Vertical handover decision algorithm in heterogeneous wireless networks

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Abstract: With the recent progress in the area of cellular communication the issue of inter cells handover without dropping an on-going connection with the base station has arisen. In this paper, the focus is on the performance of vertical handover. Various proposed interconnection architectures for vertical handover in heterogeneous networks were studied. Two different algorithms to make the decision on when and to which network perform a handover were considered. In the first of them the decision is based on the received signal strength (RSS). In the second one a fuzzy logic system that uses RSS, bandwidth, battery power and packet loss as the input parameters is proposed. The simulation results show that the algorithm based on fuzzy logic leads to a reduction of the number of handovers and a minimization of the power consumption as compared to the first algorithm used here and the existing algorithms.

Keywords: vertical handover; wireless local area network; WLAN; WIMAX; UMTS; LTE; LTE-A; received signal strength; RSS; heterogeneous networks; fuzzy logic; simulation.

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Vicent Pla received his ME and PhD in Telecommunications from the Universitat Politècnica de València (UPV), Spain, and the BSc in Mathematics from the Universidad Nacional de Educación a Distancia, Spain. In 1999, he joined the Department of Communications, UPV, where he is currently an Associate Professor. His research interests lie primarily in the area of modelling and performance analysis of communication networks. During the past few years, most of his research activity has focused on resource management in wireless networks. In these areas he has authored numerous papers in refereed journals and conference proceedings, and has been an active participant in several national and European research projects.

1   Introduction

Wireless technologies such as WLAN, WiMax, UMTS, LTE and LTE-A were developed with different standards and these technologies offer a variety of services, different data rates and diverse areas of coverage. To provide a better connection between heterogeneous networks it is necessary to perform a handover (HO) either vertical or horizontal. A horizontal HO is defined as HO between different base stations (BS) with the same wireless network interface that is started if only the base station is changed, but the technology remains the same (for example, a transfer starting from a cell WLAN1 to a WLAN2). A vertical HO is a HO between base stations that use different network interfaces (wireless network interface, such as WiMax, WLAN,…) meaning that it is carried out in the case of a change of the network and type of technology (for example, a transfer of a WLAN cell to a UMTS cell). It is this second type of HO that is the focus of this study. It is for this reason that it will be considered that whenever the term HO in our paper is used, it will, in fact, refer to the vertical HO.

The HO process is divided into two parts, one is the HO decision process and the other is the HO execution process. In the HO decision process both the mobile node and network decides when the HO process will occur. After the completion of the HO decision process, the HO execution process continues. The HO execution process collects the supplementary network information such as the address detection time in mobile IPv6 and when the HO decision will occur and detect process overlaps. The HO process is required when the following situation occurs: When the motion of the user equipment (UE) is very fast, for example, the movement of the user's equipment from one cell to another during an ongoing session, there will be interference phenomena caused by the user's equipment from the near cell. These are some basic points due to which the network decides that the HO process is required. The main aim of the HO process is to allow the mobile users to roam freely from one mobile network to another either within the same network or a different one. To achieve the load balancing in the different cell HO is also required, and it is also necessary to maintain good radio quality of the link between the mobile users and the serving BS and to minimise the interference level.

This paper presents the performance analysis of vertical HO in heterogeneous networks and focuses mainly on the study of the received signal strength (RSS) in the reach of mobile station using MATLAB. MATLAB was used because it offers a wide range of possibilities for simulation of different wireless networks and the key contribution of this work concerns the implementation of the HO between five types of access networks: (WLAN, UMTS, WiMax, LTE and LTE-A) in order to provide a seamless vertical HO across heterogeneous access networks such as these The RSS in the proposed interconnection architectures was implemented mostly between LTE and LTE-A networks and several parameters (RSS, bandwidth, battery power and packet loss) were considered, using fuzzy logic to make the decision on when and which network to perform a HO to.

Moreover, the vertical HO decision (VHD) based on RSS only, the VHD based on fuzzy logic and the other VHD algorithms were compared. The rest of the paper is organised as follows. Section 2 describes the vertical HO procedure. Section 3 describes the related work. Section 5 presents the simulation environment with results and discussion. Finally, Section 6 concludes the paper.

2   Vertical HO procedure

A vertical HO can be divided into four steps:

- determination of the surrounding systems
- analysis of the quality of service (QOS) available on the detected systems
- determination and selection of the most appropriate network
- implementation of the vertical HO.

All these steps must proceed so as to ensure a vertical HO without cuts and must be proactive. 'Proactive', expresses the idea that the client must be able to precisely obtain user expectations in terms of QOS and the performance, in order to make the best possible decision.

2.1   Determination of active systems in the radio environment

This is the first step of the vertical HO, and is crucial. Thanks to this step, the cognitive terminal can determine the list of candidate networks for the vertical HO. Indeed, once the terminal has successfully detected the presence of a signal, it would know to which system the detected signal belongs. This identification must be done without the terminal attempting successive connections to each of the active systems.

2.2   Analysis of the quality of discovered systems

Once these systems have been identified, the terminal undertook a series of measures regarding the link quality that can be attained in each network. The horizontal HO based on the metric of the received signal power generally is triggered. Unfortunately, this metric is not sufficient to trigger a vertical HO.

To find the best system, the HO procedure requires more information and parameters in order to decide to which system it must switch to. This information and parameters are more commonly known under the name of 'metric of HO'. They are parameters measured by the terminal in order to give an indication on the feasibility of the vertical HO and to help with the choice of the target system. Besides the signal report with noise, for a vertical HO there are additional parameters to take into account, for example:

- Static user preferences that refer to a list of services to which the user has subscribed, and a preference list indicating the priority of services in case of scarce resources.

- Dynamic measures that contain a list of supported or unsupported services on the network; a list of active or suspended services; and an indicator on the QOS delivered. These parameters include the monitoring and analysis of networks such as the reception power settings, bit error rate, the block error rate, the effective rate, the battery status, the coverage area, the access cost, security and services available.

2.3 Decision and selecting the most appropriate network

Once vertical HO metrics have been identified, they are collected in a measurement report and transmitted to the upper layers, i.e., to the entity in charge of the HO decision, to make a decision. This decision is based on the QoS requirements of the application used by the user. Once the decision is made and the target network is selected, the execution procedure for the vertical HO is triggered. Note the HO can be executed by the mobile, which is known as mobile-controlled HO (controlled terminal mode), or may arise from a decision-making entity of the network, in this case known as network-controlled HO (controlled network mode), or even jointly in cooperation with both, then this is the mobile-assisted HO (user controlled network and assisted terminal). Controlled terminal mode is a decentralised decision. While the network mode is controlled, it is mainly used in circuit-switched networks. The advantage of this mode is that the network monitors its load and can avoid saturation of resources that cannot be controlled in terminal mode. Finally, the controlled network mode is used by terminal served by the UMTS network.

2.4 Implementation of vertical HO

Once the network targets have been selected, the entity responsible for execution, terminal or network, is informed of the HO to be achieved. Thus, connection needs to be switched from the current network to the selected network in the most available transparent way.

This last stage includes also the stages of authentification, authorisation and transfer of identity of the user towards the new access point (AP). The fact that the terminal must be able to rock from one network to another means that the terminal must be equipped with a flexible radio architecture which enables it to change its connection parameters in order to adapt to the network chosen by the vertical HO process.

The HO mechanisms have a four different phases: HO initiation, system discovery, HO decision, and HO execution as illustrated in Figure 1.

Figure 1 HO phases (see online version for colours)
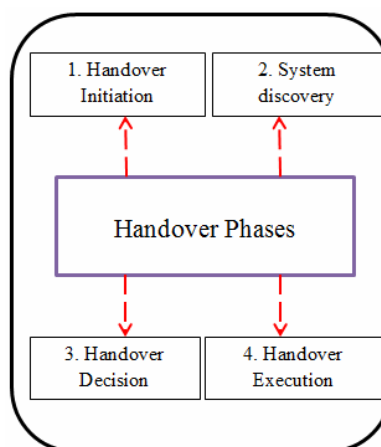
3 Related work

Many VHD algorithms have been proposed in the research literature, most of them have designed their VHD algorithms depending on the signal strength received by the mobile terminal, where HO decisions are made by comparing the received signal strength with the threshold values. These algorithms which use signal strength as their basic HO decision indicator are called RSS algorithms. However, the data rate achieved by a mobile terminal is related to its signal to interference and noise ratio (SINR), which is a function of the interference in the network, as well as the distance between BS and AP to the mobile terminal. RSS based VHD occurs when the mobile terminal receiving power approaches the threshold value regardless of the QoS needed, thus rendering RSS-based VHD not to support user's QoS requirement. On the other hand, SINR based VHD supports multimedia QoS requirement depending on the achievable data rate which leads to seamless vertical HO.

1 "RSS measurement for vertical handoff in heterogeneous network" by Ayyappan and Dananjayan (2008). In this paper, a method is proposed to evaluate the performance of vertical HO in terms of received signal strength measurement using suitable propagation model for heterogeneous network employing cellular, WLAN and HIPERLAN.

2 "A study of RSS based vertical handover decision algorithms" by Gavali and Patil (2015). This paper represents the RSS based VHD algorithms and a comparison of these VHD algorithms.

3 "A smart triggering scheme to reduce service interruption during heterogeneous handovers" by Huaiyu et al. (2008). In this paper, a smart triggering scheme was proposed, which based on received signal strength indication (RSSI) predication. The RSSI could vary when the MN moves, due to the effect of

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shadowing and fading. An exponential average of smoothing predication method was adopted to predicate the RSSI. The link status would be recorded and compared with the trend of RSSI. When the predicated RSSI is below the predefined link going down (LGD) threshold, and the long-term trend of RSSI is going downward, a pre-trigger event will be generated.

4   "Predictive link trigger mechanism for seamless handovers in heterogeneous wireless networks". Here, another RSSI-based predicative link trigger mechanism was proposed. The HO procedure may fail due to too early or too late to trigger. The required HO time is estimated at first, and then a predicative link trigger mechanism is executed once the filtered sample power is less than a predefined predication start threshold. The threshold is determined by the required HO time. If the value is less than the minimum power level, the HO procedure is initiated.

5   "Algorithmic Vertical Handoff decision and merit network selection across heterogeneous wireless networks" by Kunarak and Suleesathira (2013). In this paper the RSS is predicted by back propagation neural network which is beneficial as it performs the handoff early. Dwell time value depends on the user speed and moving pattern. The policy for triggering a handoff is that the RSS conditions are consistently true during dwell time, so that unnecessary handoffs are avoidable.

6   "An adaptive vertical handoff algorithm based on UMTS and WLAN" by Ling et al. (2014). In this paper a vertical handoff (VHO) algorithm based on UMTS and WLAN integration framework is proposed in order to make it more effective, reduce the ping-pong effect and interruption probability.

7   "IEEE 802.21 based vertical handover in WiFi and WiMax networks" by Bathich et al. (2012). This paper evaluated the SINR based vertical HO algorithm and RSS based vertical HO algorithm in terms of the maximum downlink throughputs. The Shannon capacity determines the maximum achievable data rate for a given SINR and carrier bandwidth.

8   "Combined SINR based vertical handoff algorithm for next generation heterogeneous wireless networks" by Yang et al. (2007). This paper proposes a novel VHO algorithm which uses received SINR from various access networks as the handoff criteria. This algorithm considers the combined effects of SINR from different access networks with SINR value from one network being converted to equivalent SINR value to the target network, so the handoff algorithm can have the knowledge of achievable bandwidths from both access networks to make handoff decisions with QoS consideration.

9   "A combined vertical handover decision metric for QoS enhancement in next generation networks" by Vegni et al. (2009). This proposed combined VHO approach contains both RSS and SINR parameters are in terms of both end user efficiency, i.e., cumulative received bits, and network performances, i.e., VHO improves QOS for mobile users, a data rate gain parameter.

10   "Distance-based scheme for vertical handoff in heterogeneous wireless networks" by Mardini and Al-Ghadi (2012). This paper proposes a distance-based scheme for vertical handoff (DSVH) for heterogeneous wireless networks. The main goal of this scheme has been achieved. It is to enhance and provide higher overall system performance in terms of minimising service disconnection probability during VHO as compared to the SINR based VHO scheme.

11   "Signal strength ratio based vertical handoff decision algorithms in integrated heterogeneous networks" by Sanjay and Reddy (2014). This paper proposed the signal strength ratio (SSR) based VHO algorithms and the average received signal strength (ARSS) based VHO algorithms for integrated networks of wireless local area network (WLAN) and 3G networks and evaluated the performance of the proposed VHO algorithms in terms of the number of handoffs and decision delay.

12   "Predictive RSS with fuzzy logic based vertical handoff algorithm in heterogeneous wireless networks" by Kunarak and Suleesathira (2010). This paper proposes a predictive RSS and fuzzy logic based network selection for VHO in heterogeneous wireless networks. The RSS predicted by back propagation neural network is beneficial as it avoids dropping calls if it predicts a mobile is moving away from the monitored wireless network. In addition to the RSS metric, the residence time in the target network is predicted which is taken into account for the handoff trigger.

13   "Fuzzy multi-parameter based vertical handoff decision algorithm". In this paper Bin et al. (2013) proposed a fuzzy multi-parameter based VHO decision algorithm this study considers five parameters of network and user, and applies a multi-mode smart terminal based speed adaptive VHO policy to improve the network update speed and lower network blocking probability.

14   "A fuzzy logic approach for quality of service quantification in wireless and mobile networks". In this paper, Farnaz et al. (2014) evaluated a method using fuzzy logic to improve the quantification of QoS level for both homogeneous and heterogeneous networks.

15   "Fuzzy logic based layers 2 and 3 handovers in IEEE 802.16e network". In this paper, Bchini et al. (2010) studied a fuzzy logic based scheme for fast selection of best BS and of HO technique at the HO time in order to minimise the delay during HO for sensitive multimedia traffic.

16   "Complexity-consistency trade-off in multi-attribute decision making for vertical handover in heterogeneous wireless networks". In this paper, Chinnappan and

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Balasubramanian (2016) used the fuzzy logic to estimate the necessity of HO and to determine the user satisfaction degree based on critical parameters, such as mobile terminal speed, network load and service cost.

17 "A fuzzy logic-based communication medium selection for QoS preservation in vehicular networks". In this work Bouali and Senouci (2016) developed a fuzzy based framework to select the best communication medium in a heterogeneous vehicular network and considers several features that affect the decision process, which are available from the network such as received signal strength (RSSI), network density, vehicle speed and service cost.

4 Results and discussion

4.1 HO performance in heterogeneous networks

Mechanism of HO has four different phases: initiation of HO; HO decision making; selection of network; and execution of HO process. HO decided by QOS parameter, such as strength of the signal and quality of the network link, etc., is known as initiation of HO. In HO decision making, the signal strength and the QOS parameters of the neighbouring networks are measured and a decision is taken to select the best network suitable to perform the HO. Network selection phase identifies the best suitable network among all the available networks chosen to perform the HO. Execution of HO deals with establishment of connection, release of connection, and network security aspects as show in Figure 2.

Figure 2 Mechanism of HO vertical in wireless networks (see online version for colours)
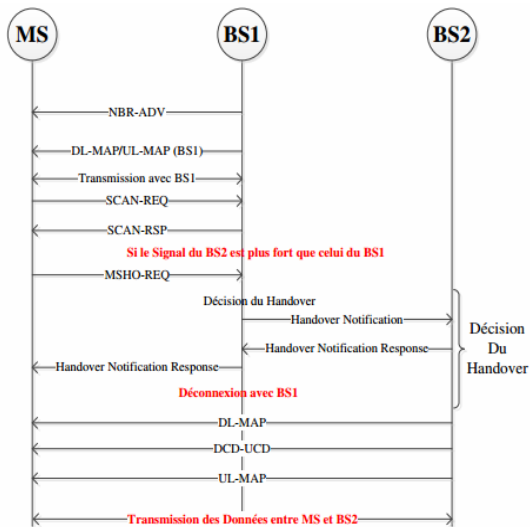
In WLAN there are two reasons to run a HO: the signal level and the traffic load. Signal level: if the signal level provided by a base station is no longer satisfactory, a HO

onto another base station is initiated if it provides a higher signal level. Traffic load: due to the traffic load, a BS cannot provide bandwidth and optimal service quality.

Figure 3 Proposed interconnection architecture of WLAN and UMTS (see online version for colours)
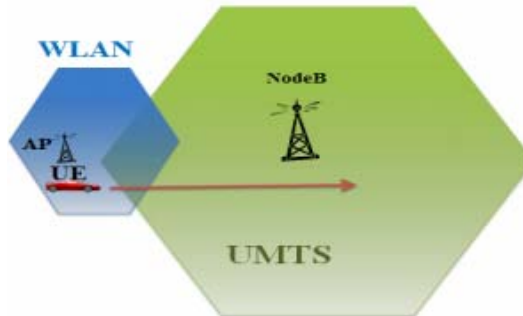

In the UMTS, HO is performed if the signal level reaches a certain threshold value specified by the radio network controller (RNC). It can be applied for the uplink and downlink it can also be implemented if the cell traffic becomes too heavy. HO in UMTS still depends on the user's mobility, traffic distribution, bandwidth and change of service.

Figure 4 Proposed interconnection architecture of WLAN and WiMax (see online version for colours)
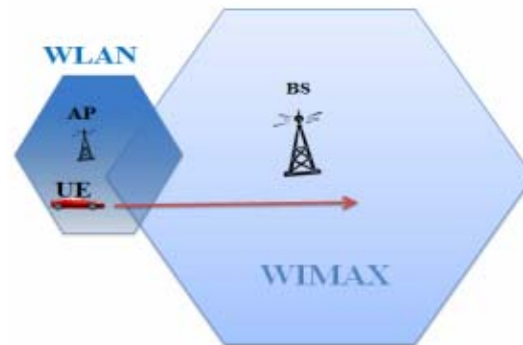
Figure 5 Proposed interconnection architecture of WiMax and UMTS (see online version for colours)
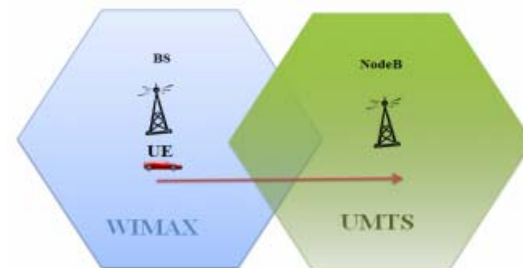

In WiMax, the decision for the HO can be started by the MS or by BS. During the process of HO, the MS has the right to

cancel the procedure and to recommunicate again with the previous ones.

In the LTE, the HO is started by the UE, who sends a measurement report to the e-NodeB source, this last will decide to carry out the HO or not, the e-NodeB source makes its decision based on the report of level of power received.

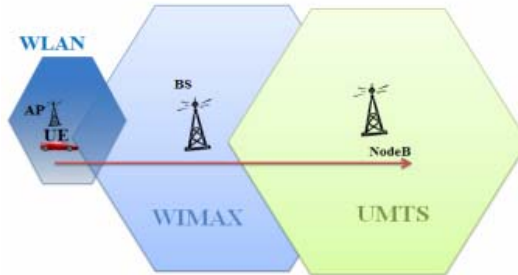**Figure 6**   Proposed interconnection architecture of multi WLAN and UMTS (see online version for colours)
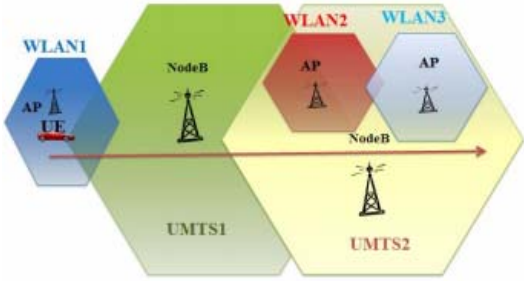
To illustrate our simulation, interconnection architecture between different networks has been designed:

- Figure 3. Initially a situation according to which a mobile station would move at constant speed since a WLAN network towards nearby networks UMTS was imagined.

- Figure 4. Secondly, a situation according to which a mobile station would move at constant speed since a WLAN network towards nearby networks WiMax was imagined.

- Figure 5. As can be seen, in this proposed interconnection architecture, the trajectory of station mobile is from WiMax to UMTS.

- Figure 6. This interconnection architecture shows the HO between multi-WLAN and UMTS and the MS moves from WlAN1 to UMTS2.

- Figure 7. In this interconnection a situation according to which a mobile station would move at constant speed since a WLAN network towards networks nearby WiMax and UMTS was imagined.

- Figure 8. In this proposed interconnection a situation in which a mobile station would move at a constant speed from a WiMax to a neighbouring LTE network was imagined.

- Figure 9. This simulation represents the combination of three technologies WLAN, WiMax and LTE. The movement of the mobile station from a WLAN network to a neighbour network WIMAX and LTE.

- Figure 10. The last simulation represents the combination of LTE and LTE-A. The movement of the mobile station from a LTE network to a neighbour network LTE-A.

4.2   *HO decision based on RSS*

There follows a simulation of the HO situations, in particular HO based on the strength of the signal received (RSS). The proposed algorithm is aimed at vertical HOs in heterogeneous networks. It makes the VHD from the first network to second network taking into account the RSS of the mobile station during its movement.
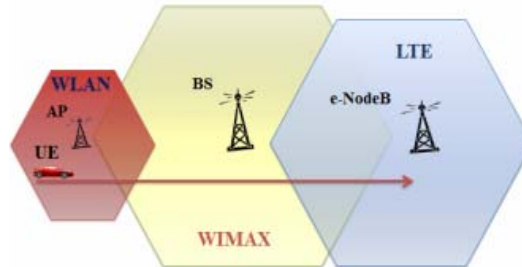
Figure 7   Proposed interconnection architecture of WLAN, WiMax and UMTS (see online version for colours)

Figure 8   Proposed interconnection architecture of LTE and WiMax (see online version for colours)
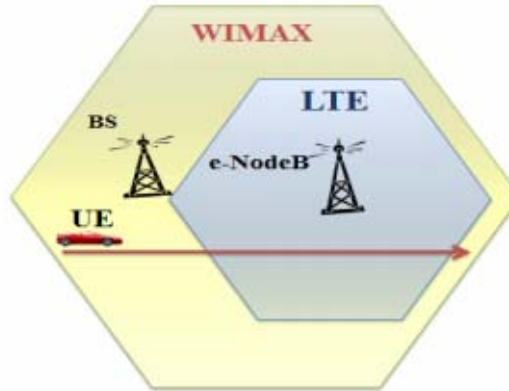
Figure 9   Proposed interconnection architecture of LTE and WiMax (see online version for colours)

The whole process of decision the HO is illustrated in Figure 11. This algorithm is in charge of making a decision about when and where to trigger the HO. This decision

should consider several parameters in order to choose the best candidate network.

This implementation consists of a main program 'main.m' which will call upon 11 other functions that are defined to carry out various tasks: calculation of the slow/fast fading, calculation of the shadowing, and the functions checking if one is in the coverage area of network WLAN, WiMax, UMTS, LTE or LTE-A, these expressions are defined in (1), (2), (3) and (4). The file 'main.m' includes the most important parts of the implementation process, the initialisation of the values of frequencies, the required conditions for the implementation of HO, the speed of the mobile station, etc.

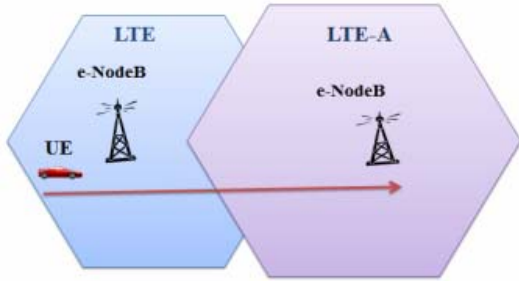**Figure 10** Proposed interconnection architecture of LTE and LTE-A (see online version for colours)

Figure 11 Proposed VHD algorithm (see online version for colours)

The parameters of simulation of the HO in five networks are illustrated in Table 1.

The general formula of computation applied in the programs is:

$$RSS = P_t - \left(F_{slow} + F_{fast} \right) \qquad (1)$$

where P_t is the transmitted power and the slow and fast fading are defined by:

$$F_{slow} = PL + F_{shadow} \qquad (2)$$

where F_{shadow} denotes shadow fading.

$$PL = PL(d_0) + 10 \log(d/d_0) + X_\sigma \qquad (3)$$

where $PL(d_0)$ the path loss propagation model, n is the path loss exponent, d is the separation between transceiver and MS in meter. X_σ is a zero means Gaussian distributed random variable with standard deviation σ. The reference distance d_0, the path loss exponent n and the standard deviation σ, statistically describes the path loss for an arbitrary distance between transceiver and MS.

$$F_{fast} = 10 \log \left(E(|R(t, k)|^2) \right) \qquad (4)$$

where $E(|R(t, k)|^2)$ is the mean value of $R(t, k)$. All this gave rise to the results below.

Figure 12   RSS between UMTS and WLAN (see online version for colours)
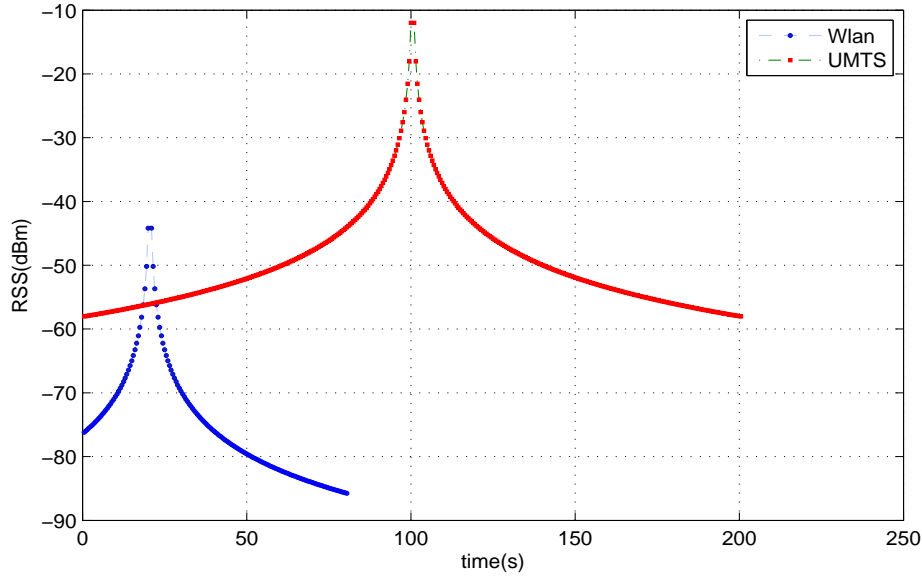
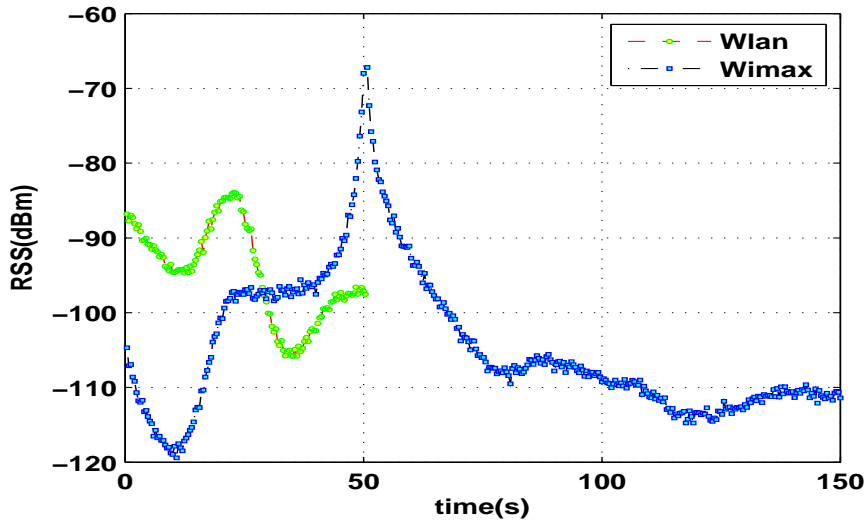**Figure 13**   RSS between WLAN and WiMax (see online version for colours)

Table 1   Parameters of simulation

Parameter	Value				
	LTE (3GPP)	*LTE-A (IMT)*	*WiMax IEEE 802.16e*	*WLAN IEEE 802.11g*	*UMTS WCDMA*
Bandwidth	10 MHz	100 MHz	5–6GHz	20 MHz	5 MHz
Interval	0.4 second	0.4 second	0.4 second	0.4 second	0.4 second
Frequency	2.6 GHz	3.7 GHz	3.5 GHz	2.4 GHz	2.1 GHz
Speed of mobile station	10 Km/h	10 Km/h	10 Km/h	10 Km/h	10 Km/h

Figure 14 RSS between WiMax and UMTS (see online version for colours)
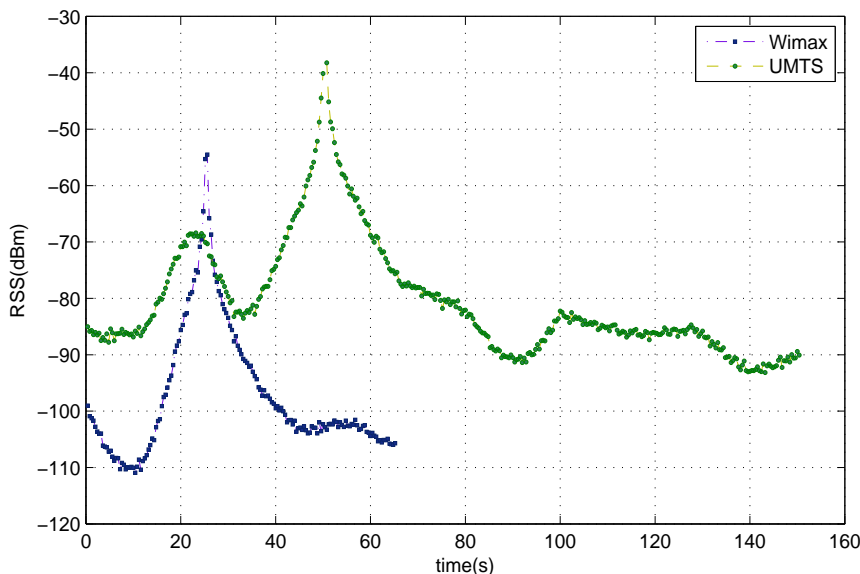
From Figure 11, it is noted that before the significant time t = 20s the station is still connected to NodeB of UMTS because its received power is still greater than the power received at the AP of WLAN. After time t = 20s the power received by the AP becomes greater than the power received by NodeB. Therefore, the first HO is carried out immediately after t = 20s, the MS continues to connect to the AP of WLAN to the second significant time t = 40s, after which time the power received by NodeB becomes greater than power received by the AP, therefore, the second HO takes place and the mobile station is connected to NodeB of UMTS.

The following simulation of Figure 12 contains two networks WLAN and WiMax. The WiMax station was located much closer to that of WLAN, so a one HO is made of WLAN to WiMax at t = 40s when the MS disconnects from the AP of WLAN and connects to BS of WiMax.

In Figure 13, the networks WiMax and UMTS complete the simulation, but by taking into account, at this stage, the effects of the fast fading, as well as shadowing.

These results are slightly different from the first implementation. Indeed this time, the WiMax station was placed much closer to that of UMTS. Thus, a 1st HO is made from WiMax to UMTS, and then at some point, the mobile is replaced in its original configuration where an HO WiMax to UMTS, always through power measurements, made at intervals.

Figure 14 shows the simulation of two UMTS networks placed several hundred meters away from each other, and functioning on different frequencies. Three WLAN networks were placed a short distance away in such a way as to allow a certain coverage zone of the WLAN and UMTS networks higher definition.

Furthermore, it was decided this time to make a movement of the mobile station which is quasi-random but always towards an adjacent network.
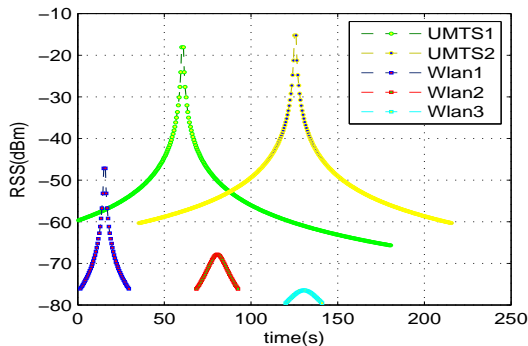
Figure 15 RSS about heterogeneous networks (see online version for colours)

Figure 15 shows the model illustrated in Figure 6, the trajectory of the mobile station is from WLAN1 to UMTS2 and the mobile station uses WLAN1, UMTS1 and UMTS2 which depends on the signal strength. It is clear from the results that the first HO took place at t = 20s when the signal strength of WLAN1 network is lower than the UMTS1 network. As the MS moves away, the signal strength goes on decreasing from higher value of –20 dbm, therefore the second HO is executed at t = 80s, and the mobile station is still connected to the Node B of UMTS2.

For the rest, the same calculating made functions are applied, each time with particular regard to slow and fast fading, shadowing, calculation of cover, etc.

In addition, there are times chosen for a displacement of the mobile station which would be quasi-random, but always in direction of an adjacent network.

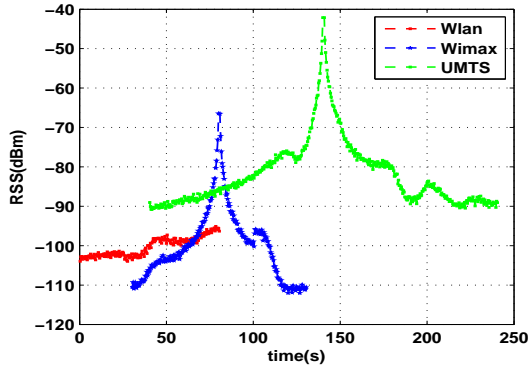**Figure 16**   RSS between WLAN, WiMax and UMTS (see online version for colours)

Figure 16 shows the simulation of three networks WLAN, WiMax and UMTS. The 1st HO is made from Wlan to WiMax at t = 60s when the MS disconnects from the AP of WLAN and connects to BS of WiMax as the MS moves to UMTS the second HO is carried out at t = 70s when the MS connects to Node B of UMTS and the received signal of UMTS becomes greater than WiMax.

Once the network receives a powerful signal, the mobile station carries out a HO in order to keep a maximum reception power regardless of its different positions. Whatever the case, it is clear that WLAN does not really constitute a mobile network when compared to WiMax and UMTS. The WLAN covering power remains lower.
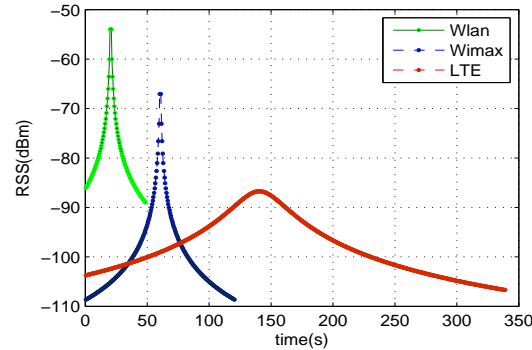
Figure 17   RSS between LTE and WiMax (see online version for colours)
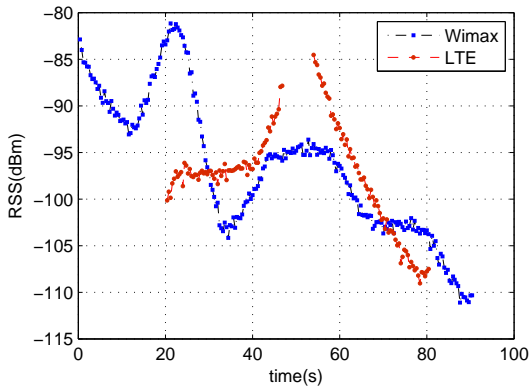
In Figure 17, the RSS between LTE and WiMax according to time is shown. The blue curve represents the power of the WiMax radio link and the red curve shows the power of the
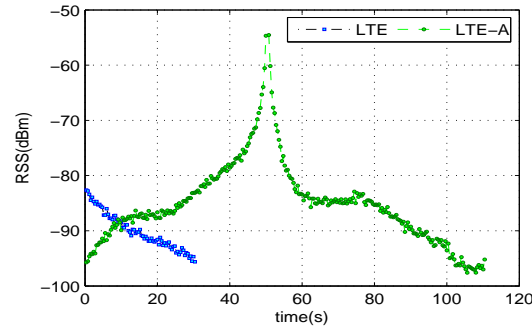
LTE radio link. From the figure, it can be seen that the power of the WiMax radio link decreases gradually as MS moves and enters the overlap area. Then, a new link is detected and the MS starts the first vertical HO process at t = 30s, while the second HO starts at t = 70s, especially in the midpoint of the overlapping area, where the RSS from BS is pretty low.

Figure 18   RSS between WLAN, WiMax and LTE (see online version for colours)

In Figure 18, RSS between WLAN, WiMax and LTE according to time. Each colour refers to one of the networks mentioned above, and here are the representations of the different measurements made by the mobile station as it moves along its path. Each of the above networks has been at one time or another dominant network diagram. Of course, every time a network has benefited from the strength of the stronger signal, the mobile station has performed a HO to keep maximum signal strength in different positions.

Figure 19   RSS between LTE and LTE-A (see online version for colours)

In Figure 19, the RSS between LTE and LTE-A according to time is shown. The blue curve represents the power of the LTE radio link and the green curve shows the power of the LTE-A radio link. From the figure, it can be clearly seen that at a time t = 10s the RSS from LTE-A exceeds that from LTE, thus at this moment a HO from LTE to LTE-A will be inititiated.

4.3 HO decision based on multi criteria-approach using fuzzy logic

In this approach four values are considered to make the HO decision; the first value is RSS, the second value is bandwidth, the third value is battery power and fourth value is packet loss. Consequently, the fuzzy system will require these four values as inputs, to obtain one output value (weight value). The Weight value obtained from the fuzzy system is used to enable the system to make a decision to perform the HO between different networks based on the input values.

4.3.1 HO decision controller

In this part of the paper fuzzy tool box and Simulink have been used to perform the simulation. The whole process can be explained briefly as:

Fuzzy logic quantative decision algorithm (FQDA), which is an algorithm used widely in VHDs because of its simplicity. Fuzzy logic interference system (FIS) is a part of FQDA. The FIS contains number of functional blocks that are explained as:

- Fuzzifier: input values are converting in the form of membership functions with the help of fuzzifier. The range for these membership functions are also specific to fuzzifier.

- Fuzzy rule database: this defines the set of if-then rules that were useful one in decision making criteria for the HO. The number of rules depends upon the number of parameters used and the set of membership functions.

 Rules can be calculated with the following expression or formula:

  $$[x]^m$$

  where x = number of sets and m = number of parameters.

- Defuzzifier: this block converts the membership value into the single output value. There are two types of FIS: Mamdani FIS and Sugeno FIS.

In this paper Mamdani type FIS is used and the block diagram of basic FQDA is shown in Figure 20.

Figure 20 Block diagram of the fuzzy logic system (see online version for colours)
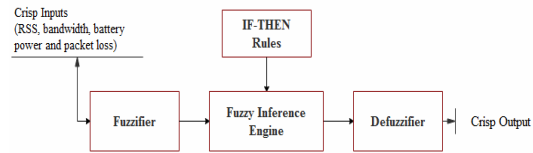
Four parameters have been proposed. Some of parameters depend upon MT and some depends upon the network conditions. The threshold values for each parameter are explained in Table 2.

Table 2 Parameters of simulation

Metrics	Low	High	Unit
RSS	−100	−70	dBm
Bandwidth	0	60	Bits/s
Battery power	0	5	Watts
Packet loss	0	54	Packets/s

According to the expression used in FIS the number of rules for the four attributes can be calculated as:

$$[3]^4 = 81$$

Here three is the number of membership function, which is low, medium and high. The output fuzzy decision sets are aggregated into a single fuzzy set and passed to the defuzzifier to be converted into a precise quantity, the HO factor, which determines whether a HO is necessary or not.

The range for output function (HO factor) is from zero to one.

From the working flow illustrated in Figure 21, to make a decision to perform the HO based on RSS, there are two parameters: RSSc for the current cell and RSSn for the neighbouring cell. When RSSc < RSSn the rest of the input parameters are fed to the fuzzy system which computes the HO factor. If this factor is above a predefined threshold (0.7 in our case) the HO is performed.

**Figure 21** Working flow of VHD using fuzzy logic (see online version for colours)
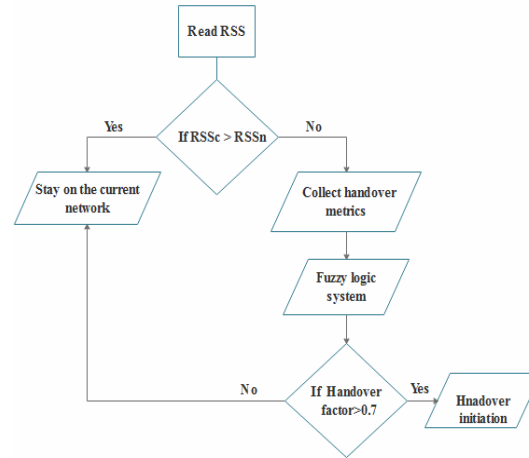
4.3.2 Modelling and simulation of a fuzzy system

In this experiment, the model proposed in Figure 10 is used, where the MT moves away from the LTE towards the LTE-A. The objective of the HO from the LTE to LTE-A is to improve the QoS. Fuzzy logic algorithms can be implemented in the MN as a HO decision engine to provide rules for decision making. The input parameters (RSS, bandwidth, battery power, and packet loss) are fed into a fuzzifier, which transforms them into fuzzy sets by

determining the degree to which they belong to each of the appropriate fuzzy sets via membership function. Figure 22, shows the input and output scenario for fuzzy logic.

Figure 22   Input and output scenario for fuzzy logic (see online version for colours)
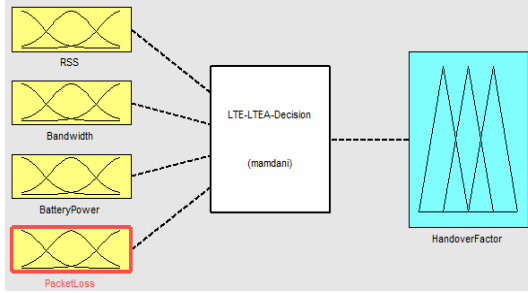
Each of the input parameters is assigned to one of three fuzzy sets, for example, the fuzzy set values for the RSS consist of the linguistic terms: weak, medium, and strong.

The fuzzy set values for the inputs bandwidth, battery power and packet loss are low, medium and high. The fuzzy sets are mapped to corresponding Gaussian membership functions because of their concise notation and having the advantage of being smooth and differentiable at all points. The fuzzy set values for the output decision variable HO are (lower, low, medium, high and higher).

Figures 23 and 24 illustrate the RSS, the bandwidth, the battery power and packet loss fuzzy sets.

After defining our input and output parameters, the fuzzy sets are fed into a fuzzy inference engine where a set of fuzzy IF-THEN rules is applied to obtain fuzzy decision sets. The output fuzzy decision sets are aggregated into a single fuzzy set and passed to the defuzzifier to be converted into a precise quantity during the final stage of the HO decision. The figure shows some IF-THEN rules that were applied for our fuzzy HO decision algorithm.

Some of The 81 IF-THEN rules are defined as follows and are shown in Figure 25:

- IF RSS is weak, and bandwidth is low, and battery power is high, and packet loss is high, THEN the HO factor is higher.

- IF RSS is strong, and bandwidth is high, and battery power is low, and packet loss is low, THEN the HO factor is lower.

- IF RSS is medium, and bandwidth is medium, and battery power is medium, and packet loss is medium, THEN the HO factor is medium.

If HO factor is greater than 0.7, the MT initiates HO to choose the LTE-A; otherwise the MT stays in the current access network (LTE).

Figure 26 illustrates the surface viewer for the fuzzy HO decision in the case of constant battery power and packet loss. As was expected, when the LTE RSS is good and its bandwidth is high, the system chooses to not perform a HO.

Figure 23   Membership function plots, (a) RSS (b) service cost (c) battery power and (d) packet loss (see online version for colours)
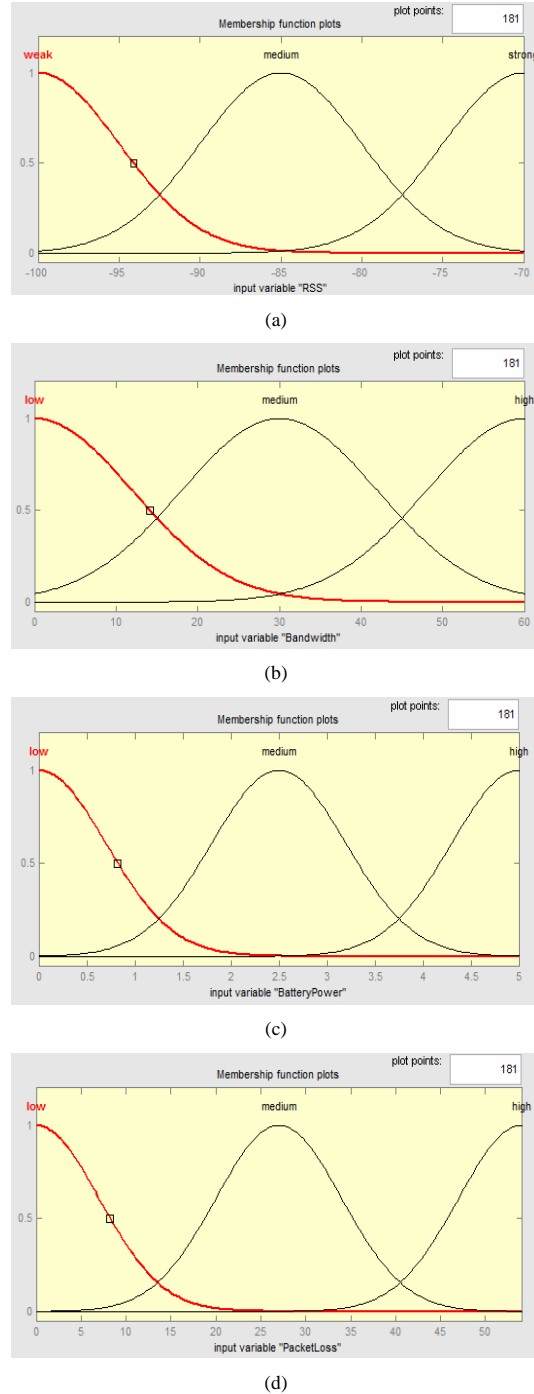

(a)

(b)

(c)

(d)

Figure 24 Membership function for output variable HO factor (see online version for colours)
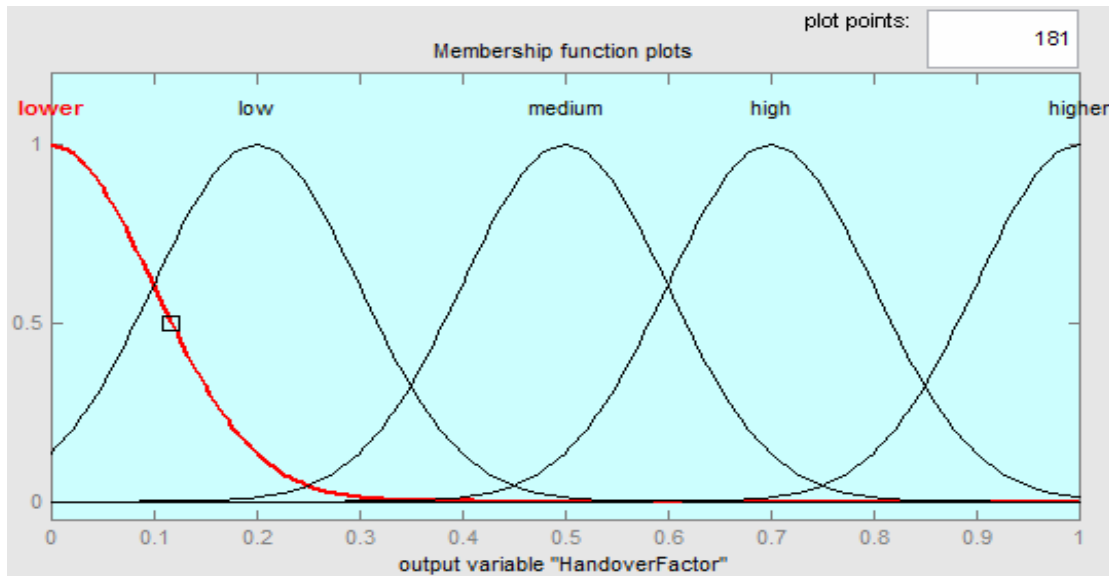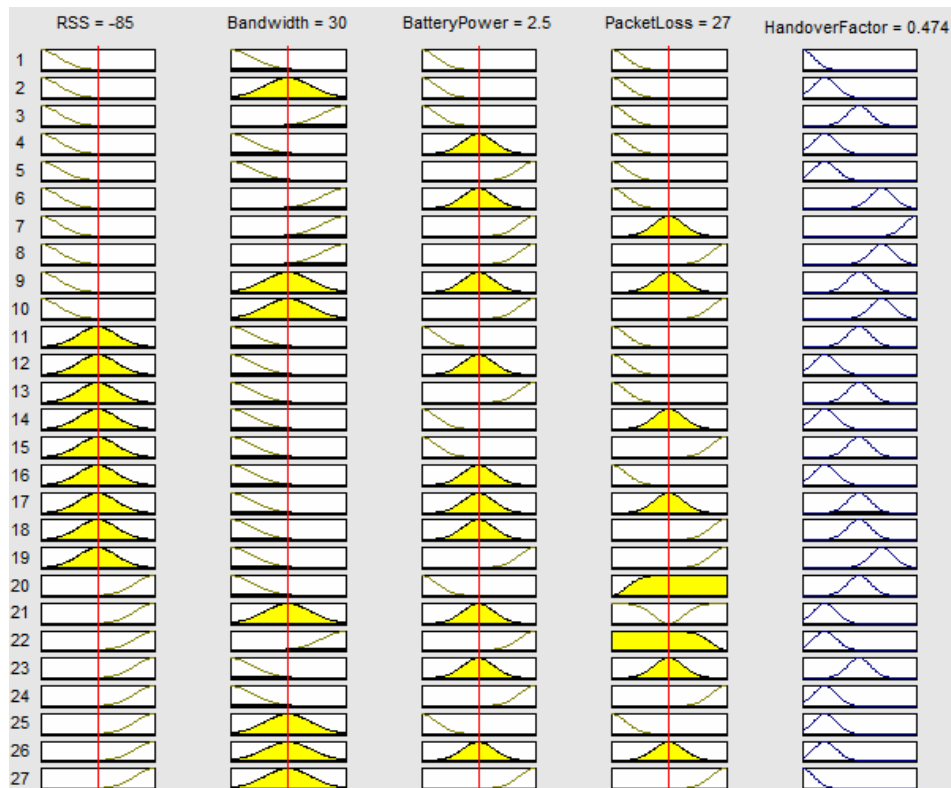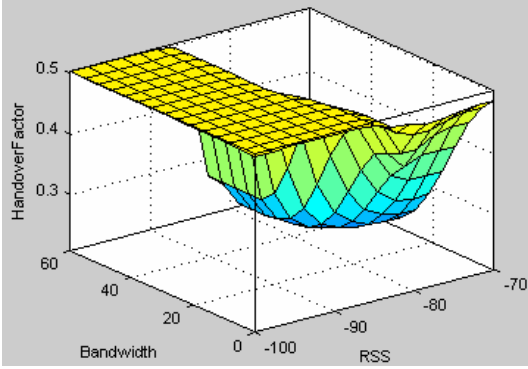

Figure 25 The fuzzy inference rules based on the Mamdani fuzzy inference system (see online version for colours)
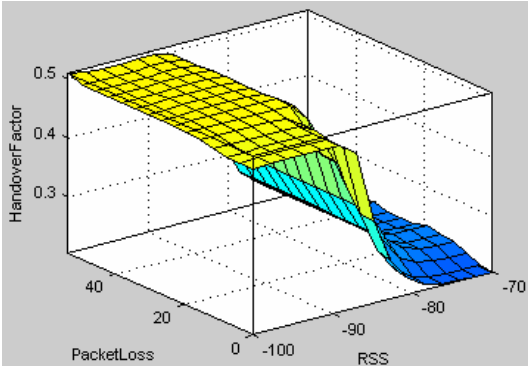
Figure 26   Surface viewer for the fuzzy HO in the case of constant battery power (2.5) and packet loss (30) (see online version for colours)

Figure 27   Surface viewer for the fuzzy HO in the case of constant battery power (2.5) and bandwidth (27) (see online version for colours)

The same behaviour is observed in Figure 27 when the battery power and bandwidth were kept constant, when there is low packet loss the system chooses to not perform a HO.

Figure 28   Surface viewer for the fuzzy HO in the case of constant bandwidth (27) and packet loss (see online version for colours)
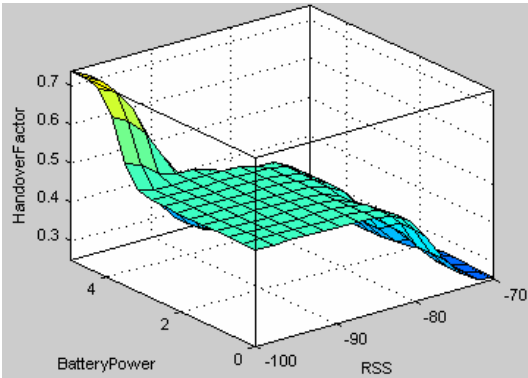

Figure 28 shows the variation of the HO decision while keeping the bandwidth and packet loss constant. When the signal strength is weak and the battery power increases the fuzzy system tends to prefer the LTE-A and performs HO from LTE to LTE-A.

4.4   Comparison between vertical HO algorithms

Figure 29 illustrates the HO count for each VHD algorithm based on fuzzy logic, RSS, SNR and the traditional approach. It can be seen that the VHD based fuzzy logic results in a substantial reduction in comparison to the other algorithms.

Figure 29   Comparison of HO counts for different approaches (see online version for colours)
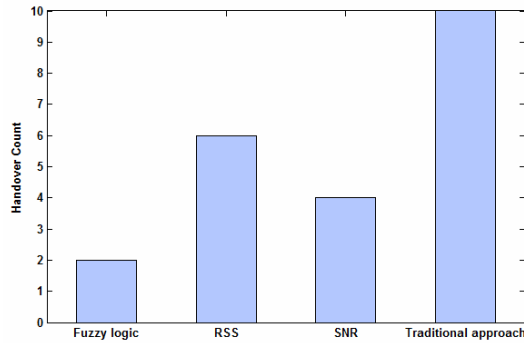
Figure 30   Comparison of power consumption for different approaches (see online version for colours)
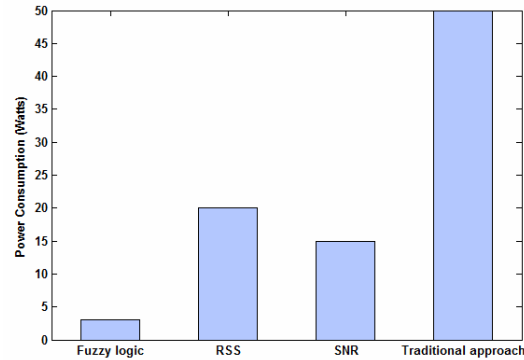
In different networks, the power consumption of the terminal device differs. The users generally choose the network with lower power consumption. The simulation results in Figure 30 show that the VHD based on fuzzy logic leads to lower power consumption compared to RSS, SNR and the traditional approach.

Therefore, it can be concluded that the VHD based on fuzzy logic provides an overall better performance than other vertical HO algorithms as a consequence of taking into consideration several parameters:

- RSS: is the most widely used parameter because it is easy to measure and is directly related to the satisfaction of user.

- Bandwidth: system available bandwidth is the major decision factor when terminal choose HO network.

- Battery power: battery power may be a significant factor for HO in some cases since wireless devices operate on limited battery power. For example, when the battery level decreases, handing off to a network with lower power requirements would be a better decision.

- Packet loss: packet loss is defined as the number of packets lost during the HO. It is the amount of packets that are lost or corrupted and finally cannot reach the desired destinations.

5 Conclusions and future works

The main aim of the HO process is to allow the mobile users to roam freely from one mobile network to another whether the network is the same or different. To achieve the load balancing in the different cell HO it is also necessary to maintain a good radio quality of the link between the mobile users and the serving BS and to minimise the interference level. This paper gives an impression of the main factors which are being affected by the vertical HO and shows how the RSS for HO varies according to different networks, especially in the midpoint of the overlapping area, where the network receives a powerful signal and in this case the mobile station carries out a HO.

Therefore our proposed vertical HO scheme guarantees seamless mobility and service continuity by using a concept of RSS in heterogeneous networks. Furthermore, the second algorithm based on fuzzy logic leads to a reduction in the number of HOs and a minimisation of the power consumption as compared to the first algorithm and the existing algorithms. As a follow up for this research work, two topics for future research investigations are suggested. There is a study of SINR and QoS between different types of HO in heterogeneous networks which asses the energy cost of different vertical handover (VH) schemes, however, designing and implementing new algorithm with energy support in heterogeneous networks would be an interesting line of research.

Acknowledgements

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