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Abstract:

The work presented in this deliverable focuses on optimizing the cellular connectivity by allowing mobile user terminals to handover to IEEE 802.11 based WiFi hotspots given two different cellular technologies, namely mobile WiMAX (802.16e) and LTE. Network simulation studies are used to investigate the feasibility of letting the handover decision depend on location information, by comparing the proposed location based algorithms to conventional power based approaches. These algorithms rely on a fingerprinting database, which can map a mobile user's position into an expected throughput of the networks in range. Additionally, an extension that connects heterogeneous mobile terminals to infrastructure via multi-hop, while using location information to minimize interference, is sketched.

Results from this work show that location information is very useful in handover algorithms, as it can be used to predict future connectivity conditions. This has been found useful for enhancing the users' experience of quality of service, as the amount of handovers, which lead to a few seconds of service interruption each time they are performed, has been reduced. Similarly, the proposed algorithms focusing on throughput have shown to deliver an enhanced throughput when the movement speed is moderate and a high accuracy localization system is used.

Keyword list:

Heterogeneous wireless networks, radio access technology (RAT), radio access network (RAN), mobile WiMAX (IEEE 802.16e), LTE, WiFi (IEEE 802.11), handover, multi-hop, cellular, hot spot

Executive Summary

This document presents the outcome of WHERE Work Package 3 Task 4, which concerns "Optimized Cellular Connectivity using Positioning Data". The document contains an initial introduction followed by two main chapters (2 and 3) that deal with handover optimization, another main chapter (4) that deals with optimized multi-hop cellular connectivity, a common conclusion, and references.

The two chapters concerning handover optimization focus on optimizing the cellular connectivity by allowing mobile user terminals to handover to IEEE 802.11 based WiFi hotspots given two different cellular technologies, namely mobile WiMAX (802.16e) and LTE. As a handover from one link technology to another requires setup and initialization of the new connection, the handover itself has a negative impact on the user quality of service in terms of throughput and delay. This means that handover algorithms should carefully select which handovers to make by estimating and maximizing the expected user quality of service. The major focus of this work has therefore been to develop suitable algorithms for deciding when to handover between cellular connectivity and WiFi hot spots. A common requirement for these algorithms is a fingerprinting database, which can map a mobile user's position into an expected throughput of the cellular network and hot spots in range.

In chapter 2 the analysis focuses on a scenario with several WiMAX (IEEE 802.16e) cells and one WiFi (IEEE 802.11) hotspot. A detailed network simulation shows that the position based algorithm reduced the number of handovers compared to power based algorithm. This leads to fewer interruptions experienced by the user, however at the cost of a slightly reduced throughput.

In chapter 3 the considered scenario consists of a global cellular LTE network as well as many randomly placed and occasionally overlapping WiFi hot spots. Two efficient handover algorithms are proposed and evaluated using detailed network simulations. An evaluation is performed of the impact of varying positioning accuracy, varying movement speed, and different WiFi hot spot deployment accuracies, and the outcome is compared to the case where LTE is always used and to the result of a genetic algorithm with perfect knowledge. The results show that inaccuracies in predicting the mobile user's future position, especially for high movement speeds, have a significant negative impact on the achieved throughput. Another main result is that when speed is not too high, the position-based handover decision is clearly useful with high accuracy positioning systems.

Finally, in chapter 4, we outline an approach that allows heterogeneous mobile terminals to connect to infrastructure in a multi-hop manner, while using location information to minimize interference. This work item is very closely related to the work presented in WHERE D3.6 that deals with two-hop relaying techniques for homogeneous wireless networks, and is here included as a bridge to scenarios with heterogeneous mobile terminals, which is the topic of this deliverable.

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List of Acronyms and Abbreviations

Term	Description
3GPP	3rd Generation Partnership Project
AP	Access Point
B3G	Beyond 3G
BLER	Block Error Rate
BS	Base Station
CDF	Cumulative Distribution Function
CPICH	Common Pilot Channel
CRRM	Common Radio Resource Management
DHCP	Dynamic Host Configuration Protocol
EDCA	Enhanced Distributed Channel Access
FDMA	Frequency Division Multiple Access
GSM	Global System for Mobile Communications
HO	Handover
HSDPA	High-Speed Downlink Packet Access
HSPA	High-Speed Packet Access
LTE	Long Term Evolution
MAC	Medium Access Control
MIP	Mobile Internet Protocol
MT	Mobile Terminal
NRTV	Near Real Time Video
PHY	Physical
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RSSI	Received Signal Strength Indicator
SINR	Signal to Interference and Noise Ratio
SNR	Signal to Noise Ratio
UMTS	Universal Mobile Telecommunications System
WCDMA	Wideband Code Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network

1. Introduction

Wireless communications covers today a wide array of applications, with a multiplicity of services and for a tremendously increasing number of mobile users and new services. Among other, for pico-networking Bluetooth and ZigBee are having wide usage, IEEE 802.11 and HiperLAN families of standards, called WiFi systems covers the wireless local area network (WLAN) systems, GSM, UMTS with its packet based target High-Speed Packet Access (HSPA) covers the metropolitan area networks, being now WiMAX and LTE under studies, deploying to wireless users bit rates from now only available in fixed wired networks.

The future leads towards an environment where wireless communications will exist in every scenario of life to provide the end user the “flexibility and choice”, to enhance the quality of life of the individual. The vision is beyond 3G communications, which is tending towards a diverse wireless networking world, where scenarios define that the user will be able to attain any service, at any time on effectively any network that is optimised for the application at hand.

Thus we are approaching a future global infrastructure, where several systems can coexist to support transparent end-to-end communications, in an efficient, cost-effective manner, not only for operators optimization of usage and consequent income of their infrastructures but for the users best quality of services, at a cheaper price and with continuity, since being always connected has a negative impact on the battery life.

The dynamic time-varying nature of the networks topology and channel conditions in wireless networks makes them probably the least understood and predictable among the existing communication networks. As a result, understanding of wireless networks requires extensive prototyping and experimentation, in order to uncover new insights that lead to improvements in systems inter-connections. This is particularly true for the next generation of wireless systems. This requires the development of new strategies to get access to the resources provided by different networks and manage them.

Handover is one of the most important functionalities to support user’s global mobility and to fulfil the need for integration and interoperability of existing mobile systems. Intra-system and inter-system handovers have raised much research attention in recent years.

Particularly, in the multi-RAT scenario many issues that condition the communication optimization have been under study. The basic one is the service provisioning, which means that when a system is no more available in terms of signal coverage one might want to hand-over to other that can continue to provide service. For power consumption optimization; while some RATs are more power efficient than others in normal circumstances, propagation conditions will always be related to the power that is consumed. Operators may prefer to balance load in over-loaded system in a particular period of time handing over users from one system to other for the continuity of service providing. Due to the intrinsic dynamics of mobile wireless users sometimes it is not suitable to handover a user to a more efficient network for the service that the user is experiencing if the mobile can provide successive handovers, to avoid the so called ping-pong effect.

In the literature some handover decision algorithms based on location information already exist. In [KPP08] the authors present a survey and categorization of vertical handover decision strategies in heterogeneous wireless networks. Specific examples from the literature where location information is used in the handover decision are presented in the following.

One example of such exploitation of location information is given in [CS05] where a Location Server Entity provides the information such as coverage area, bandwidth and latency of available wireless networks around a mobile terminal, which is used by the mobile terminal to have only needed radio interfaces turned on at any given time and to handover to the best network at the right time; thereby saving power and enhancing the user’s quality of service.

A similar approach is presented in [PKH+00], where the authors propose a system architecture that integrates geo-location capabilities into WLAN networks. This is used to allow the MT to get information that it is approaching a WLAN AP and should prepare to handover. In both [CS05] and [PKH+00] the handover itself is triggered by the RSS level increasing above given thresholds or user preferences, and the ping-pong effect is reduced by use of dwell timers.

Another example from the literature is presented in [SSW08]. This approach considers the connection duration, QoS parameters, mobility and location information, network access cost, and the signalling load incurred on the network for the vertical handoff decision by formulating this problem as a constrained

Markov decision process. They compare the performance of this scheme with and without velocity information and show that the best performance is obtained when the velocity is considered.

In [ZCL06] the authors propose a dynamic programming handover algorithm that uses location information to decide when to handover. Historic and current location information is used to predict the user mobility and in turn sojourn time within range of high speed hot spots, in order to avoid harmful handovers. They show by simulation studies that the proposed algorithm optimizes the user's satisfaction compared with other recently proposed schemes.

A context-aware vertical handover approach that can integrate a variety of wired and wireless technologies (2.5G, 3G, 4G, WLAN, and Bluetooth) is proposed in [BI04]. The first step in the handover process is to select a subset of candidate networks by using location information. In the second step an Analytic Hierarchy Process method is employed to maximize user device preferences and application bandwidth, while minimizing jitter, delay, and loss as well as bandwidth fluctuations, to optimize the user perceived QoS. Evaluation results are presented from a prototype implementation.

Similar work is presented in [WFP+06]; where the authors propose an architecture for collection and distribution of context information in order to allow handover between different networks. The evaluation of the proposed architecture is based on a prototype scenario that considers as context information the mobile node's location and the traffic load of access networks as well as the signal strength. Their study however, focuses mostly on the performance of the context information distribution system.

In this work we will evaluate how the knowledge of the positioning information can help in the multi-system handover decision. The considered scenarios are centred on a HO procedure between a WLAN and cellular technologies. For simulation studies we have chosen to work with the widely-spread IEEE 802.11 for local area networks and with the promising upcoming technologies IEEE 802.16e (Mobile WiMAX) and LTE for cellular connectivity.

We have proposed several algorithms for exploiting location information in the handover decision; aiming at even load distribution and high throughput, and we compare these to typical algorithms that are based on measurements of received power.

In our investigations we focus both on the impact on QoS, specifically in terms of the number of handovers where service interruptions may occur, and on the overall system perspective in terms of the service throughput.

Initially, in chapter 2, we consider a centralized approach to making the handover decision, which ensures load balancing in an isolated case with a WiFi hotspot inside a WiMAX cell under the assumption of perfect knowledge of positioning information.

Secondly in chapter 3, we consider the hand-over optimization from a system perspective, assuming that the handover decision is taken at the mobile device in a scenario where we have many LTE cells and many WiFi hotspots. Here, we consider unloaded conditions in the different cells and hotspots, but we relax the assumptions on perfect positioning information and consider different levels of inaccuracy, as well as different movement speeds of the mobile user device, and different deployment densities of WiFi hotspots.

Finally, in chapter 4, we outline an approach that allows heterogeneous mobile terminals to connect to infrastructure in a multi-hop manner, while using location information to minimize interference. This work item is very closely related to the work presented in WHERE D3.6 that deals with two-hop relaying techniques for homogeneous wireless networks, and is here included as a bridge to scenarios with heterogeneous mobile terminals, which is the topic of this deliverable.

2. Location assisted RAT selection for B3G Network optimisation

2.1 Introduction

In this work we will evaluate how the knowledge of positioning information can help in the multi-system handover decision, using particular case of the 802.16e, the so called Mobile WiMAX and 802.11e, the Mobile WiFi.

The concept of handover in wireless mobile communications was introduced to maintain the service availability when subscribers move away from serving radio access entity, saying the cell/Application Point. When the handover occurs from one network technology to another is the so called vertical handover. In [VHO1] is shown a vertical handover between UMTS and WiFi where QoS based decision is made. Since the appearance of the WCDMA (UMTS), Soft-Handover has been introduced in order to extend and improve the capacity and coverage. The WCDMA used the fact that cells coverage are separated by spreading codes to increased the notion of coverage, in opposite of the GSM case that hardware expense would need, since cells are separated or distinguished by frequency bands. A part of being more power consuming solution HSDPA, which uses fast scheduling and fast cell selection, shown to be more efficient in packet based applications. It had been shown that hard handover is recommended instead soft-handover for the packet based HSDPA [PT04].

This chapter includes the notion of positioning information and fingerprint database to propose a vertical handover between the most recent versions of the standards of WiMAX and WiFi.

The remaining of this section is organized as follows. Section 2.2 describes the WiMAX and WiFi coexistence scenario. Section 0 describes the models and parameterization for hard-handover, while the section 2.4 presents the proposed algorithm for RAT selection based on Soujourn time. Section 2.5 presents simulation scenario and models used for WiMAX and WiFi, performance metrics, and numerical results that measures the diversity gain obtained with Common Radio Resource Management (CRRM). In section 2.6 we present the conclusions and suggestions for further work.

2.2 Network Coexistence Scenario

An algorithm for RAT selection is proposed for handover decision between WiMAX (802.16e) and WiFi (IEEE 802.11e). The addressed scenario is depicted in Figure 2.1. An IP-based core network is assumed to act as the bridge between WiFi, and WiMAX. The depicted scenario is aligned with future wireless trends that envisage a B3G network, a network of wireless networks through which the user can attain the same service, as covered by the 802.21 standard, which details are neglected in this work. Within this IP cloud, we envisage a cooperative networking entity that logically communicates with WiMAX, and WiFi to provide this networking bridge, more specifically referred as the Reconfiguration Module entity, which is responsible for: i) gathering system and user specific information; ii) processing this information according to operator specific criteria; and iii) triggering new hand-over events minimizing the so called Ping-pong effect, while maximizing the system performance in terms of a certain metric. Moreover, it is assumed that a common operator deploys either systems, or those systems from different operators share a service level agreement to cut-out any constraint related to heterogeneous systems management.

This scenario addresses the delivery of near-real-time video (NRTV) services that can be streamed either over WiMAX or WiFi systems. The end user is currently subscribing to an IPTV service, which is currently also being delivered by either over the WiFi hotspot or the WiMAX system.

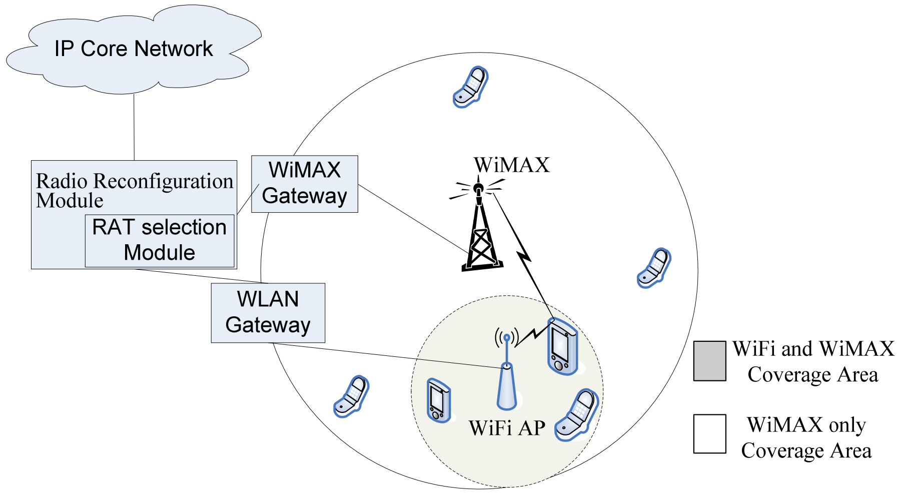

Figure 2.1: Coverage area for WiFi, WiMAX and for both systems.

The study will mainly be focused on the criteria for handling a handover event, whilst neglecting architectural aspects of the intersystem handover, (tight/loose coupling, centralized or de-centralized), including signalling aspects. It is assumed that the values for the metrics used in proposed algorithm, i.e., channel state, positioning information, are available and can be obtained with no errors. By using signal strength, positioning information and predicting a mobility pattern not neglecting the load measurement for both systems, based on the Sojourn value, the algorithm selects the RAT which the user should be attached to. The details and decision criteria are the scope of the work presented in this section and is detailed in the sub-section 2.4.

2.3 Models and parameters used in hard-handover

In this sub-section are described details of handover procedures and parameters, in order to identify and justify the choices for the proposed algorithm. We will use the hard-handover approach for the vertical handover analysed, where multi-mode terminals are assumed. We describe the hard-handover procedures, the used parameters, and its constraints and optimization methods.

2.3.1 Ping-pong effect

Typical radio propagation environment is characterized by fluctuations in the received signal power due to slow fading caused by buildings and obstructions as well as fast fading resulted from multiple propagation paths the receivers exposes. Handover theoretically deals with these variations in the cells boundary where there is a signal decrease from one cell and increase of the other cell. As results of user mobility in the cell boundary, being these fluctuations fast and occur in frequent increase and decrease of signal strength. These signal fluctuations will lead to many handovers if a user is going to simply handover to a cell which provides a better quality of signal, when the user is moving from one cell to another. This impact, very significant around the cell boundary, forces the user to handover forth and back between two cells. This normally is referred to as Ping-Pong effect.

To effectively reduce this Ping-Pong effect normally two mechanisms are adopted in hard handover algorithms, which are named as the Averaging Window and the Hysteresis value. They are explained below.

2.3.2 Averaging Window and Signal Hysteresis

The averaging window is basically a filter that is applied in the received signal in order to average it during a certain period. The averaging window is applied so that N instantaneous measured received energy over interference plus noise (Ec/Io) samples of the pilot (or preamble) to be averaged with the same weight. N is indicated as the size of averaging window. For instance, the i^{th} averaged Ec/Io from pilot channel from cell j can be presented as,

$$Avrg(Ec/Io)_{i,j} = \frac{1}{N}\sum_{k=1}^{N}(Ec/Io)_{j,i-k} \tag{2.1}$$

The hysteresis value, *Hyst*, is used to prevent immature handovers. When pilot of the best candidate cell is better than current serving cell by *Hyst*, the handover will be performed.

By doing this, the handover algorithm now can be explained as,

$$Avrg(Ec/Io)_{\max} - Avrg(Ec/Io)_{serving} > Hyst \tag{2.2}$$

where $(Ec/Io)_{max}$ indicates the best CPICH among candidate cells and $(Ec/Io)_{serving}$ corresponds to the CPICH of current serving cell.

Alternatively, this algorithm with averaging window and hysteresis can be illustrated by Figure 2 as follows for the case of two cells of same standard access system.

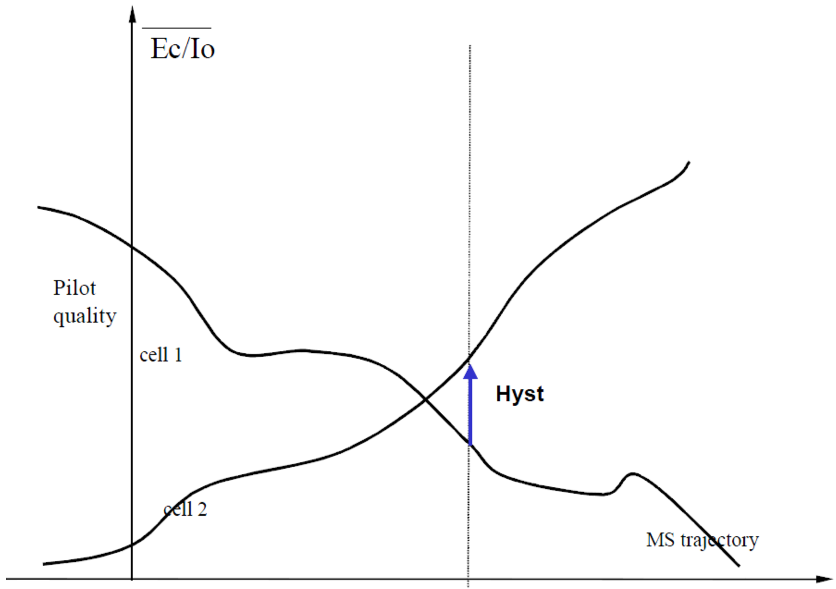

Figure 2.2: Graphical description of the HO parameters based on pilot level.

While the averaging window N and the hysteresis *Hyst* prevent for successive handover avoiding the Ping-Pong effect, sometime these will lead to late handover in some cases provoking firm degradation of communication quality. For this purpose the selection of the averaging window and the hysteresis are crucial for the network performance and communication continuity [MA04].

2.3.3 Dynamic/variation of the radio channel and handover

In the previous sub-section was presented the Ping-Pong effect and methods to minimize it, using the average window *N* and hysteresis *Hyst*.

The optimizations of these parameters are a difficult task since they depend on the channel variation. In other words, they should depend on the speed and on the environment morphology. Figure 2.3 shows examples of the average received power from the initial serving base station, in function of the hysteresis and averaging window, taken from simulations in the UMTS network, in urban environment and mobile speed of 36 km/h done in the MATRICE project [MA04].

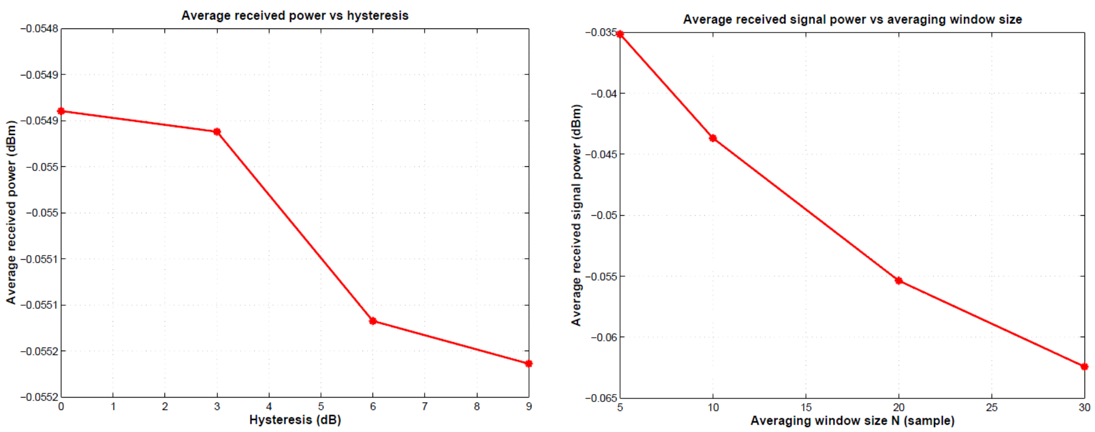

Figure 2.3: Average received power for UMTS versus hysteresis values and averaging window size [MA04].

Optimization point and instant of handover decision will essentially depend on system dynamics tracking and measurements prediction. In other words, if we can track the dynamics of the system by the meaning of the channel variation, optimized point for the handover decision can be reached. This is being one of the most important challenges on the study of handover algorithms, and had been based on channel parameters characteristics evaluation [YY02, UJ00].

In this work we propose to use positioning information and average channel knowledge in the environment, by the meaning of the fingerprint [WH09] in parallel with future positioning tracking to take the handover decision. The algorithm is explained in next sub-section.

2.4 Inter-system handover - Sojourn time based algorithm

2.4.1 Sojourn time

In this section an algorithm is presented for vertical HO decision selecting whether HO should be performed or not, based on Sojourn time of a mobile in each RAT during a given period.

The sojourn time theory is based on Little's theory, and Sojourn time corresponds to amount of time that an entity remains in Steady State in the system S during its motion. Figure 2.4 shows an entity that enters and moves across S2 while being in S1.

If the arrivals and motion of entities into the system S can be characterized by stochastic process the Mean Sojourn Time is the steady state period that the entity remains in S. The steady state amount of entities is given by the flow of entities into S times the Mean Sojourn Time.

In the case of wireless system, we will assume that the Steady State time is the time that the received signal $SIR_{i,j}$ on the MS i from the RAT j is above a threshold Th_j. The flow of entities can be attached to the call arrival rate and the transit duration as the call duration.

Figure 2.4: Motion of an entity in systems S1 and S2.

The Little theorem referenced above, is a model to relate the concept of the Sojourn time model in systems with wireless mobile networks. We use this notion to propose an algorithm that aims to optimize the achievement of the instant of the HO decision. We aim to minimize unnecessary inter-system Handovers.

The proposed algorithm is based in two principles which are, (1) a fingerprint database [WH09] of average SINR is available in evaluated area; (2) positioning information of mobile station (MS) are available in the system. The proposed algorithm is based on the fact that if the motion of an MS can be tracked predicting future locations of the MS, unnecessary handover can be avoided if averaged propagation conditions are known in the motion area. Moreover the optimal instant of handover decision can be made, optimizing the instants that the MS can be attached to one RAT or the other.

If successive handover from one RAT to the other should not be made after a period of T, due to the Quality of Service degradation related to the handover, a Sojourn time $S_{i,j}$ based on estimated conditions of each mobile i in relation to the RAT j can be calculated. The selection of the suitable RAT can only be performed if is assured that the Sojourn time is equal to T as presented below.

We have proposed a function that will give a meaning of the Sojourn time during a minimal stated period T for each RAT j, and the best RAT j to be attached, is the one that fulfils the requirement given in the equation (2.3)

$$\arg \underset{j}{Max}(S_{i,j}^{t0->t0+T}(t)) \tag{2.3}$$

Being

$$S_{i,j}^{t0->t0+T}(t) = \int_{t_0}^{t_0+T} f_{i,j}(t)dt \tag{2.4}$$

Where,

$$f_{i,j}(t) = \begin{cases} 1 \text{ if } \mathrm{SINR}_{\mathrm{i,j}}(\mathrm{t}) \geq Service\_\mathrm{threshold}_{\mathrm{j}} \\ 0 \text{ if } \mathrm{SINR}_{\mathrm{i,j}}(\mathrm{t}) < Service\_\mathrm{threshold}_{\mathrm{j}} \end{cases} \tag{2.5}$$

The success of the proposed algorithm is directly attached to the precision of positioning information available and the accuracy of the prediction algorithm for future positions. Concerning the future positions next section is presented the mobility prediction algorithm.

2.4.2 Mobility prediction

2.4.2.1 Mobility model

The mobility model is based on 3GPP model [ET98]. The model is a pseudo random mobility model with semi-directed trajectories. Mobile's position is updated according to the decorrelation length (as defined in section 1.2.1.4 in reference [ET98]), and direction can be changed at each position update according to a given probability. Direction can be changed within a given sector to simulate semi-directed trajectory.

Mobile's speed is constant and the mobility model is defined by the following parameters:

Speed value: 3 km/h

Probability to change direction at position update: 0.2

Maximal angle for direction update: 45°

Mobiles are uniformly distributed on the map and their direction is randomly chosen at initialization.

2.4.2.2 Mobility prediction

Several works have been made in order to predict the mobility pattern and prediction, and for various applications. Specifically for terrestrial application, saying pedestrian mobiles, and vehicular are the most common. Location-based services and applications is the field that being made most of the investigation of this subject. Specifically in this project, this topic is subject of research in the task T4.2 of the Work Package 4.

Among many methods proposed for the mobility and positioning tracking e.g. using Markov, White Noise [PH06], we are use in this work the Least Mean Square Error method, fitted to linear function, assuming availability of present and past positions. The future positions are estimated using previous 50 positions samples, obtained each measurement period, which is 0.4s. In this work we will assume perfect position information, since the errors will become available in the positions prediction algorithm.

2.5 Numerical Results

2.5.1 Simulation Scenario and Models

The scenario is based on a covered WiMAX area with WiFi Hotspot, as described in section 2.2. The WiMAX is cellular system with 3 tiers in a hexagonal layout consisting of 19 cells. To minimize the simulation duration due to complexity, we consider for transmission purpose only the central cell, being all the others acting as interfering cells. 35 users are uniformly distributed in the central cell, moving at the speed of 3km/h and experiencing high-priority NRTV video traffic at 64 kbps characterised by the 3GPP model [3G04].To confine the movement of the mobiles on the central WiMAX cell, wrap-around technique is applied in the simulation on the edge of the central WiMAX cell. One WiFi hot-spot is inside of the central cell, with respective radius presented in next table. The simulation sample duration is 6 min real-time, and results were collected for 20 simulation samples. The mobility model is based on the 3GPP model for outdoor urban presented in [ET98]. More details about the simulations platform used in this work please refer to [AJA08] for the WiMAX platform and [VO08] for the WiFi part. Main simulation parameters are presented in Table 2.1.

Parameter	WiMAX (802.16e)	WiFi (802.11)
Tx Mode	-	EDCA (MAC Tx mode)
CRRM HO measurement period	0.4s	0.4s
CRRM HO decision period	10s, 20s	10s, 20s
Scheduler	MaxCI	Round-Robin
Link Adaptation	BLER 10%	-
Radio propagation model [ET98]	3GPP Urban + Fast Fading	ITU 2GHz propagation (Path Loss)
Cell type	Omni	Omni
Bandwidth	-	Variable with the user SNR
Environment	Urban Micro Cell	Outdoor Hotspot
Cell Radius	175m	100m

Table 2.1: Main HSDPA and WiFi simulation parameters.

In the simulations we do not use a fingerprint database itself. The notion of fingerprint database is used in sense that with channel models used, one can calculate the average channel, composed by path loss, shadowing loss, in each position, given the position coordinates. The multiple cell scenario is created in the beginning of the simulation, and based on this, the average SINR can be calculated for any position in the environment. We assume that all cells are transmitting with maximum power and the only transmitting conditions that change, are the modulation and coding scheme for link adaptation.

2.5.2 Simulation Results

The performance of HO algorithms is measured in terms of the Number of handovers occurred during the simulation period and Overall System Throughput, since the handover performance can be characterize these two metrics. The Throughput is 3GPP named Service Throughput [3G01] which often referred in the network based literature as Goodput [VO08], which are the correct transmitted bits per second. The proposed handover algorithm, now on called positioning-based handover performance evaluation is compared to the conventional Power-based HO algorithm.

There are some parameters that should be introduced which are the measurement period which is the period that signals strength is measured for the handover decision, and handover decision period, used in the positioning-based HO proposed algorithm. Measurement period is 0.4s which is approximately measurement period in the cellular GSM network. The handover decision period should be related to the sometimes objective and other subjective parameter which is the Quality of Service degradation during a handover. If we assume a handover delay around 2-3 seconds, some communications cut during this period, and a QoS target of 90%, two values of the handover decision period can be proposed for the positioning-based HO, of 10s and 20s. These parameters are summarized in the Table 2.2.

Parameter	Positioning Based HO	Power Based HO
HO measurement period	0.4s	
HO decision period	10s, 20s	-
Number of Windows	-	10
Signal Hysteresis	-	3dB

Table 2.2: Handover parameters.

Figure 2.5 presents the number of handovers occurred in each case, named using the positioning-based HO and using conventional power-based HO. One can notice that substantial less handover number occurs in the proposed positioning based HO algorithm due to the conventional power-based HO algorithm.

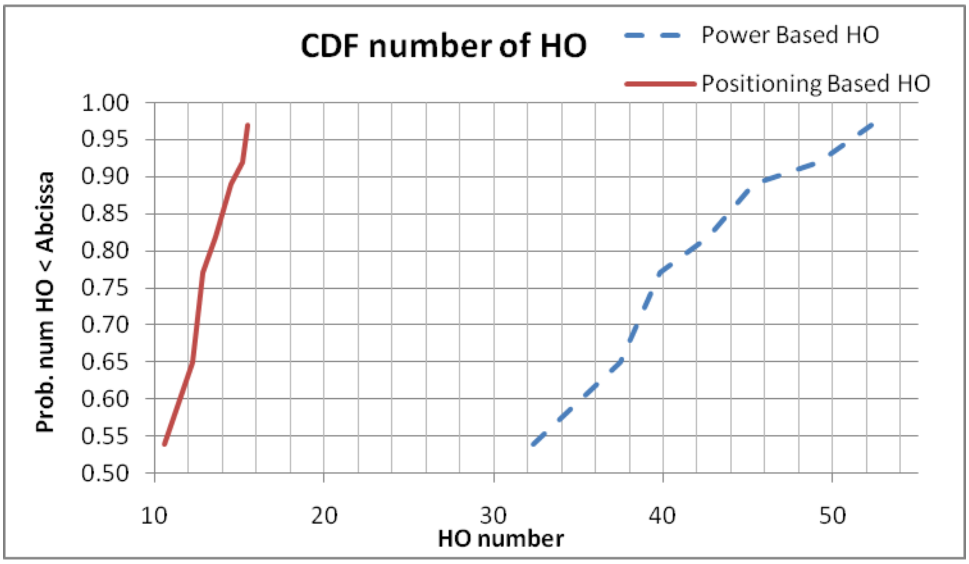

Figure 2.5: CDF of number of Handovers with Positioning-based HO and Power-based HO.

Figure 2.6 presents the system throughput. One can notice a decrease on the throughput when using the Positioning-based HO. This can be explained by the fact that the positioning algorithm failure to track the mobility due to the re-evaluation period. Increasing the evaluation period we will have more precise handover decision but can be sometimes a late handover decision, which lead to some degradation in the throughput.

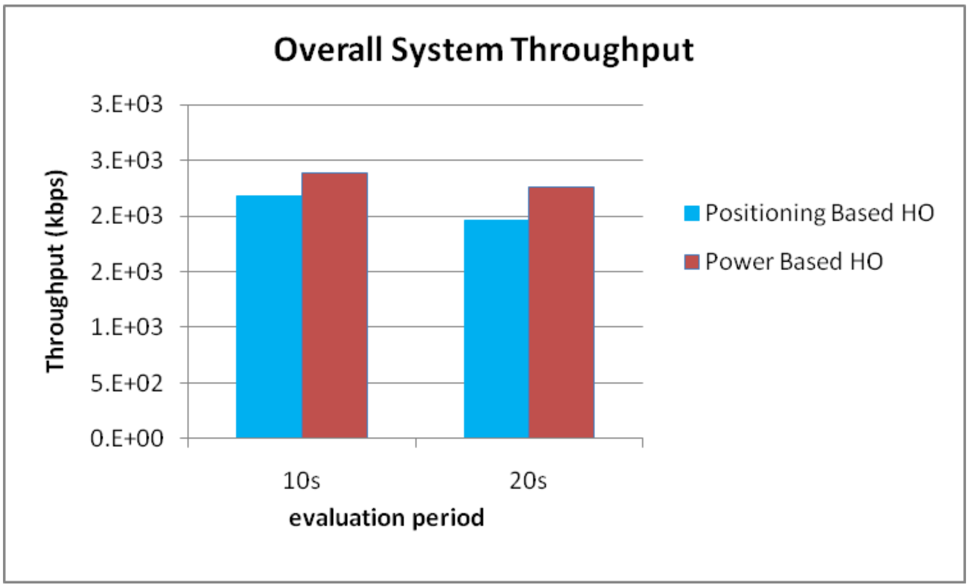

Figure 2.6: Overall system throughput with Positioning-based HO and Power-based HO.

From the obtained results one can notice that there is a QoS gain using the proposed Positioning-based that is evident in the number of Handover which is clearly lower than the Power-based HO. The obtained QoS gain has a trade-off on the system throughput which decreases slightly. This decrease on the system throughput can be explained by failure of the mobility tracking algorithm for expected mobile positions.

2.6 Conclusions and Future work

In this section a positioning-based vertical handover algorithm using the mobile WiMAX (802.16e) and mobile WiFi (802.11) standards was presented. The algorithm uses the notion of the existence of a fingerprint database with average channel measurements in a given area and availability of positioning information of each mobile. The proposed algorithm is based on the ability on the short-period future positioning tracking to for either provides a handover decision. The results showed that there is a QoS gain of the proposed algorithm, over the traditional power-based handover, translated in the reduction of the number of handovers. The results showed a trade-off of overall system throughput decrease when using the proposed positioning-based algorithm.

From the obtained results, we believe that optimization of the proposed algorithm can be reached, depending on the ability of the futures positioning tracking. In the lack of a good positioning predicting algorithm, a joint positioning-based, power-based algorithm, with flexible HO decision period, can be an intermediate solution with trade-off on number of handovers, and overall system throughput.

3. Location assisted hand-over prediction for WiFi and LTE

3.1 Introduction

In this part we consider location-based handover enhancement for improved throughput. Specifically, we consider the case with two different communication technologies, namely a cellular LTE network and IEEE 802.11 based WiFi hotspots. Our results will be based on these technologies; however, the proposed algorithms are general and can easily be adapted to other handover scenarios.

Assuming the throughput is higher on the WiFi network than on the cellular network, it may be beneficial to perform a handover to the WiFi network to achieve an increased throughput. However, it may not be beneficial to handover to a WiFi network, if the connection is only available for a very short period of time. In this case the cost of the handover may very likely be higher than the gain. The main problem we address is how location information can be used to guide the selection between the ubiquitous cellular network and any locally available WiFi networks. A main assumption in this work is the availability of a fingerprinting database that contains the average throughput of all available networks for the considered geographical area. In this chapter we consider a few different handover decision algorithms that are described in detail in section 3.3. Here we give a short overview of the algorithms:

LTE only – This algorithm always connects to the nearest LTE base station, which happens in a seamless manner. This algorithm serves as a comparison for the result of the other algorithms, in the sense that the throughput of the other algorithms should never go below the throughput of this algorithm. If that is the case, no advantage is achieved by making handover to WiFi.

Optimal with no handover delay – This algorithm connects to the network with the highest throughput at any given time. As each handover to or from a WiFi access point has a cost of a 2-3 seconds delay, as described in section 3.2.4, the handovers determined by this algorithm is not necessarily the optimal choices. However, due to its simplicity, this algorithm is suitable for being run online.

Location-based Heuristic Prediction Algorithm –This is a heuristic online algorithm we have developed that uses previous movement history, location information and a fingerprinting map for predicting the expected throughput at future positions. Based on this the algorithm determines when a handover should be performed.

Genetic algorithm – In order to evaluate the goodness of the different algorithms, it is interesting to compare their performance to the optimal handover decision. Since this is not practically feasible to compute due to complexity, we have proposed this algorithm, which iteratively tries to find the best choices of the handover, while considering the 2-3 seconds handover delay. This algorithm represents an estimate of the optimal sequence of what we can achieve in each scenario, but it is not intended for online use.

In this chapter we first introduce the considered scenario in section 3.2. Secondly, in section 3.3, we describe the proposed algorithms for handover decision that were outlined above. Hereafter, in section 3.4 we present simulation results, and finally in section 3.5 we conclude this chapter.

3.2 Evaluation scenario

3.2.1 Scenario area

The considered scenario is a bounded area which is completely covered by LTE cells each with a range of 500 m in a hexagonal pattern as shown in Figure 3.1. Additionally there are WiFi hotspots, with shorter coverage range of 100 m placed randomly in the scenario. For simplicity in the mobility prediction used in the proposed heuristic algorithm, the WiFi hotspots are placed so that their entire coverage area is within the bounded area as sketched in Figure 3.2.

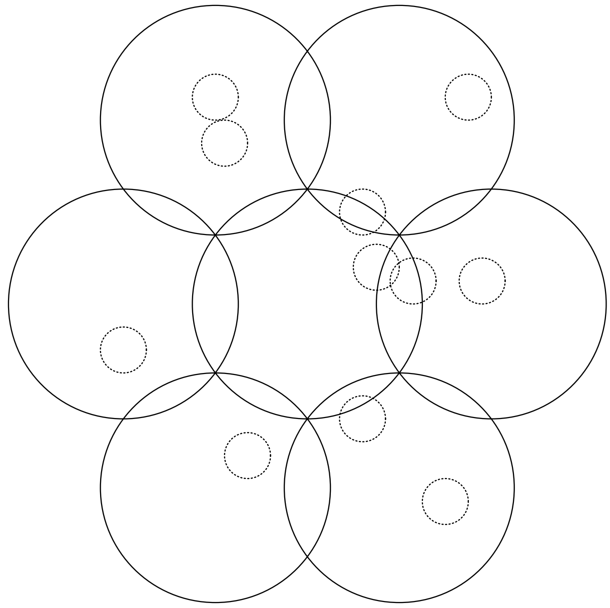

Figure 3.1: Example of LTE coverage (solid) and WiFi coverage (dotted).

3.2.2 Mobility model

The movement is a modified Random Waypoint Model (See [WHE45]), where waypoints are placed randomly along the edge of the environment. The mobile user will therefore never change direction within WiFi coverage, which is assumed to simplify the mobility prediction. At this point we are interested in assessing the performance of handover decision algorithms and therefore we use a very simple and predictable mobility model. A future step in this work is therefore to use more advanced mobility models as well as movement prediction models.

We consider different movement speeds for the mobile user, ranging from pedestrians (0.1-2 m/s), bicycles (2-7 m/s) and up to vehicular speeds (7-13.89 m/s). The movement speed is kept constant in each simulation run.

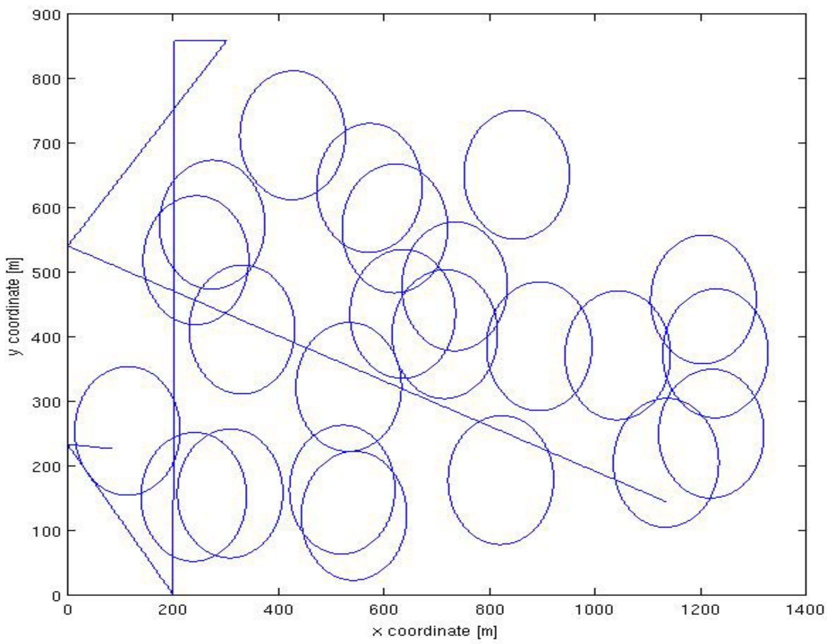

Figure 3.2: Example of WiFi AP distribution (circles) and movement trajectory of a single user (lines).

3.2.3 Throughput models

As mentioned, the entire environment is covered by LTE cells and WiFi hotspots. Rate adaption schemes are assumed for both WiFi and LTE. The relationship between distance from the base station or access point to the mobile user and throughput for LTE and WiFi is shown in Figure 3.3. These models are used both for creating the fingerprinting database mapping positions to throughput and as the experienced throughput used in the simulation.

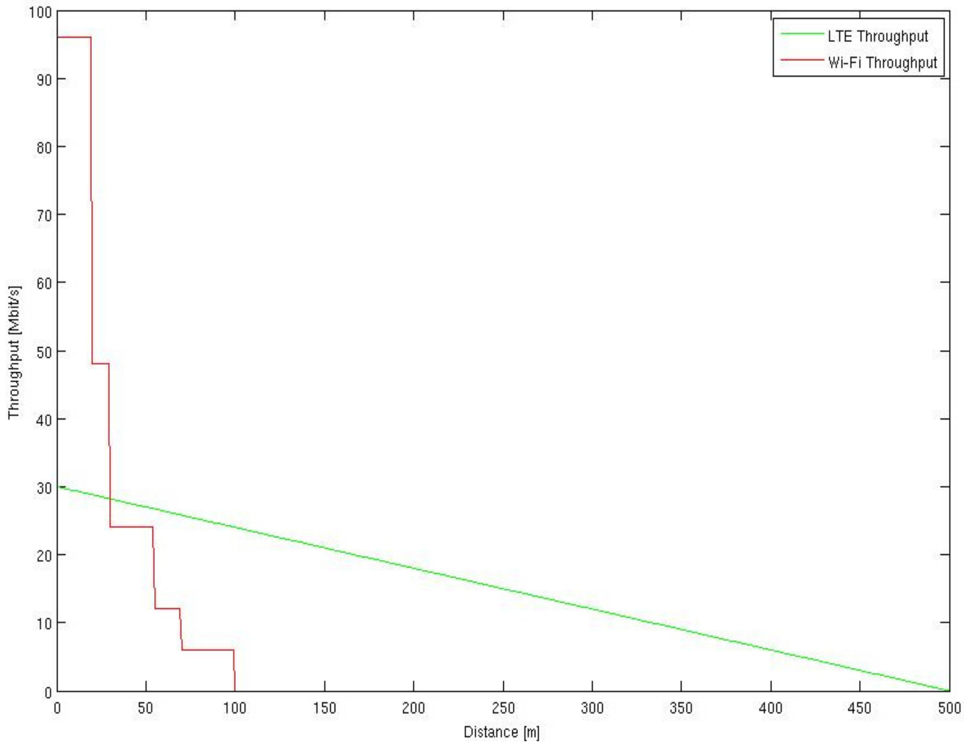

Figure 3.3: Distance-throughput relationship.

We consider a range for LTE of up to 500m. The throughput rates for LTE are based on [KR08]. The WiFi range is up to 100m, which has been determined using the following path loss model from [G05]:

$$P_r = P_t + K - 10 \cdot \beta \cdot \log_{10}(\frac{d}{d_0}) \tag{3.1}$$

Where β is the path loss coefficient, K is a unit less constant that depends on antenna characteristics and channel attenuation, P_t is the transmit power and P_r is the received power, and d_0 is a reference distance from which K is calculated. With a K=-40.045, β=4, a minimum of -90dBm received, and transmit power on 20dBm this leads to a range of approximately 100m, which therefore is chosen as the maximum distance of WiFi. The WiFi rates are based on [LMT04].

3.2.4 Handover Delay

We assume that the delay for handover between LTE cells is insignificant compared to the delay when handing over to/from WiFi, so we disregard it in the following.

The expected handover procedure from LTE to WiFi or between two WiFi networks is described in the following. To perform a handover to a WiFi network, the following actions are taken:

1. Discovery of networks through scanning.
2. Authentication.

3. Association (for steps 1-3 see [IEEE07] for details).
4. IP obtainment through DHCP (see [PJ95] for details).
5. Mobile IP registration (see [PMV98] for details)

The discovery of networks typically takes around 0.5 s. This is due to a timeout, since a mobile device waits a certain time before proceeding to the next step to ensure that all relevant WiFi networks are detected. The second and third steps are typically very quick, since the communication is local with the AP.

The time spent for the DHCP session is unknown, but empirical tests indicate that it easily takes up to 2 seconds, and almost never less than 1 second.

If Mobile IP (MIP) is used, it is necessary to register the obtained IP address with the home agent. This can in principle take some time if the round trip time to the home agent is large. We will assume that the delay due to MIP registration is 0.5s. Of course, in cases where MIP is not used, this delay can be disregarded.

Adding these figures, we get an estimated hand over delay of:

$$T_{H.O.} = T_{WiFi} + T_{DHCP} + T_{MIP} \approx 0.5 + uniform(1\ldots2) + 0.5 = uniform(2\ldots3) \text{ sec} \quad (3.2)$$

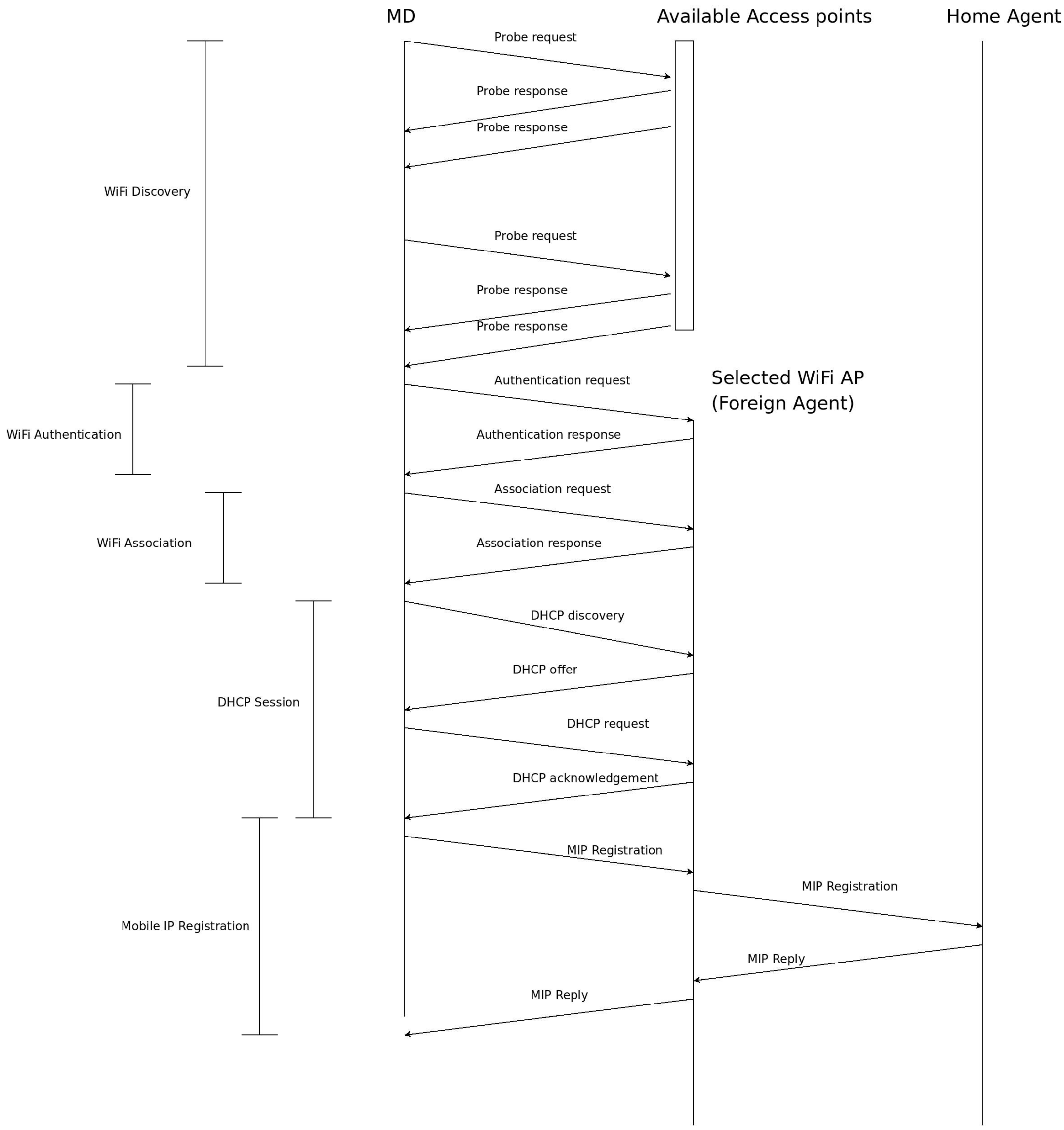

Figure 3.4: Action sequence for hand over to a WiFi network.

3.3 Algorithms

In this section we present the proposed algorithms for determining when to perform handover and to which network, to achieve the highest throughput. An example of the throughput of different networks for a mobile device that moves through a sample scenario is shown on the figure below:

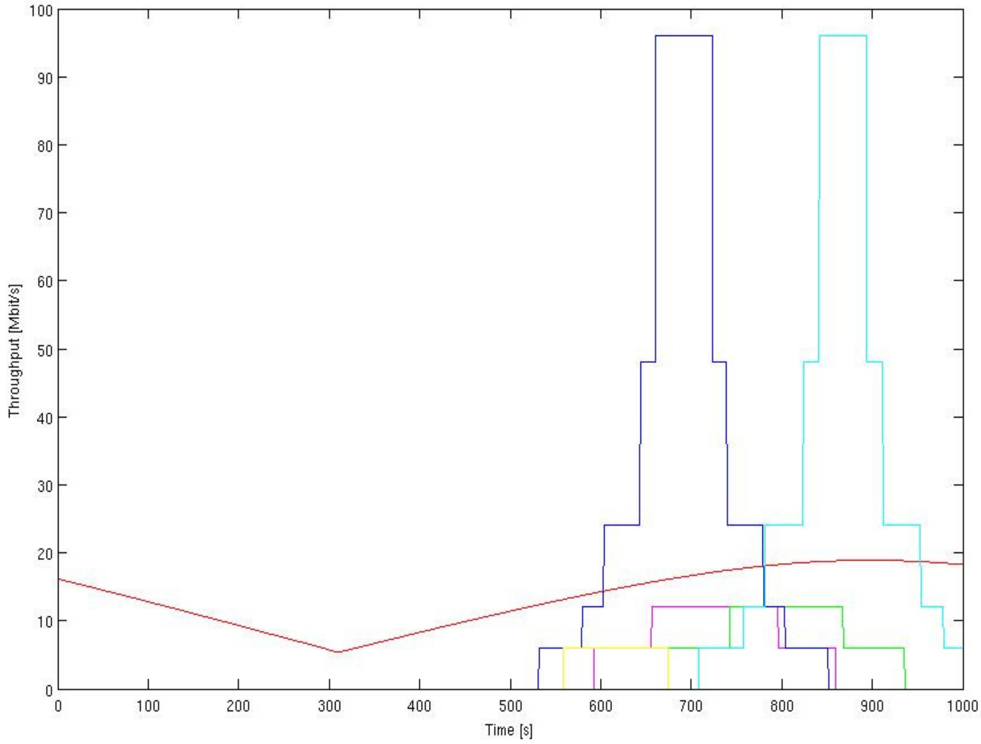

Figure 3.5: Example of available networks.

The red graph shows the throughput when connected to LTE and the other colours are when connected to different WiFi APs. It is easily seen that for the first 500 seconds, LTE is the best choice, since it is the only choice. But hereafter it becomes less obvious when to perform handover, and to which network to obtain the best result, since the curves are overlapping.

In such cases where we have many possible connectivity options, it is not straightforward to determine when to connect to which network. Considering a brute force algorithm that tries out all possible hand-over options and finds the combination that delivers the highest throughput, we quickly run into complexity problems. Assuming we have 10 possible networks over the next 30 time steps, we would have to search through 10^{30} handover sequences to determine the best. The problem cannot be easily simplified, since every hand over to a WiFi network is associated with a penalty of 2-3 seconds without any throughput. The cost of performing a hand over in terms of throughput therefore depends on the movement trajectory of the node and the positions of all APs and base stations.

This section, describes how the positioning information may be used in a few different computationally efficient algorithms which all have the purpose of trying to optimise the average throughput by predicting the best time instants to perform handovers. Also, we propose a genetic algorithm for estimating the optimal handover sequence.

In these algorithm descriptions, the term sequence will be used to explain the choices of the different algorithms. In Figure 3.6 a sequence of 5 steps is shown. Each element of the sequence describes what network to connect to at consecutive time steps.

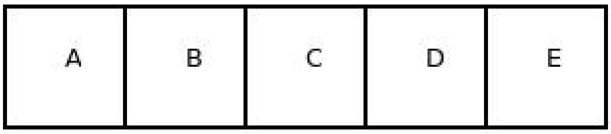

Figure 3.6: Example of a sequence.

The next subsections details the different algorithms used for performing the choice of which network to connect to.

3.3.1 LTE Only Algorithm

This algorithm stays on LTE for the entire period of time, and therefore does not suffer from the hand over delay. Handover between LTE base stations is assumed to happen seamlessly.

3.3.2 Optimal with No Handover Delay

This algorithm does not look ahead in time, but simple performs a handover to the network that has the highest expected throughput at any given time. As the name reflects, it does not consider the handover delay. Since each handover is in practice associated with a handover delay, the resulting throughput is not necessarily optimal. Even though the assumption of no handover delay is not very accurate, we include the algorithm due to its simplicity and for comparison purposes.

3.3.3 Location-based Heuristic Prediction Algorithm

This algorithm estimates the future positions of the mobile device for a fixed number of future time steps by linear extrapolation of the 10 last estimated positions. For each of these future positions, the algorithm creates a list that specifies which network has the highest expected throughput at each time step. Starting from the current time step, the algorithm looks ahead and calculates the expected throughput for each sequence of consecutive and identical entries in the list. If the algorithm reaches a sequence of identical entries, where the gain of doing a handover (with 3 seconds initial handover delay) exceeds the throughput it would achieve if no handover is performed, the algorithm schedules the handover and waits until this handover has been performed.

The algorithm may be run online since it does not require a search of all possible combinations of choices, but instead performs choices in a greedy manner. The currently implemented movement prediction is very simple and assumes constant speed and linear movements. However, the algorithm could in principle be extended with a more advanced movement prediction algorithm to support more advanced mobility models.

An example of how the algorithm works in practice is shown in Figure 3.7. For simplicity, we assume the expected throughputs are constant and that the throughputs are A=2 and B=4.5 in bytes per second. At each time step the number of consecutive similar elements is found. We assume the mobile node is connected to network A initially, but that network B has the highest expected throughput of all available networks for the next 6 time steps. At the first time step ahead in time, network B is thus found as the best choice. Since the count of time steps where B is the best is less than the handover time (1 s < 3 s; notice we use the largest possible handover delay of 3 s), there is no need to calculate the gain. In step 2 and 3 network B still has the highest throughput and the count is increased. But since the count is not larger than the handover time, there is still no point in calculating the gain. In step 4, the count becomes larger than the handover time, and the gain is calculated. The gain is found by summing the amount of bytes that can be transferred in these 4 time steps for both the situation where a handover is performed to network B and for the situation where nothing is done, and considering the difference. In this example, the gain is 1*4.5 - 4*2 = -3.5 bytes, which is not a positive gain. The algorithm therefore looks further ahead to time step 5. Here the gain is 2*4.5 - 5*2 = -1 bytes, which is also not positive. At time step 6 the gain becomes 3*4.5 – 6*2 = 1.5 bytes, which means that there is a benefit of making a handover to network B. The algorithm schedules the handover at the beginning of the sequence at time step 1 and terminates.

Generally, whenever the algorithm reaches an element in the list that is different from the previous, the count is set to zero. This means that if in the example in Figure 3.7, at time step 5 there was an A, the handover would not be performed. This simplification can cause problems if the there are many nearly equally good choices, since the algorithm only considers the one best connection option at each time step.

A possible enhancement of this algorithm would therefore be to compare the time/throughput achievable with different possible sequences based on a few of the networks with the highest throughput, and select the best one. Of course it will be necessary to ensure that the complexity of the algorithm does not increase too much for it to be feasible as an online algorithm.

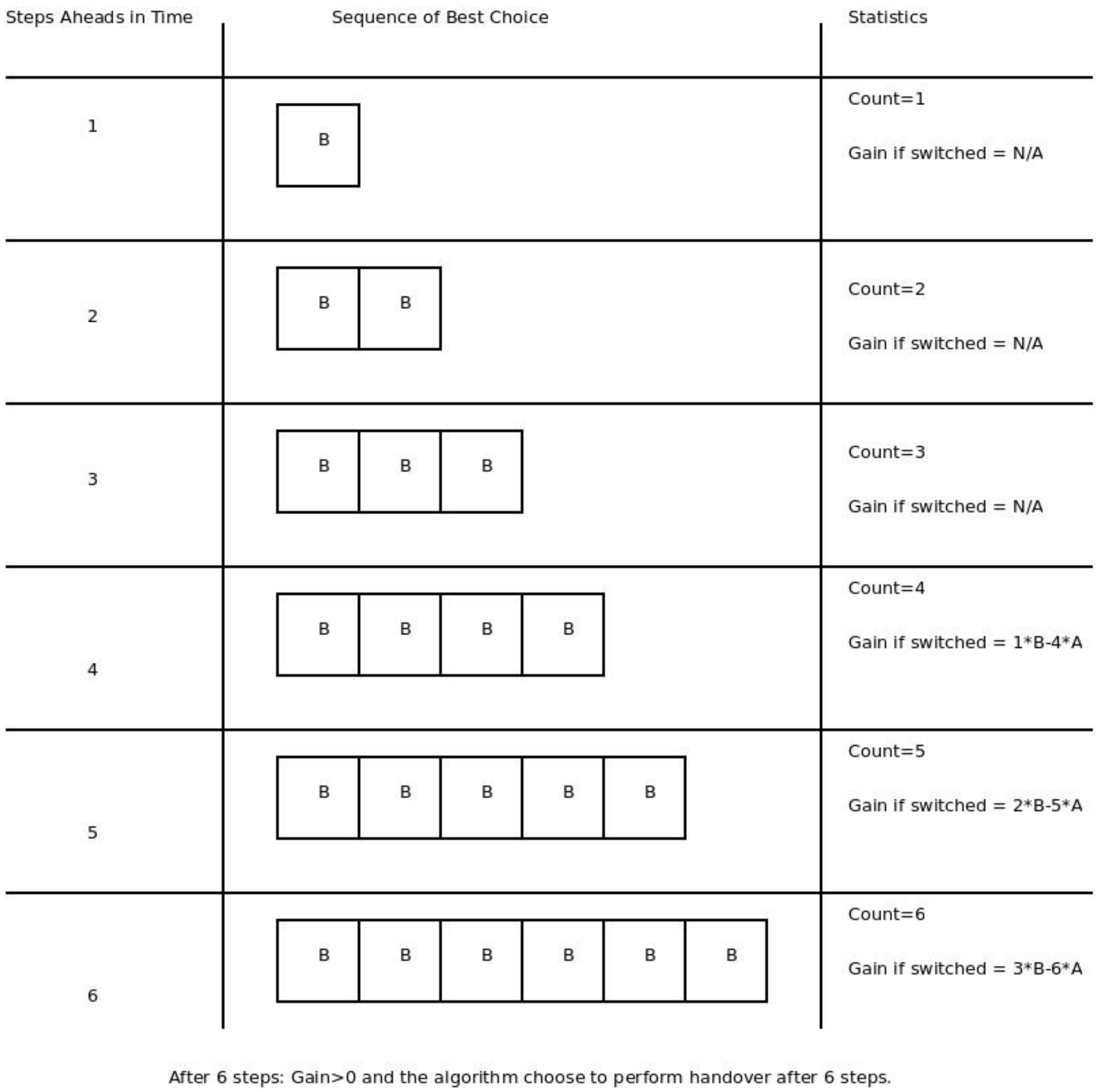

Figure 3.7: Example of location-based heuristic algorithm.

3.3.4 Genetic Algorithm

This algorithm is not intended to be used online; rather we use it to estimate the maximum achievable throughput in a given scenario. We can use this result to evaluate how well the other algorithms perform. As we use this algorithm for comparison, it has perfect knowledge of entity positions and throughputs, i.e. it is not affected by positioning errors. The algorithm attempts to determine the optimal handover sequence for a complete simulation run, by iteratively improving the optimal handover sequence guess using mutation and cross-over operations inspired by genetics. The algorithm works with a pool of candidates for the optimal handover sequence, which it iteratively tries to enhance in terms of the overall average throughput of the scenario. This average throughput is calculated using a so-called fitness function, which simply evaluates the performance of a specific handover sequence in a given scenario.

The genetic algorithm works as follows:

- Create three random good first guesses of the optimal handover sequence.

- Generate pseudo random guesses to fill the pool of handover sequence candidates.
- LOOP:
    - Sort the list in order of decreasing overall average throughput and keep the J handover sequences with the highest throughput.
    - Generate L mutated sequences based on any of the J best.
    - Generate K crossover sequences based on the J best.
    - Fill the pool of handover sequences with POOL_SIZE-J-L-K pseudorandom sequences.
- END_OF_LOOP

where J=3, K=5, L=5, and POOL_SIZE=20.

When the desired number of iterations has been performed, the handover sequence which has the highest average throughput is used as the estimated optimal handover sequence. In the following, each step in the algorithm is detailed.

3.3.4.1 Random good first guesses

For good first guesses, we use sequences corresponding to the outputs of the three other algorithms: LTE only, location-based heuristic prediction, and optimal with no handover delay.

In the first iteration, the rest of the pool is filled with pseudo random sequences. Mutations and crossover sequences could also be used in the first iteration.

3.3.4.2 Pseudo random generation of a handover sequences

Since the genetic algorithm is an offline algorithm, a list of distances to all APs is available. Based on this, this algorithm generates a random sequence of APs within a distance of range+delta at each time step (where delta is a small distances included to ensure all interesting APs are considered).

3.3.4.3 Sort the list

The pool of sequences is sorted in descending order of the average throughput. The throughput for each sequence is calculated using a so-called fitness function, which plays back the given scenario with the proposed handover sequence and adds a 3 seconds delay for each handover, and calculates the overall average throughput.

3.3.4.4 Generate mutated sequences

A mutated sequence is generated as follows:

- Randomly choose one of the J best handover sequences.
- Iterate through the handover sequence and with 10 % probability, do a random mutation, i.e. change the value at that time step to a random choice. The 10 % probability is an arbitrarily chosen value.

This procedure is performed for each of the generated mutated sequences, to create the L different mutated sequences.

An example of three mutations from the same parent is shown in Figure 3.8.

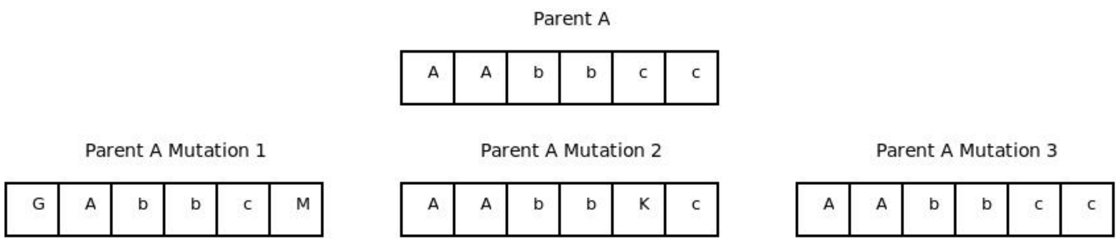

Figure 3.8: Example of mutations for genetic algorithm.

3.3.4.5 Generate crossover sequences

A cross-over sequence is created as follows. For each time step in the handover sequence, the network used in each time step is taken from any of the J best handover sequences with a uniform probability.

An example of how the crossover could happen is shown in Figure 3.9:

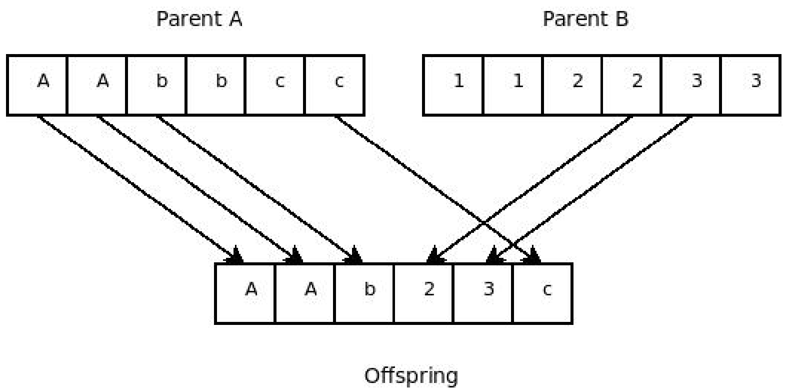

Figure 3.9: Example of cross-over in genetic algorithm.

Here Parent A and Parent B contribute to create an offspring. For each element of the sequence, it is randomly chosen whether to take the element from Parent A or Parent B.

3.3.5 Output of the Genetic Algorithm

An example result of the algorithm is shown in Figure 3.10:

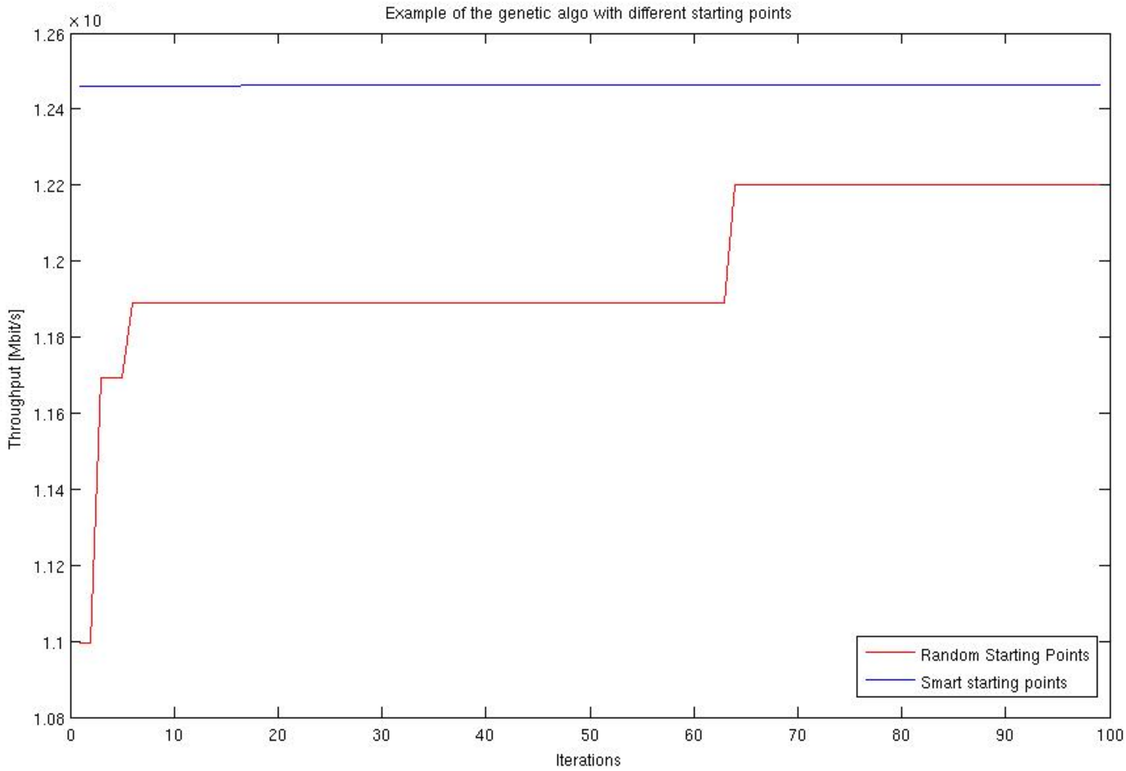

Figure 3.10: Convergence of genetic algorithm.

The figure shows an instance of the genetic algorithm with two different types of starting points. The red curve is with random initial guesses only, whereas the blue curve is with good initial guesses as described above. As shown, the blue curve only improves slightly from the initial guess. The red curve improves many times, but is still much lower than the blue curve. The blue curve does not improve very much, and the tendency shown here, is somewhat repeated for 1000 iterations, i.e. the blue curve has not improved significantly. Therefore, in the following, only 100 iterations of the genetic algorithm will be performed.

As shown, the instance of the algorithm improves the throughput slightly compared to the initial guesses. In more complex scenarios the benefit of the genetic algorithm would most likely be clearer. If infinite time was available, the genetic algorithm would be able to find the optimal handover sequence. In order to keep simulation run times at a tractable level, we will use the result given after 100 iterations and use this for comparing the other algorithms.

3.4 Results and Discussion

This section presents the simulation results. All simulations are run for 1000s, and the genetic algorithm is run for 100 iterations.

For the proposed algorithms we vary the following parameters:

- deployment density of WiFi APs
- positioning error
- movement speed

Initially, we investigate how well the simplest handover decision algorithm, the "optimum no handover" performs compared to the LTE only algorithm. No positioning error is considered in this result set. The results are shown in Figure 3.11.

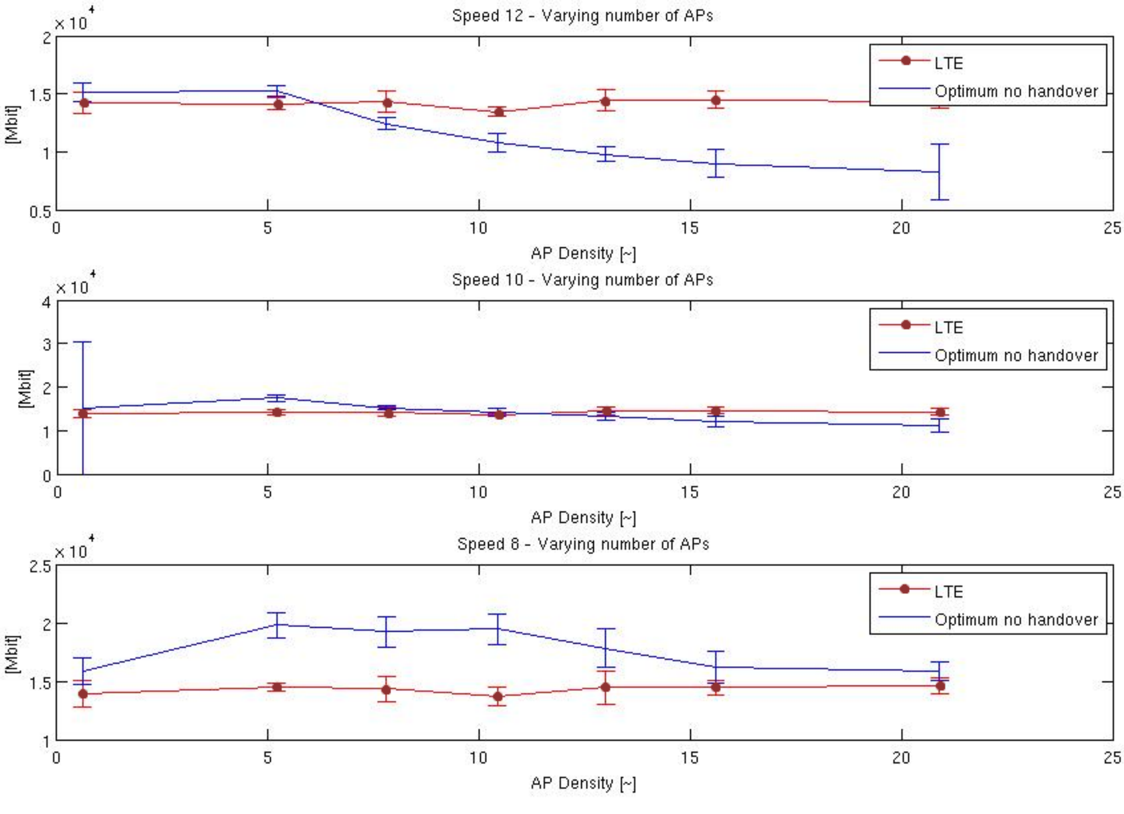

Figure 3.11: Results for varying number of APs and different movement speeds.

The access point density, shown on the x-axis of the figure, is the average number of APs in range. Notice that in all three plots, the LTE curve is constant, only varying slightly due to statistical differences between the runs.

For the movement speed of 12 m/s, we see that the achieved throughput for the "optimum no handover" algorithm drops below the LTE curve around an AP density of 5. A similar, however less pronounced tendency can be seen in the plot for 10 m/s speed also at a density of 5, and at a density around 11 for the 8 m/s plot. For the two lower plots, we further see an initial increase from a density of 1 up to a density of

5. We notice that this initial increase is higher for lower the movement speeds. Thus, it seems that for slow movements, where the mobile node potentially has connectivity for long time in each hotspot, the benefit of the handovers that the "optimum no handover" algorithm decides is bigger than the cost. However, at some point, the increasing number of APs provokes too many handovers and the throughput goes down.

The most important result from this section is the fact that at some point the optimal no handover becomes worse than the LTE only algorithm. This serves as an argument for why a heuristic algorithm is needed to ensure an algorithm that does not drop below the LTE due to a combination of movement speed, position error, and access point density.

The next three sections details what happens for all the algorithms when varying the movement speed, access point density, and position error.

3.4.1 Varying Movement Speed

Another set of results is shown below, where two position errors is applied for different travelling speeds.

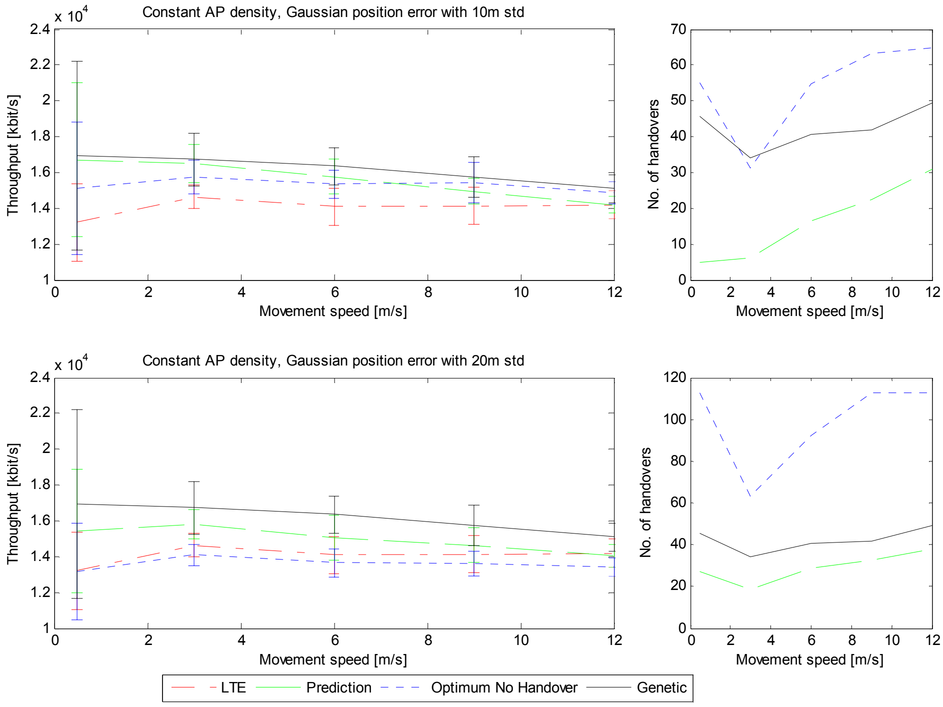

Figure 3.12: Results for varying movement speed.

The most interesting result here is the fact that the heuristic prediction algorithm is affected a lot less than the optimum no handover algorithm. This is mainly due to the fact that the prediction algorithm uses a trajectory estimate based on an average of previous positions; hence it smoothens out some of the position error. When looking at the number of handovers, it is shown in both cases of the position error, that the prediction algorithm performs less handovers than both the genetic and the optimal no handover algorithm, while it maintains a reasonable throughput.

Note here, that the performance of both the prediction algorithm and the optimal no handover algorithm decreases when the speed gets higher.

3.4.2 Varying Access Point Density

In the figure below, the effect of increasing access point density is found for movement speeds of 3 m/s and 12 m/s.

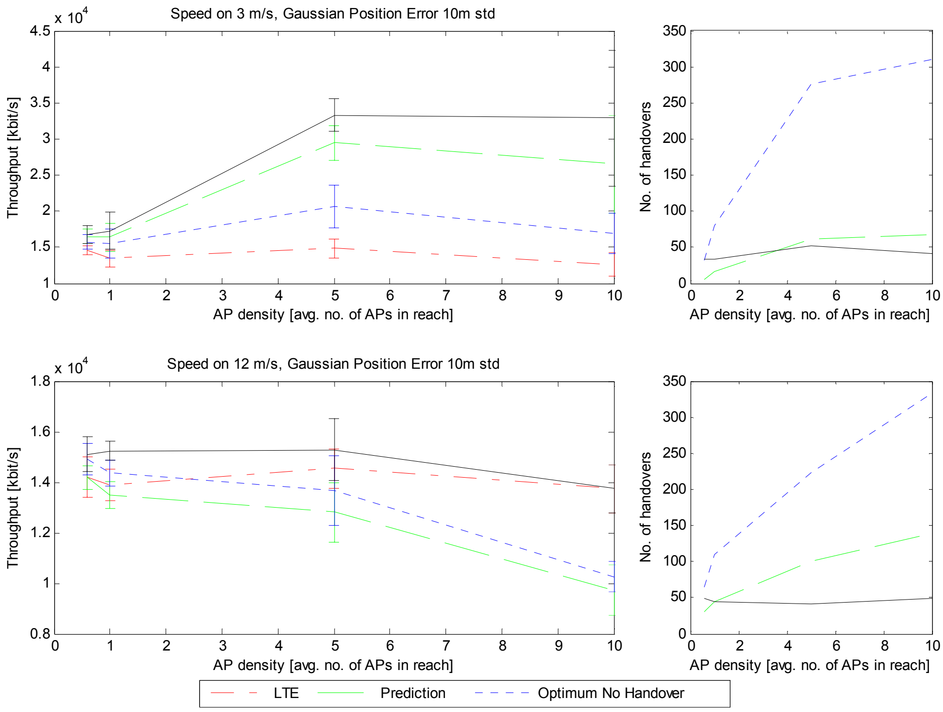

Figure 3.13: Results for varying AP density.

As shown in the figure, when speed is low, both the prediction algorithm and the optimal no handover algorithm performs much better than the LTE only. However when speeds get high, both the prediction algorithm and the optimal no handover algorithm both get lower than the LTE only algorithm. This corresponds with the previous section where it was seen that the performance in terms of throughput decreases when speed is increased. This is a result of the position error, which has a greater influence on movement prediction when movement speeds are large.

Interesting in this section, is also the graph showing the number of handovers. Both the optimal no handover algorithm and the prediction algorithm are higher in terms of number of handovers than the genetic algorithm when speed is high. This leads to the result, that these algorithms perform a lot of unnecessary handovers when speed is high. This leads us to the following speculation, that if it is possible to limit the number of handovers, e.g. by increasing the demands for performing the handovers, it might become possible to enhance the performance of these two algorithms.

The reason for the prediction algorithm to have such poor performance when speed is high is a combination of:

- Low time in range of an access point. Making lower gain when joining since the time in range is lower.
- The direction and speed estimates are obtained by using the last 10 positions, this may result in a wrong direction estimate; hence the predictions may become erroneous.

Considering that for a movement speed of 12 m/s the mobile node will quite often reach the border of the environment and change direction, this may also be a contributing factor to the low performance. Therefore an additional similar simulation has been performed where only the size of the scenario has been increased.

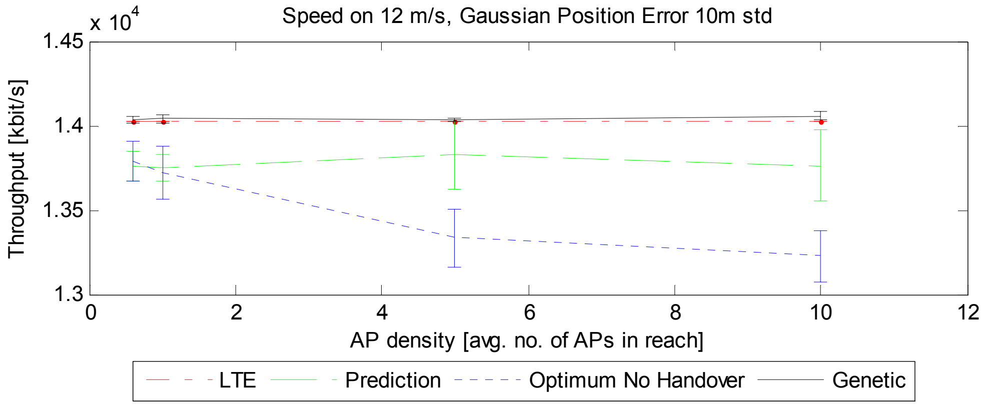

Figure 3.14: Varying AP density, larger environment.

As shown in Figure 3.14 the prediction algorithm now does not go below all other algorithms. However it still performs worse than the LTE only. This is, as mentioned before, due to the inaccurate direction and speed estimates which lead to bad decisions.

Currently the algorithm, after finding a time to perform the handover, waits until that time before performing the handover. Since the algorithm looks up to 20 seconds into the future, this is approximately 240m ahead with a speed of 12 m/s. If the direction or speed is just a little bit wrong, it may happen that the algorithm is planning to connect to an AP that is actually not in range when the waiting time has elapsed. Since the handover time both ways is 3 seconds, this leads to a total of 6 seconds of no connection. This happens quite often in settings where speed is high, and therefore the prediction algorithms perform worse than the LTE only.

3.4.3 Varying Position Error

As mentioned previously, the proposed algorithms are relying on positioning information to lookup the expected throughput for a geographical location. Since positioning algorithms, which can be used to estimate the location of the mobile device operate with some inaccuracy, we here investigate the impact of varying position errors. Positioning algorithms that could be used to deliver position estimates for the proposed algorithms have been developed and analyzed in WHERE Work Package 2. Figure 3.15 shows results for varying position error, with fixed movement speed on 3 m/s and with an access point density of 0.6, corresponding to 23 access points for the entire area.

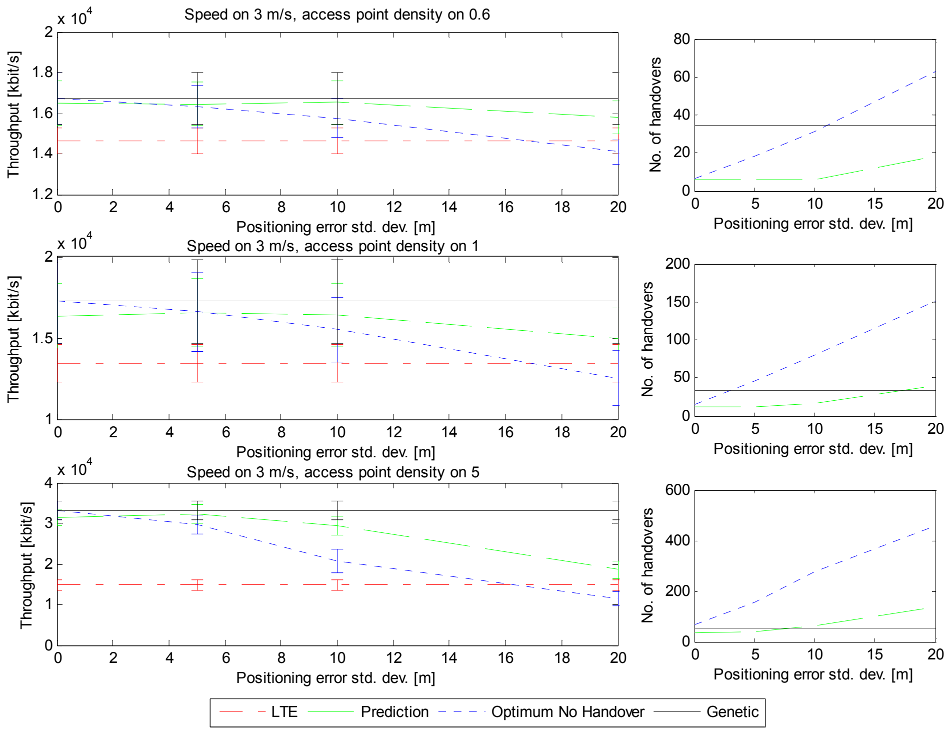

Figure 3.15: Results for varying positioning error.

The plots in Figure 3.15 show that when the position error increases, the optimum no handover decreases faster than the prediction algorithm. As shown in the graphs of the number of handovers, the number of handovers very quickly increases when the position error is increased. This of course leads to a reduction of the throughput of both of the online algorithms in terms of throughput which is shown on the graphs.

Considering the specific impact of positioning error, we see that for all considered densities, a std. dev. of the positioning error of 5 m does not have a significant impact. Around 10 m, the impact is significant, but performance is still better than LTE. Above 10 m, the benefit from performing handover is almost nonexistent.

The plot could also be made for very high speeds, but as shown in the section where the speed was varied; when speeds get high, the gain of performing handovers gets very low.

3.5 Conclusions and Future work

In this work we have considered the problem of determining when and how a mobile terminal should handover between LTE and WiFi networks in scenarios with ubiquitous LTE coverage and randomly deployed WiFi hotspots. As the task of finding the optimal sequence of handovers that result in the optimal throughput is very complex for realistic scenarios, we have proposed 2 location based algorithms that are based on simplifying assumptions and therefore are light enough to be run online. These algorithms rely on positioning information and a map of LTE base stations and WiFi access points to work. We have compared these algorithms to the LTE only case and the estimated optimal result, which was obtained by use of a genetic algorithm. The algorithms were evaluated under varying conditions in terms of WiFi access point deployment density, positioning error, and movement speed.

Our results showed that a high movement speed has a negative impact on the performance of the proposed algorithms, due to the potential benefit of performing a handover becoming small when less time is spent in each WiFi hotspot. Also we saw that increasing the access point density was initially beneficial, due to more options for achieving a higher throughput, however at some point the big selection of access points to choose from seemed to confuse the simplified online algorithms. Finally, we showed that position-based handover makes sense when speed is not too high, and positioning error is below 10 m std. dev.

Given that the proposed heuristic prediction algorithm does not cope well with high access point densities and high movement speeds, an obvious future work item would be to make this algorithm more robust. One possible improvement would be to not let the algorithm plan a handover too far into the future without re-evaluation the expected benefit as time progresses.

In this work we have considered the time it takes to handover from LTE to WiFi or back to be around 2-3 seconds, which is a result of a series of actions related to association and IP address obtainment. If this process was optimized, for example by early preparation of the handover through the network, which would be possible given the availability of positioning information, the benefit of location-based handover enhancement could be further increased.

4. Interference Aware Wireless Multi-hop Strategies

4.1 Brief Overview

Sections 2 and 3 addressed the location-assisted heterogeneous routing in a network coexistence scenario. The main focus is on the handover issue from the network-layer aspect (or called the RAT selection). Alternatively, this section aims at studying location-aided heterogeneous routing techniques from the PHY/MAC layer viewpoint, which is focused on the interference aware multi-hop selection. This contribution can be regarded as an extension of the location-assisted relaying techniques addressed in D3.6 to heterogeneous networks. Moreover, this work will not touch a specific wireless standard as considered in the previous chapters, but try to provide a PHY solution to the general model of network coexistence scenario.

We consider a wireless environment where a Mobile Terminal (MT) of Service 1 (or RAT1) wants to communicate with another MT of Service 2 (or RAT2). There are several intermediate wireless networks including Access Points (APs) and MTs. The problem is defined as, how to select an appropriate wireless route that offers the maximum throughput with the minimum influence of QoS to other wireless networks. This seemingly simple problem needs to deal with many challenging research issues such as link reliability, seamless coverage, multi-service handover, interference, and is not easy to be solved in general. Hence, our focus is only on a special problem about efficient PHY/MAC multi-hop strategies with the consideration of avoidance of the co-channel interference. With respect to the knowledge of network side information, we study two cases, i.e. the case with perfect side information, and local position information, respectively.

4.2 Scenario and System Description

Figure 4.1 illustrates an example of the considered scenario for the heterogeneous multi-hop networking. This example is an extended version of the WHERE C3-B scenario addressed in [W08]. As we can see, it is clearly a service heterogeneity network where MT1 in Service 1 wants to communicate with MT2 in Service 2. However, MT1 cannot reach MT2 through a direct link, and thus have to form a multi-hop communication with the help from those carefully selected MTs. The study of heterogeneous networking follows two key conditions as below:

Condition 1: APs from different services do not have a wired link with each other. Otherwise, the wireless route can be easily replaced by the wired route. This condition might hold for some emergency cases where wired links are destroyed.

Condition 2: Cells are orthogonal with each other either in time, frequency or code to avoid inter-cell interference or inter-service interference. In this section, we will consider only a special case where involved cells use different frequency band, and in-cell users use FDMA.

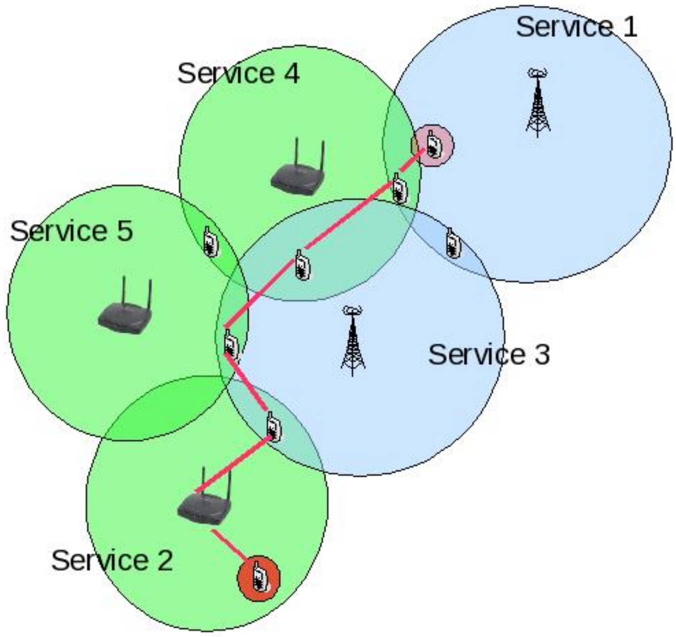

Figure 4.1: An example of scenario for the heterogeneous multi-hop networking.

Based on the above system description, the heterogeneous routing can be described as the following mathematical model. Define X_i to be the i th MT within the Service (Cell) X, where X can be replaced by any symbol corresponding to a specific wireless service (cell). Basically, each cell can be formulated as a set of MTs denoted by $\mathbf{X} = \{X_0, X_1, \cdots, X_k, \cdots\}$. Consider a heterogeneous network consisting of a number of sets such as $\mathbf{A}, \mathbf{B}, \mathbf{C}, \cdots$ An MT denoted by $A_0 \in \mathbf{A}$ wants to choose a partner to form the first hop. Assuming this partner is from a set $\mathbf{X}$ (e.g., $X_0 \in \mathbf{X}$), the operating frequency $f_{A_0 - X_0}$ for the $A_0 - X_0$ communication should offer the maximum transmission rate denoted by $R_{A_0 - X_0}$ with no co-channel interference caused to other existing communications. The above procedure will repeat until the final destination is reached. However, the above routing approach is very complex due to the very high degrees of freedom. Alternatively, we introduce a heterogeneous networking concept proposed by the OVERDRIVE project (see Figure 4.2), where a number of wireless Agents are placed on the cell edge. Those agents have strong cognitive capability as well as the multi-band access functionality. Such a system design can effectively reduce the complex heterogeneous routing problem into the following two simple cases:

Case 1 In-cell multi-hop: MTs within the same cell form a multi-hop communication. The operating frequency of this communication is within the frequency band allocated to this cell.

Case 2 Inter-cell multi-hop: Communication between two MTs located within different cells must go through a carefully selected agent.

Accordingly, the heterogeneous routing approach can be implemented by employing two basic steps:

Step 1: each cell determines an optimal route between two agents (including MT1 and MT2);

Step 2: select those agents that can offer the maximum transmission rate.

The above steps should follow the maximum-flow min-cut principle to calculate the maximum achievable rate. On the other hand, selection of an optimal route requires the full network side information (e.g. instantaneous channel quality information of all possible links, position information of APs, MTs, and agents) available at wireless agents. This condition is not practical for a large heterogeneous network. The above observation motivated the proposal of a location-aided multi-hop approach. Therefore, this work can be looked as an extension of relaying techniques addressed in D3.6 to heterogeneous networks.

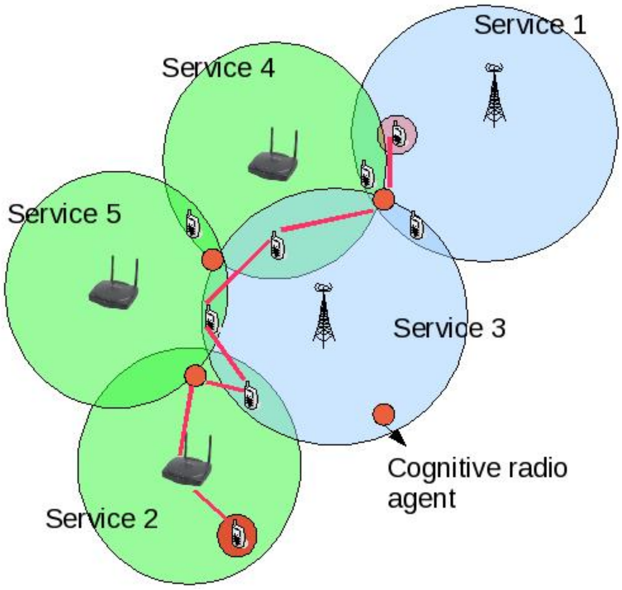

Figure 4.2: An example of the heterogeneous networking with cognitive agents.

4.3 The Location-Aided Approach

The location-aided approach is based upon the following assumptions:

A1. Each AP knows the real-time position of all in-cell MTs and agents;

A2. Each AP has a location-related fingerprinting database that pre-stored the average channel quality information about the in-cell AP-MT and Agent-MT link. The size of fingerprinting database is related to the number of APs, Agents, and MTs. In order to reduce the size of database, we usually store the average channel quality information between a fixed network node (such as AP, Agent) and a specific area.

Moreover, the link with higher average channel quality supposes to support higher transmission rate. Then the in-cell route-searching algorithm can be implemented as

Step 1	The AP collects position information about in-cell MTs and agents within this cell;
Step 2	Determine the average channel quality of each point-to-point link through looking up the fingerprinting database;
Step 3	Use the maximum-flow min-cut principle to calculate the transmission rate for each possible route;
Step 4	Keep those routes that offer the maximum transmission rate for each agent-to-agent link.

Table 4.1: In-cell route-searching algorithm.

Based on the successful in-cell route searching, all agents will send the knowledge obtained in Step 4 to the AP of Service 1. Then the AP will again use the maximum-flow min-cut principle to select the optimal route in the agent level. Figure 4.3 illustrates a simple example in order to elaborate the above algorithm. As we can see, the maximum transmission rate in this example (i.e. 2Mbps) can be achieved through the selected route.

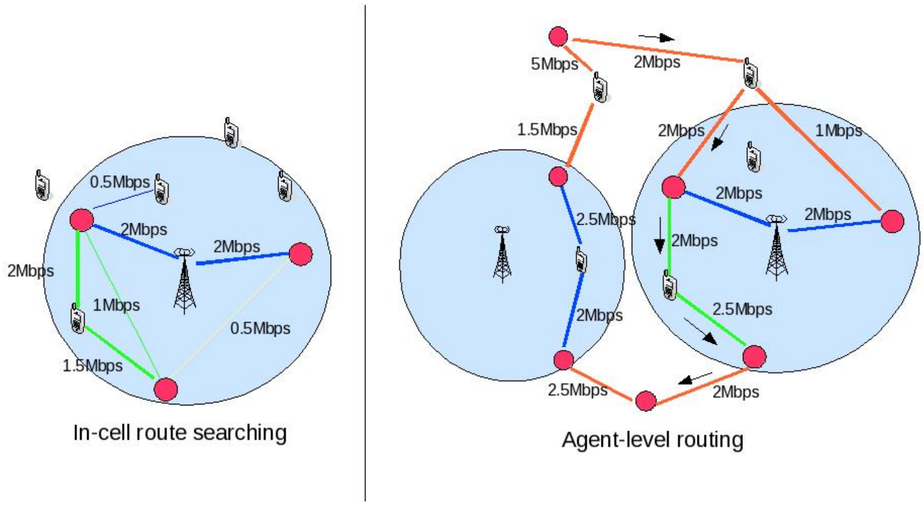

Figure 4.3: A simple example about the proposed route-searching algorithm.

4.4 Conclusions and Future work

In this section, we presented a simple heterogeneous routing approach through exploitation of the location information and wireless agents. The proposed approach required the fingerprinting database to provide average channel quality information between Agent-to-MT links. The maximum-flow min-cut principle was used to determine the maximum transmission-rate between two agents. Future work aims at evaluating the proposed algorithm in a practical heterogeneous networking environment.

5. Conclusion

In this deliverable we have presented the outcome of WHERE Work Package 3 Task 4, which concerns "Optimized Cellular Connectivity using Positioning Data". We have considered two types of cellular networks, namely mobile WiMAX (802.16e) and LTE. As a means for optimizing the cellular connectivity, we have considered the possibility of the mobile user to handover to IEEE 802.11 based WiFi hot spots for increased throughput. As a handover from one link technology to another requires setup and initialization of the new connection, the handover itself has a negative impact on the user QoS in terms of throughput and delay, which means that handover algorithms should carefully select which handovers to make, by estimating and maximizing the expected user QoS. The major focus of this work has therefore been to develop suitable algorithms for deciding when to handover between cellular connectivity and WiFi hot spots.

This work relies on the assumption that the throughput of cellular base stations and WiFi hot spots can be achieved from the position of the mobile user, through a fingerprinting database based on averages of previous co-located channel measurements. By using this database and by extrapolating short-term future mobile user positions from past observations of mobile user positions, the proposed algorithms are able to predict the expected future connectivity conditions. Hereby the usefulness of handovers can be estimated in advance and the optimal handover strategy can be determined. However, as the actual channel conditions may vary from the expected values obtained from the fingerprinting database, network simulations are performed to evaluate the experienced performance and to compare with power-based algorithms that rely on instantaneous channel measurements for determining the handover strategy.

In chapter 2 we focused on a scenario with several WiMAX cells and one WiFi hotspot and found that the position based algorithm reduced the number of handovers compared to power based algorithm. This lead to fewer interruptions experienced by the user, however at the cost of a slightly reduced throughput. The throughput reduction was mainly contributed to the inability of the system to accurately track and predict the movements of the mobile users.

In chapter 3 the considered scenario was slightly different, as we here considered a global cellular LTE network as well as many randomly placed and occasionally overlapping WiFi hot spots. The fact that many connectivity options are available at each time instant meant that algorithms for handover making decisions needed to be efficient. We proposed a 2 such efficient algorithms and evaluated these for varying positioning accuracy, varying movement speed, and different WiFi hot spot deployment accuracies and compared them to the case where LTE is always used and to the result of a genetic algorithm with perfect knowledge. Here we also found that inaccuracies in predicting the mobile user's future position, especially for high movement speeds, had a significant negative impact on the achieved throughput. Another main result was that when speed is not too high, the position-based handover decision was clearly useful for positioning errors (std. dev.) up to around 10 m.

Finally, in chapter 4, we outlined an approach that allows heterogeneous mobile terminals to connect to infrastructure in a multi-hop manner, while using location information to minimize interference. This work item is very closely related to the work presented in WHERE D3.6 that deals with two-hop relaying techniques for homogeneous wireless networks, and is here included as a bridge to scenarios with heterogeneous mobile terminals, which is the topic of this deliverable.

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