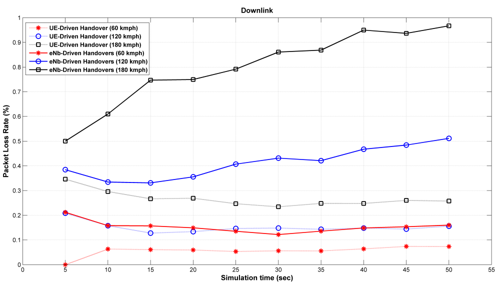
(a) Downlink



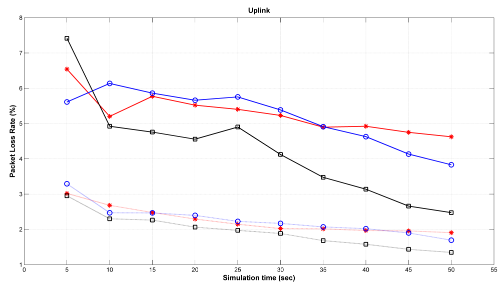
(b) Uplink

Figure 5.20: Behaviour of Delay over Time using User-Driven Handover Scheme in LTE Macro/Femto Cells in Streaming traffic.

DL and UL Delays For sensitive application like video streaming, the shortest end-to-end delay, the better the application performance. Thus, in our scenarios we compute the average end-to-end delay for the three velocities. The results are presented in figure 5.20, it shows the average delay for downlink and uplink. Results show that UE Triggered scheme provides the lowest end-to-end delay in different speeds for both downlink and uplink flows. This is due to the good performance of our proposed scheme in terms of number of handover.



(a) Downlink



(b) Uplink

Figure 5.21: Behaviour of Packet Loss Rate over Time using User-Driven Handover Scheme in LTE Macro/Femto Cells in Streaming traffic.

DL and UL Packet Loss Rates Concerning Packet Loss Rate, it is used to evaluate the network reliability, and is defined as the total number of lost data packets divided by the total number of transmitted data packets. We compute the packet loss rate of the three considered velocities, results shown in figure 5.21 describes the packet loss rate for downlink and uplink, the proposed scheme has the lowest error rate for all the traffic speeds.

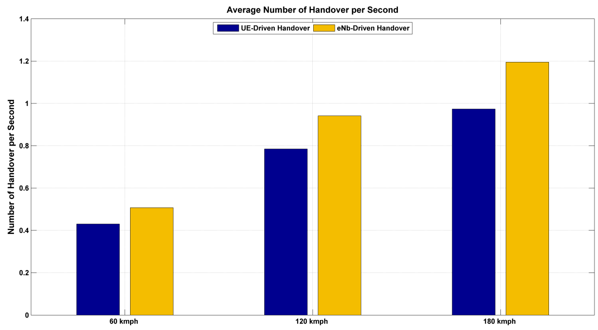


Figure 5.22: Average Number of Handover per Second using User-Driven Handover Scheme in LTE Macro/Femto Cells in Streaming traffic.

Average Number of Handovers The ping-pong handover is a very frequent anomaly in the mobile networks, which can cause inefficiency, call dropping and degrading of the network performance. The ping-pong handover in LTE means two consecutive handovers between the source and the target eNBs and vice versa. Coverage parameters, user location area and its mobility and speed are the main causes of ping-pong. The ping-pong effect takes place by dint of the frequent movement of UE between the source and the target eNB, or high signal fluctuation at the common boundary of the eNBs. The ping-pong movement in LTE is one of the most crucial problems which reduce the quality of the connection and degrade the performance of the handover. Since the limitation of ping-pong effect is a mandatory task and considering the high speed scenario we adopt, we consider the number of handover as an important metric to prove the effectiveness of our scheme. In figure 5.19, we calculated the average number of handovers handled per second. Obviously, the UE triggered selection performs less handovers comparing by the eNB triggered cell selection. The proposed scheme reduces the number of unnecessary handover. Moreover, the speed of nodes has an impact on the number of handover. UE triggered a handover only if needed. Thus, if the current connected cell still reply to the QoS requirements, handover does not take a place, even if a better cell exists.

5.3.3 Matching Scheme Performance Evaluation

To analyse the performance of the proposed algorithm in real time, we consider two scenarios whereby 2 APs are deployed, $\nu = \{$ Wi-Fi, LTE$\}$. In the first scenario, we fixed $\lambda_{max} = 5$ and the number of users

UEs to 10 simulating four Application Traffic: Conversational, Streaming, Interactive and Background as presented in table 5.2. Meanwhile, in the second scenario, we enlarged the hotspot size, increased $\lambda_{max} = 15$ and varied the number of users $\chi = \{5, 10, 15, 20, 25, 30\}$. The simulation parameters are shown in Table 5.8.

Table 5.8: Simulation Parameters and Network Configuration of Matching-based Scheme Scenario.

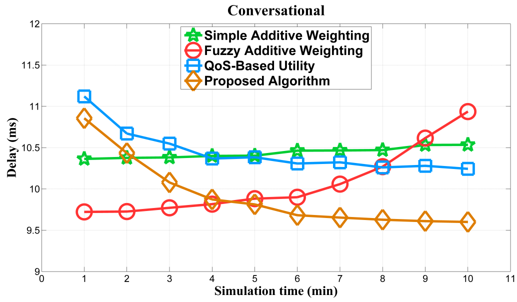
Name	Value
Hotspot Size (L)	1000
Number of Nodes	Scenario 1: 10 / Scenario 2: $\{5, 10, 15, 20, 25, 30\}$
Quota λ_{max}	Scenario 1:5 / Scenario 2: 15
Mobility model	Steady State Random Waypoint
Simulation Time (s)	650

User satisfaction, which depends on the QoS perceived by each application, is an important factor for successful access point selection, it will make it much easier for an UE to roam from one AP to another, within a single or multiple cooperating providers. Thus, in the first comparison, we consider the time delay and packet loss rate over time in each type of traffic. In the second comparison, we dissect the throughput and number of handover while increasing the number of users.

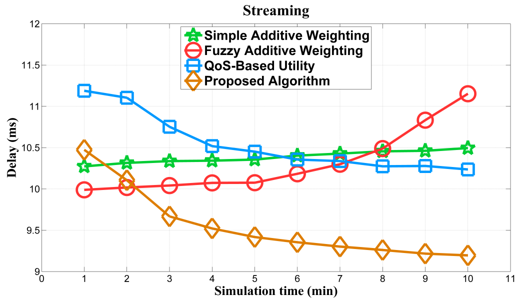
5.3.3.1 Scenario 1

Our proposed algorithm consist of a QoS aware access point selection expressed by the QoS metrics considered during the decision and a context aware approach that integrate the type of traffic used by the mobile user in the decision of the next handed network by generating a set of weights for each type of traffic. Therefore, in the first scenario, we fairly compare the performance of proposed algorithm with a simple weighting Drissi and Oumsis (2015a), a fuzzy weighting Drissi et al. (2016b) and a QoS-based schemes Drissi et al. (2017a) over time and the results are presented for each type of traffic.

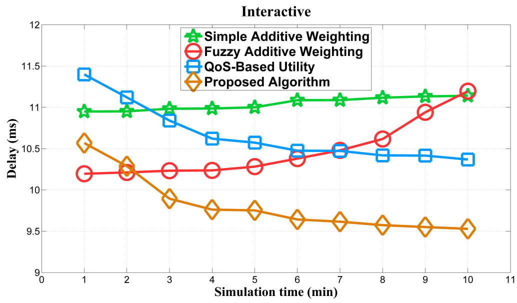
As depicted in Figure 5.23, access point selection based on matching algorithm represents the best way for avoiding the degradation of the delay time in the network due to the time cost of running the algorithms. As well, our solution offers an optimized selection for ensuring a load balanced network and improving, thereby, a long-term performance for upcoming users. Indeed, in different types of traffic, the proposed solution is the one in which the delay declines the most, whereas the simple weighting scheme provides an almost steady delay, the fuzzy weighting scheme does not hold up over time as the delay increase firmly. While the delay in QoS based utility does decrease but not sufficiently compared with the proposed solution.



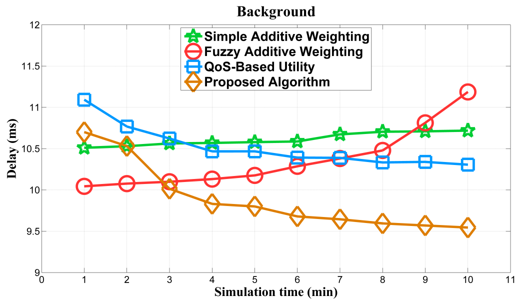
(a) Conversational Traffic



(b) Streaming Traffic



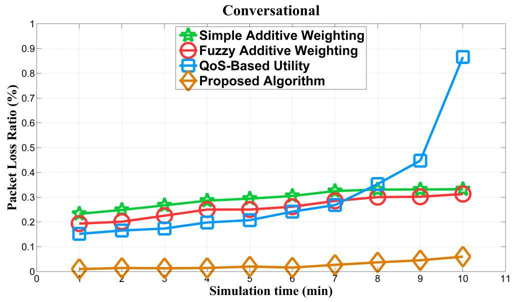
(c) Interactive Traffic



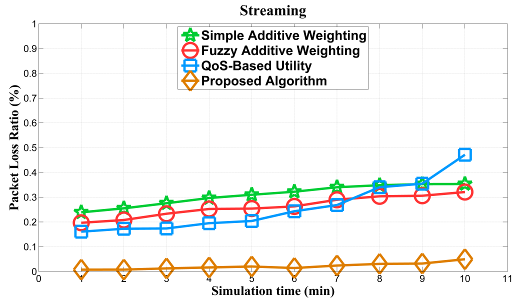
(d) Background Traffic

Figure 5.23: Average empirical delay over time under the proposed algorithm compared with AHP and Fuzzy Schemes Drissi et al. (2017d) and Utility SchemesDrissi et al. (2017a)

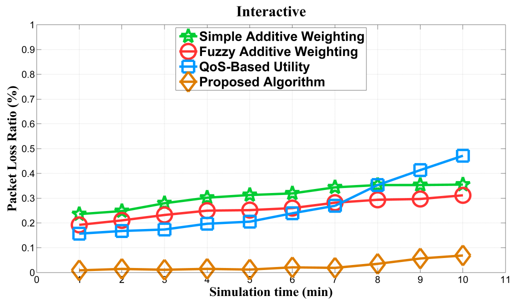
Figure 5.24 shows the average packet loss rate over time in network. The average packet loss within the proposed matching users and access points based on QoS and the user's context scheme achieves the accurate packet loss level in different types of traffic and yields a noteworthy performance gains. The packet loss rate provided by the proposed solution represents a very slow rise, but still way too decreased related to the other schemes.



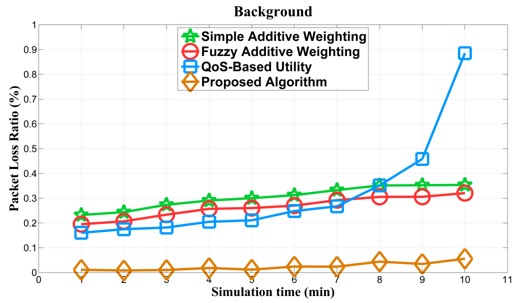
(a) Conversational Traffic



(b) Streaming Traffic



(c) Interactive Traffic



(d) Background Traffic

Figure 5.24: Average empirical packet loss rate over time under the proposed algorithm compared with AHP and Fuzzy Schemes Drissi et al. (2017d) and Utility SchemesDrissi et al. (2017a)

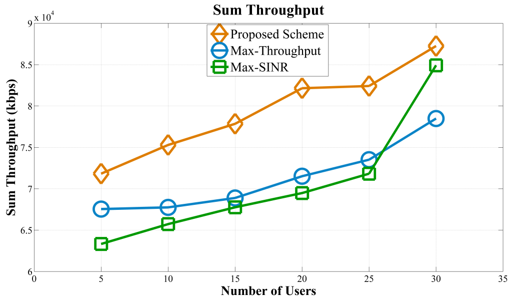
To better assert the performance improvement of the delay and packet loss rate, we generated the improvement rate of the proposed scheme related to the best baseline in each type of application. The results are presented in table 5.9.

Table 5.9: General Improvement Rate of Delay and Packet Loss Rate of the Proposed Matching Algorithm.

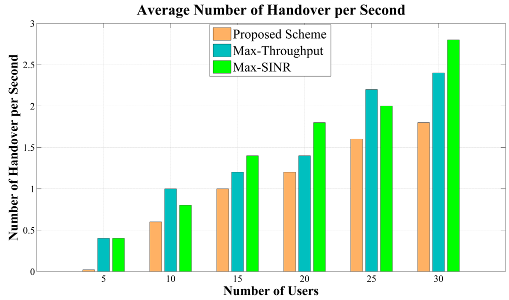
	Conversational	Streaming	Interactive	Background
DELAY	15.64 ↘	19.9564 ↘	18.3464 ↘	15.9364 ↘
PACKET LOSS	35.2864 ↘	31.3764 ↘	31.9264 ↘	35.9864 ↘

5.3.3.2 Scenario 2

In a second scenario, we compare the performance of the proposed scheme with the Max-SINR user association (which is the original scheme used by each user to connect to the suitable access point Andrews et al. (2014)) and Max-Throughput scheme Aryafar et al. (2013). Yet, in heterogeneous environment, such association of users to different access points will unbalance and direct the traffic to the AP that provide the best SINR or Throughput, by dint of ignoring the other QoS parameters during the process of selection in the overlapped zones. A suitable association scheme is a scheme which establishes high throughput for all EUs despite their greediness. Thereby, we consider the throughput as a function of number of users. Figure 5.25a shows the sum throughput while varying the UEs numbers. We compare the proposed matching with Max-SINR and Max-Throughput schemes. The proposed matching scheme provides a throughput higher than the compared schemes.



(a) Empirical Sum Throughput as a function of number of users.



(b) Average Number of Handover per Second as a function of number of users.

Figure 5.25: (a) Empirical Sum Throughput and (b) Average Number of Handover per Second as a function of number of users, under the proposed algorithm compared with Max-SINR and Max-Throughput schemes.

The ping-pong is a very commonplace aberration and one of the most frequent problems in the context of heterogeneous networks. It can lead to call dropping and unwanted handovers, thereby, lowering the network performance. The ping-pong handover in heterogeneous network means two successive handovers between the source and the target APs and vice versa. Thus, we consider the number of handover in the comparison to show the leverage of the proposed scheme. In figure 5.25b, the average number of handovers as function of the number of users is depicted. Patently, the proposed scheme performs less handovers comparing with Max-SINR and Max-Throughput schemes. The proposed scheme reduces the number of superfluous handovers. The proposed scheme trigger handover only if needed.

5.3.4 Discussion

With improvement in both delay and packet loss rate, in the first contribution, FAHP granted a network selection decision that enabled a ubiquitous vertical handover. FAHP provided weights that enabled a fast and intelligent vertical handover considering the time taken by the terminal to calculate the score of each decision. FAHP weights enabled also a seamless vertical handover considering the number of packet dropped during the handover execution. The results of the comparison conducted for this contribution, showed that both SAW and MEW approaches were more suitable for web browsing, while VIKOR was more favourable for voice, video and emailing. The FAHP-VIKOR algorithm produced the least delay and packet loss rates for the four applications except for Interactive applications where VIKOR performed less than SAW in terms of delay and less than MEW algorithm in terms of packet loss rate. Although the SAW method is trivial and simpler to implement among all existing MADM methods, it has several disadvantages such as the compensation for cost criteria by performance criteria. This compensation makes it possible to mask the weaknesses of a QoS metric, which can have adverse consequences in the decision-making phase. For example, for the vertical handover problem, the weighted sum method can choose a network that does not meet user requirements in terms of quality of service. Also, its lack of precision in identifying the ranking of alternatives is another disadvantage. If its accuracy is high (low difference between ranking values), it makes it easy to identify the ranking order and to easily select the best alternative. The MEW method has the same advantages and disadvantages as the SAW method. Another criticism to MEW is around penalizing alternatives that have bad values for their attributes. Among MADM methods, the great contribution of TOPSIS besides its easy application is its introduction of the ideal and anti-ideal notions. However, certain limitations characterize this method such as the criteria that must be a cardinal form, or the number of handover and unnecessary handover, which are high, and the Rank Reversal: this phenomenon characterizes the majority of MADM methods and more particularly TOPSIS method. This anomaly means that the ranking order is changing overtime when new alternatives (or criteria) are added or deleted. Yet, TOPSIS must not be eliminated since its ideal and anti-ideal alternatives are used by VIKOR and among its strong factors in finding the compromised ranking. Noting that in three out of four applications VIKOR selected the network with the lowest delays and packets lost rates during the handover.

In the first work, the vertical handover was handled without mobile users speed nor the network overloading condition, which could occur in the rare case of large number of terminals and application using the proposed framework and competing on the same network. Those limitations were faced by the second and third proposed algorithms, where a novel utility based network selection was proposed and then enhanced using matching game theory in the purpose of balancing the load on the available networks. The evaluation of the second algorithm showed that the more the speed increase, the less the algorithm performs. Yet, the proposed scheme is advantageous for high data rate applications for a speed up to 40 m/sec. It reduces the delay and packet loss ratio, and consequently improves QoS comparing with SAW scheme with a low speed of 10 m/sec comparing to the previously proposed algorithm. The same approach was customized for heterogeneous LTE cells, in-which Femtocells deployment covers a wide range of environments in public areas such as enterprise buildings, airports, shopping malls and highways. For this scenario, where the open access mode is used, the performance evaluation and comparison of UE triggered cell selection and eNB triggered one in environment that contains macrocells and femtocells was compared. In low, medium and high speed scenarios, the use of UE triggered handover against eNB triggered one improves the QoS of downlink and uplink in terms of throughput, delay, packet loss rate and number of handovers. As squaring up to problem of the overloading network, the matching algorithm, indeed, reduced the delays and packet loss rate comparing with the previously proposed algorithms for all types of applications. It shortens the delay and packet loss rate by 19% and 35% respectively. It reveals also that the proposed scheme provides a higher throughput, avoid needless handovers comparing to some literature works and wherefore revamps the QoS.

5.4 Conclusion

In wireless heterogeneous networks, the compulsory QoS perceived by users and affordable from operators can be attained through an ubiquitous vertical handover that fuses the mobile users prerequisite and networks capacities. In order to reach the required QoS for all types of traffic and avoid service discontinuity in heterogeneous networks, we implemented and compared, in this chapter, the Multi-Criteria Decision Framework for Network Selection over LTE and Wi-Fi for an ubiquitous and real time network selection based on MADM, Utility Function and Matching game.

In the first approach, the fuzzy enhancement made to AHP coupled with four ranking Methods, ie TOPSIS, VIKOR, MEW and SAW has proven its effectiveness. FAHP is used to produce the fuzzy weights in favour of ranking the candidate networks regarding the multi criteria concept. The fuzzy improvement enables to raise the QoS in all types of traffic, comparing with the use of classical AHP weights. It is due to the fact that the choice of the selected network is not distorted by the human intervention. Indeed Simulation experiments with Network Simulator NS3 showed that the use of FAHP weights achieves a momentous enhancement of the quality of QoS with all MADM methods. Thus, FAHP can decrease packet loss and end-to-end delay in all types of traffics. Furthermore, we suggested for each type of traffic, the most suitable scheme that minimize Delay and Packet Loss Rate. The perspective of this work can be conducted by running more sophisticated simulations and test-beds in a real heterogeneous environment.

In the second approach , we proposed a context-aware scheme of network selection based on utility function and considers both mobile user's needs and provider's constraints. The selection decision function is defined as a utility function consisting of QoS parameters. We have considered four real time applications. Simulation results showed that the proposed scheme is advantageous for high data rate applications even if user move with the high speed of 40 m/sec. It reduces the delay and packet loss ratio, and consequently improves QoS.

Finally, the third approach, we proposed a QoS -aware and context-aware scheme of network selection based on matching theory which considers both mobile user's needs and provider's hindrances. The decision operation inflicts the agreement of both sides. Indeed, the matching of UEs to APs considers preferences lists based on utility function on the network side, consisting of four QoS metrics, i.e., throughput, delay, jitter and bit error rate. Whilst, on the user side, a set of weights are generated to express the context awareness of the type of application used by each user. The UEs/APs matching algorithm is implemented in a topology of Wi-Fi/LTE heterogeneous network alongside the baseline schemes. Simulation results reveal that the proposed scheme is propitious for all types of applications. It shortens the delay and packet loss rate by 19% and 35% respectively, provides a higher throughput, avoid needless handovers and wherefore revamps the QoS.

In this simulation campaign, the small sample size is a limitation. Yet, all network simulations can only approximate the behaviour of a real system with specific characteristics. Thus, the grand challenge of this paper is using simulation experiments to reach credible comparisons and conclusions so that can be relatively correlated to larger networks. Thus, in next chapter, efforts are deployed to consider more sophisticated simulations in a large scale topology in a real heterogeneous vehicular environment.

Chapter

6

Application for Heterogeneous Vehicular Network in V2X Scenario

Contents

6.1 Introduction

In high-speed scenarios, such as in the V2X network as shown in figure 6.1, a critical problem that affects the QoS of a certain service is the next-handed network selection. Thus, we focus our work in the second phase of handover procedure. The decision function is set as a multi criteria utility function which considers three use case related parameters, namely: e2e latency, reliability, and data rate. We have considered four V2X applications.

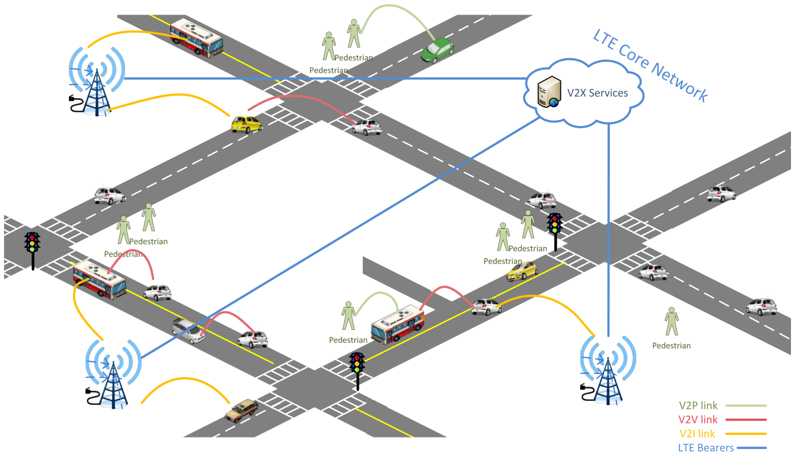


Figure 6.1: Illustration of Using LTE Bearers for V2X communications.

In the handover initiation, while being connected to a certain cell, the vehicle performs neighbour cells measurements and utilities calculations and compares the obtained outcomes with the the utility of the current network. In case of a better alternative, the vehicle triggers handover to the network.

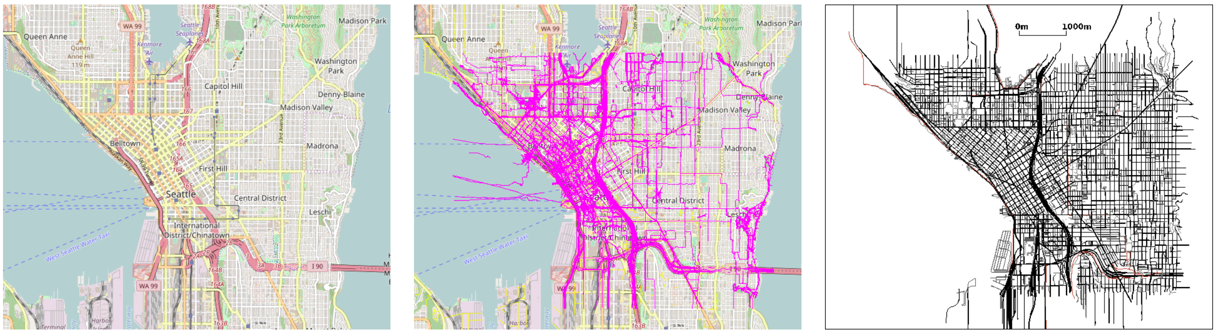
In order to catch the content level of a vehicle, we assess the normalized content of vehicle considering e2e latency, reliability, and data rate of the neighbouring networks including the serving network. Thus, the utility should be high and the decision is made accordingly.

We used, thereby, the previously proposed algorithm that computes the optimal stable matching entailing the assignment of all vehicles to the most suitable network regarding the type of the service each vehicle requires. The proposed approach prioritizes networks with higher relevance to different use cases and enables seamless connectivity to vehicles. Simulations results are provided to evaluate the performance of the proposed approach in high mobility V2X scenarios compared with the existing baseline scheme.

6.2 Network Configuration et Simulation Parameters

6.2.1 Network Topology

To evaluate the proposed Handovers for vehicular networks, We performed a set of simulation experiments over a realistic urban environment in the city of Seattle, Washington Wang et al. (2015), we used three different tools to collaborate harmoniously. Hence, the covered area of interest is captured from the OpenStreetMap tool Haklay and Weber (2008) as depicted in Figure 6.2a, then the SUMO tool Krajzewicz et al. (2012) is used to generate the vehicles' routes and movement patterns as shown figure 6.2c to be used finally by NS-3 network simulator Riley and Henderson (2010) as a mobility model.



(a) Captured Area of Downtown Seattle. (b) Traffic Map of Captured Area. (c) Traffic Map Extraction.

Figure 6.2: (a) Captured Area, (b) Traffic Map and (c) its Extraction of Seattle City.

6.2.2 Application Scenarios

Four scenarios with different V2X types of application were generated, (see Table 6.1). Those services are a Client-Server based applications with different requirements implemented on top of IP and using either UDP or TCP. x_{min} and x_{max} are the minimum and maximum requirement of the link-layer for V2X communication which cover four use cases, the values are provided in Table 6.1.

Table 6.1: Parameters Requirements for V2X Services.

Use Case	Communication scenario	Max e2e latency (ms)		Reliability (%)		Data rate ($Mbps$	
		x_{min}	x_{max}	x_{min}	x_{max}	x_{min}	x_{max}
Advanced Driving	Emergency Trajectory Alignment (EtrA)	2	4	98	100	25	35
Remote driving	Teleoperated support (TeSo)	15	25	98	100	20	30
Platooning	eV2X support for Vehicle Platooning	20	30	88	95	10	15
Extended Sensor	Video data sharing for assisted and improved automated driving (VaD)	45	55	88	95	7	12

In the simulation campaign, we varied the number of vehicles: 100, 200, 300, 400, 500 and 600. Each time, all the applications are ran by the total number of the vehicle. 25% of the vehicles used one among the four applications.

6.2.3 Network Deplyement

The experiments are operating the proposed schemes apace with the Max-SINR user association (which is the original scheme used by each user to connect to the suitable access point Andrews et al. (2014)) and Max-Throughput scheme Aryafar et al. (2013), under the same network configuration, whereby 41 femto LTE base stations, of radius 500 m and 6 macro LTE cells,of 1000 m radius are deployed using the network simulator 3 (NS-3) Riley and Henderson (2010). The LTE cells are distributed as shown in figure 6.3 in $6000 - By - 7000\ m^2$ area. The behaviours of QoS metrics considered by the schemes are calculated, in this paper, using the built-in FlowMonitor NS-3 tool that tracks per-flow statistics at the IP layer including throughput and latency and reliability.

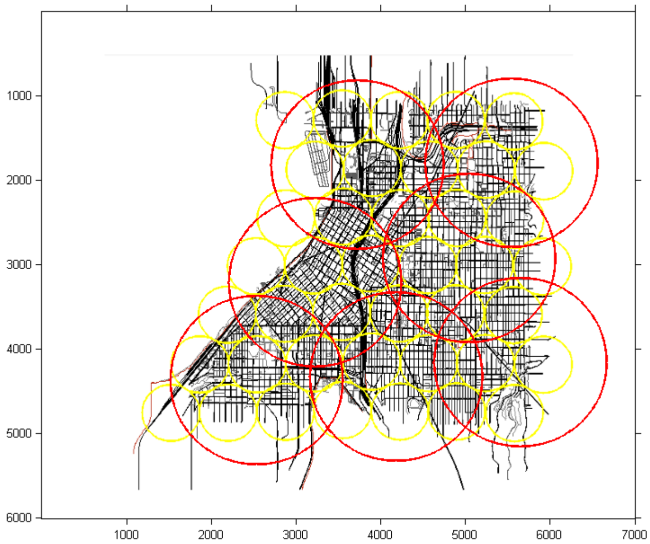


Figure 6.3: LTE Base stations mapping in the simulated area.

Throughout the simulations, the decision of the next handed network is a function of e2e latency, reliability, and data rate, As reported in table 6.2 below.

Table 6.2: Realistic Traffic Model With Simulation Parameters of the City Scenario.

Size of The Area (Km^2)	$6 * 7$
Number of BS	41 small and 7 macro cells
Number of Vehicles	100, 200, 300, 400, 500, 600
Speed of Vehicles	Between 25 and 50 m/s
Available Networks	LTE
LTE Range (m)	500
Channel Bandwidth of LTE (MHz)	10
Mobility model	
Application Traffic (25% of vehicles per application)	Advanced Driving (Emergency Trajectory Alignment (EtrA)) Remote driving(Teleoperated support (TeSo)) Platooning(eV2X support for Vehicle Platooning) Extended Sensor (Video data sharing for assisted and improved automated driving (VaD))
Simulation Time (s)	650

6.3 Evaluation Criteria

The objective of the experiments is to analyse and compare the effectiveness of proposed selection. To this end, we analyse the QoS metrics, delay, packet delivery and throughput, inasmuch as those QoS metrics translate the satisfaction of greedy mobile users. In addition, delay and packet delivery change constantly over the simulation each time the selection process is called. On one hand, delay is concerned by the time taken by the algorithm to converge which involves the time from the sending and receiving a packet by the source to the destination. On the other hand, a certain number of packets are lost during the vertical handover execution which has an influence on the Packet Delivery Ratio in addition to the throughput that increase with the increasing number of vehicles. All results are obtained by averaging over a large number of independent simulation runs.

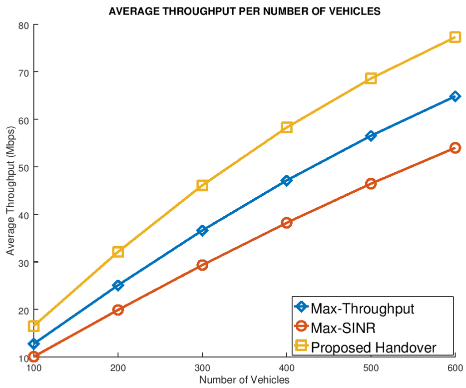
- **Delay**: is the time elapsing from the sending of a packet by the source until it is received by the destination.
- **Packet Delivery Ratio (PDR)**: is defined as the ratio of data packets received by the destinations to those generated by the sources.
- **Throughput**: is the number of messages successfully delivered per unit time.

The following section details the development of the network throughout the simulation.

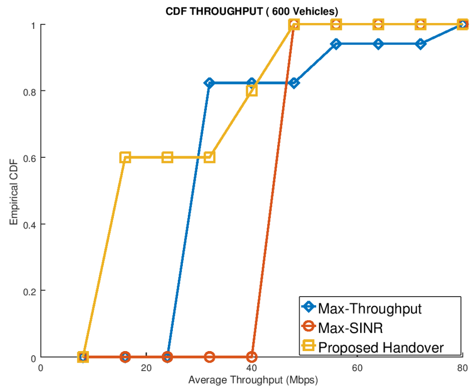
6.4 Evaluation Results

The performance result of the previously proposed matching algorithm along side with the most popular network selection algorithms, Max-SINR and Max-Throughput Andrews et al. (2014) Aryafar et al. (2013) respectively are detailed in terms of Throughput, latency and reliability.

6.4.1 Throughput Measurements



(a) Average Throughput (Mbps)

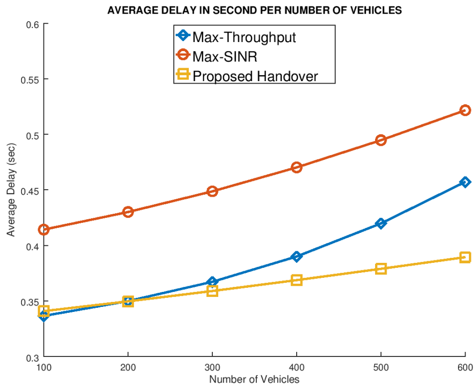


(b) Empirical CDF of Throughput.

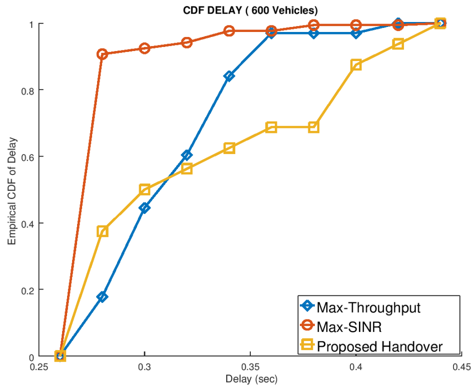
Figure 6.4: (a) Average Throughput in Mbps per Number of vehicles and (b) Empirical CDF of Throughput (600 Vehicles.

Figures 6.4a and 6.4b present the effects of traffic density on throughput using the proposed algorithm along side with the max-throughput and max-sinr algorithms. The proposed approach shows about an average of 20% gain in throughput over the max-throughput scheme and 20% over the max-sinr scheme. This smaller gain occurs because handovers only make up a small portion of the total time in which a vehicle receives packets. It is also observed that throughput performance begins improving at a lower vehicle density. The probability results 6.4b in 600 vehicles show that max-sinr' throughput probability is lowest, this is due to the occurrence of packet collision before saturation is reached, which only has a noticeable effect on throughput. Further deterioration in max-throughput is observed, as the bad choice of selected network causes an increase in the collision rate. The proposed method in 600 vehicle topology again shows a better possibilities of a good performance.

6.4.2 Delay Measurements



(a) Average Delay (sec)

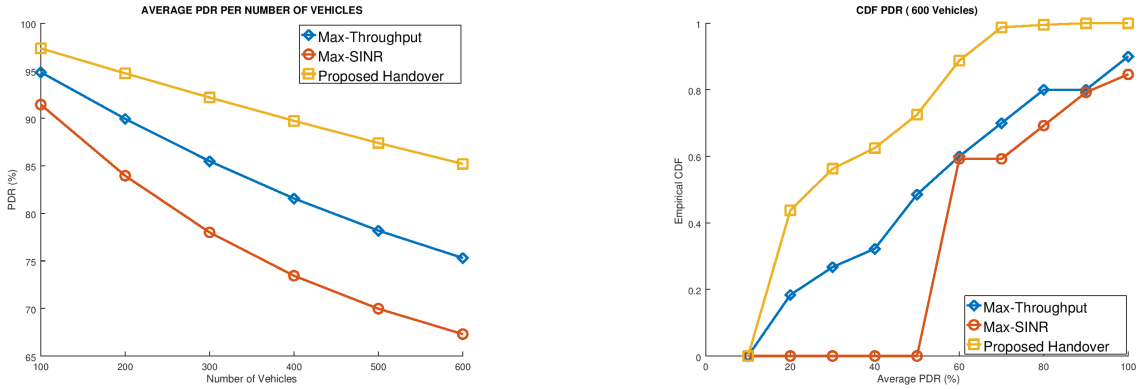


(b) Empirical CDF of Delay.

Figure 6.5: (a) Average Delay in seconds per Number of vehicles and (b) Empirical CDF of Delay (600 Vehicles).

In figure 6.5a and 6.5b, we analyse the impact of traffic density on the different algorithms. Figure 6.5a presents the effect of traffic density on latency, in the urban environment. As expected, the delay performance closely mirrors the throughput results, but shows smaller differences between approaches. The latency values are consistent until the networks begin reaching full saturation at about 500 vehicles, when high collision rates and longer network access times occur. Above 200 vehicles, we observe a 350 ms latency increase for the proposed approach, a 450 ms increase for max-throughput, and a 500 ms increase for max-sinr algorithms. Traffic density affects max-throughput and max-sinr algorithms latency the most, due to their bas cell selection during the handover; The proposed handover maintains the most consistency because it removes the ping-pong packet exchange that otherwise occurs during the handover, reducing the costs of collision rates and network access times. Figure 6.5b illustrates the results when 600 vehicle are deployed. Here, the probability of reaching highest delay belongs to max-sinr algorithm, followed by max-throughput. The proposed algorithms presents the lowest probabilities in reaching lowest delay in a dens topology.

6.4.3 Packet Delivery Ratio Measurements



(a) Average PDR (%)

(b) Empirical CDF of PDR.

Figure 6.6: (a) Average PDR per Number of vehicles and (b) Empirical CDF of PDR(600 Vehicles).

The goal of establishing simulation is to assess the quality of communication which can be quantified through the measurement of PDR. The applications streams are encoded in packets which are transmitted through the selected interface. Figure 6.6a and 6.6b show the results of average packet delivery ratio for different types of application for over various loads. The packets sent, when running the proposed algorithm, present a high success rate, especially for a small number of vehicles. For Max-Throughput algorithm, lower PDR was observed at larger topologies between the flow source and the destination. Nevertheless, the PDR is above 80% in most of the experiments. In the obstructed line-of-sight scenarios caused by vehicles and buildings, the PDR decreases as the number of vehicles increases. The foremost reason is that signal undergoes attenuation caused by simultaneous connections. The Max-SINR algorithm presents a lowest packet delivery ratio. The impact of the cell selection is quite visible in the quality of the radio link and consequently in PDR. Figure 6.6b illustrates the results when 600 vehicle are deployed. Here, the probability of reaching lowest reliability belongs to max-sinr algorithm, followed by max-throughput. The proposed algorithms presents the highest probabilities in reaching highest reliability in a dense topology.

6.4.4 Discussion

In future ITS, the vehicular network is the basic infrastructure and plays a critical role. The vehicular communications have broad market and attracted more attentions recently. In this chapter, the previously proposed load balanced network selection is proposed as an integrated solution for V2X communications based LTE-V2X deployment. Compared with the most popular algorithms, Max-Throughput and Max-SINR, the proposed algorithm presents an enhancement in terms of latency, throughput and reliability. In addition, the LTE-V2X topology inherits the advantages of LTE including natively high mobility support, high capacity, and flexible spectrum distribution. Moreover, LTE-V2X have to develop new features to meet the challenges for V2V communications, such as congestion control with heavy density traffic and low cost broadcasting. The standardization of LTE-V2X has to be harmonized and collaborated with organizations and alliances. Since LTE is the mainstream 4G mobile communication technology and with large industrial foundation, LTE-V2X can exploit economies of scale and with a short time to market. By levering the technology research and industry of LTE with stakeholders and through the cross-industry cooperation, LTE-V2X will be actively promoted in the standard body and industry.

6.5 Conclusion

In this section, we introduced a novel architecture that integrates LTE networks with vehicular scenarios. In this architecture, a cell is selected to connect ordinary vehicles with the LTE network. throughput, reliability and latency of cells are all taken into consideration when clustering vehicles and selecting vehicle cells. Cell discovery and handover scenarios are also considered and adequate solutions are presented. The envisioned LTE for V2X network is expected to prevent frequent handovers at LTE base stations. By using this topology, all vehicles can access fairy the network. On other hand, by implementing the previously proposed matching algorithm, bottlenecks and congestion across the path towards a single cell can be eliminated.

Conclusions and Future Works

In this chapter, we summarize our major contributions and discuss future research directions.

Conclusions

Next generation networks are expected to be dense, complex and heterogeneous. Therefore, the need of new vertical handover schemes happen to be the most efficient solution for a seamless connectivity. This work aims investigating the fundamental benefits of deploying a multi-criteria network selection algorithm in heterogeneous network from two aspects: network selection proposition and performance study. Three algorithms have been proposed for the general case of heterogeneous networks, whereas the performance study has been evaluated for two scenario types: Cellular and Vehicular. Specifically, the main contributions can be summarized as follows.

The network selection proposition aspect of this thesis was sectioned in two approaches:

- Framework for Multi-Criteria Network Selection based on MADM.
  We first detailed the mathematical modelling of MADM methods used in our proposed model. Then, we described the architecture of our selection algorithm, which is levering a combination of multi-criteria decision making methods to ensure that appropriate network is selected for a certain type of traffic and considering a number of QoS metrics that due to their interdependency, a weight distribution phase is required. The framework has been implemented in two variants of weighting distribution algorithms AHP, and FAHP. To ascertain thoroughly the weights of QoS metrics impacting the decision for each application, AHP is generally applied. But its classical form comes with biased rules that are dealt with through an enhanced version FAHP that has proven its performance when combined with the other well reputed ranking methods, namely: MEW,SAW, TOPSIS and VIKOR. We explained the functioning of each variant and present some limitation of the contribution.

- Load Balanced Network Selection Algorithm in High Speed Heterogeneous Networks.
  In the first work, the vertical handover was handled without mobile users speed nor the network overloading condition. Those limitations were squaring up by the second and third proposed algorithms, where a novel utility based network selection was proposed and then enhanced using matching game theory in the purpose of balancing the load on the available networks.

The second approach is the utility function for high speed scenarios. For network selection decision, utility function assigned to the satisfaction that a network provides to mobile users. Different available networks with different user preferences will have different utility values. We proposed a context-aware access network selection based on utility function that takes into consideration user's and QoS preferences. It aims at maximizing the user satisfaction while meeting application QoS when connecting to a target network. The proposed approach prioritizes networks with higher relevance to different types of applications and enables seamless connectivity to mobile user and applications. Thus, network resources are conveniently managed to support diverse services that might be considered by mobile users.

This approach was enhanced using the matching game theory, a winning the 2012 Nobel Prize, which provides a mathematically tractable method for personnel assignment problem in two distinct sets. In wireless networks, the matching was applied for mobile users and access points. We enhanced the latter solution by proposing an network selection scheme that provides a load balancing technique based on matching theory. This scheme focuses on enabling simultaneous invocation of applications with different traffic and QoS characteristics. We formulated, thereby, our problem as a matching game, aiming to meet the required QoS of cellular users, randomly distributed in heterogeneous networks coverage, then we proposed an algorithm that computes the optimal stable matching entailing the assignment of all users to the most suitable network regarding the type of the service each user need in high speed environment.

In the performance evaluation aspect, two scenarios have been adopted. Cellular and Vehicular scenarios:

- Performance Evaluation of the proposed schemes in Cellular network.

  The three algorithms were evaluated to the purpose of proving their applicabilities in a mobile environments considering Cellular application namely, Conversational, Streaming, Interactive and Background for a ubiquitous and real time Network Selection over LTE and WLAN.

  In MADM scheme evaluation, The fuzzy improvement enabled QoS enhancement in all types of traffic, compared to AHP weights. The use of FAHP contributed to a decrease in packet loss rate and end-to-end delay in all types of traffics. Indeed Simulation experiments with Network Simulator NS3 showed that the use of FAHP weights achieves a momentous enhancement of the quality of QoS with all MADM methods. Thus, FAHP can decrease packet loss and end-to-end delay in all types of traffics. Furthermore, we suggested for each type of traffic, the most suitable scheme that minimize Delay and Packet Loss Rate.

  In addition, the utility scheme, where the selection decision function is defined as a utility function consisting of QoS parameters, was evaluated in low, medium and high mobility scenarios compared with the previous baseline scheme. Simulation results showed that the proposed scheme is advantageous for high data rate applications even if user move with the high speed of 40 m/sec. It reduces the delay and packet loss ratio, and consequently improves QoS.

Finally, the matching enhancement was implemented in a topology of Wi-Fi/LTE heterogeneous network alongside the previous schemes. Simulation results reveal that the proposed scheme is propitious for all types of applications. It shortens the delay and packet loss rate by 19% and 35% respectively, provides a higher throughput, avoid needless handovers and wherefore revamps the QoS.

- Performance Evaluation of the proposed schemes in Vehicular network.

  In high-speed scenarios such as the V2X, the network selection dedicated to 5G systems in V2X Scenarios is more critical. Thus, the previously proposed matching algorithm was performed in vehicular scenario where four V2X application were implemented such as: Advanced Driving, Remote driving, Platooning and Extended Sensor. The performance evaluation was implemented in a large scale topology. Results show that the proposed algorithm is more accurate compared to baseline algorithms for vehicular applications.

Future Works

There are several research directions in which the work can be extended.

Short-term Perspective Work

Multi-Path Stream Over Heterogeneous Networks:

In the coexistence of variety of network technologies, it is interesting for a mobile user to use more than one channel to send data instead of having to choose one access point. We are actually studying the possibility of Multi-Path networks selection for a user to reduce the application delay, connection time and guarantee the quality of the user experience (QoE). In this context, the new architecture would support the QoE.

Vanets-LTE Coexistence:

V2X communications technology is expected to revolutionize the ground transportation system by providing a safer, smarter, less polluted, and more entertaining environment for people on roads. To support V2X applications for a large number of vehicles, interworking between Vanets and cellular network technologies is a promising approach.

Handover Triggering:

In this work, the vertical handover in heterogeneous environment is handled without considering handover triggering techniques, purposefully, to be able to highlight the potentials of the schemes in real time under a vying conditions, however, this could subdue the handover process in a real environment. In the future works, efforts will be deployed to consider handover triggering in the network selection process.

Long-term Perspective Work

A mobile Access Point:

Throughout this thesis, we considered a stationary base stations. However, an interesting idea is to use the public transportations and their mobility to deploy the access points. Public transportations usually move along a fixed route track, it means that it is possible to predict the moving direction of mobile relays. This moving network also comes with challenging problems in terms of mobility management. To study how mobility affects the system performance and handover rate, it would be interesting to study this evolving technology.

5G Interesting topics

Among others, my research interest topics lie on Device to Device (D2D) communications, Millimetre-Waves (mmWaves) and Full Duplex, which aim to meet requirements of 5G networks. In fact, distribution of users is important in future wireless networks. Using load balancing tools are primary to analyse and derive performance of next generation technologies:

- In D2D communications, users can communicate directly or act as relay to forward the traffic of other users to the nearest base stations. This can improve spectrum utilization, overall throughput, and energy efficiency while enabling new peer-to-peer and location-based applications and services. In this direction, efforts can be directed in studying issues including: Energy efficiency, Resource allocation and Spectrum sharing between cellular and D2D users.

- Due to potential of availability of wider bandwidths, the mmWaves bands above 30 GHz hold promise for providing high peak data rates in specific areas where traffic demands are very high. Many interesting aspects can be tackled such as evaluation of the coverage and the rate of mmWaves systems and developing new channel models.

- Full Duplex, currently, the 5G network has become a keyword among researchers and engineers in the communication society. As a candidate of 5G technologies, full duplex has been received great attention and discussed a lot. Full duplex wireless system can maximally achieve doubled spectral efficiency by transmitting and receiving signals at the same time and frequency. Due to advances in both radio and digital processing, full duplex can now be implemented at reasonable cost and without complex radio hardware.

List of Publications

International journals

Maroua Drissi and Mohammed Oumsis Multi-Criteria Vertical Handover Comparison Between Wimax and Wifi, ***Information***, Multidisciplinary Digital Publishing Institute (MDPI) Switzerland, pp 399–410, 2015. **Scopus**. ISSN: *2078-2489* .

Maroua Drissi, Mohammed Oumsis and Driss Aboutajdine, A Multi-Criteria Decision Framework for Network Selection over LTE and WLAN. ***Engineering Applications of Artificial Intelligence***, Elsevier Limited, pp 113–127. Impact Factor: **2.894**. **Scopus**. ISSN: *0952-1976*.

Maroua Drissi, Mohammed Oumsis and Driss Aboutajdine, Enabling V2X-Application-Aware Handover in LTE-based Heterogeneous networks. Submitted to ***Wireless Communications and Mobile Computing***, John Wiley and Sons Ltd. (submitted on August, 2017). Impact Factor: **1.899**. **Scopus**. ISSN: *1530-8669*.

Maroua Drissi, Mohammed Oumsis and Driss Aboutajdine, A Load Balanced Network Selection Algorithm in Heterogeneous Networks using Matching Game. paper submitted to ***IEEE Transactions on Vehicular Technology***. (submitted on September, 2017). Impact Factor: **4.006**. **Scopus**. ISSN: *0018-9545*.

Zineb Squalli Houssaini and Imane Zaimi and **Maroua Drissi** and Mohammed Oumsis and Saïd El Alaoui Ouatik, Trade-off between accuracy, cost, and QoS using a beacon-on-demand strategy and Kalman filtering over a VANET . ***Digital Communications and Networks***. (2017). **Scopus**. ISSN: *2352-8648*.

Book Chapters

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Maroua Drissi, Mohammed Oumsis and Driss Aboutajdine, A Context-Aware Access Network Selection Based on Utility-Function for Handover in WLAN-LTE Environment, ***Advances in Ubiquitous Networking 2***, LNEE 397,pp 57–66, Springer International Publishing, 2017. **Scopus**.

International Conferences

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Maroua Drissi, Mohammed Oumsis and Driss Aboutajdine, VIKOR for multi-criteria network selection in heterogeneous wireless networks, ***International Conference on Wireless Networks and Mobile Communications (WINCOM), 2016*** . October, 2016, Fez Morocco. doi: 10.1109/WINCOM.2016.7777195, Page(s): 82 - 86, IEEE Xplore Digital Library. **Scopus**.

Maroua Drissi, Mohammed Oumsis and Driss Aboutajdine, User-Driven Handover Scheme in Long-Term Evolution (LTE) Macro/Femto Cells for High Speed Scenarios, ***In Proceedings of the International Conference on Big Data and Advanced Wireless Technologies (BDAW), 2016*** . November, 2016, Blagoevgrad, Bulgaria. DOI: https://doi.org/10.1145/3010089.3010115, Page(s): 1 - 6, ACM, New York, NY, USA. **Scopus**.

Appendix: Network Simulator 3

About NS-3 Riley and Henderson (2010)

NS3 has been developed to provide an open, extensible network simulation platform, for networking research and education. In brief, NS3 provides models of how packet data networks work and perform, and provides a simulation engine for users to conduct simulation experiments. Among the reasons for which we have used NS3 is the fact that it perform studies that are more difficult or not possible to perform with real systems, to study system behaviour in a highly controlled, reproducible environment. The available model set in NS3 focuses on modelling how Internet protocols and networks work. Many simulation tools exist for network simulation studies. The feature of NS3 in contrast to other tools is that NS3 is designed as a set of libraries that can be combined together and also with other external software libraries. While some simulation platforms provide users with a single, integrated graphical user interface environment in which all tasks are carried out, NS3 is more modular in this regard. Several external animators and data analysis and visualization tools can be used with NS3. However, NS3 is used at the command line and with C++ and/or Python software development tools.

FlowMonitor Module

The Flow Monitor module goal is to provide a flexible system to measure the performance of network protocols. The module uses probes, installed in network nodes, to track the packets exchanged by the nodes, and it will measure a number of parameters. Packets are divided according to the flow they belong to, where each flow is defined according to the probes characteristics (e.g., for IP, a flow is defined as the packets with the same protocol, source (IP, port), destination (IP, port) tuple.

The statistics are collected for each flow can be exported in XML format. Moreover, the user can access the probes directly to request specific statistics about each flow.

Mobility Module

In ns-3, special Mobility Model objects track the evolution of position with respect to a (Cartesian) coordinate system. The mobility model is typically aggregated to an node. There is a different motion behaviours the node can follow.

The initial position of objects is typically set with a Position Allocator. These types of objects will lay out the position on a notional canvas. Once the simulation starts, the position allocator may no longer be used, or it may be used to pick future mobility "waypoints" for such mobility models.

Most users interact with the mobility system using mobility helper classes. The Mobility Helper combines a mobility model and position allocator, and can be used with a node container to install mobility capability on a set of nodes.

Motivation For NS3 Use

In networking, the most used imulator is with ns-2 (a popular tool that preceded NS3), the most visible outward change when moving to NS3 is the choice of scripting language. Programs in ns-2 are scripted in OTcl and results of simulations can be visualized using the Network Animator nam. It is not possible to run a simulation in ns-2 purely from C++ (i.e., as a main() program without any OTcl). Moreover, some components of ns-2 are written in C++ and others in OTcl. In NS3, the simulator is written entirely in C++, with optional Python bindings. Simulation scripts can therefore be written in C++ or in Python. New animators and visualizers are available and under current development. Since ns-3 generates pcap packet trace files, other utilities can be used to analyze traces as well. In this tutorial, we will first concentrate on scripting directly in C++ and interpreting results via trace files. But there are similarities as well (both, for example, are based on C++ objects, and some code from ns-2 has already been ported to NS3). The highlight differences between ns-2 and NS3 consist in:

- It provides features not available in ns-2, such as a implementation code execution environment (allowing users to run real implementation code in the simulator), NGN

...

- It provides a lower base level of abstraction compared with ns-2, allowing it to align better with how real systems are put together. Some limitations found in ns-2 (such as **supporting multiple types of interfaces on nodes**) have been remedied in ns-3.

Ns-2 has a more diverse set of contributed modules than does NS3, owing to its long history. However, NS3 has more detailed models in several popular areas of research (including sophisticated LTE and Wi-Fi models), and its support of implementation code admits a very wide spectrum of high-fidelity models.

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