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Master thesis by:

Juras Klimasauskas

Supervisor:

Albena Mihovska

[DESIGNING THE ALGORITHM FOR NETWORK DISCOVERY AND SELECTION IN HETEROGENEOUS RADIO NETWORK ENVIRONMENT]

Preface

The report has been written as a project for 10^{th} semester during the period of 2011 February 1^{st} – 2011 December 1^{st} (extension of the project was requested). The project proposes an algorithm for network discovery and selection in a heterogeneous scenario involving next generation wireless networks. The proposed algorithm has been implemented in C++ and its performance has been evaluated by simulations. Currently, new radio access systems (e.g., LTE-Advanced, WiMAX) are getting deployed, while the legacy systems are also maintained defining the telecommunication systems environment as very dense and highly heterogeneous. Such developments pose a new challenge for the traditional network discovery and selection mechanisms. Instead of following a straightforward procedure of detection and attachment, now an optimized network usage is very much dependent on a proper access network discovery and selection procedure. When multiple access networks are available, users may have difficulty in selecting, which network to connect to and how to authenticate with that network. The proposed algorithm includes an extended set of selection parameters that refer to key performance indicators when deciding on admitting, dropping or handover of users from one network to another. The performance has been evaluated for three scenarios and in terms on number of users being served.

The report is structured as follows: Chapter I gives an introduction on the topic. Here, the problem formulation is given, the methodology and contribution of this work. Chapter II describes the various state-of-the-art mechanisms and presents the proposed algorithm in relation to the existing mechanisms. Chapter III describes the Algorithm development and analysis including parameters selection and importance to the system. An analysis on the choice of software tools for the implementation is given in Chapter IV. Chapter V presents the final implementation and performance results. Chapter VI concludes the work.

The literature references are marked with square brackets for the whole report (i.e [5]). Equations are denoted with brackets, taking into account the chapter number and the position of the equation in the chapter, for example (4.1) for the first equation of chapter four. The lists of references are provided after each chapter. Figures and Tables are numerated in the same way, and are always preceded respectively by the term Figure or Table. The list of Figures, acronyms and tables are provided at the end of the report.

Aalborg, December 1st, 2011

Juras Klimasauskas

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Chapter I. Introduction

In this chapter the general situation on the topic is analyzed, then the problem formulation, methodology and contributions of the thesis are presented.

I.1 Background

Currently, standardization (e.g., International Telecommunication Union-ITU [1], European Telecommunications Standards Institute-ETSI) and related bodies are looking for answers to the following questions of next generation radio systems: definition, closely related radio technologies and their functionalities, key technical characteristics, requirements, performance, benefits, the potential applications, the operational implications, capabilities that facilitate coexistence with existing systems, possible spectrum-sharing techniques and the effect on the efficient use of radio resources. For example, according to the evaluation process of ITU-R, International Mobile Telecommunication-Advanced (IMT-A) candidate proposals need to fulfill a set of 13 minimum performance requirements and provide coverage in a number of deployment scenarios, namely: *indoor hotspot, urban micro-cell, urban macro-cell, rural macro-cell and suburban macro-cell* [2]. The IMT-A systems are meant to support low to high user mobility, various data rates, support for multiple environments while having capabilities for high quality multimedia applications and provide a significant improvement in performance and quality of service, and their research and development was prompted by an ever increasing number of mobile traffic and devices using Internet Protocol (IP) services [3]. The overall trend is that new radio access systems are getting deployed, while the legacy systems are also maintained defining the telecommunication systems environment as very dense and highly heterogeneous.

In the quest for the fulfillment of such requirements, technological advances have been made in enabling areas, such as smart antenna design, spread-spectrum technologies, software-defined radio (SDR), cooperative communications, and cognitive radio (CR) systems bringing a new level of dynamics into radio communication systems. This implies that new parameters must be taken into account during overall network monitoring and measurements in relation to overall network performance and during handover of users.

The above developments pose a new challenge for the traditional network discovery and selection mechanisms. Instead of following a straightforward procedure of detection and attachment, now an optimized network usage is very much dependent on a proper access network discovery and selection procedure. When multiple access networks are available, users may have difficulty in selecting, which network to connect to and how to authenticate with that network.

ETSI and the Third Generation Partnership Project (3GPP) [4] specified the Access Network Discovery and Selection Function (ANDSF) as part of the evolved core packet network for the Long-Term Evolution (LTE) systems [5]. The ANDSF contains data management and control functionality necessary for providing network discovery and selection assistance data to the User Equipment (UE, mobile station, MS) as per operators' policy. The ANDSF is able to initiate data transfer to the UE based on network triggers, and respond to requests from the UE. The ANDSF is located in the subscriber's home operator network and the information to access it should be either configured on the UE or discovered by other means. Push mechanisms enable the ANDSF to provide assistance information at any time to the UE. Pull mechanisms provide the UE with the capability to send a request to the ANDSF in order to obtain assistance information for access network discovery and selection.

In future heterogeneous wireless systems, it is likely that users will have access to multiple networks simultaneously. Today also it is very common for different systems to coexist at the same area. For example in most of the cases there is coexistence of Global System for Mobile Combinations (GSM) and UMTS and also in many areas (that are growing very quickly) there is WLAN access available. Being able to access many systems can be a benefit, but there is a need to have mechanisms to decide at each moment which network is the most suitable for the users. This mechanism is called "network selection" or "access selection" and is a key mechanism to the normal operation of a heterogeneous wireless network. It is executed in three cases, namely when a user makes initial access to a network, when the user makes a new service request and when there is a handover request. Regarding each of these cases, the network selection has different objectives and it uses different criteria to make its decisions.

I.2. Problem formulation

For any access network, the problem is selecting the "best" access at a given time. There are too many parameters that can be utilized to decide about the "best" access and they will be presented below. When there are many networks available at the users area, the user should select one network to be connected to and receive the service he wants. In order to be able and have a choice of connecting to any network he should have a multi-mode terminal with many network interfaces. Basically network selection in a wireless environment can be divided to different sub problems:

- Selecting which interface(s) to power on
- Selecting which network to attach, if any
- Selecting which AP to attach, if any
- For application: which interface to use on a multi-RAT terminal

There is no doubt that in the future communications, the multi-interface devices will be used widely and as the device itself will be required to perform more and more tasks which will increase the power usage, interferences, and disruptions from other networks. Therefore, this could be defined as problem as well and needs to be analyzed. It is important to find a so-called most suitable mechanism to perform network discovery and selection in heterogeneous networks, find the "best" network available (from user perspective) and seamlessly handover to selected network without any interruptions to the user. In today's networks, where the horizontal handovers are mainly performed, the common parameter considered to decide on a handover is the received signal strength (RSS) but as analysis shows it is clearly not enough when considering handovers in heterogeneous networks.

Without a doubt the handover decision making mechanisms within heterogeneous network will pay crucial role among users and operators in the future. At the end this could lead to the network where users will be always and anywhere connected with the best Quality of Service (QoS). And as for the operators, there are possibilities to make profit from better utilized networks leading to increased user capacity and greater profits.

The purpose of the project is to examine the already existing network discovery and selection mechanisms and issues among heterogeneous networks and propose a new algorithm for network discovery and selection with an enhanced set of parameters to consider during the selection procedure.

The algorithm has been evaluated through simulation results for a reference scenario including several radio access networks (RANs), namely (WiMAX and WLAN, LTE-A, GPRS). The results demonstrate how more parameters considered can influence the results in network selection and discovery mechanisms and related to QoS, and how it reduces unnecessary handovers when the user is on the move and balances the network load.

The main objective of the project is to create the algorithm which makes the discovery of available heterogeneous networks around the user and makes the decision to which network to connect depending on specific QoS parameters and decision making mechanisms discussed later on.

I.3. Methodology

The proposed field of study revolves around the discovery and selection algorithms between heterogeneous networks. As it is going to be presented later on, the issue of handover between heterogeneous networks is highly dependent on the proper policies. RAN discovery and selection (NDS) in heterogeneous wireless networking environments is a complex process. It may require a lot of energy as well as time in order to get it successfully accomplished. Normally, the consumption of these resources will increase in proportion to the number of infrastructures that are available to the user. It is obvious that this procedure needs to be carefully tackled for achieving optimal resource management and efficient vertical handover execution.

A complete analysis needs to take into consideration the mostly recommended and required parameters to perform network selection and discovery such as the following:

- **Terminal capabilities**- these refer to support of the multi-interface capability, what is the power usage of the terminal and etc. Also it is important to consider if the user has the authorization to connect, service cost or connection cost, which might play important role when user is sensitive to the price.
- **Bandwidth** availability at the target networks,- it is mostly useful when specific application is required to be used and to keep load of the network balanced, without which congestion could be caused, which is also the parameter to be considered for the handover decision.
- **Received signal strength (RSS)** have to be considered, using this parameter the threshold of acceptable signal degradation can be used for handover decision making. Also it is important to avoid Interference between the networks.

In this work the following set of selection parameters has been adopted:

- **Terminal capabilities**
- **Battery status (if it can support the new radio interface)**
- **RSS - SINR level**
- **Mobility aspects (speed and direction)**
- **Type of service and requested grade of service.**
- **Bandwidth availability at the target network - congestion caused.**
- **User's preferences/profile/subscription (to be merged with "Privileges")**
- **Cost**
- **AAA for the new network**

In general the vertical handover can be caused by physical events referring to the network interface availability and by user policies and preferences. The decision criteria are indicators of whether or not a handover is needed. The criteria could be coverage, bandwidth, latency, link quality, received signal strength, signal to interference ratio, cost, security level, velocity, battery power, user profile, QoS, etc. Criteria helps to choose the best network and decision policy represents the influence of the network on when and where the handover occurs. As the example the traditional handover decision policy between the same networks is based on RSS only and looks like as follows [6]:

- RSS: choosing the new Base Station (BS)

  if RSSnew > RSSold.

- RSS with Threshold T: choosing the new BS

  if RSSnew > RSSold and RSSold < T.

- RSS with Hysteresis H: choosing the new BS

  if RSSnew > RSSold + H.

- RSS, Hysteresis and Threshold: choosing the new BS

  if RSSnew > RSSold + H and RSSold < T.

But when heterogeneous networks are involved using only RSS, this consideration is not enough for a variety of reasons as discussed above.

Another aspect to take into consideration are the mobile users, or the users in the cars or other fast moving transportation, it is important to analyze the mobility aspects such as speed and direction, battery status (if it is available to be used). When the user is on the move there is a higher risk of being disconnected or transferred to other networks a lot of times, in other words, we experience the so-called ping-pong effect (when moving out and back to the same network (cell) within very short time), which can drain the battery. Because of that this is a very important parameter to be considered to avoid unnecessary handovers knowing that the user will be soon at the same network .However, the user might tolerate the slight degradation of QoS, which makes the user requirements very important as well.

Another main consideration is the delay required to make the handover to the target network. Priority here should be considered as well. If the user can tolerate a delay higher than expected, then the delay plays crucial role when making the handover decision. For example, if the user runs the real-time application, such as a video call, if the user needs to be handover to another network, he/she might lose the connection.

To verify the algorithm, several simulation tools were studied and investigated, namely, simulations were performed within NCTUns software [7] and the use of C++ and Perl languages. The networks considered for simulations were the following: In NCTUns the simulations assumed a scenario of WiMAX and WLAN models, and when using C++ simulations, a larger set of networks were included in the scenario, namely, LTE-Advanced, UMTS, WLAN, and GPRS networks.

I.4. Contributions of the thesis

The main contribution of this paper is the development of the network selection and discovery algorithm in a heterogeneous radio network scenario. First, the analysis of the state of the art was carried out. Then, the algorithm was proposed and developed with an enhanced set of selection parameters. Thirdly, a software tool analysis was performed as there is a lot of various free and licensed software to perform network simulations (like OMNET,OPNET, MATLAB, NCTUns, NS-2 and etc.). The deficiency of some of the software tools was shown. Simulations were performed with NCTuns and C++. Finally, the actual implementation results and problems faced during the algorithm implementation in NCTUns and C++ were presented.

I.5. References

[1] International Telecommunication Union (ITU) at www.itu.int.

[2] Report ITU-R M.2133 “Requirements, evaluation criteria and submission templates for the development of IMT-Advanced”, 2008, at http://www.itu.int/publ/R-REP-M.2133-2008/en.

[3] Doc IMT-ADV/1-E “Background on IMT-Advanced”, July 2008, at ITU-R, www.itu.int.

[4] Third Generation Partnership Project (3GPP) at www.3gpp.org.

[5] ETSI TS 124 312 V9.1.0, “Universal Mobile Telecommunications System (UMTS); LTE; Access Network Discovery and Selection Function (ANDSF) ” (2010-04)

[6] Meriem Kassar, Brigitte Kervella, Guy Pujolle (2008) “An overview of vertical handover decision strategies in heterogeneous wireless networks” Computer communications.

[7] NCTUns home page at http://nsl.csie.nctu.edu.tw/nctuns.html

Chapter II. State of the art network discovery and selection mechanisms analysis in heterogeneous wireless networks

In this chapter the state of the art mechanisms and general requirements on network discovery and selection are analyzed. The Chapter is organized as follows. Section II.1 gives an introduction; Section II.2 analyzes existing state of the art network discovery and selection mechanisms in heterogeneous network.

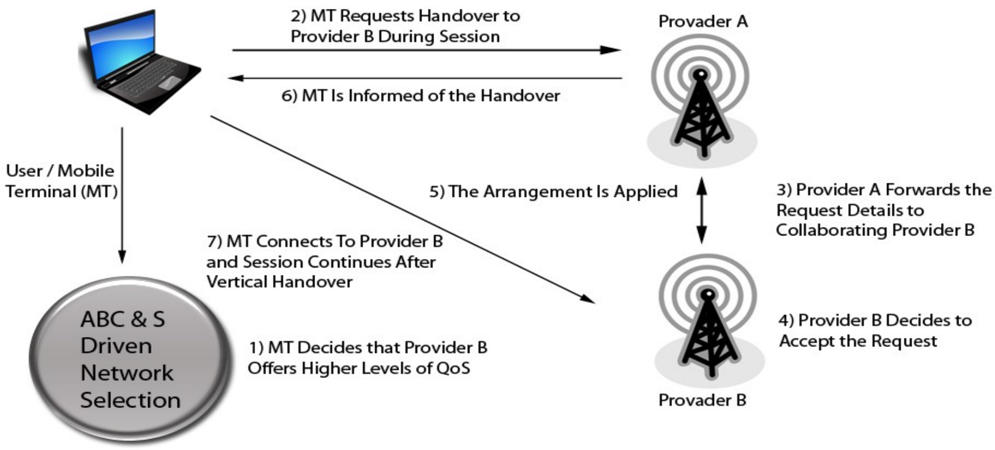
II.1. Introduction

Before beginning to analyze the available state of the art mechanisms in network discovery and selection in heterogeneous wireless networks, some basic information on the topic is given.

A heterogeneous network here means a combination of several networking technologies and access to these technologies when needed, taking into account different kind of communication requirements at specific situations and user needs. By using these kinds of networks, users are more flexible where several technologies are available to be used within the same coverage, or area of presence. It is well known that different technologies provide different characteristics like cost of service, bandwidth offered, security levels, converge and so on[1]. Having this information about different networks the users can save money on services, energy consumption, be connected as long as possible by choosing the right network to operate in. In the heterogeneous networks automatic RAT selection is very important aspect to be considered, as majority proposed solutions focuses on the selecting best RAT during handover, at the same time avoiding handover as long as possible. To deal with this problem, various solutions can be applied: fuzzy logic, for minimizing the number of needed handovers and maximizing the user satisfaction while increasing the overall system complexity [2], cost functions, used for calculating the cost of alternative RATs taking into consideration weighted metrics and parameters [3], policy based schemes which take into account rules to be performed in certain events and the main problem with this approach in case of combining several policies - to avoid conflicts between them. The latter, however, increases system complexity.

In heterogeneous networks, to satisfy the user by providing always best connected and served concept, the network selection needs to be a continuous process until the decision is made. The example on always best connected and served process in the case of handover is shown in Figure II.1 [3].

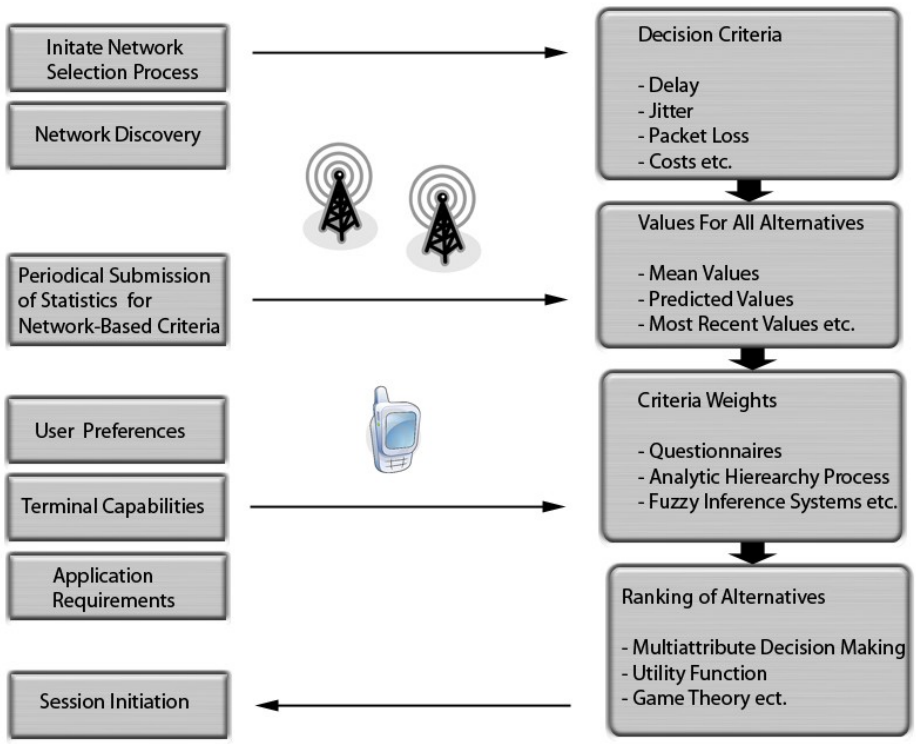
Figure II.1: ABC&S-driven service provider change



To choose the network to which to connect, first the network discovery has to be performed. Network discovery refers to the ability to determine, and then find the available access networks within the area where the discovery is performed. Network discovery is the first algorithm performed during vertical handover (vertical handover means the handover between different access-points in different networks like WiFi to WiMAX) while horizontal access refers to handover to the next cell within the same network. The Horizontal handover as mentioned in first chapter usually only uses signal strength mechanisms to trigger the handover between base stations.

When the network is discovered the selection is performed. Currently, network selection is done manually where the user selects the network he/she wants to connect to and is able to connect. In heterogeneous networks when devices will have a variety of radio access technologies implemented, the RAT selection will play a crucial role in the functionality of the whole network. The Main steps involved in the network selection are shown in Figure II.2 [3].

Figure II.2 : Main steps in network selection [3]



From Figure II.2, we can observe the main four steps considered in the network selection process. First the decision criterion is selected, where identification of parameters as delay, jitter, cost etc. are considered. In the second step values for all alternatives as performance of each alternative are considered. The third step considers the importance of each parameter, in other words, weighs the parameters by using different methods (Questionnaires, Analytic Hierarchy Process), and the final step performs the ranking of the alternatives which is based on inputs considered in previous steps [3].

In the following section the analysis of the already existing state of the art methods for network discovery, selection in heterogeneous wireless networks are presented, which gives us the knowledge about what is already done on the topic.

II.2. Examples of existing state of the art network discovery and selection mechanisms in heterogeneous networks.

In this section a literature study was performed and several papers were analyzed.

II.2.1 A dynamic network discovery and selection method for heterogeneous wireless networks

The first paper analyzed is "*A dynamic network discovery and selection method for heterogeneous wireless networks*" [4]. In this paper the authors introduced an intelligent handover decision model called TAILOR (Intelligent Handover Decision Model for Heterogeneous Networks), which mainly selects the access network by dynamically considering a variety of network selection parameters such as: QoS offered by the network, cost of service, the QoS of applications running at the moment, the preferences of the end-user, wireless signal perception, power requirements of each network interface. Also, the method introduce a new network discovery approach, which reduces power consumptions when the network discovery is performed on devices such as smart phones, PDAs which are very sensitive to the power usage.

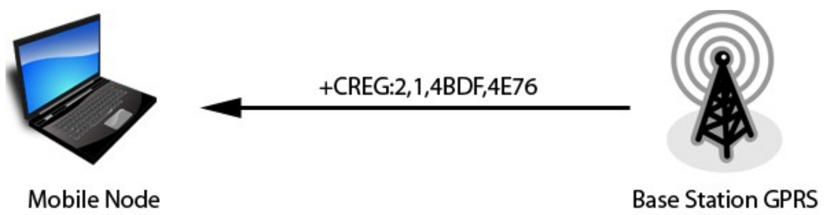
The Proposed method using mobile-controlled handover decision enables the mobile node to select the best network depending of various criteria's such as network conditions, costs, user preferences and so on. The handover process is divided in three phases: Network discovery, handover decision and handover execution. In the network discovery the mobile node determines what wireless networks are available. The Handover decision is responsible for decision to which network to connect and the handover execution performs the actual switch to other network to transmit the data [4].

The paper focuses on the network decision in means of energy efficiency which is done by introducing the cell-id based location-management technique avoiding continuous interface activation. Cell-id can be used only in GSM, GPRS and WCDMA networks. The basic idea of using cell-id technique is that the base station (BS) continuously broadcasts information of their mobile users to the network and the information that is included within the broadcast is [4]:

- Mobile Country Code (MCC) – Each country network operator has unique country code to be used
- Mobile Network Code (MNC) – this code identifies the network operator used.
- Location Area Code (LAC) - a group of cells managed by the network operator in an area.
- Cell ID (CI) – the unique cell id on which it operates.

The basic Network discovery using Cell-id is presented below [4].

Figure II.3 : Network discovery using cell-id

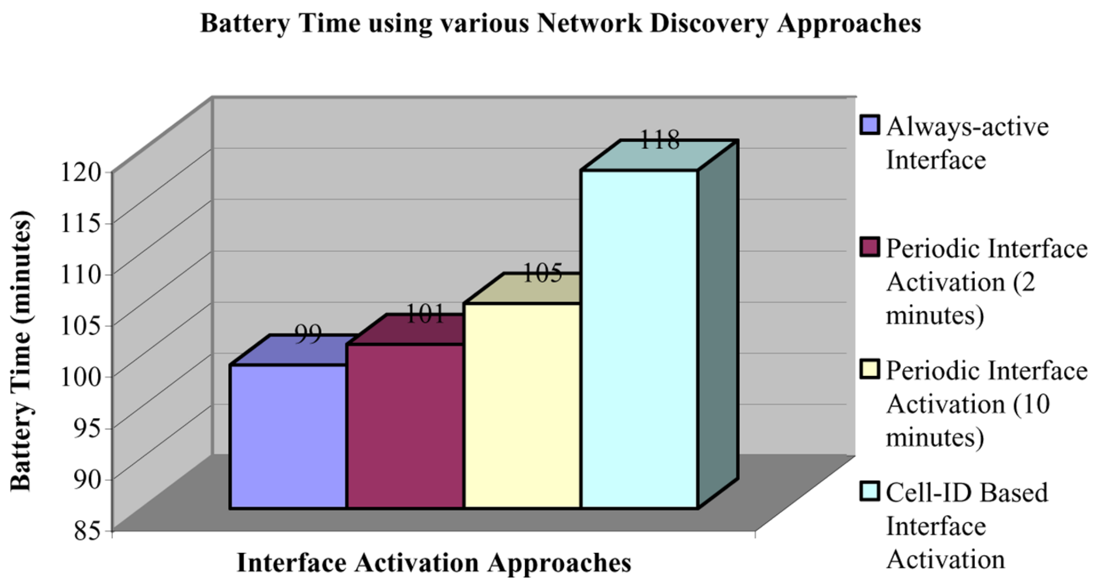


The values obtained from the information broadcasted from the BS are transmitted to the hotspot location server on the wired network via the GPRS network interface assuming that GPRS network is always available for monitoring and receiving the information about the presence of smaller networks like WLAN, Bluetooth, etc.

When the mobile node changes its cell, which is indicated by the cell-id, it transmits the information of the MCC, MNC, LAC and CI to the Hotspot Location Server (HLS) which is database of the hotspot locations. HLS makes sure that the information received corresponds to wireless hotspots inside the cell, if it is found, HLS returns the CIs of the cells containing the hotspots to the mobile node, and in case not found, the HLS returns the message to the mobile node with a NULL flag set. Basically regarding the power consumptions in this situation while discovering the hotspots, the scanning for the WLAN is activated only when the message from the HLS indicates presence of the wireless hotspots in the current cell. If the message indicates no hotspots in the current cell then the mobile node deactivates its WLAN interfaces which reduce the power consumptions. And this is a different approach comparing to conventional techniques where continuous WLAN scanning is performed. By using cell-id mobile node transmits information only when cell is changed and because of that information is not needed to be transmitted continuously which also saves the bandwidth [4].

In the experiment performed, the cell-id performance in reducing the power usage can be clearly seen. The graph below shows the results obtained comparing with the other available techniques [4]. And this is very important considering that equipment used will be equipped with more than just few wireless interfaces.

Figure II.4 : Total Battery life time comparison with other network discovery approaches



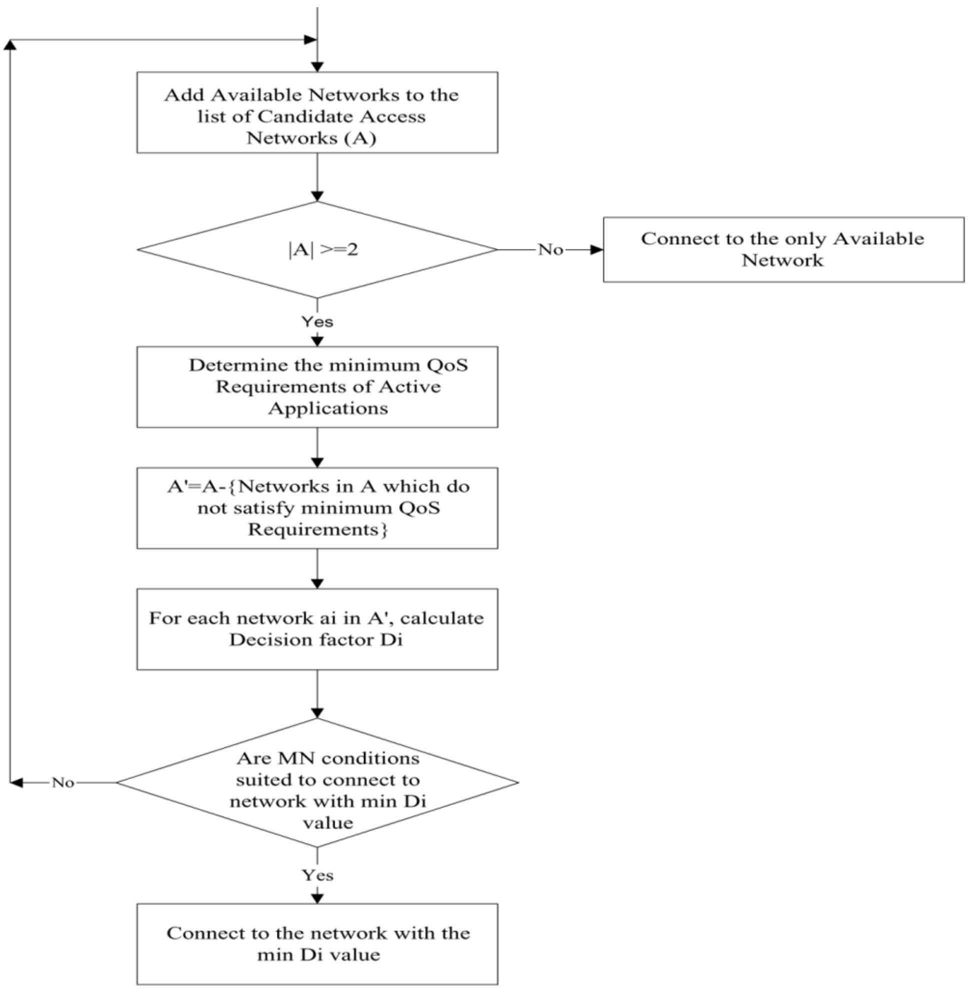
Moreover regarding the power consumptions TAILOR introduces the Battery Monitor (BM) module which keeps track of the transmit power of each network interface. This can be very useful in situations when the mobile node is on low battery and needs to operate as long as possible which could lead to the decision to handover to network which require low power which could be due to distance from the access point, environmental conditions, etc[4].

In case of mobile node discovers the hotspot it has to decide if it needs to switch or not. The authors introduced the TAILOR approach as more reliable, because it takes into consideration more characteristics of the network that other available access networks considers, like incorporating QoS requirements of active applications executing on the mobile node. And as the example in the homogeneous networks only signal strength and channel availability are considered to perform the handover.

In order to efficiently perform the handover user preferences are also considered for greater user satisfaction as the user itself sets its preferences which is stored in user profile file consists of options as follows[4]:

Cost*: Don't care, Lowest*
Bandwidth: *Don't care, Highest*
Power saving Always on: *Yes, No*
Power Saving ON when Device Power Low: *Yes, No*
Consider QoS Requirements of Running Applications: *Yes, No*
Auto Network Select: *Yes, No*

Figure II.5 : TAILOR decision algorithm



Continuing on, the TAILOR architecture presented in Figure II.5 above shows how the TAILOR operates. At the beginning the list of available networks is collected (A) depending on mobile node position. If there is only one available network, then it connects to it, if there are several networks available, then networks are evaluated and depending on user's needs selects the best one for the specific user. The decision function Di is calculated by minimum requirements required of the running user applications. The lower Di value obtained the better network is in means of cost, power consumptions and bandwidth [4].

Figure II.6: TAILOR middleware

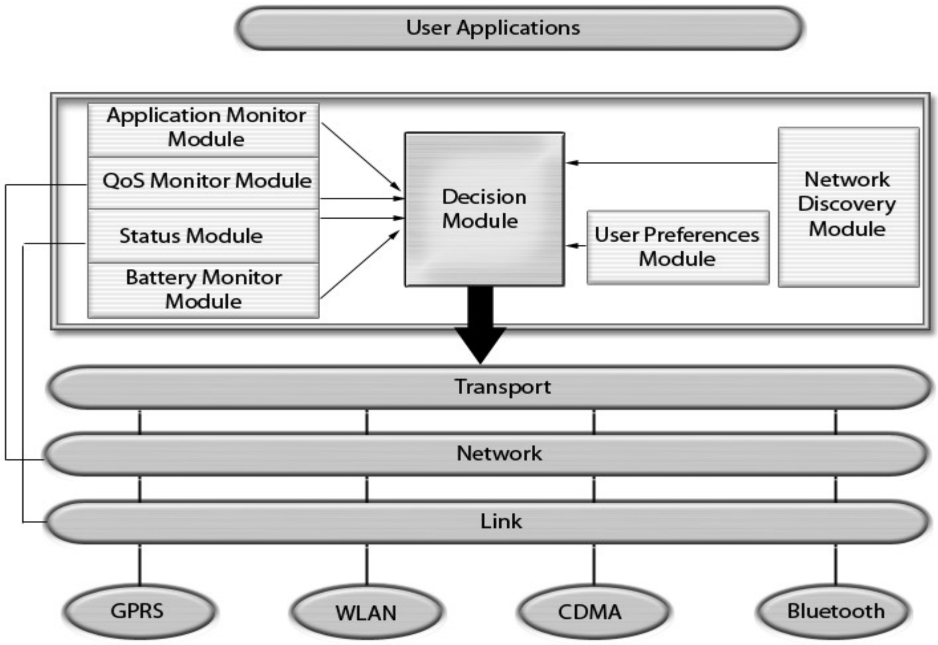


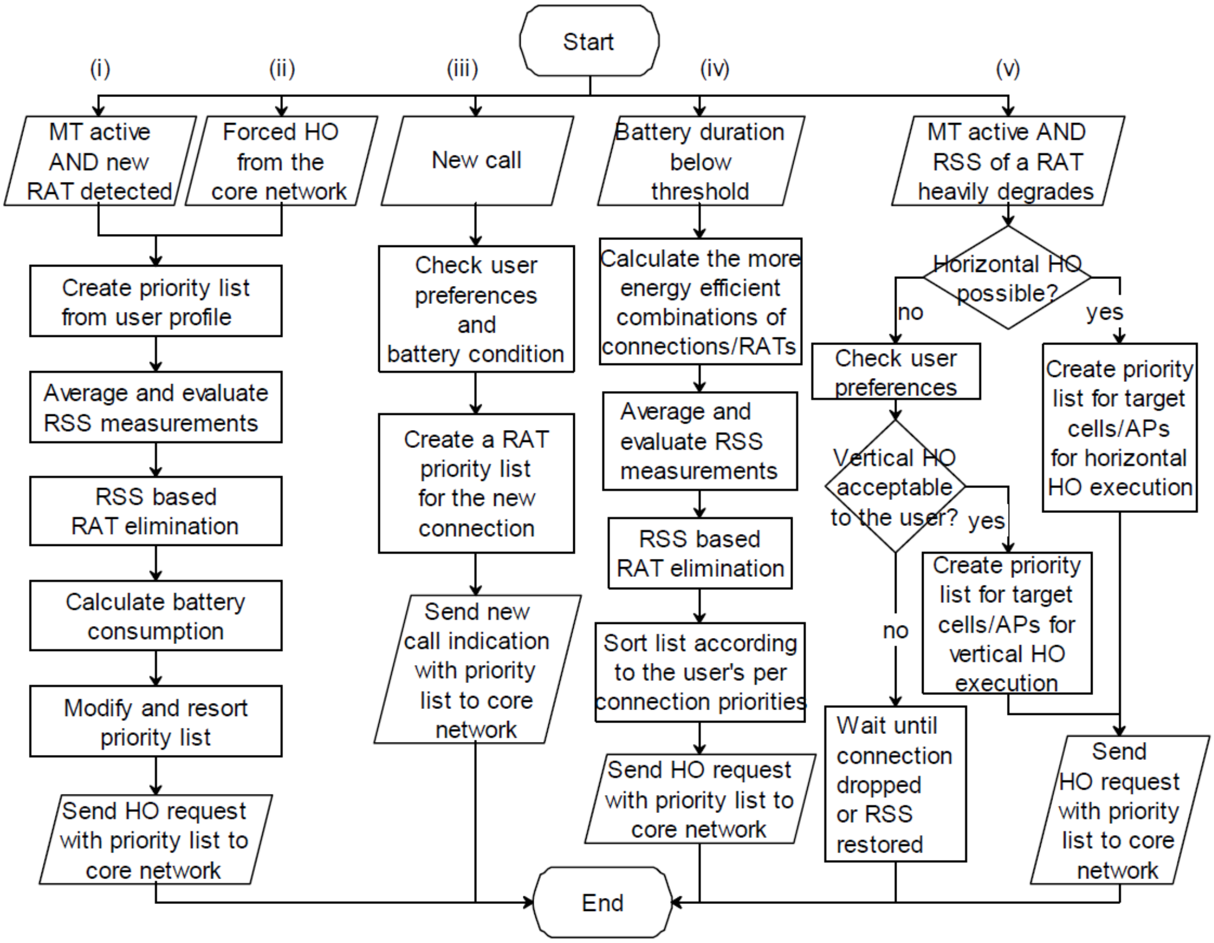
Figure II.6 represents the middle ware of TAILOR. Where QoS monitor module is responsible for obtaining the information about QoS parameters offered by each network. The networks which do not meet the requirements are discarded. Battery Monitor module – monitors the mobile nodes battery status and consumptions in different networks. Status module – Checks the status of the mobile node like moving speed. User preferences module – as mentioned before it holds the user specifications. Application Monitor module – monitors for the applications being used and their requirements to operate fluently. All of these modules specifications after successful evaluation are transmitted to Decision module to make the final decision on the network to be used [4].

II.2.2. Network Selection Algorithm for Heterogeneous Wireless Networks: from Design to Implementation

The second paper focuses on new Radio Access Technology (RAT) selection mechanism where each mobile terminal connection is handled separately, meaning that the flexibility and user satisfaction is increased (by user satisfaction in heterogeneous networks means: if the QoS offered is high and the cost is low then the user's satisfactory is very high). Basically, the proposed mechanism has two parts, the first part deals with the Mobile Terminal (MT) side and the second with network side. In this kind of mechanism the core network processing load is reduced as some processing is executed at MT side. The outcome of the mechanism is to find the best network for the user in case of the handover which also considered in horizontal and vertical access [5].

The first algorithm proposed is on the MT side which takes into consideration user preferences, QoS, battery duration, received signal strength, power consumptions of radio interface. The main purpose of the processing in the mobile terminal is to create prioritized list of target RATs which meet the requirements of the user. The following Figure II.7 shows the proposed algorithm process in MT [5]:

Figure II.7: Mobile Terminal Algorithm



In the Figure II.7, the first two triggers namely “i” and “ii” are similar when the mobile terminal is active and the new RAT is detected, or the forced handover is required because of i.e. load balance purposes. The priority list of user preferences is created next (consisting of costs, QoS and battery duration). After the list is created the system checks if the network discovered meets the requirements and the quality needed to support the services by evaluating Received Signal Strength (RSS). If the requirements are not met, then these networks are eliminated from the list. In the battery consumption part the mobile terminal calculates the battery consumptions on all interfaces involved, so that to modify the priority list depending on the user specified priority for the battery consumptions. And finally at the final stage, the list is created starting from best to worst and send to the core network for a final decision.

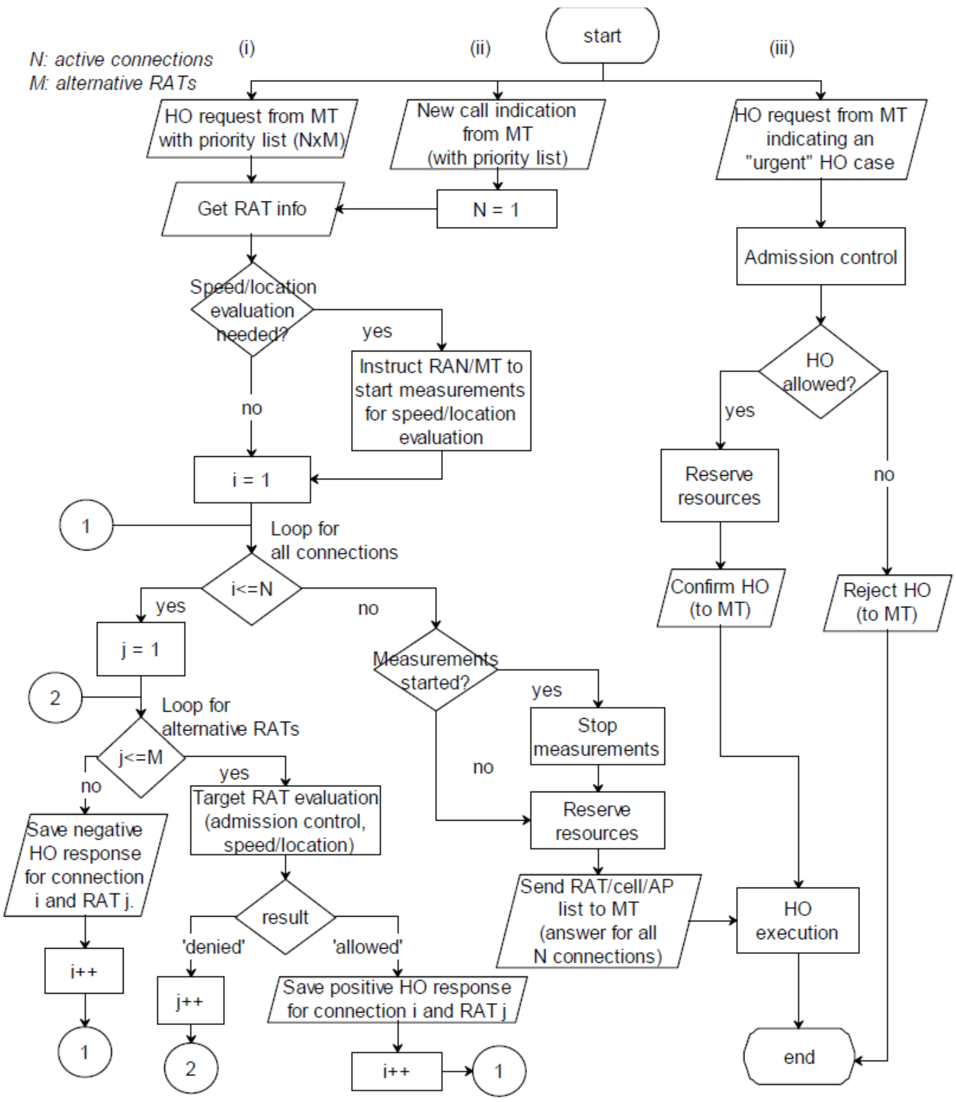
The next trigger namely "iii" becomes active in case of new call, where the algorithm checks the user preferences and battery consumptions for creating the priority list for new connection and sends created list to core network to initiate the call [5].

The "iv" trigger is activated when the battery threshold is below the set one, the threshold here is set by the user and can be turned off. When the threshold is reached the network calculates and finds new network which would maximize the battery life (i.e. the closer cell within the same network if possible) and sends the created priority list to the core network for handover initialization [5].

And the final trigger "v" is activated when the signal is going down leading to possibility to be disconnected. In this case the algorithm proposes that the mobile terminal has to decide what to do depending on the user preferences. The priority in this case is given for the horizontal HO if possible, because if the user is in the network which meets all requirements is better to stay within the same network and less latency is obtained. If it is not possible the vertical HO is processed as discussed before, or if the user does not accept vertical handover when it waits until disconnection or signal restores [5].

The second proposed Algorithm is for the core network as shown in the Figure II.8.

Figure II.8: Core network algorithm



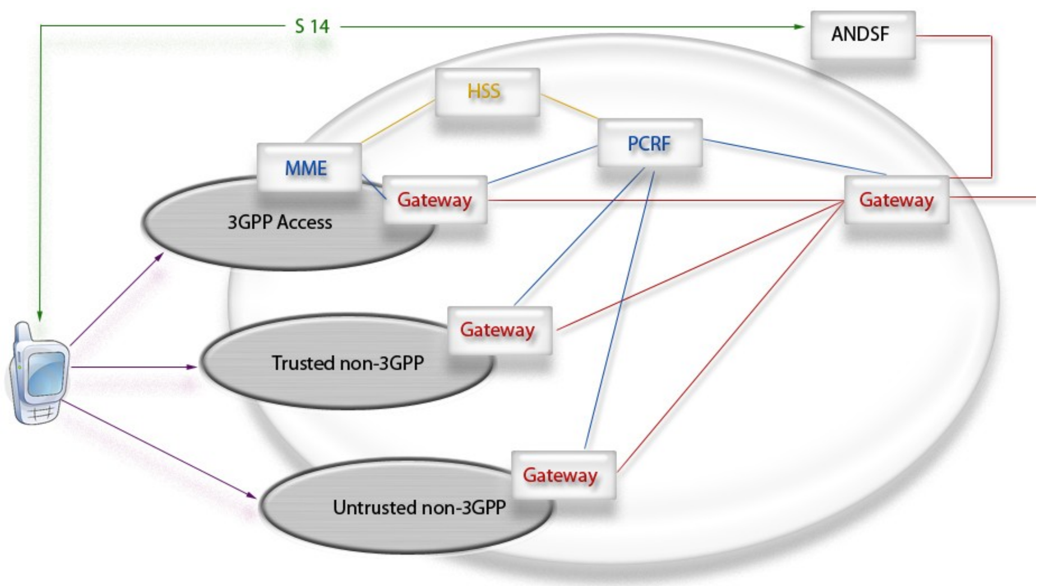
The core network algorithm is performed to make final decision on new connection or handover to an existing one. The architecture of the algorithm presented above consists of total three triggers. In short the first trigger is dealing with HO request from mobile terminal with the priority list created from mobile terminal algorithm, the second trigger is the new call indication from a mobile terminal and the third trigger deals with immediate handover process to see if it is feasible [5].

II.2.3 Access Network Discovery and Selection in the Future Broadband Wireless Environment

The third paper analyzed here is from 3GPP and presents a new network called Evolved Packet Core (EPC) for network discovery and selection with network balancing mechanism for seamless mobility between wireless networks as LTE, LTE-A, GSM, cdma2000, WiFi, WiMAX. The Basic idea is to perform network discovery and selection functionality in the 3GPP EPC. The proposed system can function also without the access network discovery and selection function and this enables faster integration into existing architecture with no need to modify other components.

The architecture of THE EPC is presented in Figure II.9 below [6]:

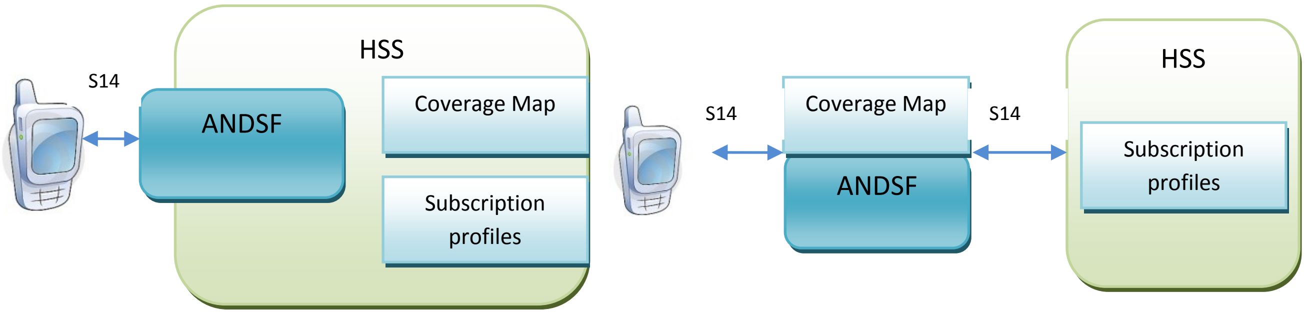
Figure II.9: EPC Simplified Architecture



In short, the exchange of the data is supported by gateways, where gateways are managed by the PCRF which stands for Policy and Charging Rules Function which "*makes the subscription based decisions on the access control and on the resources to be reserved for each data flow of the UE*"[6]. For 3GPP networks the information about location and authentication, authorization is stored in a Home Subscriber Service (HSS) from IP Multimedia Subsystem (IMS). For the connection between non-3GPP accesses networks Access Network Discovery and Selection Function (ANDSF) are performed on the top of the EPC and Client Mobility Manager (CLiMM) in the User Equipment which is presented as S14 in architecture. For more detailed information about the architecture proposed by 3GPP user is welcome to read more on [6].

What is the most interesting from this paper regarding network discovery and selection in heterogeneous networks is the Subscription Profile Based ANDSF which is considered to be one of the network discovery and selection parameters. In this way when the request for network is performed ANDSF is able to select access network which is in the area of the mobile device and select only the networks which are allowed to be connected to. The architecture of the Subscription Profile is presented in Figure II.10 [6].

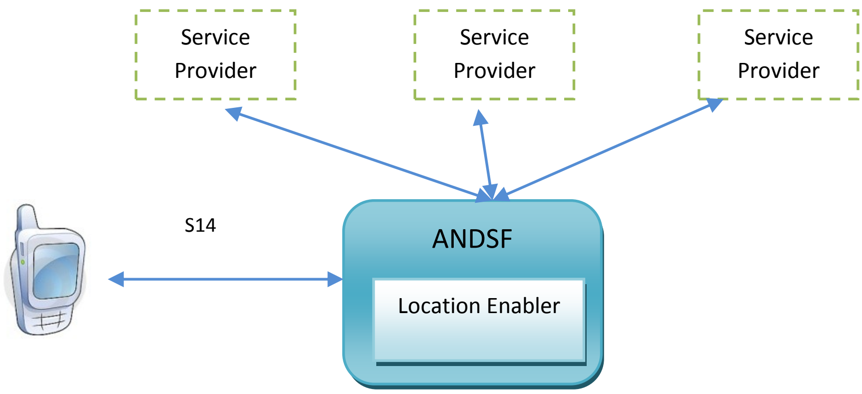
Figure II.10: Two cases of Subscription Profile Architecture



From the architecture we observe two cases of how the ANDSF could be implemented. The first ANDSF could be integrated into HSS and the second one to create new interface between ANDSF and HSS. Using the first case we obtain faster responses to the UEs because of no other communication, but the disadvantages of this case is that the complexity is increased for integrating and matching the information in the Coverage Map (meaning dynamic information about available networks in the area) with the information of the subscription profile and to push information to the mobile device. Also the security is decreased, because if the UEs can transmit queries directly to the HSS possible, attacks on the storage itself can be performed. To overcome these disadvantages the second approach is suggested to separate ANDSF with interface to the HSS to obtain same functionality. In this case the direct communication with database is avoided and other functionalities regarding network discovery and selection can be integrated.

Other presented functionality of the ANDSF is the Location Enabler which basically is used for determining the location of the mobile device. The main idea behind this is that using the Location Enabler, Service providers do not need to perform the location discovery separately for each service like it is in other state of the art solutions. In this case the communications over wireless link is reduced. The proposal is illustrated below [6].

Figure II.11: Novel Location Enabler Functionality for the ANDSF [6]



To make this proposal possible the interface between ANDSF and service provider have to be created. In this direction for the moment there is only one proposal in EPC called Rx – "interface which allows the services to notify the PCRF on the resources that have to be reserved for specific data flows" [6].

Moreover femto-cells discovery and selection is proposed to be used within ANDSF. Femto-Cells basically allow obtaining the same resources as an operator controlled BS meaning that if we place the femto cell within the user premises then we will have short distance access for specific amount of users with the increased throughput. "The femto-cells are considered as a novel type of access networks with similar characteristics as the WiFi access networks. The discovery and selection information send by the ANDSF to the UE will include this new category." [6].

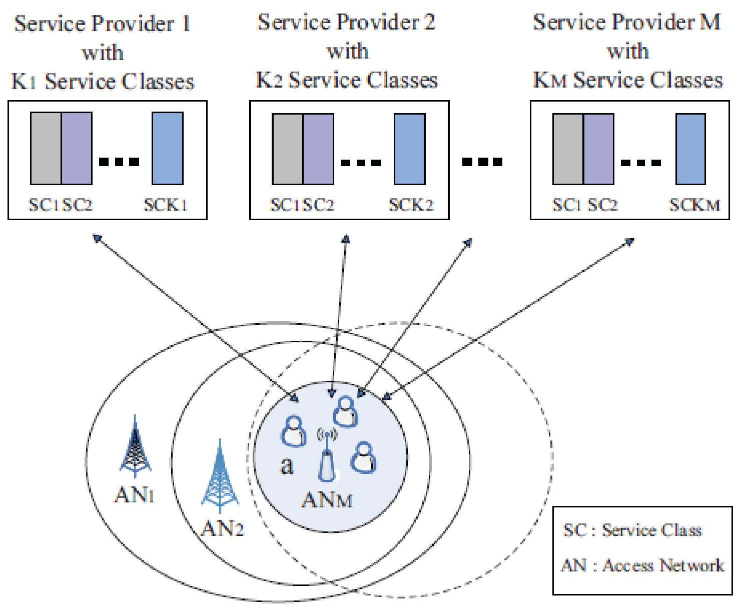
In conclusion, the EPC access network discovery and selection functionality can be developed as dynamic discovery or location enabler. Also the extensions on functionalities, optimization can be easier integrated like i.e. the mentioned femto-cells usage for better service. 3GPP created TR 22.912 specification which specifies the network selection procedures requirements for non-3GPP access types integrating automatic and manual selection as well as operator and end-user management. The full specification can be found in reference [7].

II.2.4 Optimal Bandwidth Allocation with Dynamic Service Selection in Heterogeneous Wireless Networks

The fourth paper analyzed in this part introduces two-level game framework for dynamic decision making in heterogeneous networks. Two-level game means that there is a game between users and service providers to obtain strategies for dynamically selecting the services by the users and allocating the bandwidth by the service providers and as outcome achieving optimal bandwidth allocation. The dynamic decision of service selection by the users is created using evolutionary game. Evolutionary game is: "The competition among groups of users in different service areas to share the limited amount of bandwidth in the available wireless access networks" [8]. By using this game, service providers can observe the selected services by the users and assign the bandwidth dynamically. The authors of the paper found that none of the existing methods for network selection and rate control problems in heterogeneous networks (i.e. Evolutionary game, Markov Decision Process for flow assignment among different networks [9]) considered the problem of the optimal bandwidth allocation in which users can change service selection dynamically [10].

The proposed system model is presented below in the Figure II.12 [7].

Figure II.12: System model of multi-class heterogeneous wireless networks



The model above represents M access networks (ANM) where each access network belongs to specific service provider who can provide number of services classes with specific QoS requirements. When the users are sharing the same service class each of them will share the same amount of bandwidth and its quality [10].

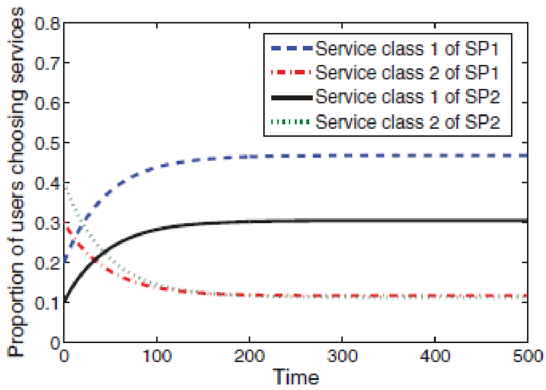
In this sense as it was mentioned the authors created two-level game which consist of:

- **Lower-level game**: users compete to select the available access network in means of obtaining maximum QoS performance. The users are able to select service selection strategy at any time instance depending on observed performance and congestion conditions. In the game the players are active users at specific time and the strategies are choices of particular service class from service provider and finally the payoff of the players are QoS satisfaction level [10].
- **Upper-level game**: the service providers having the information about the dynamic service selection behavior can optimally allocate the bandwidth for greater profits. But from this scenario a problem can appear, if you assign higher bandwidth for service you can attract more users, but at the same time you decrease the performance of other services which reduce total profits obtained. In this sense using upper-level game bandwidth allocation from service provider can be performed. In the game the service provider is the player, the strategy is the dynamic control off bandwidth allocated to different service classes and the payoff is the higher profits [10].

The control strategies can be **open-loop** and **closed-loop**, in this paper the authors consider open-loop strategy for its simplicity as it does not need any feedback information from the system. For solution of bandwidth allocation differential game authors suggests to use open-loop Nash Equilibrium ("Denote $\vec{\gamma}_i(t)$ the open-loop bandwidth allocation strategy of service provider *i*. The strategy profile $\Phi =$

$\{\vec{\gamma}(t), \vec{\gamma}_{-i}(t)\}$ is an open-loop Nash equilibrium if for each service provider $i \in \{1,2,\ldots,M\}, \vec{\gamma}_i(t)$ is an optimal control path given other service providers' control strategies $\vec{\gamma}_{-i}(t)$." [10]).

Figure II.13 Dynamics of service selection



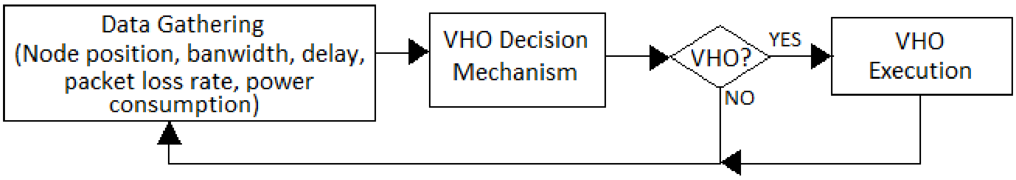
The following is the example of service selection of users under bandwidth allocation control. The example is done by setting the parameters of the networks, in this case it is considered to be IEEE 802.11b access point and IEEE 802.16 base station to provide two service classes to the 20 users as it is shown in Figure II.13. The main parameter for this example could be mentioned is the price and bandwidth allocation. For two service classes of two service providers are P_{11} = 0.2, P_{12} = 0.1, P_{21} = 0.3 and P_{22} = 0.25. As the result from optimal control strategy the authors created reader can observe that service providers assigns more bandwidth to the first service class than second due the higher price and as the outcome first service class has more users to deal with, meaning that because of user mobility the number of users differs in time creating possibility to have congestion in the network which must be controlled by adjusting bandwidth allocated to the service class with higher price [10].

II.2.5 Simulation of Vertical Handover Algorithms with NCTUns

The last paper [11] considered to be most important and useful for the simulations and focuses on vertical handover algorithm simulations using NCTUns tool. This paper presents vertical handover algorithms tests over WiFi/GPRS and WiFi/WiMAX mobile networks by implementing additional components within the tool using its API and scripts written in C and Perl languages. Here, the authors focus on creating the vertical handover algorithm simulation using the NCTUns tool as no one tried before to simulate this using this tool because of not having a vertical handover component [11]. Basically, the paper presents three simulation cases: The first is when parameters such as network bandwidth, cost and mobile node mobility are used in a cost function to make a decision to which network to connect.

The Figure II.14 represents the general scheme of the Vertical Handover Algorithm (VHA) simulation.

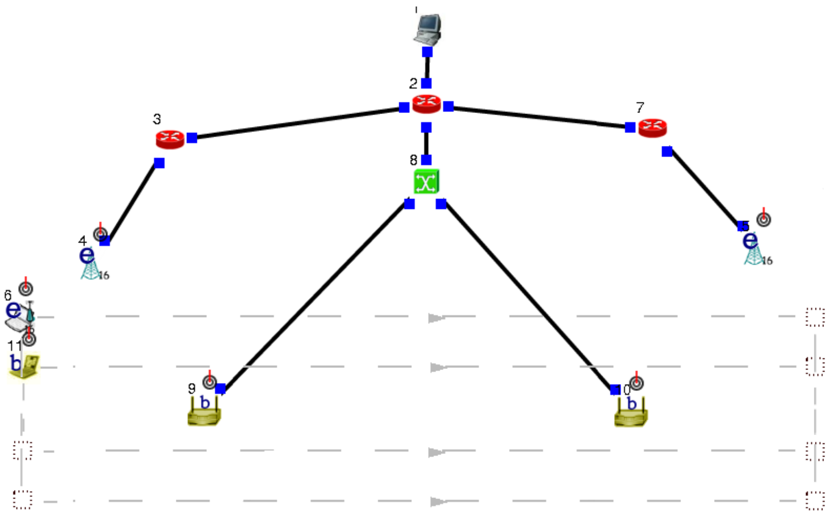
Figure II.14: Vertical Handover Algorithm



At first, the data of the nodes is collected and then the data is sent for further consideration like, if it is necessary to perform the handover or not, by using specific calculations such as the price function where each component is weighted by the importance before the decision is made. Moreover the handover is also delayed for some time to make sure that the network is stable and to avoid unnecessary handovers in other words avoiding ping-pong effect (when the node goes and comes back to the same network). The "dwell time „method was chosen for avoiding the unnecessary handovers (the period during which a dynamic process remains halted in order that another process may occur. [12]). After all of this is considered and calculated the handover is executed.

The Figure II.15 below presents the topology of the WiFi/WiMAX mobile networks. During the simulation the authors found out that the multi-interface node within the tool does not work properly and found the solution to use two separate nodes WiMAX (802.16e) and 802.11b which would move at the same speed, destination, act like it would be multi-interface mode.

Figure II.15: WiFi/WiMAX mobile network topology



The proposed cost function takes into account parameters such as: bandwidth (bit rate), battery consumption, monetary connection cost and mobility speed. Then all the components are given the weights by the user who decides how important each parameter is from 0 to 1. The proposed cost function is displayed below:

$$f_i = W_b ln\frac{1}{B_i} + W_c lnC_i + W_v ln\frac{1}{V} \qquad (2.1)$$

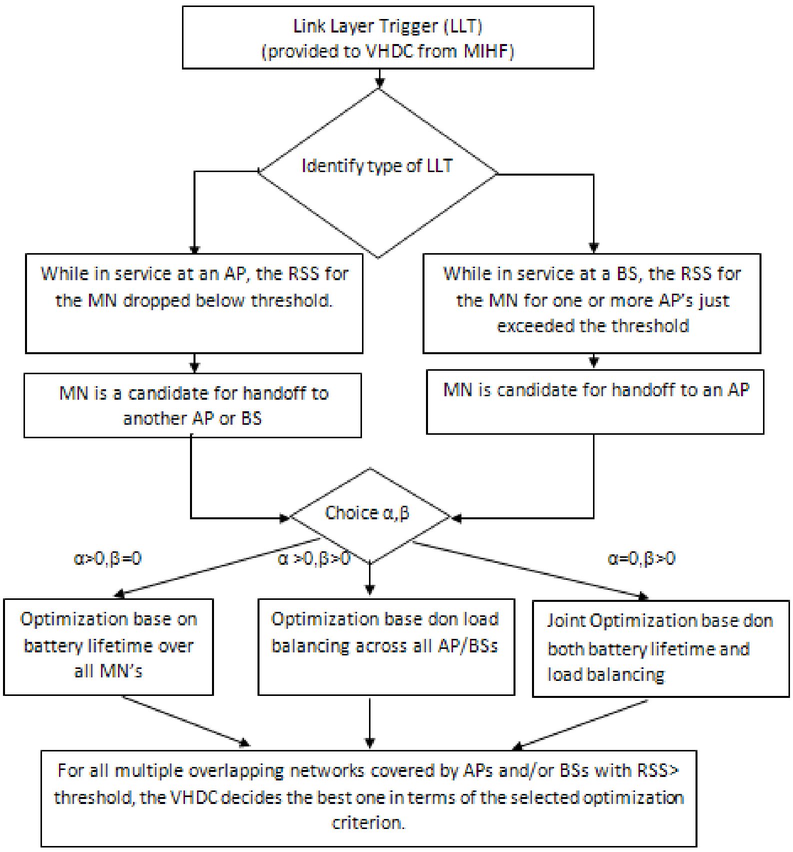
Where W_b, W_c, W_v are weights for bandwidth, cost and velocity. Bi is bandwidth, Ci is cost and V is the velocity of the node.

The second case focuses on application requirements as bandwidth, latency, packet loss rate. The proposed algorithm is divided in three components:

- **The Application manager** who is responsible for the application requirements within the mobile node, meaning that it specifies the ideal values of the parameters for the network conditions.
- **The Network Manager** is responsible for determining which network meets the requirements of the multi application profile abstraction.
- **The Network layer** takes the measurements of the parameters continuously so that network manager could compare them with the requirements of the multi application profile abstraction.

The last case deals with load balancing mechanisms and optimizes battery consumption. Here, it is mainly the purpose to lower the battery consumption and balance the load on the networks. Figure II.16 shows the presented scheme for vertical handover algorithm on load balancing and power consumption the authors of the paper used for simulations.

Figure II.16: Vertical handover algorithm on load balancing and power consumption



The algorithm basically identifies the link layer trigger which can be because the RSS is dropped below the set threshold or exceeded the threshold and moves to the decision making. On the decision making depending on the conditions it can choose to either optimization base on battery lifetime over all mobile nodes, optimization based on load balancing across all access points and base stations or do both of them. And as the result VHDC (virtual handover decision control) decides, which is the best network to be connected to, considering selected optimization criteria's.

II.3. Summary of the chapter

For better view of analyzed papers in this chapter the short summary on mentioned methods is required and is presented in table below with their provided advantages and disadvantages.

Table II. 1: Summary of state of the art analysis

Method	Advantage	Disadvantage
Game theory	Users are considered to be players aiming to obtain best connection from their interest. And the strategy comes from operator ho aims for highest payoff possible.	Equilibrium is not always achieved.
Utility function	Simplest approach for obtaining user specified network ranking which usually are QoS metrics.	Less criteria are taken into account which decreases the quality of intelligent and dynamic schemes which requires more parameters to be considered
EPC	Seamless mobility between different networks, fast integration and extension within EPC which not requires changes in architecture parameters apart of ANDSF.	Increased delays for connection by minimum 1,5s.
TAILOR (CELL-ID)	Reduced power consumptions while making network decision and selection and monitoring power levels while connected to the network.	Extra load on mobile device, no security is considered, needed GPS connectivity all the time for networks discovery which additionally increases the price of service.
MT&CN decision Algorithm	The load is divided between mobile terminal and core network for final decision.	Messages exchange delay between MT and CN can increase the time to make handover
VHA using NCTUns	Big variety of parameters considered and more realistic results obtained because of the Linux Kernel usage to perform simulations.	Does not support VHA and as consequence requires creating separate components using C and PERL languages to perform handovers within the tool causing user position evaluation not very accurate when considering close range networks [12].

From all considered and analyzed approaches the continuous work for developing innovative network decision and selection method NCTUns simulation tool and some utility function are considered to be a good start, as it provides the best methods for achieving better throughput of the network and it is one of the main aims of this thesis.

The next Chapter III will be focusing on actual metrics for network discovery and selection to be considered using utility functions followed by mathematical equations for QoS guarantees and etc.

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[12] Dwell time definition at http://www.its.bldrdoc.gov/fs-1037/dir-013/_1850.htm

Chapter III. Algorithm development

In this chapter the algorithm development is analyzed in more detail, taking into account the metrics consideration, calculation, then, the proposed algorithm is presented, software selection for algorithm implementation are presented. The Chapter is organized as follows. Section III.1 gives an introduction; Section III.2 gives the network discovery and selection metrics; Section III.3 presents the algorithm.

III.1 Introduction

Network discovery in heterogeneous wireless networking environments is quite important since it may affect the end users' performance significantly. Network discovery refers to the procedure carried out by a mobile device in order to discover the presence of the wireless networks that are covering its location. The ultimate goal is to find the best possible infrastructure that can satisfy its requirements. Thus one important prerequisite for the terminals is their capability to support multiple radio interfaces.

The following aspects are considered important in relation to network discovery:

III.1.1 Energy consumption

It is the aspect considered by most authors in the literature [1]. The MT needs to "listen" to all radio access interfaces all time or periodically in order to identify the list of available networks. This procedure is energy consuming and many techniques have been proposed for its optimization. The latest proposals support the idea that network availability is bound with the specific location of the mobile terminal. So if the current location of the mobile terminal suggests that a specific wireless network is available the respective radio interface is powered on and energy consumption is reduced.

III.1.2 Time needed to discover a new network

The information regarding the availability of a wireless network that is able to support the end user's requirements should be readily available whenever is needed. This is quite important during a vertical handover not only for voice calls but also for real time data transfers since otherwise we will experience delays or even dropped calls. Supporting fast network discovery may require movement detection and a geo-location system. However both of these aspects are considered quite complex.

In [2] the authors propose a method for network discovery that is based on advertisements from the Location-Service server which knows the area that is covered by each base station. This is done via messages which when received prompt the mobile terminal to activate the suitable interface that corresponds to the advertised wireless network. Furthermore through the notion of the stability period they propose an adaptive way for executing a handover that is controlled by the quality of service offered by the current and by the target network. The HO is taking place either when the services of the current network are becoming worse in relation to the target one or if the services of the target network are becoming better than the current one.

III.1.3 Access network discovery and selection within 3GPP: Requirements and Solutions

Access network discovery and selection is a very important topic within 3GPP and several specifications have been released already regarding this matter. As it was briefely mentioned in first chapter Special emphasis is given on the subject with the introduction of the Evolved Packet System (EPS) where heterogeneous internetworking and mobility across various infrastructures is carefully considered. In the following we will review the available documents on the subject:

The service requirements for the access network discovery and selection are described in 3GPP TS 22.278 [3]. In particular the following are stated regarding mobility.

- The Evolved Packet System shall support mobility between heterogeneous access systems.
- The Evolved Packet System shall provide mobility mechanisms to support frequent handovers within and across 3GPP legacy systems or E-UTRAN and non 3GPP access systems in order to avoid service degradation.
- The Evolved Packet System shall support mobility mechanisms that accommodates access systems within Rel-7 and earlier.
- The Evolved Packet System shall be able to support mobility within and across 3GPP and non-3GPP access systems including fixed access systems

Furthermore service continuity should be supported as well as access network discovery. Regarding the latter it is mandated that the Visited Public Land Mobile Network (VPLMN) and the Home Public Land Mobile Network (HPLMN) provide to the UE with access network information pertaining to locally supported non-3GPP access technologies, in a resource efficient and secure manner. This mechanism is meant to facilitate changes, including service continuity, between 3GPP access systems and non 3GPP access systems and vice versa.

The functional requirements for the access network discovery and selection are described in 3GPP TS 23.402 [4].

The following principles apply when the UE is registered in the Home PLMN or in a PLMN which is equivalent to the home PLMN and when both 3GPP and non-3GPP accesses are available or when multiple non-3GPP accesses are available:

- The EPS network may provide the UE with assistance data/policies about available accesses located in the Home PLMN or in a PLMN equivalent to the Home PLMN, to allow the UE to scan for accesses and select an access.

- The EPS network allows the operator to influence the access that the UE shall handover to (when in active mode) or re-select (when in idle mode).

- Multi-access network discovery and selection works for both single-radio and multiple- radio terminals.

- No architectural impact is foreseen for network selection upon initial network attachment.

- The UE may provide information to the network for the retrieval of the assistance data/policies.

The following principles apply when the UE is registered in a Visited PLMN (VPLMN) and when both 3GPP and non-3GPP accesses are available or when multiple non-3GPP accesses are available:

- The VPLMN shall be able to provide Access Network Discovery information only for 3GPP and non-3GPP access networks located in the VPLMN or in a PLMN equivalent to the VPLMN.
- The VPLMN shall be able to provide to a roaming UE Inter-System Mobility Policies and such policies shall be valid only in the VLPMN or in a PLMN equivalent to the VPLMN, as per roaming agreements.
- The Home PLMN (HPLMN) shall be able to provide to roaming UE Access Network Discovery information for 3GPP and non-3GPP access networks.
- The HPLMN shall be able to provide to a roaming UE Inter-System Mobility Policies.

The above functionalities will be supported by a new network element called Access Network Discovery and Selection Function (ANDSF). An ANDSF element located in the home PLMN of a UE is referred to as the Home-ANDSF (H-ANDSF) for this UE, whereas an ANDSF element located in the visited PLMN of a UE is referred to as the Visited-ANDSF (V-ANDSF) for this UE.

The ANDSF is an optional element in the network architecture and thus a UE may or may not be able to interact with an H-ANDSF and/or with a V-ANDSF. The UE-ANDSF interaction can take place via any 3GPP or non-3GPP access technology that can be used by the UE to access EPC.

III.2 Network discovery and selection metrics

The two types of network simulation approaches were considered in this work. The first considers WLAN and WiMAX (802.16e) networks. The second scenario considers LTE-A, WLAN, GPRS, UMTS. In this section we analyze the performance metrics for evaluating the proposed algorithm (described in Section III.3).

One of the metrics should be a measurement of the user’s satisfaction level with perceived QoS: Quality of service means different things to different end users and depends on the applications and is measured by various performance parameters. The most common parameters usually are:

- **Bandwidth** – the main QoS parameter for most of the users and it is limited by the physical layer pipe between BS and client terminal (WiMAX). By having enough bandwidth among users access contention is reduced as well as latency.
- **Latency** – it is the time needed to transmit the packets and typically it is 5ms in WiMAX mobile.
- **Jitter** – is the variation of latency over different packets, and it is limited by packet buffering. The control of jitter is done in BS who makes sure that different packets receive different prioritization if needed.

- **Reliability** – says how many packets were successfully delivered. And in this case it is hard to guarantee high reliability because of wireless environment being not safe in first place comparing with wired ones (TCP packet loss problem).

Also considering user needs the following user-based capabilities need to be considered when choosing the network (which is set by the user if he/she wants these parameters to be considered):

- **Cost** – Users might be sensitive to the cost of the network and might be willing to use cheaper approach with lower QoS than more expensive one with higher QoS.
- **Battery consumptions** – It is important to be considered when handover is requested or an alternative to switch to other network is available for power saving and staying connected as long as possible when the battery is going low.
- **Velocity (for network selection required)** – It is also important to consider the speed of the user at the time when making the decision to minimize handovers. If the user is in high speed it might be unprofitable and useless to switch to the network in which user will be for a very short time (i.e short coverage networks).

The following Table III.1 presents MAC characteristics of WiMAX, WLAN and LTE-A which helps to observe the differences between these networks [5],[6].

Table III. 1: MAC characteristics of WiMAX, WLAN and LTE-A

	WLAN	WiMAX (802.16e)	LTE-A
Bandwidth (MHz)	20	1.25 to 20	40
Data rates (Mbit/s)	802.11b (11); 802.11g (54); 802.11n (200+).	180	1024
Bit/Hz	2,7	3,75	Up to 30
Duplexing		TDD, FDD	
Multiple access	CSMA/CA	OFDMA	OFDMA
Coverage	Small (depends of how much power you put)	Mid (1-5km)	Ubiquitous
Mobility	Portable	Nomadic/Full	Nomadic/Full
Targeted Market		Consumer class Semi-Mobile Wireless access	Mobile wireless access
Frequency band	2.4, 3.6 and 5 GHz	<6 GHz, NLOS	There are 43 band portions considered[6]

In order to achieve QoS for different users classes of services, depending on the requirements of the services, are considered in the following table where WiMAX mobile offers 5 categories for the prioritization of the traffic [7].

Table III. 2: WiMAX service classes

Service Class	Application	QoS Specifications
Unsolicited Grant Service (UGS)	VoIP	Jitter tolerance Maximum latency tolerance Maximum sustained rate
Real-time Packet Services (rtPS)	Streaming Audio/Video	Traffic priority Maximum latency tolerance Maximum reserved rate Maximum sustainable rate
Extended real time Packet Services (ertPS)	VoIP (with activity detection)	Traffic priority Jitter tolerance Maximum latency tolerance Maximum reserved rate Maximum sustainable rate
Non-real time Packet Services (nrtPS)	FTP	Traffic priority Maximum reserved rate Maximum sustainable rate
Best Effort (BE)	Data transfer, web, browsing	Traffic priority Maximum sustained rate

From the table above the UGS is designed to support real time data stream with fixed length data packets and the VoIP as well as the video streaming can be typical applications for this. The rtPS is designed to support real-time data streams in case of variable length of data packets, while the nrtPS is meant to support delay-tolerant data streams. The typical application for rtPS is videoconference while for nrtPS is File Transfer Protocol (FTP). The last class is the BE that means the data streams do not have any minimum service level requirement thus the only parameter that needs to be considered is the traffic priority. The typical application for the BE class are the e-mail services and web browsing [8].

The required minimum capacity per service to deliver proper service is in Table III.3 [8]:

Table III. 3: Minimum capacity requirements per service

Service	Required Capacity (kbps)
VoIP	64
E-mail, browsing	>512
Video Conferencing	174-320
Interactive gaming	85
Data	1000
Media stream	512
Peer-to-peer	500

The WiMAX key feature is delivering broadband services at vehicular speeds greater than 120km/h while maintaining QoS comparable to broadband wire line access alternatives.

III.2.1 Delays

Another important network parameter to be considered is delays. Even though each network provides its own expected delays table, it is more important to have information on what delays are most desired when specific application are in use. The following table presents the respectable delays which can be tolerated during specific service usage and are used in the simulations to set lowest and highest data rates required to make own simulation applications data rates accordingly .

Table III. 4: Data rates and delays per service

Service Class	Data Rate	Delay	Error Rate	Example applications
1. Real time collaboration and gaming	1-20 Mbps	highly interactive (<20ms)	10^{-6} - 10^{-9}	Telepresence/Videoconference Collaborative work Navigation systems Real-time Gaming
2. Geographic real time datacast	2-5 Mbps	highly interactive (<20 ms)	10^{-6}	Real time video streaming Collaborative work
3. Simple interactive applications	64-512 kbps	Interactive /control (20 – 100 ms)	10^{-6}	Presence driven transfer (heavy content) Interactive geographical maps (remote processing)
4. Interactive high multimedia	2-5 Mbps	Interactive /control (20 – 100 ms)	10^{-6}	Rich data call Control Video broadcasting/streaming Robot security
5.Simple telephony and messaging	8-64 kbps	Conversational (100 – 200 ms)	10^{-3} - 10^{-6}	Voice telephony Instant messages Lightweight multiplayer games Bets and gambling
6. Data and media telephony	64-512 kbps	Conversational (100 – 200 ms)	10^{-3} - 10^{-6}	Audio streaming Video telephony (medium quality) Multiplayer games (high quality)
7. Geographic datacast	64-512 kbps	Conversational (100 – 200 ms)	10^{-3} - 10^{-6}	Localized datacast/beacons Audio streaming
8. Rich data and media telephony	2-5 Mbps	Conversational (100 – 200 ms)	10^{-3} - 10^{-6}	High quality video telephony Collaborative work Standard data call
9. Multimedia messaging	8-64 kbps	Few seconds (>200ms)	10^{-6}- 10^{-9}	Messaging (data/voice/media) Authentication (m-payment, m-wallet, m-ticket, m-key etc.) Web browsing (light weight)
10. Lightweight browsing	64-512 kbps	Few seconds (>200ms)	10^{-6}	Messaging (data/voice/media) (medium weight) Access to corporate database (lightweight) Audio on demand Web browsing (medium weight) Internet radio
11. File exchange	Up to 5 Mbps	Few Seconds (>200ms)	10^{-6}	Access to databases (heavy weight), file systems, Video download/upload Peer-to-peer file sharing
12. Video streaming	5 Mbps	Few Seconds (>200ms)	10^{-6}	Video streaming (normal)

Therefore, the following table represents the simulated networks typical delays when the network is in the normal operation phase. Having this information will help to create and observe more reliable and realistic network simulation results in the C++ simulations.

Table III. 5: Simulated networks used delays

RAN	Typical delay value (ms)
LTE-A #1	20
LTE-A #2	100
LTE-A #3	200
GPRS	200
WLAN	20
UMTS	100

The Table III.5 above need some explanation; knowing that LTE-A has ubiquitous coverage there were three area scenarios considered, namely; LTE-A#1 representing local area, LTE-A#2 representing metropolitan area and LTE-A#3 representing wide area scenarios.

III.2.2 Utility function:

Users typically rate service quality in subjective and individual manner and the user satisfaction is dependent on the expected QoS, the user perceived QoS and the applied pricing model. The QoS is influenced by the used context and the QoS parameters of interest like the response time, or quality of video, images. From the provider point of view it is very important to provide the service quality not below the threshold set by the user who tolerates specific level of degradation but does not tolerate lower level of QoS than its set threshold (It is the providers' job to define the user's acceptable threshold).

The network performance attenuation can be obtained from the network utility function U_{Netw}:

$$U_{out} = U_{Netw} \cdot U_{in} \qquad (3.1)$$

Where U_{in} is the value of the utility function at the receiver. U_{out} Is the utility function at the sender, and U_{Netw} the end to end characterization of the performance attenuation by the network. All these parameters vary from 0 to 100 % (from worst to best). Users by rating from 0 to 100 can define the threshold for unacceptability. Operators using these thresholds can provide better services, search for bad network conditions and fix them or shut down the service for a while to obtain required QoS.

"The network utility functions can address several network influences on the service quality. In case these influences are rather independent of each other, one can define multiple network utility functions $U_{Netw,i} \in [0; 1]$ and apply the following multiplicative relationship:" [9].

$$U_{Netw} = \prod_i U_{Netw,i} \qquad (3.2)$$

III.2.3 Throughput utility function

When we speak about throughput of sender and receiver, disturbances in it are indicated by a bottleneck. At every endpoint the throughput values are measured from an observation window. Using averaging interval (which is mostly from 100ms to 1s) an average bit rate can be perceived. And using throughput resolution information about whether the path between the sender and the receiver appears as shaping or shared bottleneck can be obtained. To sum up what is written above we can write down the following parameters [9]:

- The average throughput at the sender, $m_{in}(\Delta W)$
- The standard deviation of the throughput at the sender, $s_{in}(\Delta W, \Delta T)$
- The average throughput at the receiver, $m_{out}(\Delta W)$
- The standard deviation of the throughput at the receiver, $s_{out}(\Delta W, \Delta T)$

The following will briefly describe what problems might appear when these parameters change between both ends [9]:

1. First, if the averaged throughput at the receiver is lower than the averaged throughput at the sender the portion of data might arrive in a later observation interval or get lost.
2. If the standard deviation of the throughput at the receiver is higher than at the sender, it means that the distribution of the throughput is spread more widely at the receiver than at the sender.
3. In the case when the standard deviation of the throughput at the receiver is lower than at the sender, then the distribution of the throughput is condensed because of traffic shaping. Traffic shaping means control of the traffic in order to optimize performance, improve latency or bandwidth, and so if a link between both points is saturated latency can rise substantially and by using traffic shaping to keep control over latency and volume of traffic.

As the outcome of this we can change the second formula provided above to:

$$U_{Netw} = U_m \cdot U_s \qquad (3.3)$$

Where the m-utility function $U_m = f(m_{in}, m_{out})$

Assuming that dependency is linear on the loss ratio $l = max\{1 - \frac{m_{out}}{m_{in}}, 0\}$ we can write:

$$U_m = \max\{1 - k_m l, 0\} \qquad (3.4)$$

Where k_m is the degree of utility reduction. In the function above the function goes to zero as l goes to $1/k_m$.

The s-utility function $U_s = g(S_{in}, S_{out})$ which is used for monitoring burstiness implies maximal utility when $S_{out} = S_{in}$. By using this information in case of reduced burstiness (traffic flows regularly through the network) to maintain the desired QoS level less spare capacity need to be achieved.

In the paper [9] authors concludes by introducing the linear dependency equation on the difference

$$\sigma = \frac{S_{out} - S_{in}}{S_{in}} \qquad (3.5)$$

$$U_s = \begin{cases} \max\{1 - k_a^+ \sigma\} for\ s_{in} < s_{out} \\ 1 \qquad\qquad\quad for\ s_{in} = s_{out} \\ \max\{1 + k_s^- \sigma\} for\ s_{in} > s_{out} \end{cases} \qquad (3.6)$$

From the equation parameter k_a^+ is the decrease of U_s when the standard deviation doubles, and k_s^- does the same for disappearing standard deviation.

III.2.4 Simple Additive Weighting

There are mainly four steps to perform the handover (Handover initiation phase, system discovery phase, handover decision phase and handover execution phase). The following describes the most popular handover decision phase methods like Simple Additive weighting. The decision to which network to connect is mainly done by multiple attribute decision making where network selection function (NSF) is used.

The method is well known and most often uses multi attribute decision technique. Mainly the method is based on the weighted average. “An evaluation score is calculated for each alternative by multiplying the scaled value given to the alternative of that attribute with the weights of relative importance directly assigned by decision maker followed by summing of the products for all criteria”[10].

Step 1

1. Make pair-wise comparison matrix (n x n) using the following Table III.6 [10] .It is used to compare each criterion with each other.

Table III. 6: Level of importance decision making

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak or Slight	
3	Moderate Importance	Experience and judgment slightly favor one activity over another
4	Moderate Plus	
5	Strong Importance	Experience and judgment strongly favor one activity over another
6	Strong Plus	
7	Very Strong	An activity is favored very strongly over another
8	Very, very Strong	
9	Extreme Importance	The evidence favoring one activity over another is of the highest possible order of affirmation

2. For each comparison we will assign a score to show how important it is.
3. Calculate the comparison matrix columns total and priority vector which can be done by finding the row averages.
4. Weighted sum matrix is obtained by multiplying the pair wise comparison matrix and priority vector.
5. "Divide all the elements of the weighted sum matrix by their respective priority vector element"[11].
6. Compute the average of this value to obtain λ_{max}
7. Find the Consistency Index, CI:

$$CI = \frac{\lambda_{max} - n}{n-1} \qquad (3.7)$$

Here n is the matrix size

8. Calculate CR (consistency ration):

$$CR = \frac{CI}{RI} \qquad (3.8)$$

9. Judgment consistency can be obtained by taking the CR of CI with the value from the following table:

Table III. 7: Setting random consistency

Size of matrix	Random consistency
1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

Step 2

Make a decision matrix (m x n) including m personnel and n criteria and calculate the normalized decision matrix for both positive and negative criteria as follows:

Positive criteria: $n_{ij} = \frac{r_{ij}}{r_j^*}\ i = 1, \dots m,\ j = 1, \dots . n$

Negative criteria: $n_{ij} = \frac{r_j^{min}}{r_{ij}}\quad i = 1, \dots m,\ j = 1, \dots . n$

r_j^* Is a maximum number of r in the column of j.

Step 3

Evaluate each alternative

$$A_i = \sum w_j \cdot x_{ij} \qquad (3.9)$$

Here x_{ij} is the score of the i_{th} alternative with respect to the j_{th} criteria, w_j is the weighted criteria.

III.3 Proposed NDS Algorithm

In this section the actual algorithm proposal is presented and explained.

III.3.1 Algorithm scenario:

The parameters used to take the decision about which network to select are the following:

- Terminal capabilities
- Battery status (if it can support the new radio interface)
- RSS - SINR level
- Mobility aspects (speed and direction)
- Type of service and requested grade of service (is it supported?)
- Bandwidth availability at the target network - congestion caused

- User’s preferences/profile/subscription (to be merged with “Privileges”)
- Cost
- AAA for the new network

The first thing that the network selection should check is the terminal capabilities, namely if the terminal is able to connect to the networks that exist in that area and to which of them. The terminal may have limited interfaces available so all other networks should be discarded. Of course, if we are talking about a mobile user with laptop using its battery, the battery limitation is another very important issue that should be taken into account in the network selection, since the interface for one network could utilize more battery power than some others, so this network should be avoided also. After checking these parameters, the network selection sorts out the networks that have low RSS at the user’s receiver (so they cannot serve the user) and the networks (if any) that cannot support the user’s possible mobility, i.e. if the user is moving with moderate to high speed, then he cannot connect to WLAN, because it has only a few hundred meters coverage (in the best case) and he should then connect to another network very soon.

The next step of the network selection is to check the application that the user is receiving/requesting and discard those networks that cannot support this service and sort the rest of them in priority related to which network supports best the service. The network selection should take into account also the user’s preferences and the user subscription together with the cost of connecting to the networks.

All these parameters are used in order to find the optimum network for the user. Of course the decision to accept the user in the network is not taken by the network selection algorithm, but by the admission control. Network selection works jointly with admission control for the new network. Network selection gets input from the network discovery algorithm and according to the parameters summarized above makes a list of the candidate networks for the user, sorting them with priority and sends the list to the heterogeneous admission control algorithm for admitting the user to the optimum network.

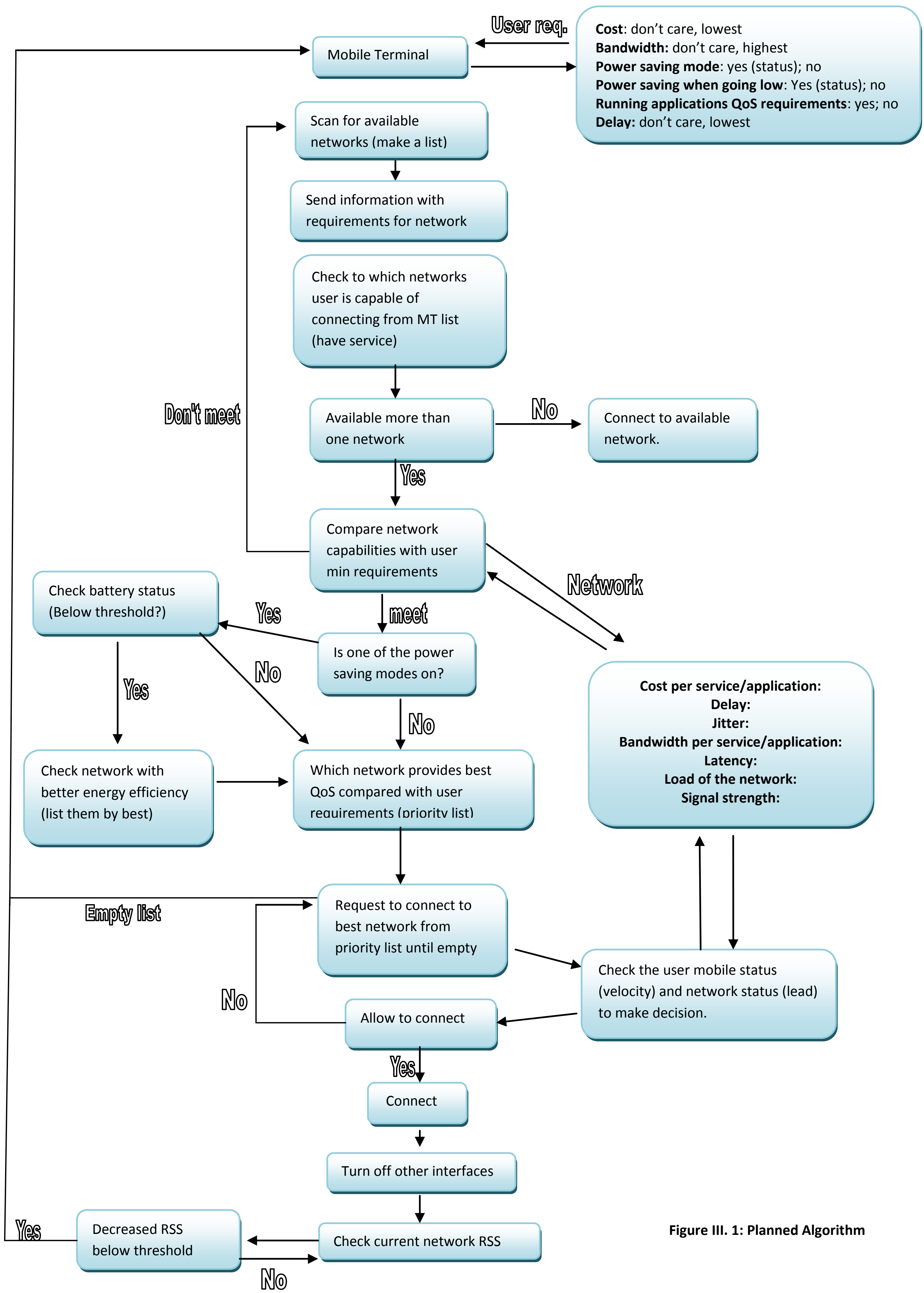

Figure III. 1: Planned Algorithm

The start of the network discovery and selection is performed at the Mobile Terminal (MT) for discovering the available networks within the MT area so that to decide which network to chose. After the networks are discovered, the ideal case would be that the information of user requirements and the list of networks are send to the network operator who checks if the user has available services (access) to these networks and updates the list of networks by eliminating the networks to which user do not have access. After that the algorithm checks if the list contains more than one network. If there is only one network, then there is no other choice than to connect to the available one, and in case if there is more than one network within the user area of presence, it continues to compare the networks capabilities with the user specified requirements where we use specific weighting, prioritization methods to make the final decision. Here again, if the requirements are not met, then we go back and make the search again. If the requirements are met, then it checks if the power saving mode is on, from the user requirements. When this falls under certain time duration, a rearrangement of the active connections is performed, in order to maximize the battery life. First, the MT finds which combinations of connections and RATs are the more energy efficient. This is feasible if the MT is aware of the power consumption of each interface. So if power mode is on, then the list of networks are prioritized depending also on the power consumptions and differentiating between price, power and QoS, otherwise in the case when the user does not want to consider power consumptions, it continues straight to creating the list of best QoS networks followed by a request to connect. Power saving mode is important considering the battery limitations of the mobile devices. The request to connect is done by selecting each network from the priority list until it connects or is empty of networks. On the network side, the operator precedes the request by making sure that no conjunction is made and can provide the resources which were expected. Then it checks if the user velocity is appropriate to be connected to the specific network. If all these considerations are met, an 'allow to connect' is given, if not, the algorithm continues to the other network in the list until empty which brings us to the beginning of the network discovery and selection algorithm.

When the user is connected to the network it is not efficient to keep other networks interfaces on, so it turns off all other not used networks interfaces and keeps track of current network received signal strength until it reaches set threshold of the signal which automatically performs new network discovery and selection.

When considering the power consumption it is important to consider what network is operating now and if it is possible to stay within the same network interface for as long as possible, because changing the networks interface increases the power consumption., In this way unnecessary handovers can be avoided by measuring the received signal strength and moving speeds.

In a typical scenario the handover is processed when the received signal strength is dropped, but to save energy it is considered to allow some kind of level of Received Signal Strength (RSS) degradation for some time, to avoid the ping pong effect (meaning switching to other network and then coming back again) because the mobile device could be just temporarily facing signal degradation, so in this case we have to consider the velocity of the mobile device to obtain the handover threshold, where below this threshold the handover has to be triggered. As suggested in the paper [11] we can use formula to adjust the observation period of RSS by :

$$T_{AP}(V) = \frac{V_0(AP)}{V} \cdot T_0(AP) \qquad (3.10)$$

Where $T_0(AP)$ is the average speed of mobile device is, $T_0(AP)$ is a constant representing the mobile device average observation period, and V is the current mobile device speed. By applying this formula we can use it when observing RSS to make a decision when is necessary to perform handover.

Depending on the velocity of the user it chooses which network to connect to and if it is not a moving user depending what services user requires.

III.4 References

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[10] Vertical Handover decision schemes using SAW and WPM for Network selection in Heterogeneous Wireless Networks By K.Savitha, Dr.C.Chandrasekar

[11] An Energy-Efficient Handover Scheme with Geographic Mobility Awareness in WiMAX-WiFi Integrated Networks

Chapter IV. Software selection (simulation tool selection)

In this chapter Section IV.1 the software selection is analyzed and reasons for choosing it explained.

IV. 1 Software considerations

In order to evaluate the proposed algorithm several tools were considered to be used: Matlab, Omnet++, ns-2, NCTUns and C++. After a full analysis of the tools capabilities and difficulties, regarding capabilities provided to create wireless heterogeneous network simulations, NCTUns was considered to be the best choice initially. For example, the ns-2 tool compared to the e NCTUns is a more complicated tool as it requires creating the full simulation environment, such as mobile nodes, protocol stack, links, traffic, functionalities and so on, which makes the network more “vulnerable” and simulations more time consuming. Omnet++ is an open source software but does support WiMAX and it would be needed to be created from scratch. And finally the same goes for Matlab, it lacks the most components needed to create the simulation of heterogeneous networks.

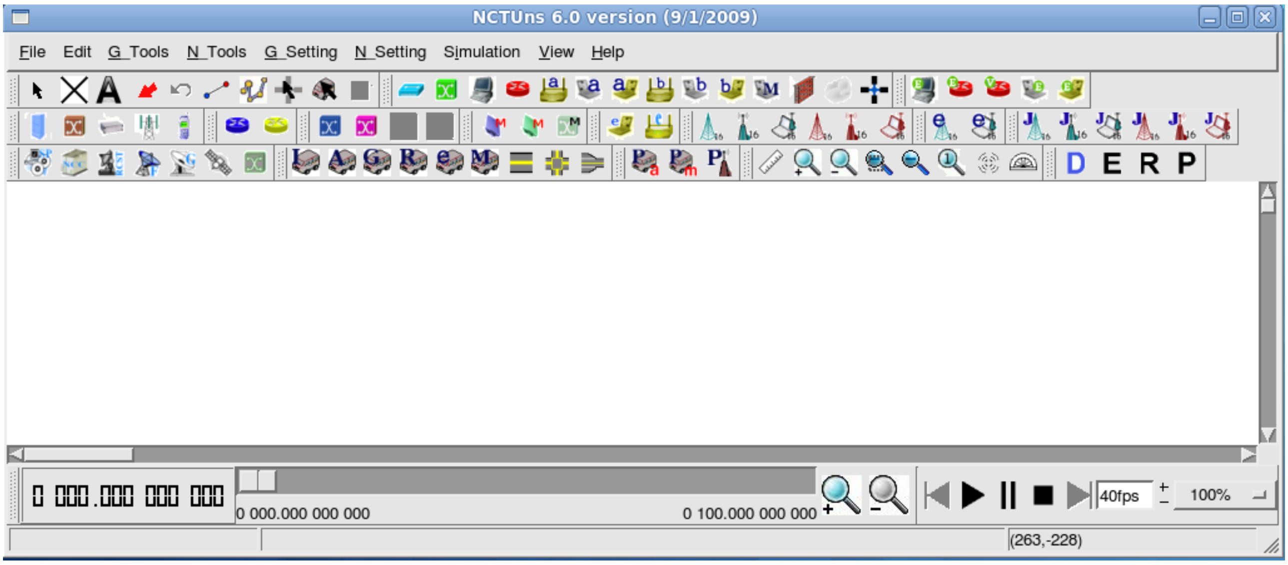
Another reason why NCTUns was chosen is because it has multi-interface mobile node which is a key functionality for the vertical handover. However, after the experimentation it showed that this function does not work properly using WiMAX and 802.11b interfaces. The same problem was also reported in [1]. The solution to this will be the use of two mobile nodes moving along the same path at the same speed to emulate multi-interface mobile node behavior.

NCTUns is an open source tool developed by the National Chiao Tung University for communication networks [2]. It can simulate and emulate a variety of protocols used in the wireless and wired IP networks. The tool is capable of simulating most representative wireless technologies at present such as wired 802.11a and 802.11b networks, ad hoc networks, WiMAX, GPRS, satellite and vehicular networks. The main problem using this program will be that it does not have vertical handover component which needed to be created using NCTUns API and scripts written in C and PERL languages.

The following will shortly describe some of the NCTUns capabilities, for a more detailed explanation on what the tool can do please, refer to [14].

A good advantage of NCTUns is that it provides graphical user interface (GUI) where all graphical designing is done and simulation itself can be observed, see Figure IV.1.

Figure IV. 1: Graphical User Interface

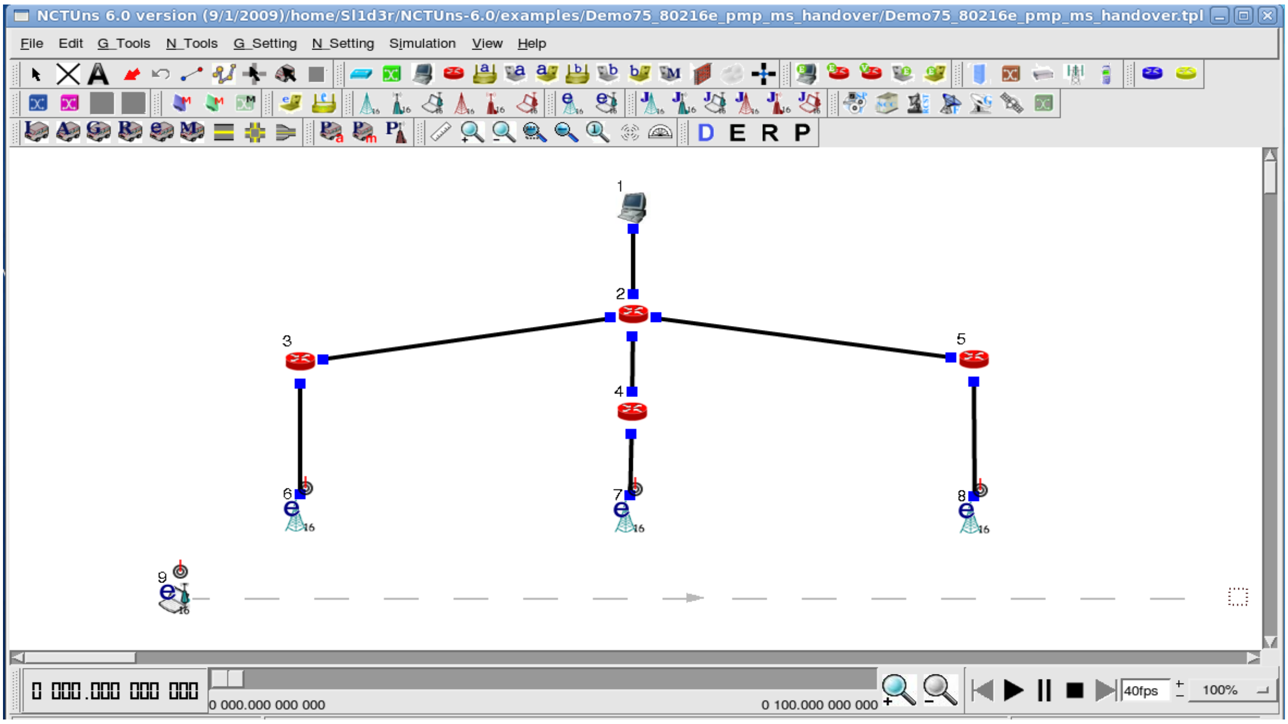


NCTUns directly uses the real-life Linux's TCP/IP protocol stack to simulate simulation results. This is the option which is more realistic comparing to other artificial functions and provides more convincing results. Moreover, as it was already mentioned the tool works only on Unix system. Because of this the simulations are carried out using Fedora 12 operating system.

NCTUns 6.0 supports the WiMAX 802.16e network for wireless communication. The network adopts the Orthogonal Frequency Division Multiple Access (OFDMA) technology to manage the link bandwidth. The same goes for 802.11b networks.

Below is the simple example of the Wimax horizontal handover network design where the user mobile node moves at constant speed and switches its BS on the move. This is what the tool is capable of doing without any modifications until it comes to the heterogeneous networks handover process.

Figure IV. 2: WiMAX topology example



The following Table IV.1 shows what within the NCTUns GUI user is capable of performing [2]:

Table IV. 1: NCTUns GUI capabilities

Stage	Component	Description
Draw Topology	Topology Editor	An environment to specify a network topology
Edit Property	Node Editor	An Environment to configure which modules to be used inside a node
Run Simulation	Simulation Operation Front –End Interface	An interface to control the execution of simulations
Playback	Packet Animation Player Performance Monitor	A player to play back logged packet transfer trace A player to plot and display logged performance metrics over time

Basically in total the tool has 8 components and they are the following:

1. The first component is the GUI, by which the user can create, edit, modify the network topology, protocol modules used within network nodes and other functionalities already mentioned above.
2. The second component is the simulation engine that provides the simulation services like event scheduling to protocol modules.
3. The third component is protocol modules which are C++ classes and are compiled and linked with the simulation engine program.
4. The fourth component is dispatcher program used for multiple simulation servers' management to increase simulation throughput. Waits client connection via TCP port 9800 and waits coordinator connection vie TCP post 9810.
5. The fifth component is the coordinator program. This program must run as long as the simulation server is functional. It registers itself with dispatcher to join in the dispatcher's simulation server. By using this program, the dispatcher is enabled to choose an available simulation server from its simulation server farm to service a job. Moreover message exchanges which happen between the simulation engine process and the GUI program are also relayed via the coordinator.
6. The sixth component is the kernel patches that simulation process could run on a UNIX machine correctly. The current version of NCTUns 6.0 runs on Fedora 12.
7. The seventh component is real-life user-level application programs. Meaning that any real-life application program can be directly run up on a simulation network to obtain realistic network traffic.
8. The eight' component is the user-level daemons (like RIP and OSPF routing daemons)

Comparing to the Opnet commercial version regarding testing WiMAX networks, NCTUns seems to be more attractive in most of the cases, but for the more highly advanced networks creation and for bigger variety of the networks Opnet is considered to be better choice although more time consuming (being another reason why alternative simulation tools was considered in this thesis). However, both tools are proprietary.

Because of encountered problems of using NCTUns (which are presented and explained in the following chapter of algorithm implementation), the C++ language for creating the simulation environment was considered to be as a continuous work tool after the initial simulations were performed with NCTuns. For c++ simulations and building the open source, the Eclipse (Helios) builder was used. The Eclipse Foundation is a not-for-profit, member supported corporation that hosts the Eclipse projects and helps cultivate both an open source community and an ecosystem of complementary products and services [3].

IV.2 References

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[2] NCTUns home page at http://nsl.csie.nctu.edu.tw/nctuns.html

[3] Eclipse home page at http://www.eclipse.org/org/

Chapter V. Algorithm implementation

In this chapter the results of the NCTUns and C++ simulations are presented and explained. . The Chapter is organized as follows: Section V.1 gives the results obtained using NCTUns simulation tool; Section V.2 gives the simulation results using C++.

V.1 NCTUns results

For the simulations using Fedora 12 operating system, I have used the latest, now commercialized, version of the NCTUns 6, and ideally I wanted to implement my algorithm using Perl and C++ language to support vertical handover, as it does not support it at the moment, and connect to it through a user graphical interface, as it is done in the previously analyzed paper [Chapter IV.2 [1]]. The Perl and C++ languages were chosen because the program only supports these languages. The idea was to create a new application which would use already existing STCP and RTCP applications for transmissions and receptions. In this way all benefits of the software such as distances, received signal strength, WiMAX and WiFi models could be used and results obtained could be more realistic for the reasons mentioned in chapter III.4. At the end the program would generate a log file showing the simulation process, like which network was selected, how many handovers was made and etc.

To ensure that the application works, the bandwidth, delay and loss at each second of simulations is collected and stored into the corresponding log files which are used during the algorithm execution , as this information is stored the algorithm can perform the simulation and make decisions when to make handover or not and to which network.

The basic idea of the created algorithm in the Perl language was to create user profile, which acts as a specific application, the user want to use at a specific moment. The profile consists of requirements for the application such as: required ideal and acceptable bandwidth, loss, delay and etc.

When the user wants to transmit, first the algorithm checks which of the networks is available in the current user position by sending the ping to the specific IP address of the WiMAX and WLAN node. If it gets the response it means that the network is reachable and continues to look if the condition of the network meets the user profile requirements. If it is met it connects and transmits, if not, it makes the handover to other network (if it is available) and again checks if it meets the user profile requirements. This process is repeated within 2 seconds interval to see if the user needs to perform a handover. The 2 seconds here acts as a ‘dwell’ time, which is used to make sure that the user is not experiencing temporary QoS degradation.

The decision making is based on the acceptable and ideal conditions of the specific application. This means that it reads the files which hold the information on network bandwidth, delay and loss and then compares these data’s to the user profile specified requirements, like if it is in ideal case, acceptable case or in between. Having this information the decision is made to which network is the best to connect the user. If the reader is interested the full code of the algorithm made within NCTUns are presented in Appendix 2.

To make it more clear about how the decision is made a part of the code regarding the Decision making is presented below:

If bandwidth >bandwidth_ideal

Coefficient_ bandwidth =1

If bandwidth >= bandwidth _acceptable and bandwidth <= bandwidth _ideal)

coefficient_ bandwidth =0;

and if bandwidth < bandwidth _acceptable

coefficient_ bandwidth =-1;

The same procedure goes for delay and loss.

After this the decision is made as follows:

Bandwidth =coefficient_ bandwidth /3; *Where 3 represents the parameters used in the decision making (the simulation at the moment use bandwidth, delay and loss parameters)*.

```
delay=coefficient_delay/3;
loss=coefficient_loss/3;

if(bandwidth <0)            {$fact++;}
if(delay<0)     {$fact++;}
if(loss<0)      {$fact++;}

if(fact>1){
        meets=0;
        #print "Network is not acceptable 0\n";
}else{
        #print "Network is acceptable 1\n";
        meets=1;
}
```

After the connection, the 'dwell' time is introduced, to make sure that the handover is unavoidably necessary, the dwell time provides the time period, in which the decision to handover might be changes as the user is moving and could be just facing the temporary degradation of the network QoS.

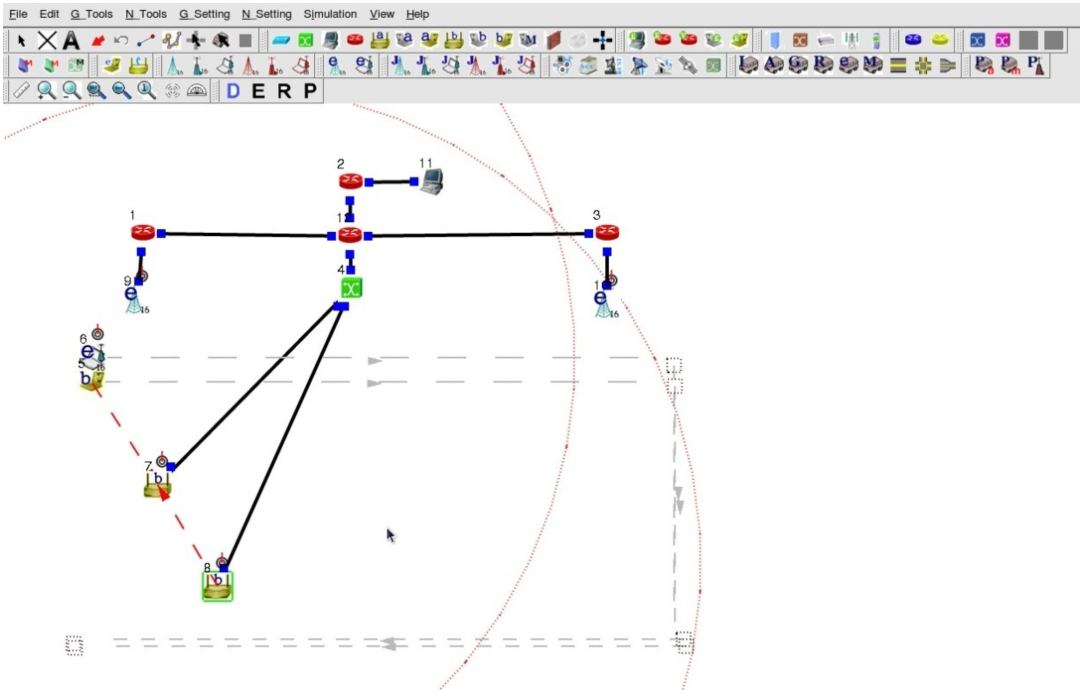
The algorithm graphical interface was created using NCTUns user graphical interface to create the scenario of the network, although as it was mentioned before to simulate a heterogeneous network there is a need of having the multi-interface node and apparently this function does not work properly in this program, therefore, it was also considered to make use of two WiFi and WiMAX infrastructure nodes which move at the same speed (10m/s) and in the same direction, even though the position of the nodes did not mach exactly, but it does not make a big difference.

The main problem during the simulation over NCTUns was to somehow to connect the algorithm with the NCTUns program core to obtain realistic simulation results, to read the values of the delays, bandwidth and loss directly from the core at each second and use the algorithm to make decisions when and where to handover. Unfortunately, due to the proprietary nature of the software tool, this could not be accomplished in the available time frame for this project. However, it showed to have a great potential in achieving very realistic and useful simulation results. What I managed to do is to generate the results log file which mainly takes into consideration the position of the node at each second and using already defined static bandwidth, delay and loss of both networks to decide if the handover is necessary to be performed. The idea for how to compose the algorithm came from [1].

The following presents what was achieved within NCTUns using the algorithm presented in this thesis.

In the Figure V.1, the simulation is done when the dwell time is tested, meaning that at one moving point where the red line (representing the coverage) does not cover the nodes, it will experience performance degradation for a short time, but as the period is less than two seconds it should not change the network.

Figure V. 1: Dwell time test network topology



The outcomes of the simulation were as follows:

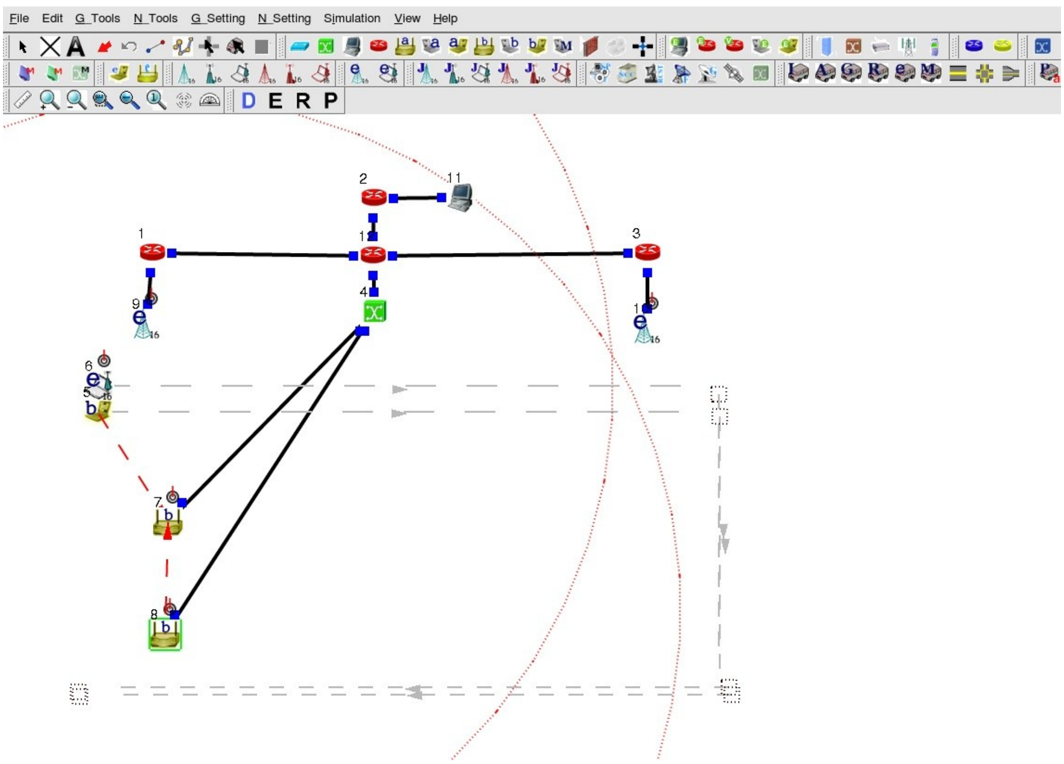
```
20 -> EVALUATING AVAILABLE NETWORKS
20 -> WiFi Network Assessment
20 -> THE network is reachable
20 -> ACHIEVABLE WiFi network
20 -> READING APPLICATIONS PROFILE
20 -> USE => BW Ideal:15 Mbps   BW Aceptable:4 Mbps   Delay Ideal:5 ms
Delay Aceptable:150 ms   Loss Ideal:2%   Loss Aceptable:8%
20 -> If the conditions of the WiFi network
20 -> THE network is reachable
20 -> ..................................................
23 -> THE network is reachable
23 -> ..................................................
```

```
25 -> THE network is reachable
25 -> ..................................................
25.015865 -> The network is unreachable
25.015865 -> The WiFi network was unreachable during the evaluation.
25.015865 -> --------------------------------------------------
25.015865 -> Handovers NUMBER SO FAR-> 0
25.015865 -> EVALUATION NEXT IN 2 SECONDS
27.015865 -> --------------------------------------------------
28 -> THE network is reachable
28 -> ..................................................
```

The simulation generated file shows that there was no handovers performed, although if there would be no dwell time the unnecessary handover would be performed. The numbering at the beginning of each line represents simulation time in seconds.

In the next Figure V.2 the scenario is that at the point where the WiFi is not reachable the network should be changed to WiMAX.

Figure V. 2: Handover to WiMAX network topology




```
20 -> WiFi Network Assessment
20 -> THE network is reachable
20 -> ACHIEVABLE WiFi network
20 -> READING APPLICATIONS PROFILE
20 -> USE => BW Ideal:15 Mbps   BW Aceptable:4 Mbps   Delay Ideal:5 ms
Delay Aceptable:150 ms   Loss Ideal:2%   Loss Aceptable:8%
20 -> THE network is reachable
20 -> ..................................................
```

```
23 -> THE network is reachable
23 -> ..................................................
25 -> THE network is reachable
25 -> ..................................................
25.015865 -> The network is unreachable
25.015865 -> The WiFi network was unreachable during the evaluation.
25.015865 -> EVALUATING WiMAX Network
25.015865  -> THE network is reachable
25.015865  -> ..................................................
26 -> FACTORS PERCENTAGE OF STANDARD: 1 0          1
26 -> WiMAX NETWORK MEET THE PROFILE, MOBILE ADVISED TO RUN THE
APPLICATION
26 -> Handovers NUMBER SO FAR-> 1
26 -> EVALUATION NEXT IN 2 SECONDS
28 -> THE network is reachable
28 -> ..................................................
```

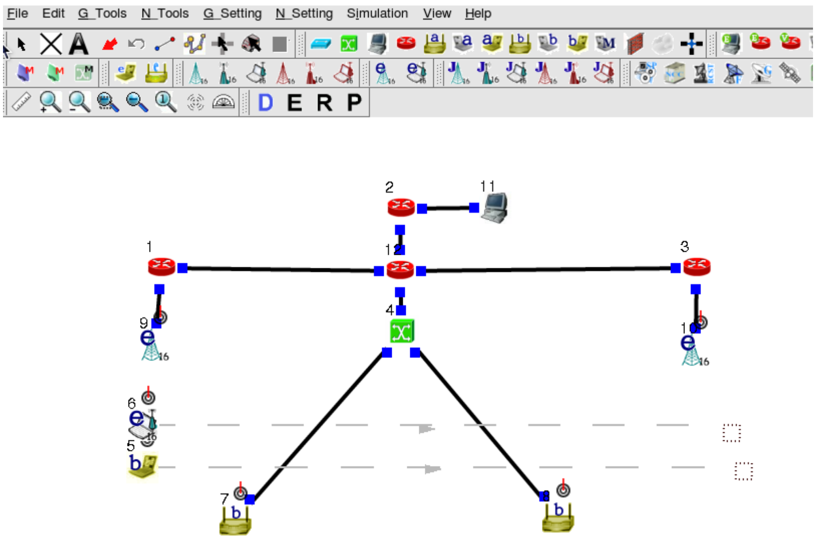
The simulation generated file shows that the handover when the WiFi network was not reachable was performed and adds 1 to the Handover number count.

The Figure V.3 below represents the scenario when the WiFi parameters do not meet the required parameters from the user.

User profile consists of the following requirements on the application [1]:

Bw ideal: 15Mbps
Bw acceptable: 10Mbps
Loss ideal: 2%
Loss acceptable: 8%
Delay ideal: 5ms
Delay acceptable: 150ms

Figure V. 3: WiFi do not meet the requirements topology



```
6 -> EVALUATING AVAILABLE NETWORKS
6 -> WiFi Network Assessment
6 -> THE network is reachable
6 -> ACHIEVABLE WiFi network
6 -> READING APPLICATIONS PROFILE
6 -> USE => BW Ideal:15 Mbps   BW Aceptable:10 Mbps   Delay Ideal:5 ms
Delay Aceptable:150 ms   Loss Ideal:2%   Loss Aceptable:8%
6 -> THE network is reachable
6 -> ..................................................
10.009425 -> THE network is reachable
11 -> THE network is reachable
11 -> THE network is reachable
11 -> ..................................................
11 -> ..................................................
15.012263 -> THE network is reachable
15.012263 -> ..................................................
15.012263 -> FACTORS PERCENTAGE OF STANDARD: -1  0         1
15.012263 -> WiFi NETWORK NOT MEET THE REQUIREMENTS OF APPLICATIONS
15.012263 -> EVALUATING WiMAX Network
16 -> THE network is reachable
16 -> THE network is reachable
16 -> ..................................................
16 -> FACTORS PERCENTAGE OF STANDARD: 1 0         1
16 -> WiMAX NETWORK MEET THE PROFILE, MOBILE ADVISED TO RUN THE
APPLICATION
16 -> ..................................................
16 -> FACTORS PERCENTAGE OF STANDARD: -1        0         1
16 -> WiFi NETWORK NOT MEET THE REQUIREMENTS OF APPLICATIONS
16 -> TIME EMPLOYEE IN THE DECISION MAKING: 11
16 -> Handovers NUMBER SO FAR-> 0
16 -> EVALUATION NEXT IN 2 SECONDS
16 -> --------------------------------------------------
18 -> EVALUATING AVAILABLE NETWORKS
18 -> EVALUATING WiMAX Network
18 -> THE network is reachable
18 -> WiMAX NETWORK ACHIEVABLE
18 -> READING THE PROFILE OF APPLICATIONS
18 -> USE => BW Ideal:15 Mbps   BW Aceptable:10 Mbps   Delay Ideal:5 ms
Delay Aceptable:150 ms   Loss Ideal:2%   Loss Aceptable:8%
18 -> CHECKING THE TERMS OF WIMAX network
18 -> THE network is reachable
18 -> --------------------------------------------------
18 -> Handovers NUMBER SO FAR-> 1
18 -> EVALUATION NEXT IN 2 SECONDS
18 -> --------------------------------------------------
18 -> ..........................................
```

Once again the results show successful handover from WiFi to WiMax where the reason for the handover is triggered by user profile requirements.

The results shows that theoretically the suggested approach is feasible and might be possible to make it fully work with the commercialized version of NCTUns where the issues regarding the multi-node functionality and data flexibility are solved. If the reader is interested in The WiMAX and WiFi physical layer parameter used during these simulations can find in the Appendix 1.

V.2 C++ results

After unsuccessful full implementation of the algorithm using NCTUns, it was decided to make simulations using C++ and create heterogeneous network discovery and selection algorithm in this language. The following simulation results are the part of full algorithm implementation and are based on user static random positioning in the selected area and using the coordinates of the user in the predefined area discover what networks are available around the user and what applications the network can handle. The networks here used were GPRS, UMTS, WLAN and LTE-A.

The following will describe the applications, users, users positioning, congestion threshold and network load considered in the simulation.

V.2.1 Applications

First of all the applications to be used in the simulation needed to be chosen, the following table describes the service classes considered to be used and the corresponding penetration factor which is required to obtain total capacity of the cell later on [2][3][4]. The penetration factors used are taken from [5]. There, it was discussed and expected that these penetration factors combined with service categories will be used in 2012.

Table V. 1: List of service classes correspondence to service class penetration factor

Service Category	Service Category Penetration factor	Service Class	Service Class Penetration Factor
Mobile Intranet / Extranet Access	31%	12. LAN Access and File Services	31%
Customized Infotainment Services	17%	8. Simple Telephony and Messaging	17%
Multimedia Messaging Services	4%	13. Multimedia Messaging	4%
Mobile Internet Access	7%	10. Geographic Data cast	1,17%
		14. Lightweight Browsing	1,17%
		15. File Exchange	1,17%
		16. Video Streaming	1,17%
		17. High Quality Video Streaming	1,17%
		18. Large File Exchange	1,17%
Location - Based Services	1%	3. Short Control Messages and Signalling	0,33%
		4. Simple Interactive Applications	0,33%
		6. Geographic Interactive Multimedia Broadcast	0,33%

Simple and Rich Voice Services	40%	1. Real Time Collaboration and Gaming	6,67%
		2. Geographic Real Time Datacast	6,67%
		5. Interactive High Multimedia	6,67%
		7. Interactive Ultra High Multimedia	6,67%
		9. Data and Media Telephony	6,67%
		11. Rich Data and Media Telephony	6,67%

For the simulation purposes here also was considered to use traffic load scenarios which were based upon information available from mobile operators [6].

The three scenarios chosen are Busy Hour, which presents the day period when high network occupation is experienced; Normal traffic, when the average network occupation is experienced and Emergency scenario, when unusually high network occupation is experienced.

V.2.2 Service classes and data rates

After the applications were considered (total of 18 service classes) the data rate requirements needed to be obtained. The table below represents the min and max rates required for each service taken from the table in (chapter 3.2.1) and added simulation data rates used in simulations [7].

Table V. 2: Min and Max data rates required per service class

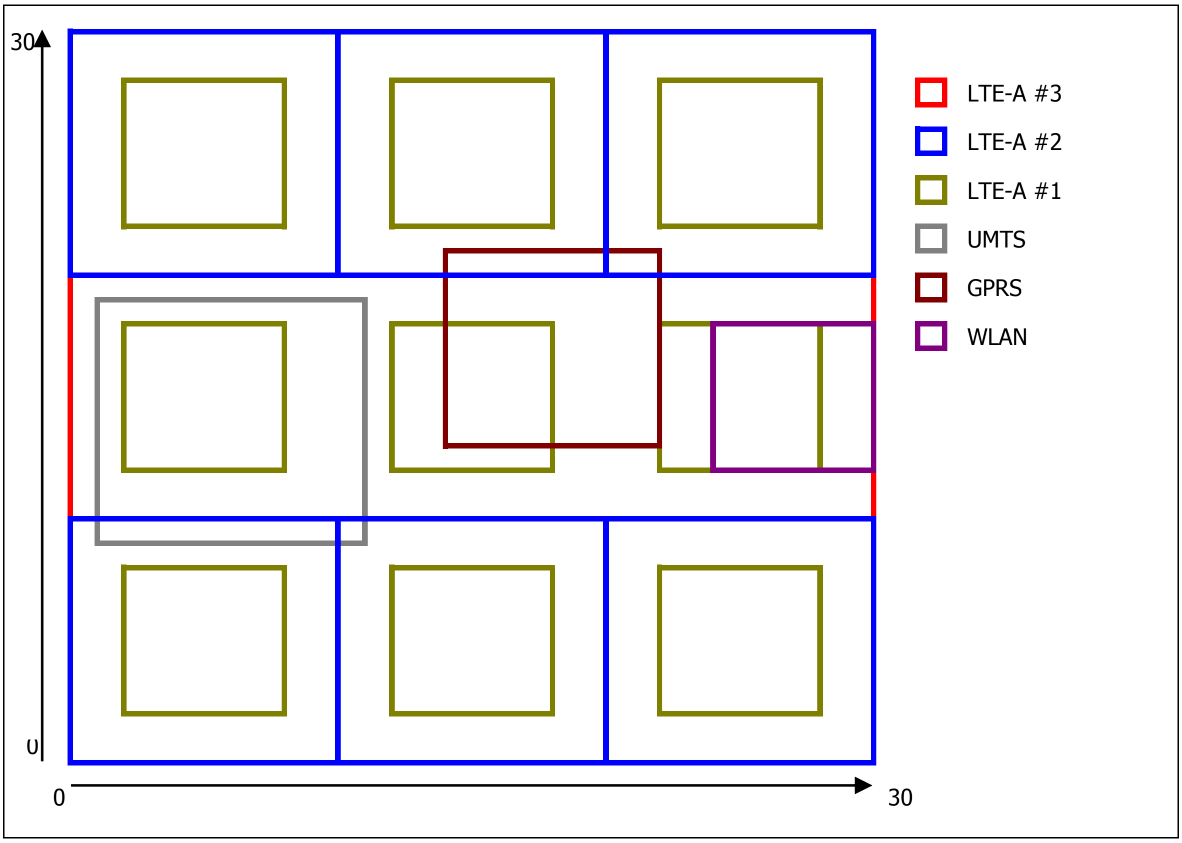
Service Class	Minimum required data rate (kb/s)	Maximum required data rate (kb/s)	Simulated data rate (kb/s)
1. Real Time Collaboration and gaming	1x1024	20x1024	5x1024
2. Geographic real time datacast	2x1024	5x1024	3x1024
3.Short Control messages and signalling	8	64	16
4.Simple interactive applications	64	512	128
5.Interactive high multimedia	2x1024	5x1024	3x1024
6.Geographic interactive multimedia broadcast	2x1024	5x1024	3x1024
7.Interactive ultra high multimedia	1x1024	50x1024	10x1024
8.Simple telephony and messaging	8	64	16
9.Data and media telephony	64	512	128
10.Geographic datacast	64	512	128
11.Rich data and media telephony	2x1024	5x1024	3x1024

12.LAN access and file services	512	50x1024	10x1024
13.Multimedia messaging	8	64	16
14.Lightweight browsing	64	512	128
15.File exchange		5x1024	5x1024
16.Video streaming		5x1024	5x1024
17.High quality video streaming	2x1024	30x1024	10x1024
18.Large files exchange	1x1024	50x1024	10x1024

V.2.3 Environment

For the environment modeling it was considered, as an example of a possible scenario, to create a 19 cell field where each cell is defined by its RAN mode, cell coverage, location and capacity. Having this information each network can be identified and located. Basically it was considered to use 9 LTE-A local area cells, 6 LTE-A metropolitan area cells, 1 LTE-A wide area cell, 1 GPRS cell, 1 UMTS cell and 1 WLAN cell. The approach was based on the one reported in [8]. The different amount of cells represent that each cell covers different amount of area. The positioning of the cells is done by placing the upper left vertex of the square-shaped cell in the area of study. It is further assumed that all legacy RANs have the same capacity and that the IMT-A RAN has twice the capacity. To determine the total capacity of the network, it has been assumed that a maximum of 5 000 users can be served within one hour. The graphical representation of cells positioning is displayed in Figure V.4.

Figure V. 4: Network cell positioning and dimensioning



The numbering here is based on pixel by pixel and the total area coverage is 900 (30X30) and the coordinates of each cell upper left vertex is represented in Table V.3. It can be observed that the full coverage is achieved when using LTE-A #3. Moreover all coverage area is covered by at least one cell and in some point's overlaps with other networks, what also provides the possibility to test collaboration mechanisms.

Table V. 3: Upper left vertex coordinates

Cell ID	RAN / Mode	Upper left vertex coordinates
cellw1_1	LTE-A #1	(02;28)
cellw1_2	LTE-A #1	(12;28)
cellw1_3	LTE-A#1	(22;28)
cellw1_4	LTE-A #1	(02;18)
cellw1_5	LTE-A #1	(12;18)
cellw1_6	LTE-A #1	(22;18)
cellw1_7	LTE-A#1	(02;08)
cellw1_8	LTE-A #1	(12;08)
cellw1_9	LTE-A #1	(22;08)
cellw2_1	LTE-A #2	(00;30)
cellw2_2	LTE-A #2	(10;30)
cellw2_3	LTE-A #2	(20;30)
cellw2_4	LTE-A #2	(00;10)
cellw2_5	LTE-A #2	(10;10)
cellw2_6	LTE-A #2	(20;10)
cellw3	LTE-A #3	(00;30)
cellumts	UMTS	(01;19)
cellgprs	GPRS	(14;21)
cellwlan	WLAN	(24;18)

V.2.4 Users

Regarding users there are three types of users created, namely users with high priority and uses high-rate Service Classes, second type of users is users who is using averagely high-rate service classes, and users from the third profile uses the lowest data-rate on Service Classes. Using these three user profiles the priority is also defined in the same order, meaning that User profile 1 has priority of 1 , User profile 2 has priority of 2 and User profile 3 has priority of 3. Services of highest priority are the most delay sensitive services (e.g., Real Time Collaboration and gaming, Geographic real time datacast, Lightweight browsing, High quality video streaming, Large files exchange), middle priority has medium sensitivity to delay (e.g., Simple interactive applications, Interactive high multimedia, Geographic interactive multimedia broadcast..), and lowest priority are services like (e.g., Short Control messages and signaling, Simple telephony and messaging, Multimedia messaging) that tolerate larger delays.

In the simulation the most important parameters are user location, priority and application. The users are located randomly within the simulation area.

Basically what happens during the simulation is when the user wants to connect; the algorithm gathers the information about the user as follows: first, it finds the user priority by identifying the user location, once the information about the location algorithm is obtained it can check which networks are available for the user. When the networks are known, the application request is checked, each application as explained above has an assigned priority level and which the networks can provide the required QoS. If there is no network, which can support the request the user is rejected. Each time when the new user comes in and leaves the load of the network is recalculated to keep track of available resources. Therefore, some network used calculations are presented next.

V.2.5 Network capacity and load

To obtain an instant value of the capacity in the cell the multiplication of the maximum number of users supported by the network during the simulation is done with the balanced data rates of each application and divided by the time interval of the simulation. As the example during the simulation the total capacity of 19cells is equal to 1164Mb/s. In mathematical expression it is presented in equation 5.1.

$$C_{total} = \frac{N_{U\_max} \times \sum_{i=1}^{N_{sc}} f_i \times DR_i \times TD_i}{FD} \qquad (5.1)$$

Where N_{u_max} is the maximum number of users (7 000 in this case)

N_{SC} is the total number of service classes (18 in this case);

f_i is the penetration factor of the i^{th} service class;

DR_i is the simulated data rate of the i^{th} service class, in Mbps;

TD_i is the typical duration, or expected download time, of the i^{th} application, in s;

FD is the full duration of the time interval, in s (3600 in this case).

To make the above calculations additional information on expected download time is required. For this reason the following table present the used values computed from maximum required data rates and file size.

Table V. 4: Typical time used to download per service class

Service class	Maximum file size (kb)	Maximum required rate (kbps)	Typical duration/ download time
1. Real Time Collaboration and gaming			5-15min
2. Geographic real time datacast			5-15min
3.Short Control messages and signalling	1328	64	21s
4.Simple interactive applications	1328	512	3s
5.Interactive high multimedia			5-15min

6.Geographic interactive multimedia broadcast	1328	5120	3min
7.Interactive ultra high multimedia			5-15min
8.Simple telephony and messaging	28800	64	7min
9.Data and media telephony			5-15min
10.Geographic datacast	34200	512	1min
11.Rich data and media telephony			5-15min
12.LAN access and file services	34200	51200	1s
13.Multimedia messaging	1200	64	20s
14.Lightweight browsing	57600	512	2min
15.File exchange	57600	5120	10s
16.Video streaming	34200	5120	7s
17.High quality video streaming	34200	30720	1s
18.Large files exchange	57600	51200	1s

These values of time are used in the simulations to obtain total capacity of the cell. The maximum file sizes are taken from [7]

After the capacity of the cell is known the load of the cell can be obtained. In order to apply the equation 5.2 the rate of each user has to be obtained which is done by using specific running applications data rate requirements.

$$L_n = \frac{\sum_{i=1}^{N_{ucell\_n}} DR_i}{C_{cell\_n}} \times 100 \qquad (5.2)$$

Where L_n is the load of the n^{th} cell;

C_{cell_n} is the total capacity of the n^{th} cell;

N_{ucell_n} is the total number of users running applications in the n^{th} cell;

DR_i is the data rate of the i^{th} user.

For the simulation set up, the amount of offered traffic is expressed in blocking probability as reported in [8].

V.2.6 Congestion thresholds

The congestion threshold Is an important parameter to evaluate the stable state of the network. In the communication systems traffic characteristics can vary over time causing unspecified utilization of the system, meaning that network can't handle the load normally. Basically the congestion happens when the total amount of traffic entering the system is greater than the outgoing capacity of the system [9]. It is observed that congestion usually occurs if the load reaches 70%. Having this information we can set several thresholds to test which value suits best in this scenario. In order to test the congestion threshold four thresholds was used (70%,75%,80%,85%).

V.2.7 Results

The following graphs represents result obtained from simulation performed using proposed algorithm. For the simulation purposes, as was mentioned in this chapter, three different scenarios were considered, namely: Normal traffic scenario, where average number of users were trying to connect (3400 users were simulated), second, Busy hour scenario, when the high number of users are trying to connect (7400 users were simulated) and the third represents Emergency scenario, when, because of some kind event, network experiences huge number of connections (10020 users were simulated).

For the comparison the graphs presented includes also the simulation results obtained when the network selection algorithm is not in used, this way we can observe how the algorithm improves network functionality and increases the network capacity when additional variety of parameters are introduced (e.g., prioritization mechanisms, taking into account user preferences, applying several congestion thresholds and other parameters described in Chapter III). The network without the algorithm uses simplified admission control and application recommended data rates as presented previously.

The following results shows how using presented algorithm the network capacity can be better utilized comparing to the network operating without the algorithm.

V.2.7.1 Normal Traffic

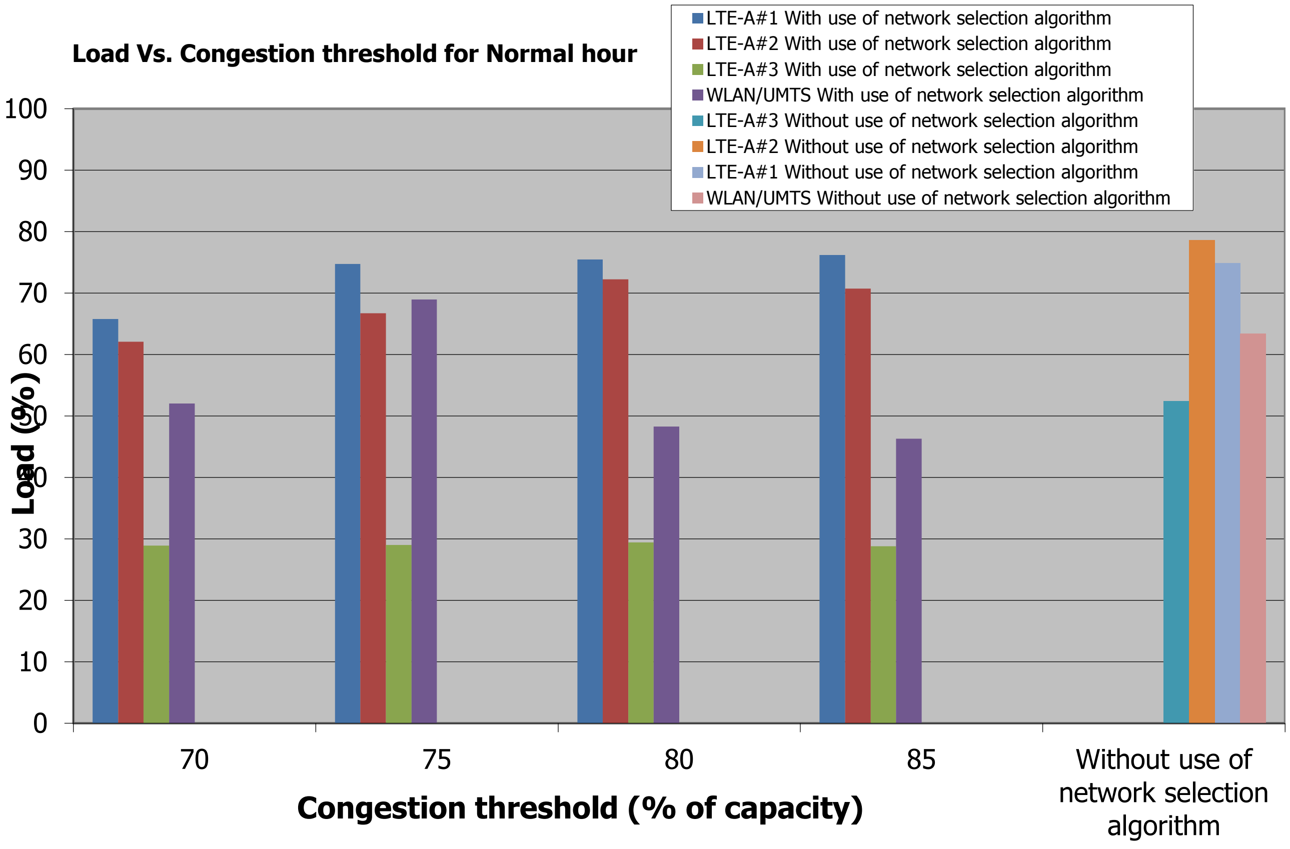
First scenario represents the networks when there are normal traffic conditions with average number of users. The main parameters here like number of users, simulations performed time used for the simulation and congestion threshold, presented in Table V.5. In this scenario the user who requires a specific application to use is served every 1,05 second.

Table V. 5: Normal traffic parameters

Congestion thresholds	Number of simulations	Number of users	Total capacity of network	Simulation time	Interval within new user is served
70%	5	3400	1164Mb	3600s	1,05s
75%	5	3400	1164Mb	3600s	1,05s
80%	5	3400	1164Mb	3600s	1,05s
85%	5	3400	1164Mb	3600s	1,05s

The Figure V.5 shows the network load when normal traffic is used and compared with the values obtained when the algorithm is not applied.

Figure V. 5: Normal traffic scenario



From the results we observe that the load between the networks using the algorithm is more equally distributed between networks and never reaches set congestion thresholds, while in the results without the algorithm the most of the load is given to the LTE-A local (78%) and metropolitan (74%) area cells leading to more complicated network handling. Moreover because of users random positioning in the selected area and not all networks available for each user the more utilized values could not be reached.

V.2.7.2 Busy Hour

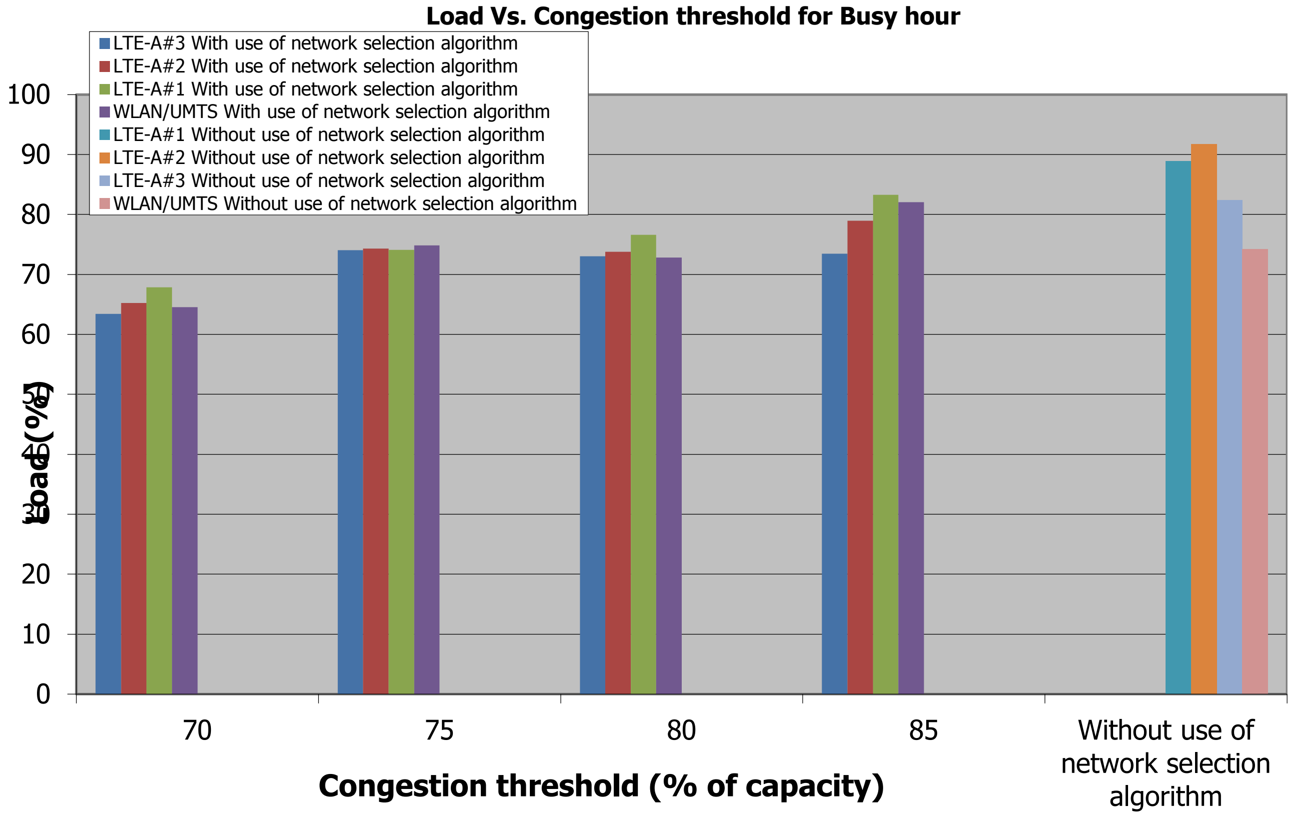
The second scenario when the load is increased shows slightly different results. The scenario main parameters were:

Table V. 6: Busy hour parameters

Congestion thresholds	Number of simulations	Number of users	Total capacity of network	Simulation time	Interval within new user is served
70%	5	7004	1164Mb	3600s	0,514s
75%	5	7004	1164Mb	3600s	0,514s
80%	5	7004	1164Mb	3600s	0,514s
85%	5	7004	1164Mb	3600s	0,514s

This time network had to serve the users twice faster than it was in normal traffic load scenario, which increases the difficulty for the network to connect all users and increases the probability to be rejected, especially when the algorithm is not in use. Therefore the following Figure V.6 shows that using the algorithm the congestion threshold was not reached and network load was utilized within the threshold values. Even though the difference on the load for the networks is not significantly different it shows that using more than one network within the area the utilization plays very important role. Also we can see that most of the load usually is held on local area cells in all scenarios, this is because it deals with users who require high data rate applications, therefore networks requires huge resources. As for the results where algorithm is not used once again the LTE-A metropolitan and local area cells experience loads close and over 90% which is way above the congestion thresholds even considered.

Figure V. 6: Busy hour scenario



V.2.7.3 Emergency Situation

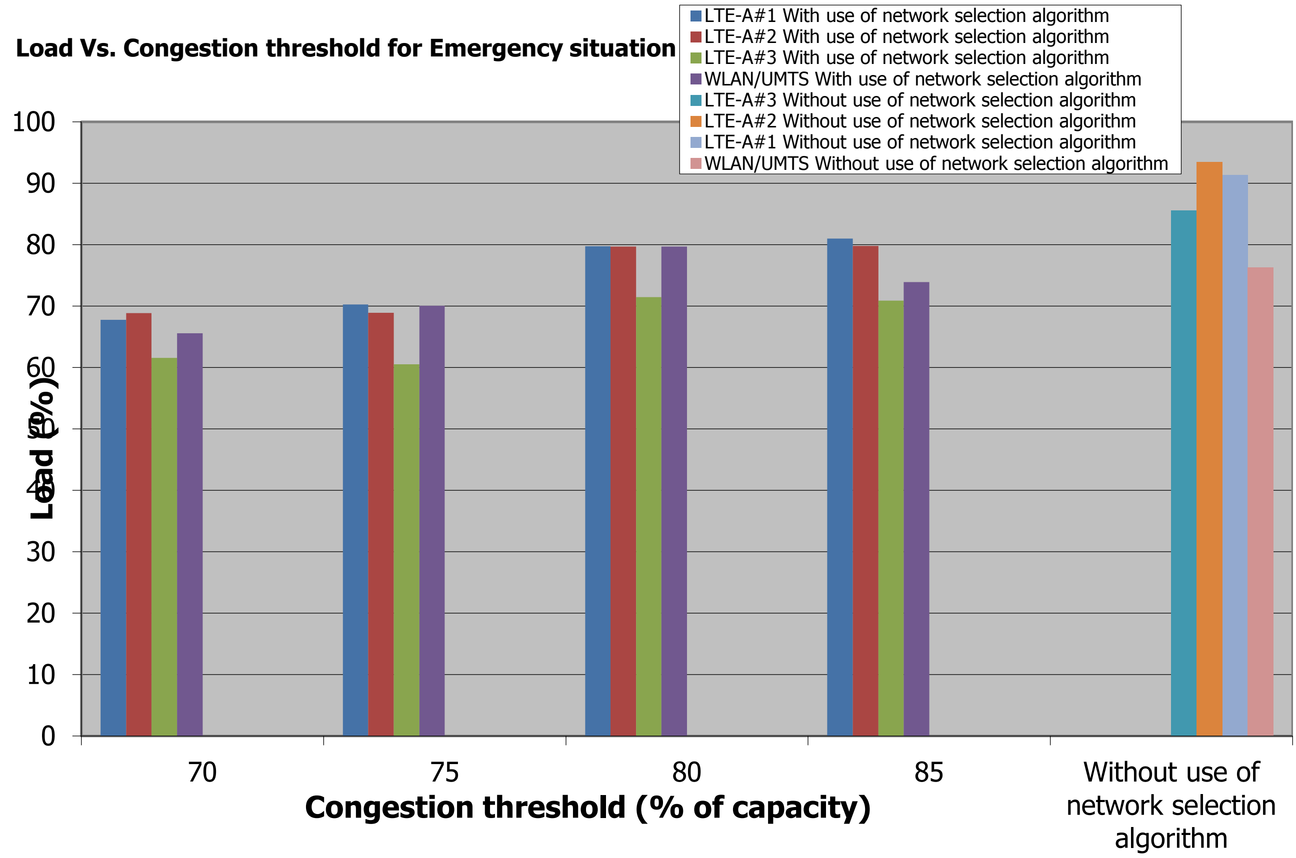
The third scenario presents the situation when unexpected huge number of users requires to be served, therefore in this scenario the networks need to serve user every 0,35s as shown in table below which increases the "challenge" to connect all users successfully.

Table V. 7: Emergency scenario parameters

Congestion thresholds	Number of simulations	Number of users	Total capacity of network	Simulation time	Interval within new user is served
70%	5	10020	1164Mb	3600s	0,35s
75%	5	10020	1164Mb	3600s	0,35s
80%	5	10020	1164Mb	3600s	0,35s
85%	5	10020	1164Mb	3600s	0,35s

The Figure V.7 once again shows that using the algorithm the load of the cells is maintained under the congestion threshold but slightly with higher values than in previous scenarios. Moreover it can be seen that when the congestion threshold was set to 75 and 80 the networks LTE-A local area, LTE-A metropolitan area and WLAN/UMTS area cells reaches the closest threshold barrier like 79,73% for LTE-A local area cells when threshold is 80% but does not cross it. As for the results when no algorithm is used the load reaches 93% of load for the LTE-A metropolitan area cells and 91% for the LTE-A local area cells meaning the network barely could serve users with good QoS and a lot of users would be rejected.

Figure V. 7: Emergency scenario



In conclusion of the results provided on C++ in this thesis it couldn't really be said that this algorithm could be huge improvement in real life networks, because there are still a lot of parameters to be considered and compared with (like introducing flexibility to the QoS degradation, take into account connected and rejected users, types of the applications and etc.) to give the ultimate conclusion on this algorithm level of benefit.

V.3 References

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Chapter VI. Conclusion and future work

In this chapter, the general conclusion of the project is presented. Moreover several future work proposals are suggested.

The future trends show that with the huge increase on the data rate demands and services quality the networks will have to support more and more users with high QoS guarantees, wherefore it is seen that heterogeneous networks where all networks can be accessed seamlessly when needed can be very beneficial in terms of bigger capacity, better utilization, QoS, profits for the operators and more. And to make it all feasible the "best" network discovery and selection mechanisms needs to be introduced. The analysis of the state of the art showed that the variety of mechanisms are available and can be implemented within existing technologies, although only the real-life simulations would show the reality of introduced mechanisms success and fails.

First the different RANs as WiMAX, WLAN, LTE-A were described. The algorithm within network selection and discovery in heterogeneous radio networks presented. After, the simulation environment and user tools description and the results of the algorithm were presented. Several conclusions were made, taking into account several simulation parameters.

During the simulations several approaches were used: at first it was considered to create the algorithm using NCTUns network simulation tool, where the potential and obtained results could be most realistic because of unique Linux's TCP/IP protocol stack used to simulate simulation results. Even after close study of the tool and its capabilities the full algorithm could not be implemented successfully, because of not being capable to connect new applications to the user graphical interface and it's provided build in modules. Therefore the only results from this approach was achieved were handover decision making mechanism. The mechanism was created using PERL language, where the main decision criteria were user node position and current communication bandwidth, loss and delay parameters. Using this information it is observed and presented that part of the algorithm is working properly when even the full connection to the simulation tool was not achieved.

The second approach was to use C++ language. The simulation was carried out using the total of 18 classes of services with the corresponding penetration factor for capacity and load calculations. In the three presented load scenarios (Normal traffic, Busy hour and Emergency traffic) we observed that in all of these scenarios the congestion threshold was not crossed, even though the closest it got was in the emergency scenario LTE-A local area cells with value of 79,73%. Even though the ultimate conclusion stating that the algorithm can be beneficial on all considered aspects of the network for users and operators can't be made, because there are still a lot of parameters to be tested, considered and compared with, as introducing flexibility to the QoS degradation, take into account connected and rejected users, power consumptions, cost scenarios, types of the applications and etc. But what can be said is that it proves that introducing bigger variety of parameters the benefit to the network discovery and selection, comparing to the cases when the algorithm is not used, is seen. From the algorithm presented results alone the network load distribution and increased capacity in the networks is seen to be improved.

However, future work might improve on the results obtained. The major improvement of this project is required to make the algorithm work within NCTUns environment, which might be possible in the latest commercialized version. By doing this more realistic and reliable simulation data could be achieved and presented. Regarding the C++ implementation improvements on maximum resources allocation and management with no congestion is required to be considered as well as the flexibility to QoS depending on user preferences and mobility aspects should be introduced.

Although the simulation prioritization mechanism was considered to be created, regarding the application required rate and serve the users starting from highest rates required to lowest rates. The more complex and reliable prioritization mechanism is required, but considering the time had for the thesis it was not feasible to include.

Finally again considering the time had on the project, several simulation tools were analyzed, as well as several programming languages as Perl and C++ have been learned. Because of being quite new to these programming languages experienced some difficulties to properly and fully implement the introduced algorithm.

LIST OF FIGURES

LIST OF TABLES

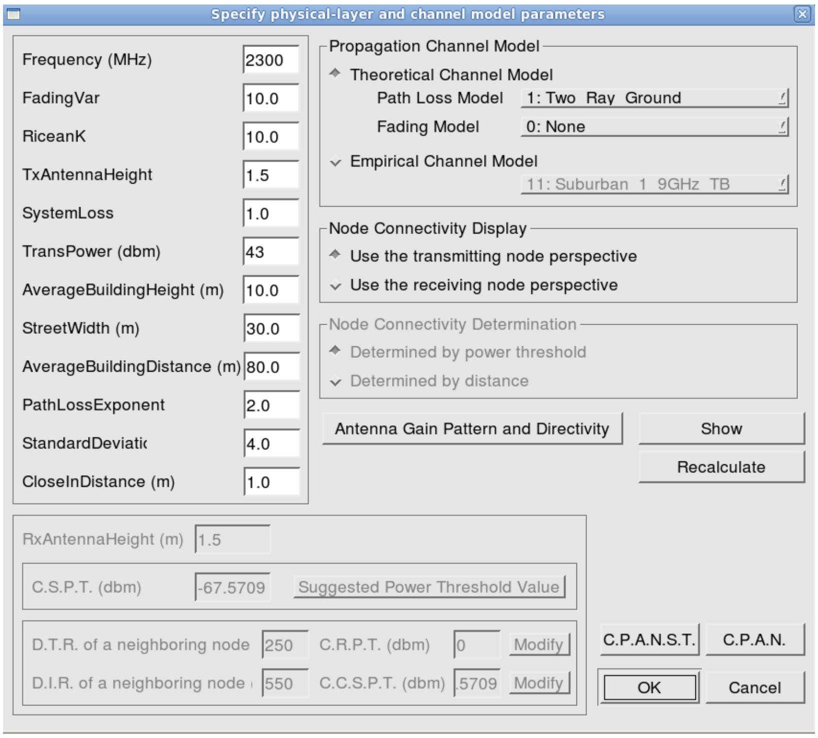
LIST OF ACRONIMS

3GPP	Third Generation Partnership Project
ANDSF	Access Network Discovery and Selection Function
AAA	Authentication Authorization Accounting
AP	Access Point
BE	Best Effort
BS	Base Station
BM	Battery Monitor
CR	Cognitive Radio
CDMA	Code Division Multiple Access
CLiMM	Client Mobility Manager
CSMA	Carrier Sense Multiple Access
ertPS	Extended real time Packet Services
FTP	File Transfer Protocol
GSM	Global System for Mobile Combinations
GUI	Graphical User Interface
HSS	Home Subscriber Service
HPLMN	Home Public Land Mobile Network
HO	Handover
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union – Radio sector
IMT-A	International Mobile Telecommunications - Advanced
IP	Internet Protocol
LTE	Long Term Evolution
LTE-A	Long Term Evolution Advanced
LAC	Location Area Code
MCC	Mobile Country Code
MT	Mobile Terminal
MAC	Media Access Control Address
NS	Network Simulator
NLOS	Non Line Of Sight
nrtPS	Non-real time Packet Services
OFDMA	Orthogonal Frequency Division Multiple Access
PLMN	Public Land Mobile Network
PERL	Practical Extraction and Report Language
QoS	Quality of Service
RSS	Received Signal Strenght
RAN	Radio Access Network
RAT	Radio Access Technology
rtPS	Real-time Packet Services
SDR	Software Defined Radio
SINR	Signal To Interference plus Noise Ratio
TAILOR	Intelligent Handover Decision Model for Heterogeneous Networks

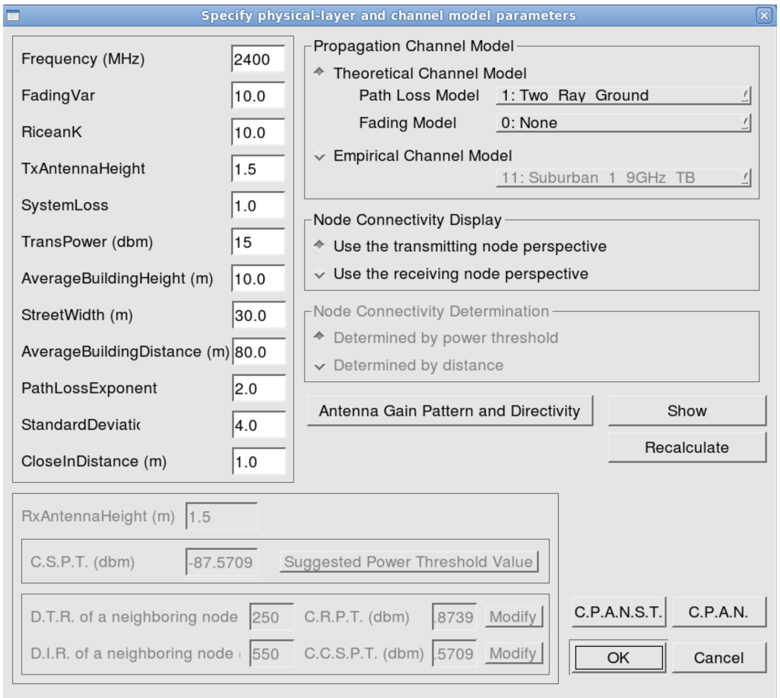
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
UGS	Unsolicited Grant Service
VHA	Vertical Handover
VPLMN	Visited Public Land Mobile Network
WLAN	Wireless Local Area Network
WiMAX	Worldwide Interoperability for Microwave Access
WCDMA	Wideband Code Division Multiple Access

APPENDIX 1: WiMAX and WLAN MAC parameters

The following figure represents the simulation parameters used within WiMAX physical layer and channel model.



The second figure represents the WLAN physical payer and channel model parameters used within the NCTUns software simulations.



APPENDIX 2: The NCTUns simulation algorithm code

Below is the PERL language script created to make vertical handovers possible in NCTUns software:

```
#!/usr/bin/perl
$iniciate_execution= [ Time::HiRes::gettimeofday( ) ];

use Net::Ping;
use Time::HiRes;

$ip_wifi=$ARGV[0];
$ip_wimax=$ARGV[1];
$iniciate_simulacion=$ARGV[2];
$sum_bw=0;
$sum_delay=0;
$sum_loss=0;
$parameters=3;
$meets=0;
$archive_log="/root/Archive/Registre.log";
$change=0;
$network_actual='F';
$network_previous='N';
$handoffs=0;
$bw_ideal=0;
$bw_aceptable=0;
$latency_ideal=0;
$latency_aceptable=0;
$lost_ideal=0;
$lost_aceptable=0;
$prom_bw=0;
$prom_delay=0;
$prom_loss=0;
$waiting=10;
$reaches=0;

`rm -f $archivo_log`;
`touch $archivo_log`;

&stop(0);
&stop(1);

$p=Net::Ping->new ("icmp");
#Starts the time to connect to the network#
$iniciate = [ Time::HiRes::gettimeofday( ) ];
while(1){
		$waiting=2;
		&log("Evaluating available networks");
		if($network_actual eq 'F'){
				#Begins the decision making#
```

```
                                &log("Evaluating WiFi network");
                                &reachable($ip_wifi);
                                if($reaches=='1'){
                                        &log("network WiFi reachesBLE");
                                        &log("Reading the application profile");
                                        &leer_profile();
                                        &log("Checking the terms of WiFi network\n");
                                        &evaluar_profile('0');
                                        if($reaches=='1'){
                                                &decide();
                &log("Procentage of standard factors: $prom_bw          $prom_delay     $prom_loss");
                                        }else{
                                                $meets=0;
                &log("The WiFi network was not reachable during the evaluation");
                                                $network_actual='X';
                                        }

#START HANDOFF

                                        if($meets == '1'){
                &log("The WiFi network meets the profile requirements and is advized to used of mobile
applications");
                                                $network_actual = 'F';
                                                if($network_previous ne 'F'){
                                                $fin = Time::HiRes::tv_interval( $iniciate );
                                                &log("Time taken to make the decision: $fin");
                                                        &continuar(0);
                                                        $handoffs++;
                                                        $network_anterior= 'F';
                                                }
                                        }else{
                &log("The WiFi network do not meet the requirements of applications");
                                                &stop(0);
                                                $network_actual = 'X';
                                                if($network_previous eq 'F'){
                                                        $iniciate = [
Time::HiRes::gettimeofday( ) ];
                                                }
                                        }
#END HANDOFF
                                }else{
                                        &log("The WiFi network is not reachable.");
                                        &stop(0);
                                        $network_actual = 'X';
                                        if($network_previous eq 'F'){
                                                $iniciate = [ Time::HiRes::gettimeofday( ) ];
                                        }
                                }

                }
```

```
		if($network_actual eq 'X'){

			&log("Evaluating WiMAX network");
			&reachable($ip_wimax);
			#$s=$p->ping($ip_wimax,1);
			if($reaches=='1'){
				&log("The WiMAX network is reachable");
				&log("Reading the profile of applications");
				&leer_profile();
				&log("Verifying the WiMAX network condition\n");
				&evaluar_profile('1');
				if($reaches=='1'){
					&decide();
		&log("Procentage of standard factors: $prom_bw			$prom_delay	$prom_loss");
				}else{
					$meets=0;
		&log("The WiMAX network was not reachable during the evaluation.");
					$network_actual='N';
				}
				if($meets == '1'){
		&log("The WiMAX network meets the profile requirements and is advized to used of mobile
applications");
					&continuar(1);
					$network_actual = 'X';
					if($network_previous ne 'X'){
						$fin = Time::HiRes::tv_interval(
$iniciate );
		&log("Procentage of standard factors: $fin");
						$handoffs++;
						$network_previous='X';
					}
				}else{
		&log("The WiMAX meets the requirements of applications");
					&stop(1);
					$network_actual= 'N';
					if($network_previous eq 'X'){
						$iniciate = [
Time::HiRes::gettimeofday( ) ];
					}
				}
			}else{
		&log("The WiMAX network is not reachable");
				&stop(1);
				$network_actual= 'N';
				if($network_previous eq 'X'){
					$iniciate = [ Time::HiRes::gettimeofday( ) ];
				}
			}
		}
		if($network_actual eq 'N'){
```

```
                    &log("The node is not connected to a network, starting next WiFi evaluation\n");
                                                &log("--------------------------------------------------");
                                                $network_actual='F';
                                                $network_previous='N';
                                                $waiting=2;
                    }
                    &log("Handovers number so far-> $handoffs");
                    &log("Next evaluation in $waiting SEGUNDOS");

                    &log("--------------------------------------------------");
                    sleep($waiting);

}

#THIS FUNCTION READS THE FILE WITH APPLICATION PROFILES

sub leer_profile{

                    open(PROFILE,"</root/Archivos/profile.txt") or die "Could not open file profile";
                    @profile=<PROFILE>;
                    #sclose(PROFILE);
                    @bw=split(":",$profile[0]);
                    @latency=split(":",$profile[1]);
                    @loss=split(":",$profile[2]);
                    $bw_ideal=$bw[0];
                    $bw_aceptable=$bw[1];
                    $latency_ideal=$latency[0];
                    $latency_aceptable=$latency[1];
                    $loss_ideal=$loss[0];
                    $loss_aceptable=$loss[1];
                    chop($bw_aceptable);
                    $latency_aceptable=~s/\\n//g;
                    chop($latency_aceptable);
                    $loss_aceptable=~s/\\n//g;
                    chop($loss_aceptable);

                    &log("Application profile => BW Ideal:$bw_ideal Mbps   BW Aceptable:$bw_aceptable Mbps   Delay
Ideal:$latency_ideal ms   Delay Aceptable:$latency_aceptable ms   Loss Ideal:$loss_ideal%   Loss
Aceptable:$loss_aceptable%\n");
                    #print "profile =
$bw_ideal,$bw_aceptable,$latency_ideal,$latency_aceptable,$loss_ideal,$loss_aceptable\n";
}

#THIS FUNCTION COMPARES THE APPLICATION REQUIREMENTS IN THE MOBILE NODEE
#WITH THE CONDITIONS OF AVAILABLE NETWORKS AND CALCULATE THE NORMALIZED FACTORS FOR
#EACH PARAMETER

sub evaluar_profile{

for($i=0;$i<$parameters;$i++){
```

```
$numero = $i+1;
if($_[0] == '0'){
		$archive_bw="/root/archive/wifi_bw.log";
		$archive_lat="/root/Archive/delay_wifi.log";
		$archive_loss="/root/Archive/loss_wifi.log";
		$ip=$ip_wifi;

}else {
		$archive_bw="/root/Archive/wimax_bw.log";
		$archive_lat="/root/Archive/delay_wimax.log";
		$archive_loss="/root/Archive/loss_wimax.log";
		$ip=$ip_wimax;
}
&reachable($ip);
#&log("VALUE reaches = $reaches");
if($reaches=='1'){
		@lecbw=`tail -10 $archivo_bw | sort`;
		#&log("lineas------------>    @lecbw");

		$lecbw=($lecbw[0]+$lecbw[9])/2;
		&log("BW evaluation $numero: $lecbw");
		#print "Average BW = $lecbw\n\n\n\n";

		@delay=`tail -10 $archive_lat | sort`;
		#print @delay;
		$delay=($delay[0]+$delay[9])/2;
		&log("Delay evaluation $numero: $delay");

		$loss=`tail -1 $archive_loss`;
		&log("% Packet loss evaluation $numero: $loss");
		&log("................................................");



		if($lecbw>$bw_ideal){
				$coef_bw=1;
		}else{
				if($lecbw>=$bw_aceptable&&$lecbw<=$bw_ideal){
						$coef_bw=0;
				}else{
						if($lecbw<$bw_aceptable){
								$coef_bw=-1;
						}
				}
		}
		$sum_bw+=$coef_bw;
		#print "COEFICIENTE BW= $coef_bw\n";
		if($delay>$latency_aceptable){
				$coef_lat=-1;
		}else{
```

```
	if($latency_aceptable>=$delay&&$latency_ideal<=$delay){
					$coef_lat=0;
				}else{
					if($delay<$latency_ideal){
						$coef_lat=1;
					}
				}
			}
			#&log("COEFICIENTE DELAY: $coef_lat");
			$sum_delay+=$coef_lat;
			#print "COEFICIENTE latency= $coef_lat\n";
			if($loss>$loss_aceptable){
				$coef_loss=-1;
			}else{
				if($loss_aceptable>=$loss&&$loss_ideal<=$loss){
					$coef_loss=0;
				}else{
					if($loss<$loss_ideal){
						$coef_loss=1;
					}
				}
			}
			$sum_loss+=$coef_loss;
			#print "COEFICIENTE loss= $coef_loss\n";
			if($i<($parameters-1)){
				sleep(5);
			}
		}else{
			last;
		}
	}
}

#THIS FUNCTION EVALUATES THE NORMALIZED FACTORS TO CHOOSE THE BEST NETWORK

sub decide{

	$prom_bw=$sum_bw/$parameters;
	$prom_delay=$sum_delay/$parameters;
	$prom_loss=$sum_loss/$parameters;
	$fact=0;

	$sum_bw=0;
	$sum_delay=0;
	$sum_loss=0;

	#print "PROMEDIO BW= $prom_bw\n";
	#print "PROMEDIO DELAY= $prom_delay\n";
	#print "PROMEDIO LOSS= $prom_loss\n";
```

```
		if($prom_bw<0)			{$fact++;}
		if($prom_delay<0)		{$fact++;}
		if($prom_loss<0)		{$fact++;}

		#print "FACT= $fact\n";

		if($fact>1){
				$meets=0;
				#print "Network is not acceptable 0\n";
		}else{
				#print "Network is acceptable 1\n";
				$meets=1;
		}
}

#THIS FUNCTION WRITES INFORMATION ON THE LOG

sub log{
		open(LOG,">>$archive_log");
		$time=Time::HiRes::tv_interval( $iniciate_execution );
		#$time=localtime();
		$time+=$iniciate_simulacion;
		print LOG "$time -> $_[0]\n";
		close(LOG);
}

#THIS FUNCTION STOPS TRAFFIC GENERATORS IN THE
#CURRENT NETWORK BEFORE CHANGE TO THE SELECTED NETWORK


sub stop{
		if($_[0]==0){
				`pkill -STOP wifi-flow`;
		}else{
				`pkill -STOP wimax-flow`;
		}
}

#THIS FUNCTION RESTARTS TRAFFIC GENERATORS IN THE
#SELECTED NETWORK

sub continue{
		if($_[0]==0){
				`pkill -CONT wifi-flow`;
		}else{
				`pkill -CONT wimax-flow`;
		}
}
```

```
#THIS FUNCTION SENDS A PING TO THE MOBILE NODE TO KNOW IF IT IS WITHIN
#THE COBERAGE AREA NETWORK

sub reachable{
		$ip=$_[0];
		$s=$p->ping($ip,1);
		if($s){
				$reaches=1;
		&log("The network is reachable");
		}else{
				$reaches=0;
		&log("The network is not reachable");
		}
}
```