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USING ANDSF FOR CONVERGENCE ACCESS NETWORK SELECTION AND SERVICE ADAPTATION BASED ON CONTEXT

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A thesis submitted to the University of Huddersfield in partial fulfilment of the requirements for the degree of MPhil

The University of Huddersfield

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Abstract

Changing contexts and requirements of mobile users necessitates a constant creative drive on the part of service providers and other experts involved to supply, improve and uphold their services. Maintaining both availability and high quality connection to desired networks are amongst the essential concerns of heterogeneous networks which are also based on considering user criteria. In this direction, a comprehensive model for access network selection and service awareness using Access Network Discovery and Selection Function (ANDSF) is proposed. The model in the present study aims to decrease the processing delay and the number of vertical handovers using the Simple additive weighting (SAW) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) algorithms in decision making part. The technical characteristics and performance of the access networks such as reliability, coverage and congestion are expressed as network context in terms of providing certain level of Key performance indicators (KPIs). The network profile is designed in a way which satisfy the User profile requirement (for example network bandwidth as a network profile should cover the required QoS as the User profile convince the UP criteria). Service level context which is transferred over session description protocol (SDP) plays a vital role in order to ensure the QoS level provisioning for end users. The ANDSF entity includes the client and server in which ANDSF server acts as the brain of the proposed architecture. They keep the user, network and service profile up ad working. Also, ANDSF acts as a first filter to apply the operator policies. This results in a decision making process based on the inputs of service, network and user context collected from different elements of the core networks. The findings show how the optimised access network selection can provides the user with acceptable Quality of Experience (QoE) level.

ANDSF-related research dealing with context-aware handover issues in the research literature have generally focused on the decision part without making it clear where these contexts come from. However, in the current project, the interfaces were explained in detail and the assumptions are expressed and the origins of contexts were made clear. In this dissertation the ability for the user or other mobile entities to communicate with the service provider is discussed. As the second subject, the possibility of service provider's profile adaptation with network context changes which is affected by the network selection mechanism was also discussed.

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List of Abbreviation

Access Network Discovery Selection Function (Andsf)

Access Point Name(Apn)

Access Point (Ap)

Analytic Hierarchy Process (Ahp)

Application Function (Af)

Application Server (As)

Basic Service Set Identifier (Bssid)

Cognitive Pilot Channel (Cpc)

Code-Division Multiple Access (Cdma)

Deep Packet Inspection (Dpi)

Domain Name Service (Dns)

Enhanced Generic Access Network (Egan)

Enhanced Information Server (Eis)

eNodeB (eNB)

Evolved Packet Data Gateway (Epdg)

Gateway GPRS Support Node (GGSN)

General Packet Radio Service (GPRS)

GPRS Tunneling Protocol (GTP)

Gray Relational Analysis (GRA)

High Speed Circuit-Switched Data (HSCSD)

High Speed Downlink Packet Access (HSDPA)

High Speed Downlink Packet Access (HSDPA)

Hyper Text Terminal Protocol (HTTP)

Inter-System Mobility Policy (ISMP)

Inter-System Routing Policy (ISRP)

Information Service (IS)

IP Flow Mobility (IFOM)

Interworking WLAN (I-WLAN)

Location Based Services (LBS)

Level Integration With Ipsec Tunnel (LWIP)

Local Operating Environment Info (LOEI)

Management Object (MO)

Media Independent Command Service (MICS)

Media Independent Handover (MIH)

Media Independent Handover Event Service (MIHES)

Media Independent Handover Function (MIHF)

Media Independent Information Service (MIIS)

Medium Access Control (MAC)

Mobile Alliance Device Management Protocol (OMA-DM)

Mobile Subscriber Routing Number (Msrns)

Multi-Objective Decision-Making (MODM)

Multiple Attribute Decision Making (MADM)

Multiple Attribute Decision-Making (MADM)

Multiple-Access PDN Connectivity (MAPCON)

Multiplicative Exponential Weighting (MEW)

Network Access Provider (NAP)

Network Profile (NP)

Network Service Provider (NSP)

Packet Data Network (PDN)

PDN Gateway (PGW)

Personal Digital Cellular (PDC)

Policy And Charging Enforcement Function (PCEF)

Policy And Charging Rules Function (PCRF)

Policy Charging Control (PCC)

Quality Of Experience (Qoe)

Radio Access Technologies (RAT)

RAN Congestion Awareness Function (RCAF)

Reference Signal Received Power (RSRP)

Service Profile (SP)

Service Set Identifier (SSID)

Serving Gateway (Serving GW)

Serving GPRS Support Node (SGSN)

Session Description Protocol (SDP)

Session Initiation Protocol (SIP)

Signal To Interference Plus Noise Ratio (SINR)

Signal To Noise Ratio (SNR)

Simple Additive Weighting (SAW)

Technique For Order Of Preference By Similarity To Ideal Solution (TOPSIS)

Third Generation Partnership Project (3GPP)

Time Division–Synchronous Code Division Multiple Access (TD-SCDMA)

Traffic Detection Function (TDF)

Traffic Flow Templet (TFT)

User Profile (UP)

CHAPTER 1

1. Background of the study

With the emergence of heterogeneous networks, delivery of different services over different access networks has been made possible. The aim of the future massive mobile market is to enable efficient communication to a high number of subscribers over heterogeneous access networks based on the requirement of different services and applications.

It is expected that the number of subscribers to mobile services would be dramatically on the increase each year [1]. In order to match and deliver different services to these various tastes, service delivery needs to be adopted with the momentary network conditions. It means that services must have different parameters in different networks. There is a requirement of enabling extra functions into the architecture enabling a high level of adaptation. Given this, there is an essential requirement for an enabler in the core network to reduce the operational costs through adaptation of the resources available for delivery of the required services. The enabler includes network selection and service adaptation together. Enabler can be located in the home network or visited network, although the home enabler rules have high priority in comparison with visited ones. Also, some agreements between home and visited operators are required to implement the enabler rules. Considering the above aims, there are some limitations in the core network which makes the implementation of them more difficult which briefly are introduced as an increase in the amount of the internal communication signalling, as well as requirement of collecting and analysing the collected information from various parts.

Currently service initiation and service adaptation processes (when context of the network have been changed or handover occurred) have high amount of internal signalling. An optimised service adaptation mechanism which reduces the amount of internal signalling is appreciated. Existing heterogeneous environments which include WiFi, 3G microcells, Piccocell and Femtocell with their evaluation parameters such as provided QoS (Quality of Service) and QoE (Quality of Experience), are affected by various mechanisms such as service adaptation process and access network selection process. Both mentioned mechanisms require sufficient information from the users, network and the services. This type of information is called context.

Both access network selection and service adaptation process can be effected by taking user preferences, service requirements and network context in to account. Service resource management can be affected by the change of the networks parameters in heterogeneous environments. Resources will be re-dedicated when the session profile is changed under two different circumstances, namely service establishment and vertical handover.

Service establishment procedure includes the negotiation of the service profile between the UE and service provider [2] (service profile shows possible service parameters). Service profile selected by the user, and thus per request, the resources are assigned by the network. When a handover occurs, the context of network is changed and service cannot be delivered with the same session profile (such as delay, bit rate, throughput, etc). In such cases, the essence is appropriate network selection which also adapts with the changes in service contexts.

Nowadays, delivery of high amount of traffic seamlessly and with appropriate speed is highly expected. The latest prediction goes as the mobile traffic will have 1000x increase in the next 10 years [3] [4]. The 5G-centric research is taking shape, but it still may not be able to address and keep up with this expected pace of mobile data traffic. Thus, one issue revolves around its sufficiency to meet the anticipated growth in traffic demand. Another tough issue is the available radio resources, which has approached its limits in the licensed band. However, there is a promising solution lying in data offloading, in which wireless local networks are developed to offload mass data from existing cellular networks. Using WiFi is also an effective solution because it provides access to harness additional spectrum and make a full use of unlicensed frequency band. Meanwhile, user equipment (UEs) normally have WiFi connection capability and building WiFi hot spots is significantly cheaper than upgrading the existing cellular networks. However, working in heterogeneous environments with the possibility to offload to WiFi has its own advantages and disadvantages. On one hand, a lot of benefits in terms of cost and convenience can occur as a result. On the other hand, such an approach brings an opportunity for the users to control their access preferences on their smartphones. One of the issues is the possibility that users only access certain operations on their smart phones. This possibility may satisfy the user in terms of cost, QoS and QoE. Yet, the services may have difficulty adapting to any new condition. Optimally, both network selection and service adaptation should consider the user preferences. However, the current mechanism for handover and resource reservation focuses solely on the seamless delivery of services, which is good, but at the price of insufficient attention to user preference and network parameters. Service adaptation and implementation requires a negotiation between mobile user, network and service in which the user preferences can interfere with service establishment and when a vertical handover (i.e. from one technology to another) occurs.

The currently-used network architecture has some limitation in communication between service platforms in one side and with the mobile on the other side in order to use the result of the agreement for access network selection and service adaptation (in the initiation and changes in context). This project describes the state of the art in access network selection and then introduces a new method to overcome the introduced limitations in order to make optimised decision in access network selection.

1.1. Features of mobile communication

It is known that the tremendous demands from market are pushing the booming development of mobile communications faster than ever before, leading to a plenty of new advanced emerging techniques. Moreover, people’s lifestyle has changed in many ways because of mobile communication. As traffic growth continues, operators will need more and more innovative functionality in their network to cope with it. Unlicensed spectrum (via WiFi or with other technologies) will continue to play an important role in this quest.

3G technologies came to provides more data, video calling and mobile internet. 3G networks reach 2mbps on stationary or non-moving devices and 384kbps on devices in moving vehicles. The extension of 3G with more bandwidth and services is 4G. 4G came in the last of 2000 and it is 5000 times faster than 3G. As the new demands such as Internet of Things (IoT), is on the increase, 5G is emerging. The major differences between 4G and 5G are the speed and latency. Because of 5G responsibilities, many more future devices and vehicles in the Internet of Things must be supported. As explained in [5] around 80% of incoming traffic of mobile data is from indoor locations and fixed users are the most consumers of the indoor providers. Data offloading comes to manage the available resources and try to stop the congestion. Offloading can bring some benefit in cost, availability, customer experience improvement and new business opportunity[6].

In all generation of telecommunication technologies, the communication is recognized as delivery of required services to the mobile user. Each service is defined with various aspects what three of most famous are security, QoS and mobility. These features are different in various communication scenarios.

Security, as a first concern, can be addressed whenever mobile technology, particularly smartphones, which have exploded in popularity in recent years are connected to the networks [7]. Mobile security is defined as the protection of devices such as smartphones, tablets, laptops and other portable computing devices, and the networks they connect to, from threats and vulnerabilities associated with wireless computing. Mobile security is also known as wireless security. Source [8] in their report introduces 5 concerns about mobile security included: device loss, application security, device data leakage, malware attacks and device thefts.

As a second concern, Quality of Service (QoS) which is understandable by the user is defined as the overall performance of a telephony or computer network. QoS is a standard of measuring the network performance measureable by some related parameters such as error rates, bit rate, throughput, transmission delay, availability, jitter, etc. Wider transmission bandwidth, various mobile devices, numerous wireless and wired access networks and more powerful application together with advances in computing technology have brought more services to be delivered with more excellent quality.

Thirdly, the mobility means when a service is accessible by a device for a specific user in one access network, it should also be accessible with that device for that specific user in another access network. Working in heterogeneous access network opens an important possibility such as handover and mobility management. We all know that the mobile communication starts with voice, but today it is expected to deliver multimedia services over heterogeneous access network with expected QoS and QoE. While QoS explain the network performance with its parameters, QoE focuses on the actual individual user experience. For QoE measurement, better network traffic analysis is required in comparison with QoS measurement. As an example for Qos Parameter, considering VOIP call, echo, conversational quality, audio level and imperfections are considering [9].

The requirement of smooth and adaptive delivery of real time multimedia services offers a new important challenge in mobility management.

1.2. The scope of the thesis

In this dissertation, the ability for the user or other mobile entities to communicate with the service provider and other entity of networks will be discussed. Information collected from different parts of network brings the possibility of adaptation in service provider's profile with network context changes. The collected information helps in an optimised decision making process in a heterogeneous network.

The resource control functionality is one of the main counterpart functions in QoS of the network. As explained before, QoS is defined as the total of characteristics of a telecommunication services on which totally can satisfy the user. The ability of a system to meet traffic demand of given size and other characteristics of under given internal conditions is a definition for QoS concept introduced by ITU [10]. Following the vision of future massive mobile network, the aim of this thesis is to develop a context-aware adaptation management framework integrated with context-aware access network selection mechanism.

This aim can be reachable after discussing and researching on below topics:

Firstly, Context-aware access network selection process is studied in various aspects. The main of this topic is to introduce a context-aware network selection which is sensitive into the user profile, service profile and network profile. Achieving this aim is possible with study about the available context (permanent and variable) in the network architecture which is transmit to the central entity to be used for decision making process. For example for a specific service delivery, when considering cost and user profile as context for decision making, an access network will be selected based on these two context. The network selection approach will select an optimized access network which can maintain at least the minimum required QoS and QoE.

In this topic, two points have high importance: one is the communication between service provider and mobile client. The other is the complexity matter of this network selection which will be compensated with the degree of customized and the overall system efficiency.

Moreover, context-aware service adaptation is defined as a behavioural change of a service in order to become better suited to the user. Despite the previous studies [11] that have been conducted in service adaptation and network selection separately, this project contextualizes the user preferences in both areas simultaneously. A server and database centre will be defined for negotiation with the service provider in order to exchange the user preferences (in this thesis ANDSF server and client) [12, 13]. Also, such a server, when introduced, can help network selection and offloading based on the user and network profiles. This solution reduces the amount of signalling for negotiation between user and service providers. Implementing such a technique makes the system sensitive to context or so called context-aware. Before delving deeper into the implementation of such a context-aware solution, a general overview of the service adaptation and network selection is necessary, which makes up the following section.

1.3. Problem statement

The final aim of this project is to propose an approach in order to maximize the user satisfaction when communicating in the multi-access network environment. With an increase in the number of subscribers, delivery of various services for various tastes is required in heterogeneous access network in this situation; service delivery needs to be adapted with the momentary network conditions in which services need to have different parameters in different networks.

The significance of the problem lies in the fact that user experience is a key point to the success of the future communications industry. Access to requested services with the right price and at the right time is important to encourage service usage. Users avoid services which they think as expensive service and they try to use services with good value. They prefer to use advantage of the choice and diversity of the access networks available in their current location to have service with requested QoS, and reasonable price which can be delivered continually in a timely manner. In today's world of telecommunication, the business and technology models are mixed. Access network selection is very important in order to deliver required service with requested criteria. Thus, Access network selection should be a more intelligent process flexible with different contexts of business and technology. Gathered context either from network or user side need to play a role in decision making procedure. This thesis presents such research challenges in context-aware access network selection procedure.

1.4. Research questions

Due to the gaps in research, the below questions are addressed for this current study.

1-What are the aspects of context-based access network selection in heterogeneous network? (In terms of different profiles)

2- How can the delivered service be adapted to the changes of the context? (user contexts and network contexts)

3-How can the contexts be translated and transferred into an appropriate entity? (What is the requirement of transferring the context, which entities in LTE/EPC network have which kind of information?)

4-what are the related context and profiles in the access network selection process?

5-Based on the data collected from the user and network context sources, which algorithms are used in order to select the most proper access?

1.5. Solution overview

In order to propose an effective context-aware access network selection and service adaptation, the changes around the access network selection and service adaptation process in review literature need to be studied. The raised challenges are categorized into different problem area for more focus.

Ideally decisions are made by decision maker which is informed about network, service and user context with acceptable accuracy. However, decision making process is a complex procedure because of below reasons:

- Decision making process is a multi-stage process
- There is always lack of some information or gathered context are imperfect
- Uncertainty of gathered information is adding to the complexity of decision making process
- Nature of mobile communication is dynamic, thus, collected Contexts are constantly changing because of various reasons.
- There are both dynamic and static inputs with temporal dependency for decision maker which increase the complexity of decision making process.
- There are limits in computing part of decision making process.

Figure (1.1) shows the connection of the different network entities in order to collect the required context from different part of network via interfaces for making the decision matrix.

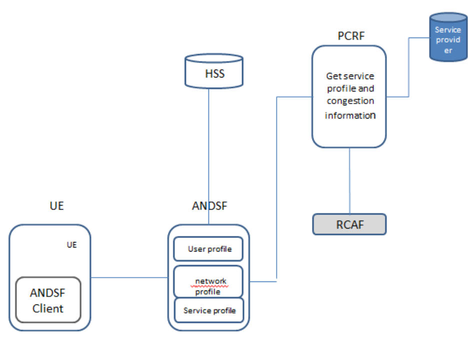

Figure 1.1:proposed ANDSF connection toward other network entity

In this theses, after collecting different context from various part of network within the framework of three profiles (user, network and service profile), an entity in the network

Access Network Discovery Selection Function (ANDSF) as a decision making process using Multiple Attribute Decision Making (MADM) method to make the final decision. This method adds control functionality over the network selection and service adaptation. The output of this study is architecture with decision maker background. Implementing this architecture leads to reduce the delay and redundancy.

1.6. Research trajectory

The trajectory for the present research consists of a few consecutive steps, First of all, analysing the relevant concepts underlying the research as well as reviewing the works that have been done previously. This step leads to raising an issue which is not given sufficient attention and defining a research question which is timely. Second step, will consist of making a hypothesis in order to address the issue raised. In the third step, the hypothesis will undergo testing, and eventually showing it to be based on a valid theory. The phases explained below reflect the actions taken to achieve the above said objectives.

Phase I, consists of the description and critical analysis of the concept and the challenges around 3G, 4G, LTE, and the context-aware systems. Various aspects of context-aware systems are categorized in three parts: application, network and system. The result and writing up of this phase leads to the discovery of some issues regarding enabling context-aware network selection and service delivery in heterogeneous networks, which in turn, leads to deriving questions based on understanding the existing projects and infrastructures.

Phase II, begins with clarifying the problem raised in phase I, and proposing a new mechanism about enabling context-aware user preferences based network selection and service delivery in LTE/EPC. Achieving this aim is possible with the study of the negotiation between LTE/EPC entities in detail in order to understand the proposed hypothesis, under the condition of defining a new interface.

Phase III, concludes with evaluating and comparing the new structure with previous structure in the research. In this phase collected context enter to the access network selection algorithms Simple Additive Weighting (SAW) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS).

CHAPTER 2

2. Background

This chapter initially explains the motivation for doing research about design of the algorithm that helps context-aware network selection. As the next step, the evolution of the network selection process and service adaptation will be studied. Network selection includes access network discovery and selection process which happens in two situations; for the initial connection and for the handover procedure. Access network selection is made conceivable when a selection of available networks, rooted in various operators, is developed to contain several Radio Access Technologies (RATs). This is performed bearing in mind that their verity and complexity is sustained while the new functionalities and features are being added. This chapter introduces Access network selection mechanisms in the review of literature generally.

2.1. Challenges and view of the future in access network selection

In light of new developments to be explained in this section, wireless telecommunication is on the shift due to some elements such as the convergence of the worlds of Internet with the world of telecom, and the urge to constantly develop the capabilities of wireless networks to meet the growing demands. Wireless networks such as WiFi, WiMax and cellular access networks have already been replaced with wired internet technologies. These technologies bring new opportunities for delivery of different and new services. Considering user preferences, network situation and service profile in order to deliver high quality of services and increase the user satisfaction plays an important role in next generation of mobile communication success.

2.2. Variety in access networks

In evolved wireless network systems, there are three key players of end user, access network and content/service provider. They are interrelated as the various services are delivered to the end users through different access networks. Service providers are known to aim for more sustainable solutions that can provide accessibility to their subscribers while being less dependent of transport provider and operator. Their motivation is to raise their customer base and make best use of their facilities to gain the highest possible prospect of revenues.

As there is a very fast evolution in network entities and user requirements, deployment of different applications supporting the flexibility in customer billing, registration and support while also maintaining and configuring themselves is a very complex issue. Although cloud approach is coming to solve the issue of service evolution, service providers needs to tackle the challenge of dynamic adaptation to each user preferences, within the available capabilities of the terminal and access networks.

While the service providers usually focus on the best delivery of service to their users, the operators are focused on maximizing their revenue by satisfying the users and service providers with the best possible connectivity. After all, the best user experience matters, which come from a reliable relationship between operators and service providers.

Such a relationship should work with various radio access networks, namely, cellular GSM, CDMA, WCDMA, HSPA, LTE, WiFi, WiMax, satellite, broadcast and home and company networks. Operators choose various set of above access networks dependent on provided services, handset capabilities. While the earlier cellular networks are focused on the QoS of the voice and sms over dedicated channels mainly and less on data rates, WLANs have their strength mainly for transport of data with higher rates. However, with evolution of network types, wider range of applications can be delivered with more usability.

An overview of historic evolution begins with GSM. GSM (which stands for Global system for mobile communication) was launched at the beginnings of the 1990s for communication between people. By the user 2010, 3 billion subscribers worldwide use GSM for communication [14]. GSM is set a common standard for Europe for wireless networks which has also was used on countries later. At this time US developed Code-division Multiple Access (CDMA) standard when using 2G phones become more widespread, the demand for data became clear, so the operators began to use next generators known as 3G. The difference between 2G and 3G is using packet switching instead of circuit switching in 2G. 2.5G systems such as CDMA 2000 and GPRS were made as additions to the 2G systems. High Speed Downlink Packet Access (HSDPA) was an development out of 3G technology in the mid 2000s. Since the growth of using some applications like streaming media which are bandwidth-intensive, the 3G networks could not fulfil the requirements, thus LTE standard first offered in Scandinavia was introduced and promised of speed improvements up to use packet switch. The early forms of mobile networks were analogous and were switched through circuit with different names respectively AMPS, TACS, NMT and C-NETZ. 2G was introduced as the second generation of the mobile phone, with different names such as GSM in Europe, Personal Digital Cellular (PDC) in Japan, CDMA in the United States. The next stage with High Speed Circuit-Switched Data (HSCSD) was called 2.5G which was called General Packet Radio

Service (GPRS) or Enhanced Data Rates for GSM Evolution (EDGE). Packet switched 3G WLANs (UMTS) plus Time Division–Synchronous Code Division Multiple Access (TD-SCDMA) were all the product of evolution of 2G . UMTS and cdma200 are the technology outcomes of Telecommunication Union (ITU) for finalizing the 3G cellular networks. GSM and UMTS were later evolved to 4G which is also called LTE. The air interface in LTE is called evolved UTRA (E-UTRA). In LTE, which began as 3.9G, the data rate was increased from 2 Mbps in 3G to up to 100 Mbps for the downlink and uplink to 50 Mbps. IMT-Advanced requirements were satisfied with increasing the data rates to 1 Gbps at low speeds and up to 100 Mbps at high speeds in LTE-Advanced (LTE-A) in Release 10. From release 13 onwards are known as the further enhancement of the LTE called LTE-advanced pro. In this release, incensement in the mobile broadband, compatibility with LTE-A and connectivity performance were considered [15] . 5G is the evolution of the LTE-A pro which is coming to provide less latency, Internet of Things (IoT), more data rate and narrowband IoT (NB-IoT) in in Release 14 [16].

2.3. General information for access network discovery

The home PLMN operator of the core network selects either a trusted access network (non-3GPP) or an untrusted non–3GPP access network. In trusted non-3GPP access network a pre-established secure links are used for communication between access network and EPC core. For an untrusted type of non-3GPP access network two different methods are applicable which in both of them a single IPSec tunnel is established to the Evolved Packet Data Gateway (ePDG) for all Packet Data Network (PDN) connections for both S2b or S2c interfaces [17].

When a multimode capable UE gets connection with the EPC through various access networks, two technologies are required. First of all, the UE needs to discover the available access networks. To achieve this aim, the network provides the necessary data regarding the availability of the access technologies according to or based on the location of the UE. Only then, as the next step, the UE select a suitable access technology which will be discussed in the next chapters extensively [18].

As an example, when a mobile terminal which is using 3GPP 2G or 3G radio access enters in area with WiMAX access, it is preferable to handover to WiMAX mobile. Classically, the UE periodically discover the neighbouring cells through the application of a radio scanning signal in the background with little assistance from the available network [19]. Although this classic method has an advantage of being simple, or without requiring any modifications in the network, it has some disadvantages. The main issue is high battery consumption specifically in fast access network scanning. Also, the discovered network has no extra information regarding the price, service, etc. [19]. In this method the UE requires two receivers which one of them working for scanning and the other one for ongoing communication. The above reasons open new research area in the discovery of access network as well as selection of function methods assisted by the network, service or user profile.

2.4. Evolution in the network selection decisions

Access network selection is generally known as a procedure in which access networks used for data communications are selected, whether they are 3GPP (such as HSPA or LTE) or non-3GPP access networks (such as Wi-Fi or WIMAX). There are various techniques for access network selection in which, network-assisted discovery solution is the most-used technique these days. In this method, network can broadcast a list of neighbouring cells from different technologies. Using the same approach, the 2G/3G cells are also upgraded in those non-3GPP neighbour cells that are broadcasted. Generally, in case of environmental changes and possible accumulated human knowledge, the traditional single criteria-based algorithms cannot act perfect. The network selection process can be considered as a complex problem as it provides a multiple mixes of static as well as dynamic parameters and at times, different parameters are involved in the underlying process[20].

As another approach, a standard entity introduced by 3GPP is applied to facilitate discovery of non-3GPP cells which is called ANDSF. The ANDSF can be updated with operator policy and provide these policies to the user mobile. The device behaviour can be affected by either rules or preferences of a dynamic operator, which are embedded in provided policy. Moreover, the provided information by ANDSF can include neighbour cells such as data about capabilities in the service and QoS, rate of charge, and a number of other attributes[21]. Because of high radio capacity, mentioned information cannot be continuously broadcasted. For better results, the information of ANDSF combines with user data in order to choose the preferable radio access technology (in this case, WiMAX or 3GPP access). The selected network satisfies the requirements of both user preferences and operator policies. In this procedure, UE is provided with rules of the connection to such networks. To make this procedure more efficient, ANDSF as an entity is introduced to provide the user with Inter-system mobility policy (ISMP), Inter-system routing policy (ISRP) as well as the Discovery Information. Unfortunately, currently proposed access network selection procedures does not cover the demands of available technologies, implementation complexity and involving all network entities in terms of their parameters[20].

The decision making parameters in access network selection process are categorized as subjective and objective parameters which can be minimized or maximized in different conditions. From the point of View of article[22], network selection procedure can be classified in four different groups:

The first criteria which is very common in access network selection is network-related criteria which considered the technical features and performance of the RANs in terms of their performance indicators (e.g. high technology, the amount of coverage, the quality and capacity of link, and elements like throughput, load, pricing, etc.) [20]. Considering the above network parameters, available bandwidth (maximum allowed bandwidth) which is measured by the network operator is the most frequently-used parameter in traffic performances.

The second is terminal-related parameters criteria such as user velocity, device supported interfaces, location information, etc.

Service-related criteria which considers packet switched network QoS metric parameters are the third group, such as jitter, packet delay, error ratio for providing the end user with services. Finally, there are user-related criteria which concern parameters related to the user (the users' profiles and preferences, the cost of service, the quality of experience as well as QoE, etc.) [20].

One or some of parameters introduced above can be considered as inputs of decision matrix. Further, how this information can be transferred to the user terminals will be issued.

In a paper [23], the CPC channels has been introduced in order to carry network information from network to the user terminal. CPC helps mobile terminal in different cases such as start-up phases or/and ongoing phases as discussed in detail.

The 'start-up' phase is when the mobile terminal is turned on, the CPC channel with optionally geographical information can help in order to detect different radio frequency. The CPC detection actually depends on the implementation of CPC in terms of physical resources used. The CPC channel caries the information about the neighbours access networks based on the location of the mobile terminal. This kind of data is sufficient to initiate a call session based on time as well as location. Therefore, CPC can provide the related information based on operator configuration, frequency bands and RATs in terminal location. This information can be used during the start-up phase beginning at 'switch on' of mobile terminals, in order to search for a candidate network to camp on [24].

The 'ongoing' phase: ongoing phase will start after start-up phase, when a mobile phone is camped on a access network. CPC channel send the periodic check of the information to detect any changes in the mobile position or network reconfigurations. Information similar to the start-up phase can be deliver to the mobile handset by the CPC channel periodically [25] .

In the recent years, the amount of IOT sensors, mobile devices with various applications and wireless sensor networks (WSN) generate massive amount of traffic. In this case 5G integration with wifi attracts a lot of concern. Employing wifi offloading even in 5G brings some benefit such as; radio resources is reached to its limitation, so wifi connection can help to compensate this shortage. Also, as user equipment have wifi connection capability and building wifi hotspot is cheap, wifi is considered as cheap access network.

Integration of 5G and wifi are proposed in different cases. In the first case, the 3GPP eNodB as the anchor is responsible to steer the traffic between eNB and Wifi AP. In this case some adaptation is required on the RLC protocol on the wifi side. Also, in this situation, wifi AP and 3GPP eNB must be co-located or connected by the back haul.

The second approach is similar to the LTE Rel-13; LTE/wifi radio level integration using on IPsec Tunnel (LWIP). In the mentioned scenario, there is a secure tunnel called internet protocol security (IPsec) between a connected UE and wifi AP. This level of integration react to the dynamic changes in the wireless link quality which is different with traditional way [26].

2.5. Access network selection stages

Radio access network selection is a very important issue which does not see its importance diminished with 5G emergence. WiFi using is introduced to overcome the existing barriers from increased rate of data traffic. Deploying WiFi access has some side effects which operators must cope with. As the operators of the WiFi access in the home are different from 3GPP access in most of the time, the un-license accesses have different authentication procedure. Therefore, handover from one access to another access is not transparent.

Access network selection can be described in four stages, which can be entitled as collection, context selection, decision making and finding execution. Each of these stages can be recursively conducted in an interactive and interlocking manner. The two main approaches (user-centric vs network centric) determine how and in what direction each of these interactions take their course.

Access network selection is also a very important issue which continues to be its importance with 5G emergence. Considering WiFi limitation, introducing WiFi access helps to overcome the existing barriers from growing increase of data traffic. WiFi accesses which is installed in the private homes, offices or other places doesn't belong to the cellular operator, and thus access has interfaces issues, because operators are on the unlicensed spectrum. As the WiFi access has different authentication process, switching from a cellular network to a WiFi access is not transparent. Already, 3GPP has made it clear how WiFi access points can be incorporated with 3GPP architecture. ANDSF is thus as an entity which follows the policy rules as well as requirements in terms of security.

There are two mechanisms namely, Media Independent Handover (MIH) and ANDSF which is defined by IEEE and 3GPP, each of which enables a seamless VHO between various technological forms. In terms of vertical handover procedure, most research divide VHO procedure into three phases of information collection, decision making and handover execution. The VHO is studied as the access network selection in the decision phase. Some of the research has been done in user-centric access network selection and network centric. While user-centric scheme's goal is connecting to the network in the optimal way and regardless of network operations, the seamless handover to the other access networks while considering network parameters is the purpose of the network-oriented access selection. Nevertheless, the user-centric access network selection is not totally self-determining because the network is impacted by the context collected by the user.

A number of studies have been done in user-centric access network selection. For example Compass project is a comprehensive study in terms of network performance based on a context-aware scheme. In that study, they use ANDSF and FUZZY logic to help the UE in order to evaluate the available access networks to find the most appropriate one which is applicable [27] .

In papers [28] and [25], the network-controlled handover management is described as having some important limits in terms of maintaining the service continuity in case of handover between two access network with different operators. Various issues such as security concerns and data continuity should be addressed. They believe that a user-centric vision is a necessary condition towards the best connected services. A policy-based power saving vertical handover in order to improve the consumption of power is the aim of the cited project.

3GPP introduces different levels of access network coupling from open to tight to very tight. In open coupling (level 1), two different access network with different billing system exist. Tight coupling involves two different access network with common billing, authentication, authorization and accounting. Very tight coupling is the final extreme type.

There are certain uses for each type of coupling. The enhanced version of Generic Access Network (eGAN) is considered as a third Generation Partnership Project (3GPP) standard which can be trusted as an instance for tight network selection. There are some disadvantages for tight network selection such as; the tight and very tight access network selection is very expensive and complex procedure which requires some modification in the terminals and access networks. The common issue between all types of coupling is that the interconnected access networks operators have different type of agreement. Thus, because of above reason a loose approach will be preferred, in which 3GPP standard introduces the Interworking WLAN (I-WLAN) for the process of loose coupling interworking between 3GPP Networks and the WLAN. Mobile IP technique is then employed as the protocol for mobility.

Access network selection issue is considered in various aspects (which context considered for selection, which method will be used and in which part of network access selection will be done). Different studies have been conducted over access network selection in which parameters can be considered for selecting appropriate access network selection. These parameters are mostly relate to the quality and availability of network and the costs thereof, which are categorized in network, user and service profiles[29].

There are a lot of efforts in order to optimize the available standard access network selection mechanisms, as well as proposals for improving the access network selection procedures. Paper [30] designs and evaluates an innovative context-aware selection mechanism that employs the fuzzy logic in its journey to choose the most appropriate Radio Access Technology (RAT). In the mentioned paper, ANDSF is aware of surrounded network information and provides the constantly updated data about the status of network.

As described before, most of the proposals in literature focus on evaluation issue of the Reference Signal Received Power (RSRP) as there are significant issues about network profile and other user profile such as the speed of movement by the user is beyond just the location and can develop into a meaningful mobility pattern. In network selection, the expenditures are also important, such as battery level, the transmission power and power consumption of the UE are all inter-related, as well as the load upon the cell and the service type

Paper [31] takes a step further and focuses on the network selection issue as a goal to connect to the always-best connected in a wireless environment which is characterized as heterogeneous. They start with fundamental study on access network selection process aspects and then as the next part, they consider the decision making mechanisms, while the major goal of this paper is to study the influence of traffic conditions on network selection process to have best connected. Paper [31]categorized the network selection algorithm in two different ways depending on the type of architecture, accuracy of the collected parameters and protocol in use: centralized and decentralized.

To round it up, the access network selection have all been studied in their different aspects of selection, condition, coupling type and algorithms/methods. Access network selection can be done based on different context (user profile, network profile and services profile. Different context network conditions such as QoS parameters (e.g., availability, utilization, etc.) which can be applied in access network selection process. Moreover, different types of access network coupling are introduced by the 3GPP standard. Finally, various type of algorithms and methods can be run for decision making process.

2.6. The contribution of the present study

As described in this section, there are various approaches in access network decision making most of which are focused on RSS strength. Also, previous researches which have been conducted about context-aware access network selection have little regard for ANDSF capacity. Although, the paper [27], employs ANDSF in order to select the most appropriate access network between 3GPP and non- 3GPP, the context which are used in selection process is different from the ones used in the current research. In other words, service as well as user profile have not been given a role to play in access networks. Most previous research, as reviewed, sufficed to considering the network profile.

The aim of the present research is specifically considering a 3GPP standard (ANDSF) to help in context collection and management. This aim is fulfilled with employing ANDSF standard to reduce the number of discovered access network, which finally leads to reduce the processing delay and the number of era handover.

2.7. Handover decision making classification

As described before, access network selection is described in for stages entitled collection, context selection, decision making and finally execution. The execution process is called handover. The handover process is categorized in horizontal, vertical and diagonal handover.

Handover process brings the capability of service delivery with high bandwidth, throughput and packet loss deduction in heterogeneous network for service providers. In contrast, mobility management that meet the QoS and QoE requirements is a big issue. It is a complicated process as it brings the capability for user to shift between data and different cellular access networks.

Thus, most of the projects in access network selection have their main focus on decision making part before handover execution, while numerous issues can affect the handover decision. These issues include the available bandwidth element, as well as the cost, security, the quality, load and coverage of network, plus the user preferences. For example a user prefers to have his email on an expensive and highly secure access while still has its own web browsing in the cheap access connection. Handover decision making process has a very important role in service QoS and user QoE. The handover control can be assisted by network or controlled through mobile element. Either way, hanover control directly impacts on the its performance and execution.

Applying different intelligent and interactive equipment like mobile phones and PDAs bring the facility of free mobility which let users freely move between different access in order to access various applications. However, there is need for providing proper QoS in order to have always best connected mechanism between different access network technologies. Many parameters regarding QoS are considered as the vertical handover decision and will be focused in the coming chapters. As a conclusion, access network selection in the decision making part is categorized in RSS and QoS based scheme, Intelligent access network selection and Context-aware access network selection, which context-aware network selection is the emphasis of our current researcContext-based access network selection

First of all, the concept of context should be made clear. Context is defined as any piece of data which can describe the situation of a person, place, or any physical object. Using the appropriate context, the system is able to sense the context changes and do the proper action[32].

In context-aware handover decision making system, an initial step can be when the context from different layers are detected and then stored in a knowledge-base for optimal use and in making handover decision making process. As validity of the context information is very important, this information is updated and taken with the user requirements. The context-based handover is thus defined as a procedure in which handover is made based on the information of the mobile terminal and the context of network [33]. In order to make a decision, the context information is transferred to the decision matrix. Decision making based on the context information leads to decrease the delay which has happened as a result of re-establishing traffic flows in the mobile nodes.

There are various vertical decision strategies informed by the context which have been divided by [34] into categories of mobile agent- based, MIH-based, mobility prediction and cooperation-based, AHP-based schemes. as detailed in the following. Based on what explained, using these five schemes, the proposed model is the closest to the agent-based decision making.

2.7.1. Mobile agent-based decision making:

Mobile agents are programs that are installed in the mobile phones and can be distributed from one client to a remote computer server. Using mobile agent brings some benefits, e.g. when a mobile agent moves, it has the ability to store the state during the movements. Also, the agent can help in decreasing the task of decision-making as the time and location of this procedure can be decided by their current state[35] .

At the paper[35], a mechanism is introduced in which context-based data is downloaded at the decision point and then will be used at the time of handover. The project has incorporated a context management framework, as well as a programmable platform and a service scheme together. The context management framework takes the role of context collection and management for different services. This is possible using a programmable platform in order to download and install the appropriate modules for the exchange of context. Synchronization and management of the context is done using service deployment scheme which consist of two different modules named context repository and adaptability manager. The project considered multiple types of context information which includes user location, velocity and the quality of service (QoS) demanded through the application. The decision making point is on the mobile network side, while the context collection point is on the side of the network.

The issue of selecting a network that is aware of QoS depends on the way Analytic Hierarchy Process (AHP) contributes to the application of user-perceived QoS for the best possible performance of handover. The functions included are maximizing application bandwidth, as well as minimizing the jitter, delay, packet loss and the variations in bandwidthh. The suggested resolution smartly decides the process of using context information and handover in a mobile-assisted manner. To test the prototype performance working with diverse decision rules, a number of wireless networks would be used, which leads to a discovery that only smart decision strategies can ensure smooth adaptations with various context alterations. Moreover, this process ensures the increase in the throughput of the system [22].

2.7.2. Context-aware AHP-based Schemes:

In order to provide the high quality of service for the mobile end user, network application and services need to be made aware of their related context and their variation. In AHP-based method, a mathematical procedure is responsible for finding and commissioning the most appropriate choice amongst various alternatives in accordance with a set of pre-defined objectives. In AHP methods, two contextual factors, namely the network side and terminal side contexts are considered. The main pre-defined objectives should also be met for decision algorithm such as the priority of interface, as well as the multiple reductions in cost, delay, Bit Error Rate and Jitter. The next element is weighting which are assigned to the network parameters in the range of 1 to 9, where 1 represents the highest whereas 9 represents the lowest score value for a chosen parameter. The above-said can be calculated using the following equation formula (comes from [36]) :

$$G = \frac{L_u - L_l}{N_p}$$

As an explanation of the above equation, the parameter G denotes the numeric space-gap between the two scores, while the scores assigned as l_u and l_1 are the highest and lowest possible scores, respectively. Np indicates the number of parameters used in decision making process.

In the next phase, each of the networks which are available will be scored in view of their capabilities, as compared with the preferences of the users configured beforehand. Finally, these networks obtain a rank based on their scores assigned and the network and the highest rank assigned is ultimately selected for performing a handover operation.

As an example for AHP based handover, a project introduced an AHP method based on HO architecture in which context information is collected from terminals and network side, while the emphasis is given to mobile initiated and controlled vertical HO for decision making. In the AHP method, access networks with their context are compared with each other in terms of pre-defined objectives.

2.7.3. Context-aware Mobility Prediction-based Schemes:

Network vertical handover will be optimized using network availability prediction. In this regard, Weetit Wanalertlak [37] in a paper introduced a method in which Behaviour-based Mobility Prediction scheme is employed to remove the incurred scanning overhead as mentioned in IEEE 802.11 networks. In such a technique, the users' behaviour is measured for more precise prediction based on information of their location, group, duration and time of use during the day. Mobility prediction is based on the user movement considering the shape and size of a building or a city area and the past behaviour of the user. In this technique the user movement history or user group movement to the next predicted cell are saved.

Availability of network is considered as another very important concern in all of the generations of access networks. However, different procedures have been employed to achieve this in each generation. In one related study a mobility prediction mechanism is performed through estimating user behaviour, handover parameters are the time of the day, duration spent in any specific network, previous record of handover, group and location. Mobility prediction is one of the most accurate issues whenever the mobile users and their direction of movements within a particular cell are well-monitored. In this scheme, the handover decision is made primarily based on the users' periodic movements, instead of RSS or any other parameter for handover. When a mobility pattern is shaped, the handover decision making would be performed beforehand. However, if the timing or routing of the mobile user is altered, the entire schema should be rebuilt which leads to a longer handover delay and higher packet loss [49].

2.7.4. Context-aware Cooperation-based Schemes:

As the name suggests, this scheme is designed for cooperation of both handover and service adaptation altogether. The proposed mechanism has a number of functional entities including the context acquisition function, context informational provider, as well as context matching and mobility management. At first, the context information relevant to the radio network is detected and collected. The context information provider is responsible for collecting the data from context which is related to the user location and sensors. As the next stage, context matching is related to joining of the CAF and CIP contexts according to the mentioned application/user preferences in order to attain optimal QoS. As the final step, which comes after handover command, the mobility management element is made responsible for seamless handover. The entities described above contribute in building the handover procedure faster than the service adaptation in order to prompt the user about the possibility of switching to a network with contains better QoS. As in this method, the resource is allocated in advance, the user experience can be improved in terms of call blocking probability, waiting and response time. However, the mentioned method leads to a higher number of handover occurrences and a so-called Ping-Pong effect. In contrast, using this method improves the spectrum utility and the desired throughput as perceived by the end user.

2.7.5. MIH-based Context-aware Schemes:

The IEEE 802.21 Media Independent Handover (MIH) provides a seamless handover between 3GPP and other families of IEEE which enables the handover from the second layer access technology to the next . In this method, information in vicinity from network and client side are collected and stored in order to make intelligent decisions. MIH protocol is residing between layer 3 and interface protocol lower layers (MAC and PHY) in IEEE based access networks and (RRC and LAC) within 3GPP based interfaces. MIH can be placed in different places, e.g. in the local terminal, or in the network elements of the access networks or even in the Information services (IS), which can contain home network policies [38].

Media Independent Handover function (MIHF) as the heart of MIH is responsible for communication among the various layers and IP layer. MIHF function can provide different services including Event and Command Service as well as Information Service. Media Independent Handover Event Service (MIHES) takes into account all MIH actions related to the detection and notifications of events corresponding to the links selection which includes link quality and link status. These events can be local or remote[39].

There are also other types of functions in research literature. Media Independent Information service (MIIS) is another type which acts as a storage infrastructure for all information. It has static link layer parameters, e.g. channel information, or the Medium access control (MAC) address of the access point (AP)) related to MIH decision. Media Independent Command Service (MICS) is through high level layers to manage the network re-configurations and the lower layers.

All in all, IEEE 802.21 aims to process the handover mechanism in three phases which includes handover initiation, preparation as well as handover execution. In the first step of handover initiation, radio measurement reports (urgent handover request or periodic informational message) from device and new radio link discovery are reported. Meanwhile, other MIHF services (MIES, MICS, and MIIS) can help in handover preparation process with scanning of other access networks close to the MN. After scanning the access network, mobile device attempts to authenticate itself in the access network, while checking the charging policies and QoS context for resource availability are the inputs of the decision algorithm. At the end of these procedures, the Handover execution step is out of scope of IEEE 802.21 [38]. In literature, Paper [40] introduced an Enhanced Information Server (EIS) to reduce the vertical handover latency using MIH standard. Applying EIS module, some information such as location, timing, and the RSS level from the UE are collected and applied for decision making so that the handover is to the best available access RAT. Although using this method, in writer's opinion, ignores the channel scanning, it may have some additional signalling in advance which can affect the entire performance.

2.8. ANDSF as a future of network selection decision making

3GPP has defined the Access Network Detection and Selection Function (ANDSF) as an entity of EPC core to support the UE for discovering the non-3GPP access network and 3GPP access network. It act the same as automatic handover process which users prefer automatic network selection based on the operator priorities saved in USIM card. ANDSF has been introduced by 3GPP with different releases. In the first release 8, an introduced interface allows an operator to offer policies regarding the WiFi network selection to the terminals and define the time and location of using 3GPP and Wi-Fi networks.

ANDSF as an optional element can be placed in the home network and visited network called H-ANDSF and V-ANDSF respectively. The ANDSF is introduced for operators to set their policy in order to assist the UE in handover process. It has data management and controls functionality for providing network discovery and selection. The ANDSF can act in two ways for user assistance. First, there is UE request to access network discovery information (pull mode operation) and then in network triggers to push the access information to the UE.

There is an interface between UE and H-ANDSF / V-ANDSF for direct queries, which is called S14. In other words, S14 reference point is applied to enable dynamic provision which must consider both Pull (UE-initiated session) and with Push (ANDSF-initiated session) mechanisms [41] . For ANDSF rules, first of all, a UE gets an IP address and then connects to the ANDSF to take some rules. The UE can provide the location information, UE profile with sending package 1 message. On the other hand, the UE may initiate the provisioning of all available information from ANDSF by sending a client initiated session alert message. Validity areas, position of the UE and availability of the access networks in terms of the location are defined by MO (Management Object) [28]. According to the 3GPP standard, the ANDSF can provide the intersystem mobility policy, the access network discovery information and the intersystem routing policy information which is explained in detail later. ANDSF can provide all types of information or only one of the above information pieces. Either the H-ANDSF or V-ANDSF then select the policies regarding inter-system mobility, discovery data of the access network and the intersystem routing policies are to be transmitted to the UE based on the operator requirements and the agreements reached in terms of roaming. The UE preferences which have been set in the handset have high priority in comparison with operator policy, in at least a few areas. In below, ANDSF provided information is described in detail:

1) Inter-system mobility policy: when a user is capable to connect to one access interface (the user cannot support connection to multiple interfaces), some operator-defined policy will be useful. In this case, the most preferable access technology based on inter-system policy is selected. These policies are provisioned in the UE by the ANDSF in the push mode or may be received by the UE based on UE Request. The inter-system mobility policy emphasizes which access type can be more preferable with which access network identifier (e.g. WiMAX with BSSID-1 is preferable to WLAN SSID2). Also, the availability of the inter-system mobility policy should be indicated by the inter-system mobility policy.

2) Access network discovery information: the ANDSF should provide the UE with a list of all types of access networks available in the whereabouts of the UE with the UE request. The provided information includes the type of access technology (such as WLAN, WiMAX, etc.), or the identifier of the radio access network (such as the SSID of a WLAN), or even the other technology specific data, such as a number of carrier frequencies and validity conditions (access interface validity).

3) Inter-System Routing Policy: when UE has IP Flow Mobility (IFOM) capability or Multiple-Access PDN Connectivity (MAPCON) capability (can route IP traffic simultaneously over multiple radio access interfaces), a list of inter-System Routing Policies can be provided to the UE by ANDSF. A IFOM UE can have different IP flows to the same PDN connection through the different access networks. Some different filters/rules are defined to route specific IP flows through prioritized APN. This filter also clarifies which access network is restricted for which IP flows.

A UE with MAPCON capability or A MAPCON UE is one that can have different access networks which run simultaneously active PDN connections all through different radio access.

Provided policies by ANDSF can be summarized as two mains steps. Firstly, the inter-system routing policy specifies when a specific access network type is restricted for a specific IP flow traffic. Secondly, the inter-system routing policy specifies which access type to be used in order to connect to the EPC. The selected access network is indicated by the access type and its identity. Also, the validity of the selected access and supported frequency band are other options for that.

A UE with MAPCON capability or A MAPCON UE is one that can have different access networks which run simultaneously active PDN connections all through. An operator/user configures preferences to route PDN connection through different radio access. Also, these polices specify the restricted radio access for a special APN to route PDN connection. 3GPP recommends to have at least one connection over 3GPP for CS fallback in which the UE must stay attached to LTE if CS Fallback or SMSoSGs is used. MAPCON policies are recommended in the case of availability of at least one APN/PDN connection in LTE. Enabling this policy produces some benefit such as reducing the signalling load in the network as well as enabling a quicker handover from WiFi to LTE.

A IFOM UE can have different IP flows to the same PDN connection through the different access networks. Some different filters/rules are defined to rout specific IP flows through prioritized APN. This filter also clarifies which access network is restricted for which IP flows. 3GPP introduces NBIFOM after IFOM. In NBIFOM technology, a PDN Connection simultaneously connected over 3GPP access (S5 connection to a PDN GW) and WLAN access (S2b connection to the same PDN GW). A NBIFOM capable UE uses ISRP in that ISRP gives reply to what APN, what IP-flow, what Access, etc.

4) Inter-APN Routing Policy (IARP): these policies indicate Which IP-flows to route across types of PDN Connections (APNs), and which traffic should be offloaded non-seamlessly to WLAN (NSWO) based on IP-traffic filters -> IP-flows x and y on APN / PDN Connection -> IP-flow z for NSWO. Non Seamless WLAN Offload [12] specific IP-flows routed not via EPC. This routing is based on policies from the operator, Local Operating Environment Info (LOEI) and user preferences.

2.9. Challenges of integration of WiFi and EPC together

As discussed in previous section, the simultaneous access to 3GPP and non-3GPP networks is already possible. But there are still challenges to be addressed in the network design. Three main challenges are considered in resent literature.

Firstly, The UE is forced by the network to camp on WiFi in terms of availability of WiFi AP. This process is automatic. In such a scenario, the UE does not consider the backhaul capacity in air interface monitoring. Hence, the backhaul connection speed of the Wi-Fi AP is lower than that of the cellular network. In that case, the UE has perhaps made a poor decision about offloading onto the Wi-Fi network. In other words, whenever the Wi-Fi AP backhaul connection speed proves to be sufficient in order to match the speed of the cellular network, it should bring about an improved QoE for the end user. To increase the quality of decision making, an end-to-end connection speed evaluation should be considered prior to traffic offloading. If so, any downgrades on the part of the QoE will be decreased.

Secondly, the processes in the next scenario looks like the first scenario, in that the UE can be prompted to choose the heavily-loaded (L) WiFi AP. In so doing, the backhaul is either sufficient or better than that of the cellular network. Nevertheless, there might be a problem of heavy load on wireless channels. This probably happens while many UEs are using the AP. Similar to the first scenario, if this happens, the situation can be resolved by providing an end-to-end connection speed evaluation before the traffic offloading.

In a third scenario, where urban places with high-density population exist, Wi-Fi APs are virtually present in all places but mostly have little overlap. In this situation, the UEs happen to often bounce between the cellular and Wi-Fi networks, which can dramatically reduce the user QoE. Moreover, a large amount of resources is just wasted on signalling, which in turn, increases the signalling traffic at the network while this radically downgrades the QoE for the user. A ready-made resolution to this situation can be to set the cellular network in a way to remain with the UE whenever high mobility is detected.

2.10. Previous research on ANDSF

ANDSF has attracted some attention in researching access network and resource reservation process recently. While some papers in literature use this entity for network selection alone, most of them implement this entity in addition to other mechanisms in order to obtain the best possible results as for network selection. Paper [2] illustrates how a new solution can work for the adapting the services to the network conditions of the mobile device in each moment and its use does not demand a complete end-to–end re-signalling. In their method, ANDSF acts as a service enabler which results in reduction of link signalling load.

Complementary to this paper, research provides another mechanism for adapting the services to the network conditions with transient nature. This type of adaptation includes decision making about resource reservation with due consideration of the preferences of the mobile device and the capabilities of the application as advertised during service connection. In their proposed novel method, again no demand is re-negotiation of the end-to-end service parameters. In all, the latter studies provided a developmental basis to launch projects which consider all important aspects in the modern era and discover further decisive elements and be inclusive of the needs of all stakeholders. They are a break from the earlier service adaptation procedure.

2.11. Service adaptation

In this chapter, a general to specific review of the significant issue of service-adaptation is elaborated.

In service adaptation process, the delivered services will be adapted by the context of the user application and momentary network connectivity conditions based on the parameters exchanged during the negotiation [2]. Currently, establishment of service has a deficiency in terms of providing a reliable mechanism for adapting to the momentary connectivity. This situation prevents the dynamic service delivery from performing in line with the momentary preferences of the mobile users. The service adaptation requires both of the decisions for reservation of resources in line with the preferences of the mobile device and users as well as the needed capabilities for adapting the application as advertised during the setting up of the service. Resource reservation is a process in which channels or bearers have been dedicated for special services. Resource reservation occurs in two situations: service establishment and handover[11].

Handover is occurred because of changing in the physical parameters of the source access network or network initiated command. Traditional access network selection for handover was based on various physical parameters such as strength of the received signal. In contrast, today, the capacity of access network to cope with the momentary conditions of the user of the mobile device play important role for access network selection. Cost is another important parameter for access network selection. For example, WiFi connection is a cost efficient way to gain access network. But selected access network must have required capacity for desired QoE and QoS. Leaving the configuration decisions to the user him/herself leaves the access network selection process with insufficient information. In order to have sufficient information for efficient access network selection which meet the users' expectation of service quality, the mobile device should interact to other entities to get required context.

In most of the previous research access network selection and resource management framework includes network part (including context collector, context repository and decision making centre) and a mobile part which is an application residing on the side of mobile node [42] .

2.12. Service adaptation and resource reservation in evolution

LTE has been deployed around the world since 2009. The gravity of LTE access network such as speed has so far attracted many users. As more users share the capacity of the network at the same time, the QoE was on the decrease. On the other hand, WiFi connection as a cost-efficient way to gain access to the internet was introduced to have wide spread coverage and availability for the devices. Users' behaviour is changed to be always-on connectivity over flat rate subscription and relying on their smart phones. Various access networks are identified by variety of connectivity parameters such as various delays and throughput. On the other hand, it is expected that services are to be delivered over a heterogeneous environment. As momentary operational cost and access network parameters varies from one access network to another, delivery of the same service is different over various access networks. For example, for downloading, one user prefers an access network with low cost and high resources such as UMTS.

Recently, mobile service providers have shifted their aims more towards optimizing the service delivery in a way that resource reservation process considers user parameters. Resource reservation modification procedure is now triggered by the mobile device either automatically by re-negotiation of the service parameters with the service providers or the request of the user. When the context of access network is changed, the mobile device has to initiate the service modification with the service provider according to its set profile[2].

In current wireless networks, it is assumed that the mobile terminal is in charge of transmitting session parameters related to the required resources for the specific services over the current access network. It shows that session parameters are negotiated between mobile device and service provider during service establishment and handover. Since, different access networks provide different level of QoS, with changes in access network parameters, the new parameters need to be negotiated between service provider and mobile device.

One of the methods introduced for resource management is estimation for required resources for special services. This enables the connectivity provider firstly to be able to authorize service provider request (e.g. according to the defined SLA) and secondly to estimate the network demand at certain locations and during the transmission time frames. This goal is achievable with extensions of the interface between service provider and the resource allocation part. QoS providing over various access networks is a critical issue, as different wireless technologies provides different QoS. The concept of estimating network demands for IP network has been introduced by Feldman et al. paper [43] proposes a method of estimating network demand based on metering records collected by the charge and account system in lieu of measure of flow-level operated on each link. One of the proposals in reference contains a different method for estimation of resources in which there is special account for the demands of a network created by multimedia services. The info collected are then transmitted based on a pre-defined schedule and to a number of pre-defined users. The input to the estimation process is also to the information obtained from the process of metering or charging.

The delivery of required services during the above said processes are listed below in five clear steps:

- **Step one is service setting-up phase:** In this stage, the user and service provider negotiate on the terms of service parameters and network.
- **Step two is resource reservation phase:** During or after the setting up of the session, the resources needed would be identified and allocated in order to make sure a certain high level of QoS would be met.
- **The third step is delivery phase:** In this step, the contents intended in the service would be actually delivered from the service provider to the user.
- **The fourth step is network context change phase:** This step is necessary since network context may be changed due to handover within the same service delivery. Thus, it would be decided if and whenever the network context changes, the session parameters have to be negotiated again between the mobile user and the service provider.
- **Finally, it is the termination phase:** In this last phase, the user is indicated that when a session is terminated, the system should be made aware of it. The session can be abruptly terminated due to a number of reasons during session setup, session update or resource reservations phase.

All the stages described above contribute to collection of context which can be outputted in service profile, later to be used in proposed scenario.

It is also noteworthy that in the service establishment process, the PCRF does all the policy-based resource reservations based on the profile obtained from the user and the service. The service profiles which can be collected through Rx interface from AF (Application Function) help better decision making when a decision is needed to the PGW through Gx interfaces.

Moreover, when a service is advertised, the user receives the data and information about all services. During the user registration session for obtaining a special service, the items of service profile are important to be set by the user, such as the service QoS, data rate, and the jitter. In accordance with the selected service profile, the service providers send out the request for resource reservation to the PCRF which is responsible for resource reservation. PCRF decides whether and how the resources are reserved based on the profiles of the users and service, as well as elements like the start time, service duration and network profile. The final decision is forced to the PGW as it is a dedicated bearer.

It is also important to consider the network demand for each service be since it is like a matrix that covers new profile, and the quality of service in question. A resolution is resource prediction of multimedia content delivery as to the data collected during the service subscription. The data can be elicited from the users with an interest in special service profile. Paper [11] proposes a novel mechanism for adapting the services to the momentary conditions of the network. In this paper, two resource data based on the user preferences would be stored, which avoids unnecessary re-negotiation between service provider and resource reservation in terms of the variations in context (Handover process). The resource reservation decision is made instead, based on the preferences of the mobile device in question and the adaptation possibilities of the application as advertised during service set up. This all can enable a more dynamic service delivery without heavy requirements on the part of procedures performed for resource re-reservation.

2.13. Service adaptation and network selection

In service adaptation process, the delivered services will be adapted by the context of the user application and momentary network connectivity conditions based on the parameters exchanged during the negotiation. This situation makes an impact on the resource reservation results in PCRF. As in heterogeneous networks, there are various access networks, selecting the proper access is according to the different criteria such as user preferences, required QoS, required QoE, network context, etc. The results of studies on network selection are varied, however, a general consensus about network selection mechanisms notes on providing seamless connectivity and guaranteed QoS. Performing a reservation of the resources in order to ensure the required QoE and methods for translations between different technologies and operators are mentioned as the most important issues, shared with all. To address such issues, IEEE 802 aims to provide overall end-to-end solutions for interworking with external networks [44]. The layer two "transport" is introduced for a query response protocols (ANQP). The proposed protocol allows users to effectively query the network selection in prior sessions.

2.14. Summary of the chapter

The chapter is about the convergence of the worlds of internet and telecommunication and the constancy of network, technologies and terminal capabilities, which are the motivation for doing research around access network selection algorithms. Various radio access networks such as cellular, GSM, CDMA, WCDMA, HSPA, LTE, WiFi, Wimax, etc are introduced by various standards in order to cope with the high demand of data transmission. Standards categorize the access networks into two the 3GPP access and non 3GPP. It was then explained how non 3GPP access network are subdivided to the trusted and untrusted access network.

Context-aware handover processes were described in four stages entitled as context collection, context selection, decision-making and execution. It was explained how sources like [36], claim that vertical handover decision can be based on different categories such as: RSS based schemes, QoS based schemes, decision function based schemes and context-based schemes and context-based schemes. In this chapter different criteria were also analysed for access network selection from projects reported in literature. The decision making part and its parameters were also analysed with a specific focus on context-based access network selection. Finally, ANDSF and Hotspot were studied as two exemplary standards for selecting the network.

Considering the methods and standard explained in this chapter, the proposed approach which is using in thesis is context aware approach assisted by ANDSF standard. The idea is employing ANDSF as an engine for decision making which maps the collected context to its rules. Context which ae using in the process of decision making are fixed and dynamic where are collected through standard interfaces from different parts of network. Because of Varity in network, service and user context, choosing the most suitable context and deploying some predefined rules on them can reduce the size of decision matrix. As much as the size of decision matrix is smaller, the time of network selection will be less. In the next chapter, the standard of ANSF will be explained in detail.

The other concept which is discussed is service adaptation process in which the delivered services are adapted by the context of the user application and momentary network connectivity conditions based on the parameters exchanged during the negotiation. It was explained how service-related information can be delivered during some process are made of service setting-up phase, resource reservation phase, service delivery phase, network context change phase and termination phase. Service providers send out the resource reservation request to the PCRF which is responsible for that. Resource estimation is an approach to reserve the required resource in case of network context changes. ANDSF can act as repository to keep the reserved resource in the resource reservation process via connection to the PCRF.

CHAPTER 3

3. Chapter on Context-awareness

Awareness of contexts has recently been and continues to be the focus of researching mobile networks. In future, the heterogeneous networks that have information about the users and services will bring a lot of benefits. As an example in heterogeneous network delivery, a special service can be possible with different options in terms of networks coverage, quality of service, cost, etc. Taking user preferences into account provides a user-centric approach in heterogeneous networks. As an example, selecting an access network requires user and service contexts. In other words, network selection algorithm can be context-aware.

Making network selection and service adaptation context-aware is possible with designing a middle-ware between mobile users, wireless operators and service providers in order to negotiate different contexts. Also, there is a requirement of central database which makes network selection algorithms context-dependent.

A system is called context-aware that can adapt itself to the location of use, the collection of nearby people, host and accessible devices, as well as related issues over time. It can be clarified that the context aware system has ability to sense the surrounding contexts and react to changes in those context [45].

In this chapter, the concept of context is explained in detail and then network elements will be studied in terms of their information which can be applied in access network selection process. The content of this chapter is the basis for designing the final proposed architecture. In this chapter, the ANDSF MOs will be explained in detail with its rules which later is used in order to reduce the size of decision matrix.

3.1. The concept

As explained previously, the user context and preferences play an important role in making the system context-aware in terms of network selection and service adaptation. In this part, the entities and the negotiation between them in the LTE/EPC (Long Term Evolution/ Evolved packet Core) network are explored to see which entity has user context and how these contexts can be exchanged.

At first, the concepts of context and their usage in different aspects will be detailed. Then, the context-aware concept as networks and systems will be explained in general.

In the next step, it will be explored how a context-aware architecture can help in access network selection and service adaptation will be studied. Moreover, the previous context-aware access network selection processes in heterogeneous networks will be explained. Finally, the weaknesses and strengths of the previous proposed scenarios are addressed and the proposed scenario will be explained in terms of signalling.

3.2. The classification of contexts

Context is categorized by Gwizdka in paper [46] into the internal and external types. The external context is measured by external hardware such as sensors which include location, light, sound, movement, etc. The second type is so called internal (or logical) context which describes the state of the user such as the context of user's goal, tasks, work, processes, and the emotional states, etc.

Having the definition of context and context-aware concepts explained, a question can be raised as the following. What are requirements for a context-aware system?

Number of parties must cooperate with each other to make a context-aware system work. This is not an exhaustive list and only the relevant parts(to the proposed scenario) is included in the following:

-location/ context technology vendors

-mobile network vendors

-content providers

-Location Based Services (LBS)/context middle ware

-context/location aware application

-different location/context aware services

-entities to determine the contexts (GPS, GSM, WiFi, etc.)

-terminals

-software platforms

-security and privacy architecture

-context representation and handling

-context rule

-context objects

In the same mod, there are various context consumers as a part of context aware applications which can consume different kinds of contexts such as navigation applications. Moreover, EPC entities will be studied in terms of their context and will be explained which entity has which kind of information.

3.3. EPC context in general

The latest evolution (release 8) of the 3GPP core network architecture is called EPC (Evolved Packet Core). The EPC has flat architecture to handle the data traffic efficiently in terms of performance and cost. The EPC is made of four network parts, and the Serving Gateway (Serving GW) is the first, while the PDN Gateway (PGW), the MME and the HSS are the next elements [47]. Each one is described in some detail in the following paragraphs before turning to their significance.

The HSS is the repository of the user related data and services provided to them. HSS stores the parameters of the users such as their IMSI, subscribed QoS, authentication data used to authenticate the subscriber, as well as properties of the circuit switch (e.g. the telephone number and the services any one user is permitted to use), mobile subscriber routing number (MSRNs) in order to correct routing, ID of MME or SGSN and properties of the packet switched such as Access point name (APN) permitted for the user, access restriction information, IMEI information, serving MME IP address. HSS has connection to the MSC, Mobility Management Entity (MME), Serving GPRS Support Node (SGSN), Gateway GPRS support node (GGSN) and Application server (AS) and optionally to the ANDSF [47].

The MME contains the context and EPS bearer context data for UEs in the ECM-IDLE, ECM-CONNECTED and EMM-DEREGISTERED states. The MME has information such as IMSI, MME id, GUTI, TAI/Cell id, subscribed PDNs, UE capabilities, security parameters, SGW IP, TEI and charging info. Also, for each PDN connection the MME has APN information in use, UE IP address and PGW address in USE. Also, for each EPS bearer whitin the PDN connection, EPS bearer ID, SGW IP& TEID, PGW IP & TEID and charging & QoS information are the information of the MME [47].

In S-GW, the basic role of serving gateway is to transport IP traffic between eNodeB and the external networks. The SGW has three different interfaces toward PGW, MME and eNodeB are named respectively S5, S11 and S1. S1 and S5 interface are user plan interface which is individual tunnel varied by user and service. In order to manage the signalling process, the MME and SGW can be defined separately in independence nodes. The SGW include IMSI and MME IP and TEID in general. Also, for each PDN connection APN in use and PGW IP & TEID are stored temporary in SGW. Finally, P-GW is the point of interconnection between the EPC core network and the external IP networks. The PGW allocate the IP address/IP prefix and policy control to route the packet traffic to and from the PDNs. IMSI and RAT in use are the general context in PGW. While for each APN in use, its APN and max bitrate are known by PGW. [47]

3.4. Significance of context-awareness in LTE

The significant of context awareness is beyond doubt in mobile communication; however, its special significance in LTE requires clarification. The lack of real-time dynamic data about the resources available as of access networks can be an example in LTE that shows how the limits are with that of the standard context-aware system. Without the available network resource information, for each handover process, all the available networks must be asked for the resources one by one and then choose the proper network. Depending on the number of available network , this process takes a lot of time [48].

3.5. EPC functional features

3.5.1. Interconnection with service providers

Apart from the functions of EPC, it also provides a control interface between the service platform and the network core (RX interface), in order to transmit different context to the applications. These contexts can be an example or an indication that resources need to be reserved for specific users.

Also, application can be aware of events happening at link and network layers. Using this technique, the applications can be adapted to the momentary UE context. As a result, the service can be customized based on the user profile, and network contexts. This trend makes the mobile instrument more responsible.

As in this project service awareness is implemented using ANDSF, some entities such as Policy Charging Control (PCC), Deep Packet Inspection (DPI) and Traffic Detection Function (TDF) are introduced in the rest of the thesis as standard application identifiers. Then, the collected context from these entities is used to set as dynamic ISRP rules. In this architecture, ANDSF is set as the central part of transmitting and receiving different context to different entities. Following the idea in the current thesis, bellow sub sections clarify the context of each network entity which can be used in the process of the decision making.

3.5.2. The PCC architecture

PCC (Policy Charging Control) provides the operators with cutting-edge tools for service-aware QoS. As different services with their own demands must be provided to the different users simultaneously, managing the available resource and providing appropriate QoS plays important role. The PCC can take a lot of roles including the counting the traffic of the users, policy controlling, charging controlling and application awareness [49].

The Application Function (AF) is a policy controller part in the application server which can interact with the application and service server. The application level signalling for the service passes through, or is terminated in, the AF. Session information is extracted from the application signalling by the AF and provided to the Policy and Charging Rules Function (PCRF) over the Rx interface. Also, the AF has opportunity in order to subscribe to certain events at the traffic-plane level. The traffic-plane events are made of events such as termination of IP session or change of access technology type. In terms of subscription of AF to the PCRF, the PCRF will inform the AF of its incidence [50].

The policy control features takes gating control and QoS control into account. Gating control reports the session events (session termination, modification)from AF to PCRF over Rx interface which shall be applied per service data flow in Policy and Charging Enforcement Function (PCEF). The gating control decision is made by PCRF results allowing or blocking a special IP packets belonging to IP flows for a certain service. On the other hand QoS control in the PCRF, assign the authorized QoS (authorized QoS class and the authorized bit rates) for the IP flows. In addition, the PCEF applies the selected bit rate to the special services and a certain service session does not exceed its authorized QoS.

A new PCC feature using TDF or PCEF enables application detection and control. The Traffic Detection Function (TDF) is a functional entity that provides application detection and control to the PCRF. The TDF should detect start and stop of the application traffic for the ADC rules [51].

3.6. PCRF functionality

Several different PCC architectures are available for PCC depending on the use case. As an example for application level-signalling between UE and EPC, the AF can be used to provide QoS information to PCRF about the application to be set up [44].

PCRF is considered as the central part of PCC and can make the service and application level policy decision in order to provide to the PCEF.

3.6.1. PCEF

PCEF resides in PDN GW which enforces the session decisions. Also, the PCEF may perform measurements of user plan traffic and report them to the charging functionality or to the PCRF.

Another entity might be included in PCC architecture is DPI (Deep Packet Inspection) which try to detect certain traffic type.

3.6.2. TDF (Traffic detection function)

As the enhancement of the PCC, The traffic detection function (TDF) introduced as an standalone entity in order to handles the coordinated applications detection and control. TDF is a functional entity that provides application detection and control to the PCRF [51]. It enables the operators to provide application awareness network control. TDF use TDF application identifier for corresponding application[52]. In 3GPP core networks, the network control flow is followed in PCC as described in a way that firstly, applications type is described by TDF and is reported to the PCRF. In the next step, the PCC rules are provided to the PCEF.

The TDF shall support solicited application reporting and/or unsolicited application reporting [53]

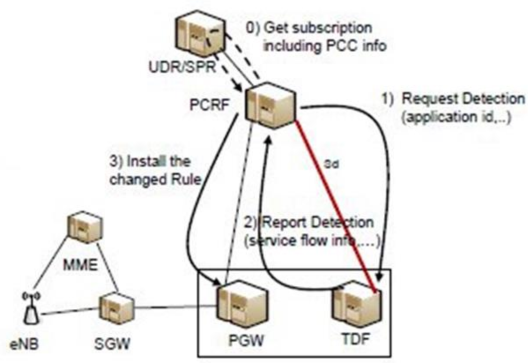

Figure 3.1 Traffic Function Detection from [54]

Figure (3.1) shows the process of how TDF can interact to the PCRF in order to get the application information from the AF and provide it to the PCRF which is Explained below steps in detail [54] :

- In the first step, the AF is subscribed which receives the initial policy.
- In the second phase, the PCRF Requests detection information such as application ID from TDF.
- TDF Reports detection information (service flow information, ..) in response to the PCRF over Sd interface.
- PCRF force the new rules to be applied in PCEF.

3.7. Which entity, which information!

The first step in making a system context-aware is collecting related information. In the first part of chapter 3, the context information of MME, SGW, HSS and PGW are described. In the rest, the context information of the rest elements will be explained in detail. PCRF can provide information such as type of IP-CAN bearer and its attributes and location of the subscriber. While PCEF include context information of the subscriber (IMSI, MSISDN, APN, location), RAT type, requested QoS and Traffic Flow Templet (TFT) filters, AF (Application Function) which is a policy part of a special application includes subscriber identifier, IP address of UE, media type and format, required bandwidth, Flow status (for gating decision), gating information, priority indicator (in order to guarantee service for an application session of a higher relative priority by PCEF) and emergency indicator.

In this thesis, the ANDSF act as a central part in decision making process. The proposed ANDSF keeps the context and use them in decision making process. In order to show how the network, user and service context can be employed by the ANDSF; rules can be assigned. The following sections elucidate the ANDSF MOs in which proposed standard ANDSF MO employed and collected context are mapped to its leaf shown in chapter 4.

3.8. Components of ANDSF in access network selection

Subscriber information repository - through this function, ANDSF can query the subscription profile related information. Also, ANDSF can subscribe to different event in terms of any subscription information modification. This part can be equipped with the subscriber repository in order to keeps subscriber related information such as user preferences. User preferences can play vital role in user-centric access network selection.

Resource Control functionality – The ANDSF is expected to be informed about the MN's momentary reserved resources. Also, in order to make a right decision in handover process for finding the right access network, ANDSF is required to have information about the available resources in specific target access. Furthermore mentioned interface can be subscribed to the event of the resource modifications event in case of changes in the access network selection decision.

Mobility Control Interface – in order to receive the mobility information from the core network ANDSF may be subscribed to the event of mobility control in which the indications on the access network selection decisions can be transmitted.

User Interface – as the most famous ANDSF interface, S14 interface is used in order to receive the required information for decision making process including location information, UE capability and user profile. Through this interface, ANDSF can push the final decision for access network selection to the UE.

Access Network Coverage Map – there is research [55] in which ANDSF is equipped with a map indicating the status of the access networks, as well as their location and their specific parameters. The map can be updated straight through the network management system.

Decision Engine – as the last part of decision making process, the engine can make the decision according to the mentioned inputs and then can trigger the handover command. It can be equipped with the policy decision functionalities.

3.9. ACCESS selection using ANDSF

The ANDSF entity is introduced by the 3GPP as the core element to help the UE in access network selection process by acting as a database to collect the network context[56].

As described before, ANDSF MO is used to manage access network discovery of data, intersystem mobility policy and the policy of inter-system routing. Information provisioning may initiate from ANDSF to UE or vice versa over S14 interface rely on XML protocol. The validity areas, as well as the position of the UE and the availability of access networks are defined by MO [28]. Management Object (MO) is defined as a collection of data related to a specific application or service. At the top, management tree is responsible for organizing all the available MOs in the UE. Using management object and management tree helps in finding and accessing each nodes directly through a unique URI by the UE and ANDSF server[57].

The connection between ANDSF and user relies on client server mode for information exchange. MO's management is the responsibility of the ANDSF server. The commands between ANDSF server and client include add, delete, get, etc., which are used to transfer the information between ANDSF server and ANDSF client in the user.

In figure 3.2, ANDSF MO is illustrated which include Policy, discovery information, UE location, ISRP, UE profile and other node. For the next features each of these nodes have many leafs. ANDSF MOs can be employed for mapping the context to some rules. As an example; each UE location is considered a context, for which a rule can be assigned.

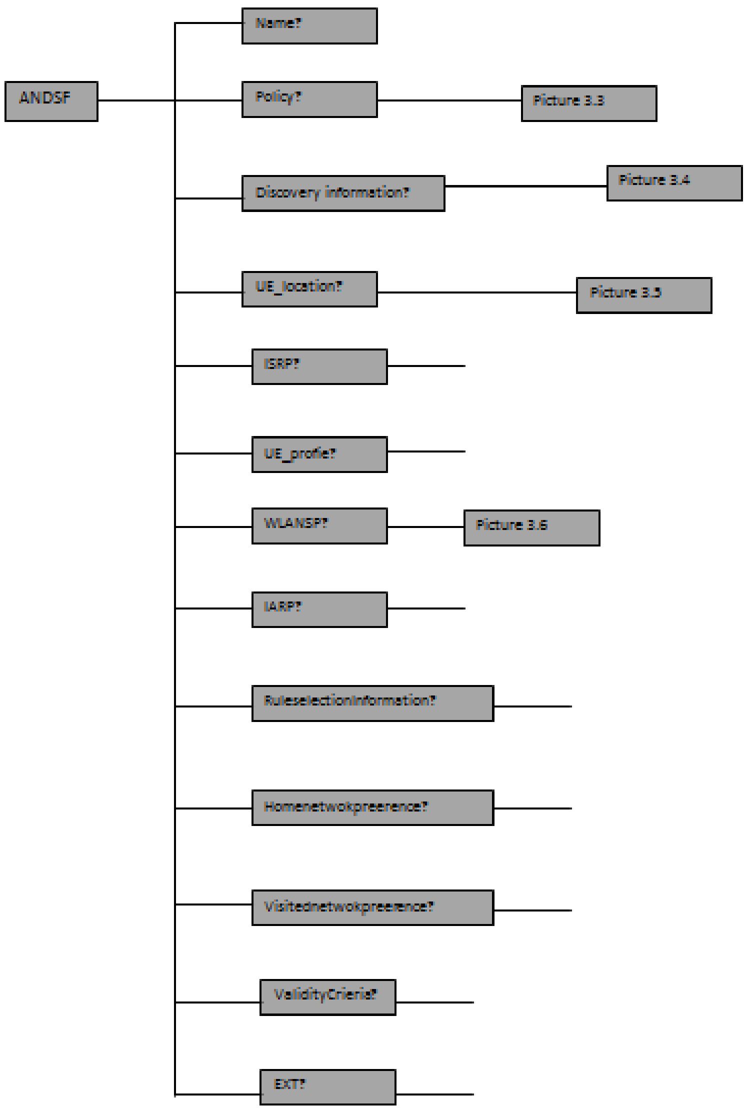

Figure 3.2: ANDSF leaf architecture (based on TS 24.312)

Creating OMA DM management and stablishing connection between ANDSF and UE consist of two steps: authentication process and transferring the mandatory management objects between UE and ANDSF server[57] . The UE uses DNS lookup or DHCP query to discover the IP address of H-ANDSF. Also, the IP address of V-ANDSF can be retrieved by the UE through DNS lookup[28] .

In the Push mechanism, the UE receives a SMS message. After connection of ANDSF and UE, six sets of information can be transmitted between them through S14 interface which will be described below in detail.

- **Policy node(ISMP)**

  Policy node includes validity area, prioritized access list and validity conditions. Validity conditions can includes location, the time of validity, current access technology and so on. The rules have number of results such as preferred access network and restricted access technologies. ANDSF can select the highest priority active rule and then UE start network reselection process. User can use tracking area code, Cell ID, WLAN SSID in order to stablish a new alternative RAN[28]. Figure 3.3 illustrates the Policy node.

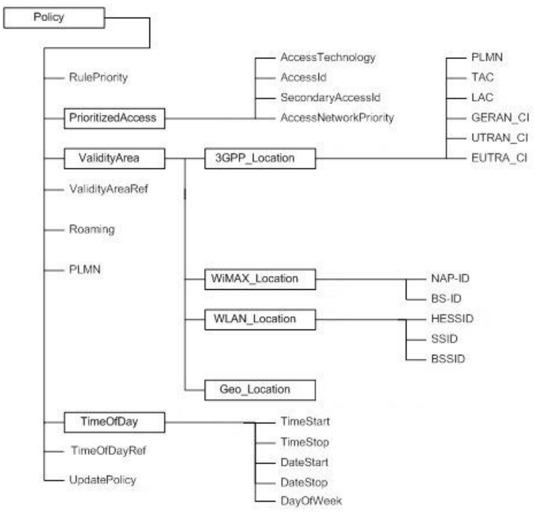

Figure 3.3 *policy MO architecture (based on TS 24.312)*

- **Discovery information**

  The UE must use a client initiated session which contains alert message to ANDSF for requesting discovery information. The discovery node indicates the RAT types in the neighbourhood of the UE specified by the TAC, WLAN SSID and cell ID. The Discovery information MO is illustrated in figure 3.4.

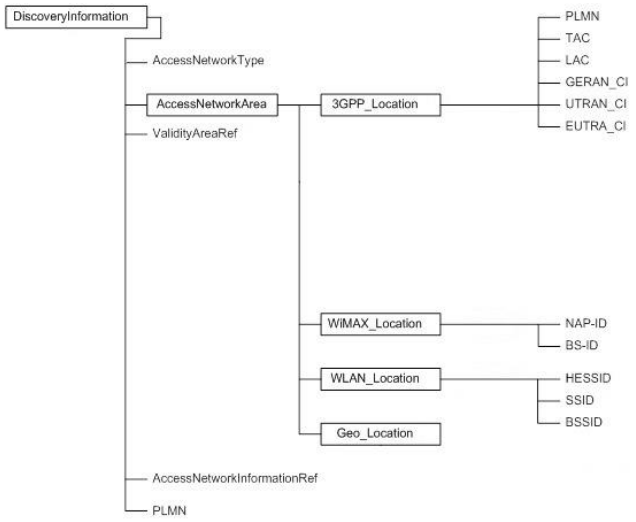

Figure 3.4: discovery information MO architecture (based on TS 24.302)

- **UE location**

The ANDSF MO has a node specify the position of the UE. The location information is sent by the UE to the ANDSF is based on PLMN identity, TAC and Cell ID and send to the ANDSF server. Also, it can be given from WiFi network by HESSID, SSID, BSSID messages sent over the beacon. In the Geo location leaf, GPS receivers can provide Latitude and Longitude information and then provide to the ANDSF server. In the Figure 3.5 the node of UE_location is illustrated.

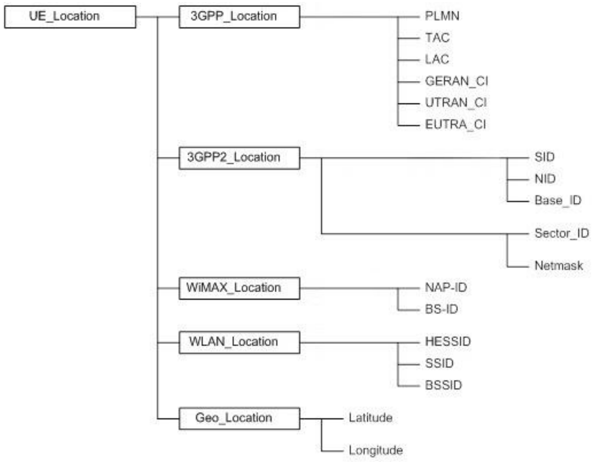

Figure 3.5: UE location MO architecture (based on TS 24.302)

- **ISRP**

  The ISRP information consists of one or some rules in which each rule has a PLMN leaf and may optionally has roaming leaf. At any time point, an active rule will be applied. When a UE roams to a visited network, there will be home ANDSF rule and visited ANDSF rules in which visited ANDSF policies has high priority. An ISRP rule can be, for Flowbased, for IFOMservices, for Servicebased, for MAPcon, for Nonseamless offload and for Non-seamless WLAN offload.

  Each of the above flow distribution rules can have validity condition taking into account including time of the day, validity area and APN which make a rule valid.

  - IFOM, this technique makes possible to route traffic based on IP flow to same PDN connection over both 3GPP and non-3GPP access
  - MAPCON leaf has responsibility to route different type of traffic to different PDN connections in 3GPP access and non 3GPP access.

- **WLANSP**

  The WLANSP node acts as a place holder for WLANSP information[17]. The Most important rule of WLANSP is to create a prioritized list of selected WLANs. The UE should use the prioritized list of selected WLANs manually or automatically. In the first method, the UE has static priority list of WLANs. While, in the automatic WLAN selection, the information of ANDSF WLANSP's node will be applied. The WLANSP node include information such as: a list of prioritized access networks in roaming partners, maximum acceptable channel load and minimum backhaul requirement which are advertised by the WiFi AP, as shown in figure 3.6.

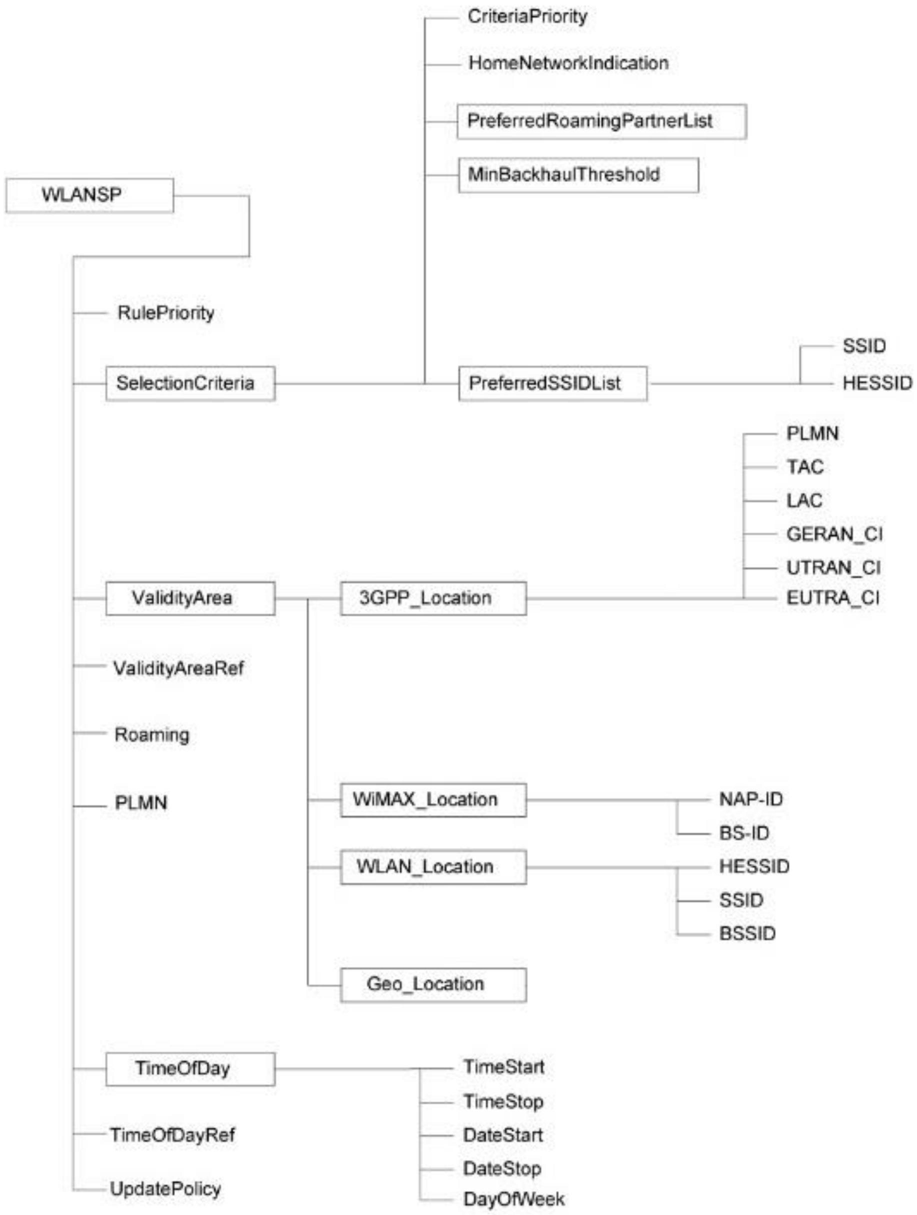

Figure 3.6: WLANSP MO architecture (based on TS 24.302)

3.10. ACCESS selection using ANDSF

In this part standard access network selection using ANDSF entity will be described in detail.

1. The UE may discover other RAT via broadcast message or via ANDSF.

2. The ANDSF pushes some information including the routing policy based on some triggers e.g. the location changed.

3. The UE attaches the other RAT and then during PDN connection setup procedure sends the routing rule to the PGW. In case of other RAT is WLAN, the UE sends the routing rule to the EPDG by VSNCP signalling. The ePDG delivers routing rules to the PGW using PMIP signalling. Otherwise, if the other RAT is EUTRAN, the routing rules will be sent to the MME by UE using NAS signalling. In the next step, the MME delivers it to the SGW/PGW via S1 and S5 interfaces.

4. The PGW initiates IP-CAN session modification procedure with the PCRF. The PDN GW provides the updated routing rules to the PCRF.

5. The Attach procedure is completed. The PGW provide UE with IP address and the indication that the routing filters have been installed at the PDN GW is provided. Per the routing policy, bear in EUTRAN is maintained by the PGW.

6. The PCRF provides appropriate QoS rules based on the IP-CAN session modification procedure which is installed in the target access.

7. The PGW enforces the routing policy and begins to split/aggregate the user data.

3.11. ANDSF shortage

As described earlier, ANDSF is one of the introduced standards in a cellular technology which helps UE in dynamic data process. Currently, ANDSF standard includes some static operator policies provided by the operator in order to help in dynamic vertical handover process. Real- time network conditions, current load of the access providers and the situation of the interfaces are not provided by the ANDSF. For such kind of information which is related to the dynamic situation of access interfaces, Hotspot2.0 was introduced by standard to help the UE in access network selection process. Although, there is not any clear standard for prioritizing between ANDSF and Hotspot2.0 yet, there is an approach in which ANDSF provides a prioritized list of access networks and then Hotspot2.0 can work on this list to make the selection, thereby skipping the 'scan' procedure.

Also, Np interface is another standard which is used in order to transmit the congestion information to the core network. As a result the ANDSF and Hotspot 2.0 and Np interface could act together for making the access network decision-making more efficient with maximizing the provided UE context [58, 59].

We know that fixed ANDSF is employed by operators but the contribution of this thesis, is this regard is both dynamic and fixed ANDSF information and rules that can be employed to reduce the size of decision matrix.

3.12. ANDSF scenarios

The access network reselection should be based on the users' request or the operators' policy which is provided by ANDSF or set in the UE.

In UE procedure, for access selection and reselection, the UE can receive information for access network selection from ANDSF. In contrast, in the EPC procedure, the ANDSF should send the access network accessible and operator's policy to the UE [17].

The ANDSF policy information about non-3GPP access from any network can be stored in ANDSF in various cases such as; when a device is not connected to the WLAN network and WiFi network, the device has no connection to a WLAN network but the WiFi interface switched on and finally in the case that the UE is connected to a WLAN network.

Regarding the location information, a location context can be stored in the ANDSF based on PLMN, TAC, LAC, GERAN-CI, SID, BSSID, WLAN-id, SSID, longitude, latitude, etc,. [28]. When a user come to a valid area, the related policy will be applied. In case of availability of two policies for a valid area, the policy in the leaf of "policy priority" will be applied.

Time information is another context which is considered as additional validity condition for setting operator policies, so operators can send policy according to the location area in a valid time.

The operators may provide the data needed about the available access networks through the ANDSF which can be used by UE in order to help in access network process. The possible values for access technology leaf are 3GPP, WLAN, Wimax and reserved.

Also, Operator can set a policy in which connection to a specific interface is restricted to a special location and time[28].

3.13. Input information

In traditional handover, access network selection is based on RSS measurements in order to reduce the ping-pong effect. There is some research in which the RSS thresholds along with link quality metrics are two important factors considered for access network selection. More recent research considered other context such as power output limitations, terminal speed and batter life. Currently, as positive user experience is important, it can take into account in decision making process.

In the current research, below contextual information is considered for decision making process:

Location Information – the received estimated location information from external mechanisms like GPS or specific access network technologies can assist the ANDSF to focus only on the access networks which are located near the UE. Also, the location information can be received from UE in query mechanism over S14 interface. This mechanism helps in energy efficiency solution for access network selection mechanism.

Momentary User Preferences – the user can play important role in access network selection process with providing user preferences information. The user preference includes a list of preferred access networks available or the radio technologies which are preferred by the user to be selected in decision making process. Quality of Experience (QoE) can be added to the preference information collected during subscription profile query or as a separate query.

Subscription Profile – the subscription profile determines the limitation of each user in terms of connecting to access network and QoS over different access network.

Active Session Profile - the resource control adopts a session for each active service which includes an account of the exact data for differentiating and the allocating resources like QoS class, guaranteed resources, etc. During the decision making process, data about the aggregated resources, need to be backed up by the accessible and existing resources on the target access network. Furthermore, when a change occurs in the resources reserved for a known subscriber, it may need a decision to be made for access network reselection. The change of the resources when needed is a result of a change in the state of the MN, such as a situation when idle to active mode is happening or a change occurs in the active services during the implementation of the procedures like when the service is being established, modified or terminated [60].

Access Network Events - the ASE needs to retain the information regarding the MN's reachability status in order to adapt the decision making to the context of MN which can be momentary. However, this type of information is made available with a definite delay from the Dynamic Subscriber Information since the ASE decisions are asynchronous (not at the same time) as the actual handover procedures. The transmission signal would be departed at a just a moment before the actual handover, while no assumption is made as to the actual time of occurrence of this handover.

Network Status Information – the status of the available access networks in the area of the UE location can be used as a trigger for access selection, which may be pushed for all subscribers in a specific area in order to maintain well or save energy.

Cost - Cost of using a particular access network is the major factor in a user-centric access network selection. Different operators can propose different billing schemes such as: for voice services billing can be based on duration, while billing can be based on the volume of downloaded data. In fact, operators can offer flat rate price for ultimate services in ultimate duration and ultimate downloaded data volume [29].

Link quality- There are some parameters such as signal to noise ratio (SNR) or signal to interference plus noise ratio (SINR) which reflects the transmission channel quality. This information can be considered as the network profile to be considered in the process of the access network selection.

3.14. Summary of the chapter

Awareness of context has recently been and continues to be the focus of researching mobile networks. It was explained that a system is context-aware when it adapts itself to the changes in the surrounding context and how they can be external and internal. In this chapter, after defining the concept of context, entities of EPC are studied in terms of their provided context. ANDSF was also described in detail. ANDSF which is introduced by the 3GPP acts as a database to collect the network context. ANDSF MO includes the policy, discovery location, ISRP, UE profile and other nodes which have been described during this chapter. The operator may provide information on available access networks through the ANDSF which can be used by UE in order to help access network selection process. It was then illustrated the possible values for the access technology of 3GPP, WLAN, and WiMAX. After all, it was explained how the operator can set a policy in which access to an interface is restricted to a special location and time.

Providing the ANDSF with the fixed rules can bring the benefit in reducing the size of decision matrix. The contribution of this chapter to the topic this thesis, as it might be clear, is to demonstrate how the building blocks function and work together as component elements of the variables of the study. The links between those elements which collect contextual information are made clear to help the whole Figure meaningful.

This chapter is finished by describing the ANDSF scenarios, ANDSF components and the input information which can be applied in a comprehensive access selection and service awareness system considering the limitation of the ANDSF in providing momentary information.

CHAPTER 4

4. Proposed scenario

4.1. Background

As a matter of timely necessity, the direction of present research has focused on proposing and evaluating different frameworks for traffic steering in heterogeneous networks. In order to evaluate an access network selection algorithm, different factors are defined. These factors are delay, load balancing among networks, QoE, QoS and network resource optimization. A relevant research, proposed a method for vertical handover between cellular and WiFi while specifically considering objects such as low latency in handoff, power saving and bandwidth overhead in handover process. This present research employs a similar approach to investigate the access network interfaces' capabilities and delineate the limits of its application, while also keeping it open to the users for obtaining and satisfying their preferences.

To fulfil both, the research findings by Anton and his colleagues in their paper [61] can be employed as a means to which a network-centric resource management framework can assist to offload the traffic. In other words, it can work as an assisting element in the decision-making process by collecting feedback and requesting network demands. Building on that idea in the present research, an Information service (IS) component keeps a database of available network profiles and user profiles to make better decisions for traffic offloading in a way that leads to achieving a certain level of QoE.

From another point of view, in a paper , a middleware is defined which claims to choose a best access interface for each application flow. They are applying various information such as surrounding context, application requirements and user or administrator preferences by defining comprehensive set of profiles in order to save all the contexts. In the mentioned research, two different layers (higher layer and lower layer) are defined in which the first one collects required information about user/ administrator preferences and the system information and application requirements. The latter part monitors available access networks, required network configuration and selection of execution procedure.

As explained in the literature review, several studies consider a middleware application in which different factors such as interface capabilities, access network characteristics, application requirements and user preferences encountered for access network selection. The middleware as middle layer is responsible to manage the collected context from lower layer and send the selected access network command to the upper layer. The difference between context-based approaches mostly returns to the point of how to collect the context, which kind of context are considered, the employed weighting algorithm and how the access network is selected from the decision matrix. Paper[31] has considered cognitive pilot channel (CPC) for collecting all the neighboured access network parameters, then users preferences and service parameters play important role in weighing the network parameters using AHP protocol.

The papers tend to reach a consensus using extra modules for context collection management. Some of these modules are entities which are not standardised, a point which can bring some difficulties for the operators. Operators usually do not prefer the network, user and service context to be accessible for other devices. ANDSF, as a standard entity for context management, is a key element in the current thesis, with its initial release 8, which then evolved with its new features in rules. It has standard interface with user and can completely be controlled by the operator. The HOME and visited ANDSF rules can be updated easily by the operators based on their agreements. In this chapter, a proposed comprehensive architecture is introduced in order to answer the raised question in the first chapter. Also in the section that follows it, the proposed scenario will be evaluated with MATLAB simulator.

4.2. Framework

Service adaptation is a concept which functions when a network context is changed (for example when handover has occurred in the system). With the aim to update the context information, re-negotiation will happen between user and service provider in order to maintain the service in an acceptable way. Thus, in order to have comprehensive framework for access network selection and service awareness, some profiles are defined in this project. These profiles are in fact the contexts collected from different part of network which will map to the ANDSF MO objects. All the network entities are responsible for collecting all related information (explained in the EPC entity information previously) in different layers, while the final decision is then made on the network side. There is a trade-off, as context collection process can affect the battery life and increase consumption. In other words, using context in decision-making process can reduce the number of extra handovers which is the process responsible for most of the battery consumption. Also, periodic access network searching is a second process with high power consumption. Now, employing ANDSF can brings some rules to omit extra handovers with a benefit of power saving for the user. In order to avoid unnecessary queries from ANDSF and the subsequent network scanning, optimisation in time of question would be required (for example, the ANDSF query can be shorter than the distance between UE and closest WLAN Ap).

Profiles are used for understanding context. Three different profiles have been defined to classify various context issues named network profile (NP), user profile (UP) and service profile (SP). They are described in some detail here. Network profile can include the information describing the network situation. An available network can guarantee a certain level of QoS, while the other networks can have certain level of resources allocated to some users. The user profile can be set as parameters that user wished for a special services such as required QOE, minimum price profile and battery power consumption. Also, for different types of applications, various classes of services are defined in which a user can expect some quality parameters. For instance, for streaming service, there is high demand on bandwidth, low latency for voice services while for synchronization there must be low packet latency.

Having considered that, two more profiles are used for an economic purpose, money-wise or time-wise. Firstly, for decreasing the overall price of traffic transmission and controlling the traffic consumption, a minimum price profile is defined for the user. This kind of profile optimises the access of the application through different interfaces. The battery power is yet the second profile, which shows the remained battery power capacity in order to restrict the extra number of handovers.

These elements are so interrelated that convincing or employing one should be consistent with the role of others as well. For instance, the network profile (NP) must convince the QoS requested by the UE in user profile (UP). Also Service profile (SP) must convince the UP criteria and so on. Therefore, the output of the decision algorithm is a selection of the network profile and service profile according to the user profile. In the rest of the chapter, the decision making algorithms for access network selection decision making part are discussed.

4.2.1. Multiple attribute decision making

In the scenario described so far, after collecting all of the context information from various parts of the network, making decision is the next step in choosing the best access network. Multiple Attribute Decision-Making (MADM) provides one such decision-making process which makes preference decisions over available characters (access networks) with different attributes.

MADM is a part of Multi-Objective Decision-Making (MODM). Generally speaking, MCDM methods are subdivided in two groups namely MADM and MODM. MCDM method is defined by a decision matrix in which a problem with N criteria (C) and M alternatives (A) are set. For each criterion, the weights are assigned for making better decision.

In paper [62] MADM and MODM are compared with each other to point to some differences. In MADM method, a decision is made based on the criteria while in MODM the defined goals are the main characters of decision-making process. MADM is a method that helps us to make decision considering available alternatives which are grouped by multiple attributes , while MADM problems can be described by a matrix with attributes in columns and alternatives in rows. Therefore, an element in matrix described with x_{ij} indicates the value of ith alternatives with jth attribute.

Alternatives are defined as the number of candidates which are monitored, prioritised and stored to be used in MADM matrix (in this present study, these are considered as different access networks).

In the MADM matrix for each alternative, different attributes (characters) are considered in decision making matrix. In the case of the access network selection, attributes can classified to upward (bandwidth, cell radius, security, battery, RSS, SNR, etc.…), or downward attributes (price, traffic, BER, jitter, packet loss, jitter, etc...) and then static (cell radius, security, price, power consumption, etc...), or dynamic (battery and semi-dynamic attributes (such as bandwidth, Bit error rate, jitter and service completion time, etc.) .

Decision matrix is a type of matrix which describes a MADM problem briefly. The columns indicate attributes and rows indicate candidates. Thus, a typical element x_{ij} of the matrix indicates the value of the ith candidate with respect to the jth attribute. Remarkably, in this project, the decision matrix is introduced with M×N size where M is the number of surrounded networks and N is the number of decision making parameters or criteria which M and N is a positive integer. x_{ij} is an array of related matrices which indicates measure of j_{th} parameter of ith network as below.

$$\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{1N} \\ x_{21} & x_{22} & \cdots & \cdots & \cdots & x_{2N} \\ \cdots & \cdots & \cdots & x_{ij} & \cdots & \cdots \\ x_{M1} & x_{M2} & \cdots & x_{Mj} & \cdots & x_{MN} \end{bmatrix} \qquad (5\text{-}1)$$

Attribute weights is yet another important concept discussed here. We know that some aspects in decision process are more important from others when ranking the candidates. Hence, weights must be calculated to show the significance of such multiple attributes. Each weight w_{ij} should satisfy some conditions:

1- Each weight is not negative $0 \le w_{ij} \le 1$
2- For each criteria $\sum w_{ij} = 1$

Before showing how to meet those conditions, the different methods of weighting should be explained. First of all, equal weighting which is the preferred procedure in most of the applications, happens mainly when the following four conditions are met: "(i) the theoretical structure attributes to each indicator the same adequacy in defining the variable to be measured, (ii) the theoretical structure does not allow hypotheses to be consistently derived on differential weightings, (iii) the statistical and empirical knowledge is not adequate for defining weights, (iv) the correct adoption and application of alternative procedures do not find any agreement" [63].

Secondly and finally, differential weighting is assigning differential weights especially when the decision is not supported by "(i) theoretical reflections that provides a meaning for each indicator or considers its impact on the synthesis, (ii) methodological concerns that helps in finding the proper techniques, which are also consistent with the theoretical structure" [63].

There are different methods for weighting which can be categorized generally in two groups as objective and subjective methods. Expert-opinion is the basis of the subjective methods while the mathematical evaluation of data is the basis of objective methods. As, the subjective method is based on expert judgment, it is naturally uncertain. On the one hand, the potential uncertainty in expert judgment is the main disadvantage of the subjective methods. On the other hand, the knowledge and experience can be sound and do not affect the objective weighting [64]. There are some methods called Entropy and variance which are categorized as objective method. From the weighting method, Eigenvector, Weighted least and Trust can be left for further study[65]. However, normalization, as illustrated in Table (5.2), is quite a good match and related to unifying various attributes in the network which have different measurement units. Thus, normalization is what can be considered as the solution to unify them. There are different methods for normalization such as max-min, square root, sum and enhanced max-min represented in the Table (4.1). For a given attribute j, x_{ij} represents the value of the ith network in terms of this attribute, and v_{ij} represents its normalized value [65].

	Normalization Function
Max-Min	$v_{ij} = \frac{x_{ij} - min(x_{ij})}{max(x_{ij}) - min(x_{ij})}$
Square root	$v_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{N} x_{ij}^2}}$
Sum	$v_{ij} = \frac{x_{ij}}{\sum_{i=1}^{N} x_{ij}^2}$
Enhanced MAX-MIN	$v_{ij} = \begin{cases} 1 - \frac{\lvert x_{ij} - Max(x_{ij}) \rvert}{max(x_{ij}) - min(x_{ij})} \, for\ upward\ attributes \\ 1 - \frac{\lvert x_{ij} - min(x_{ij}) \rvert}{max(x_{ij}) - min(x_{ij})} \, for\ downward\ attributes \\ 1 - \frac{\lvert x_{ij} - \Lambda_j \rvert}{max\{max(x_{ij}) - \Lambda_j ,\ \Lambda_j - min(x_{ij})\}} \ for\ nominal - the - best\ attributes\ in\ which \\ \Lambda_j\ is\ the\ \text{nominal value of attribute j.} \end{cases}$

Table *4.1: NORMALIZATION METHODS FOR ATTRIBUTES IN NETWORK SELECTION [65]*

4.2.2. MADM algorithms

A MADM method is a procedure which specifies how a choice can be made with special attributes. There are two major methods for MADM, called non-compensatory and compensatory models. In the first model (non-compensatory), as far as possible, desirable attributes should not be set to compromise with each other. The disadvantage of this method is that each attribute cannot be compensated by another one [66]. However, noteworthy point is that most MADM algorithms that have focused for the network selection problem are compensatory algorithms, containing simple additive weighting (SAW), Multiplicative Exponential Weighting (MEW), Gray Relational Analysis (GRA), Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS), etc. .

After preferring compensatory model, let's turn to the choice of algorithm. SAW as one of the MADM algorithms, is widely-used by most of the studies of the network selection problem using functions like cost or utility. This algorithm is described as in the following statements. Simple additive weighting (SAW) is one of the best known and most widely used scoring methods because of its plainness. For vertical handoff decisions, the parameters need different measuring units, and thus the value of the parameters is required to be normalized initially. In SAW, network ranking is based on summation of w_j

and r_{ij} where $r_{ij} = x_{ij}/x_j^+$ for benefit parameters and $r_{ij} = x_j^-/x_{ij}$ for cost parameters. Furthermore, $x_j^+ = \max_{i \in M} x_{ij}$ and $x_j^- = \min_{i \in M} x_{ij}$ and weighting vector must satisfy $\sum_{j=1}^{N} w_j = 1$. At last, the selected network is A_{SAW}^*:

$$A_{SAW}^* = \arg\max_{i \in M} \sum_{j \in M} w_j r_{ij} \qquad (5\text{-}2)$$

TOPSIS technique, as first introduced by Yoon and Hwang, is for making a decision by similarity to ideal solution. It is based on the concept that the attribute with shortest distance from the goal solution and farthest from the negotiation solution should be chosen. Weighting solution can be used as one approach in which, an alternative with minimum weight has farthest distance from the solution which is considered ideal. The decision matrix has M networks that are evaluated by N decision. The proposed method from [66] are described by the steps described below:

A. Making the normalized decision matrix in order to compare all attributes together, attributes should be changed to non-dimensional attributes. Mentioned element r_{ij} is the element of the normalization matrix R which is calculated as:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i \in M} x_{ij}^2}} \qquad (5\text{-}3)$$

B. In this step, weighted normalized decision matrix is constructed:

$$v_{ij} = w_j * r_{ij} \qquad (5\text{-}4)$$

C. Defining the ideal as well as the negative-ideal solutions by

$$A^+ = \{(\max_{i \in M} v_{ij} | j \in J), (\min_{i \in M} v_{ij} | j \in J')\} \qquad (5\text{-}5)$$

And

$$A^- = \{(\min_{i \in M} v_{ij} | j \in J), (\max_{i \in M} v_{ij} | j \in J')\} \qquad (5\text{-}6)$$

J equals to the set of benefit parameters, and J´ equals here to the set of cost parameters.

D. The set of positive and negative ideal networks were defined as the following formula

$$S_i^+ = \sqrt{\sum_{j\in N}(v_{ij} - v_j^+)^2}, S_i^- = \sqrt{\sum_{j\in N}(v_{ij} - v_j^-)^2} \quad (5\text{-}7)$$

E. Finding out the relative closest to the ideal solution were considered as follows

F. $c_i^* = \frac{S_i^-}{(S_i^+ + S_i^-)}$ (5-8)

G. The formula for selected networks which is based on this algorithm is

H. $A_{TOP}^* = \arg\max_{i\in M} c_i^*$ (5-9)

Previous techniques (TOPSIS and SAW) are used in order to find the best access network generally. In the current thesis, these techniques are employed in an optimised way. It is optimised because, as the decision matrix size is reduced in two stages which will be explained in the next part.

4.3. Proposed Architecture Procedure

After explaining the pros and cons and procedures in the previous sections, it is time for presenting the proposed scenario in the present study. For evaluation of the proposed scenario, certain factors are also defined and considered. Overall in this thesis, two of the most important reduction factors are considered as of the processing delay as well as the number of extra handoffs, since these are two significant factors that can foil ping-pong impact focused on in this study. The reduction and optimization in the mentioned parameters will be possible with reduction in size of the decision matrix. This process is due to the fact that various types of traffic classes and the role of voice connection and data connection are focused in this project. Considering the voice context, the elements of packet delay and packet jitter have more weight in comparison with other parameters. While considering the data context, the available bitrate and maximum bitrate weigh much more in proportion to other elements. It is also significant to mention that our heterogeneous networks are made of three UMTS networks that are named as UMTS1 (Network 1), UMTS2 (Network 2) and UMTS3 (Network 3) (UMTS3 does not fulfil the ANDSF rules and deleted in the first stages). Moreover, two WLANs are chosen in this architecture and these two networks are WiMAX, which are named respectively as WLAN1 (Network 4), WLAN2 (Network 5), WiMAX1 (Network 6) and finally WiMAX2 (Network 7) [67]. Figure 4.1 shows the proposed structure using ANDSF in order to apply its rules for access network selection.

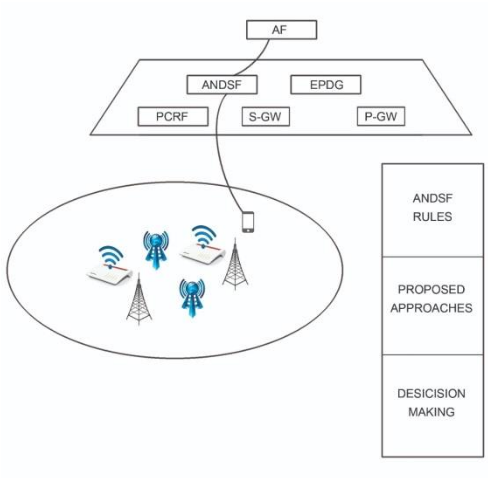

Figure 4.1: proposed scenario relation between ANDSF and network

Weights are defined based on different service delivery cases:

Case 1: all the parameters have equal weights

Case2: for voice connection; packet delay and jitter have 70% of importance and the rest of 30% is divided between other parameters.

Case3: for data connection, available bandwidth and total bandwidth have 70 percent of importance and the rest of 30 percent is divided between other parameters.

A discrete-time Markov chain is used in order to model the time changes for each of characters. Also, discrete-event simulator is use in MATLAB. Also, for each vertical handover, 50 points is considered.

The ANDSF plays its most important role as the first filter for reducing the size of decision matrix. According to what described as the ANDSF MOs' in chapter 4, some fixed rules are defined by the operator (based on ANDSF policy node information, ISRP, ISMP, user location, WLAN SP which are explained in chapter 3 in detail). Thus, some available access can be omitted from decision matrix. Here it is assumed that UMTS3 network is not allowed in the current location of the UE. Figure 4.2 shows how collected context can be mapped to the ANDSF MOs.

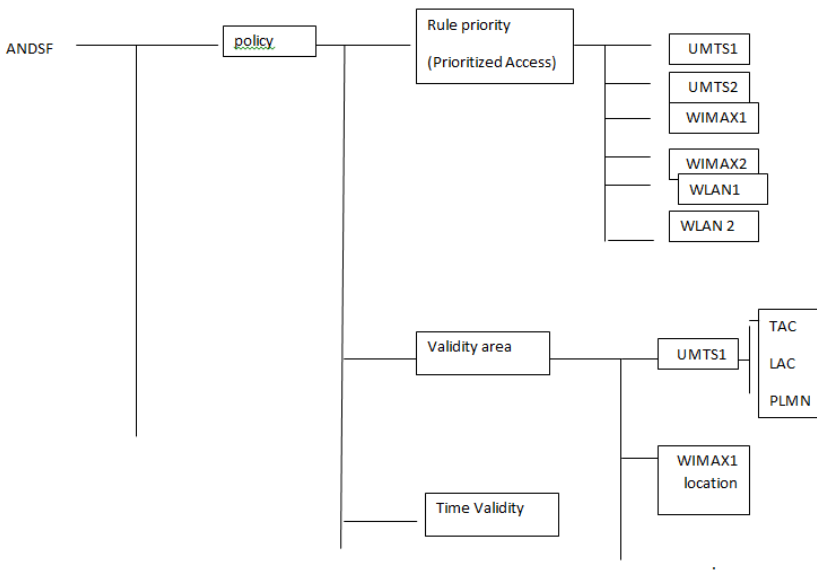

Figure 4.2: Mapping the collected context into the ANDSF MOs

The present research has followed some steps to reach the aim in order to select the optimized network:

1. Discovering the available RANs in the location of the UE (50 points for each vertical handover point is considered. However, the user movement and velocity is not taken into consideration).
2. Fulfilling the RANs criteria such as bandwidth, security requirements, QoS.
3. Constructing network profile, user profile and service profile according to the required context (mapping to the ANDSF MO).
4. Considering the ideal profile with acquired profiles and thus to ignoring some access networks (network profile must fulfil the requirements of user profile).
5. Selecting some access networks to be left out, as ANDSF rules applied in the access networks. Hence, the decision matrix become small and manageable in two steps; firstly by the ANDSF, and then by the proposed method. As fully explained in chapter 3, there are various ANDSF rules which are configured by based on various agreements with other operators. A question which is raised here about the operator rules is if an operator can set rules in an unfair way in which users are forced to connect to the operator access, so how can it be managed? This question can be answered in a number of ways. Firstly, as proposed in this thesis, user priority which is mapped into the user profile plays an important role in the final decision for handover. Secondly, according to the agreement, there is a priority between different rules provided by the home ANDSF and visited ANDSF)

6. In parallel ANDSF, the second reserved resources are saved in order to adopt the services to the context changes (because of handover).

ANDSF messages are composed of six set of information such as name of access networks, policy, discovery information, ISRP, UE profile, WLAN SP, etc. which can be initiated either by the UE or the network. The UE exchanges information with the ANDSF over the s14 interface. The interface then employs the Open Mobile Alliance Device Management protocol (OMA-DM) which is a Hyper Text Terminal Protocol (HTTP). The UE discovers the IP address of the ANDSF via a Domain Name Service (DNS) lookup, Dynamic Host Control Protocol (DHCP) query or an IP address provided in the UE by the Operator. The communication between the UE and ANDSF is either in PULL or PUSH mode. In the PULL mode, the UE makes a query and sends it to the ANDSF to retrieve information about access network discovery, ISMP or ISRP. In the PUSH mode, the ANDSF responds to the UE queries and provides the information about the access networks within the proximity of the UE. Necessary data such as Service Set Identifier (SSID) or Basic Service Set Identifier (BSSID) for WLAN, Network Service Provider (NSP) or Network Access Provider (NAP) for WiMAX are pushed to the UE. The ANDSF is, therefore, a major element in the core network which provides support for data offloading. As described earlier, a static configuration of ANDSF by the operator leads to the lack of the real-time state of the access networks nearby or in the vicinity. Therefore, if followed this way, the selected access network may not meet the QoS requirements of the users' application [68].

In this thesis, access network is proposed to be selected in different layers considering user context, and that of service and network, as explained below.

- Network-based context: the technical characteristics and performance of the access networks such as reliability, coverage and congestion are expressed as network context.

- Service-based context: some parameters such as delay (ms), jitter (ms), packet loss (per 10^{-6}, bit rate, etc..., which are transferred from service provider to the PCRF. Service level context which are transferred over the Session Description Protocol (SDP) plays such a vital role in order to ensure the QoS level provisioning for end users.

- User-based context: the profiles are defined according to the parameters which can increase the user satisfaction such as minimum price and maximum battery life time. The context can be collected from the users, saving in the application installed in the mobile device or can be fetched through connection to HSS over a diameter interface.

Therefore, as there are different approaches in context collection such as collecting from the previous section, collect recent values, data prediction, this current research assumes to collect online information over various interfaces.

As described before, ANDSF in standard has just one interface called S14 to the UE. However, there are various research studies which define diameter kind interface between ANDSF, HSS and PCRF. In [69] a functional extensions of the PCRF and ANDSF are considered in which ANDSF can receive indications from the PCRF which are then transmitted to the mobile device through the use of a minimal OMA DM PUSH mode mechanism. Paper [70] extend the ANDSF functionality in order to detect the congestion characteristics of the heterogeneous networks and handover UEs attached at the crowded network to the network which is not so crowded at that moment. 3GPP access network can show the congestion condition of uplink and downlink channel to ECN (explicit congestion notification) to ANDSF via s14 interface in the location of the UE according to the 3GPP standard.

Network profile information are as the congestion information which are collected over Np interface from RACF to the PCRF. Then, PCRF can push the collected information to the ANDSF over a diameter protocol.

Using the Session Initiation Protocol (SIP), the UE begins the establishment of a video session with a video server. Over the SIP connection, service profile including SDP (Session Description Protocol) is downloaded to the ANDSF client. SDP includes the service information (media type), required QoS, supported codec, or even security level information, etc.

In order to adopt the services to the momentary context, it is required to define a second resource in order to produce any change in the network context. The second resource is saved in the ANDSF. This process occurs parallel to the first resource reservation during service establishment.

User context can also be collected from the user saving in the application installed in the mobile device or can be fetched through connection to HSS over a diameter interface. As there is no standard interface between ANDSF and HSS, this project proposes that user context be collected from the application which UE has already used and then sent to the ANDSF repository in order to make the user profile.

The detailed information of the AP contains restriction connection capability, backhaul and congestion can be pushed by the UE to the ANDSF client.

After that, the PCRF makes a decision regarding policy on the new session. As an assumption and extension, a message is transmitted by the PCRF to the ANDSF, in order to start resource reservation. Parallel with this messaging, the congestion information is transmitted over the Np interface toward the PCRF. Congestion information is collected by the RAN Congestion Awareness Function (RCAF) and transferred to the PCRF according to the standard [58]. Hence, the access selection process would all be based on information of the service profile and network profile.

Now, let's see how this scenario works in heterogeneous networks. In order to effectively offload mobile traffic from 3GPP cells to WiFi APs in heterogeneous networks, ANDSF can regulate the cellular UEs to specify when and where WiFi roaming is possible. In addition, it should also provide the rightful selection rules for UE by IARP. For instance, only the authorized APs (AP belonged to operator or authorized provider who has roaming agreement) can be selected for this purpose. For prioritizing AP in the selection, the operator assigns AP with an integer number from 1 to 255 (one is the highest priority and 255 is the lowest) and the one with higher priority should be selected by the UE.

Considering ANDSF in dynamic access network selection brings some advantages such as using ANDSF, using threshold and using dynamic information. Using ANDSF adds some control on access network selection process in order to prevent selecting unauthorized AP. Using thresholds is to control roaming decision and select the preferable AP. Mentioned thresholds are provided by the operator and will be provided to the UE using ANDSF MO. Using the dynamic information such as the load condition of AP obtained from AP candidates using Hotspot 802.11 is to decide which WiFi AP is more preferable to offload the traffic.

Table (4.2) is a base for decision matrix and is a decision-making table. The range of acceptable profiles can be set by each vendor data sheet. The figures are generally the range of values regarding various parameters such as bandwidth in Mbps (Parameter 1), total bandwidth or maximum bitrate in Mbps (Parameter 2), packet delay in ms (Parameter 3), packet jitter(packet delay variation) in ms (Parameter 4), packet loss per each 10^6 packets (Parameter 5) and cost of data per byte (Parameter 6). The parameters are adapted from previous work [67]. Table (4.2) demonstrates the range of value of decision-making parameters for the sample networks. For MATLAB simulation, the random function is used in the introduced range in bellow table for making the decision matrix (see appendix).

Parameter	UMTS1	UMTS2	WLAN1	WLAN2	WiMAX1	WiMAX2
Available bandwidth (Mbps)	0.1-2	0.1-2	1-11	1-54	1-60	1-60
Total bandwidth (Mbps)	2	2	11	54	60	60
Packet delay (ms)	25-50	25-50	100-150	60-150	60-100	60-100
Packet jitter (ms)	5-10	5-10	10-20	10-20	3-10	3-10
Packet loss (per 10^6)	20-80	20-80	20-80	20-80	20-80	20-80
Cost per byte (price)	0.6	0.8	0.1	0.05	0.5	0.4

Table 4.2: Value ranges of the decision making parameters

4.4. The proposed scenarios for implementation

After proposing the architecture in the previous section, the present study requires proposing the scenario to achieve that. In heterogeneous wireless access networks which include 3GPP accesses networks and non-3GPP access networks, a UE which has capability of multimodal and multi-homed connection, is fixed to a 3GPP network and is subscribed to voice and video streaming. These two approaches are both considered in this study, in order to reduce the size of access network selection matrix. In this approach which can be named as a mixed approach in the proposed scenario. The demands by the user for a dedicated service have a higher priority in selecting the network amongst other requirements. As the step after that, a selection matrix is designed that omits the networks that do not fulfil the requirements set for QoS and preference of the user. The details of the steps are described as below:

The user weight module in the user client is using for assigning and normalized weight criteria. In order to reduce the processing delay in this step, the weighting parameters play such an important role in accessing the selection process that cannot go unimagined. In this approach, two different connections are considered as steps for voice connections and steps for data connection.

Steps for voice connection

Packet delay as the service profile is the most important parameter in voice connection in order to provide the required QoS. Thus, as the first step, access networks which do not meet the minimum value of the user requirements must be omitted, and so the following steps are introduced to minimize the size of decision matrix, considering the service profile.

The first approach:

Stage 1: Selecting the minimum value in packet delay (parameter 3).

$$x_{3_{min}} = \min_{i \in M}[x_{i3}] \qquad (5\text{-}10)$$

Stage 2: If $\left(\frac{x_{i3}}{x_{3_{min}}}\right)_{i \in M} \geq X_{th}$, then that specific network can be made as a candidate for elimination, in that formula X_{th} is a threshold for value comparison which has variety in accordance with the user demands and issues related to QoS and has a positive value ($X_{th} > 1$). It is important to bear in mind that only a few parameters and networks should be omitted from a decision matrix when the related threshold is bigger.

Stage 3: Selecting the smallest value for the packet jitter (parameter 4) among other networks.

$$x_{4_{min}} = \min_{i \in M}[x_{i4}] \qquad (5\text{-}11)$$

Stage 4: If $\left(\frac{x_{i4}}{x_{4_{min}}}\right)_{i \in M} \geq X_{th}$, , then that specific network gets omitted from existing networks.

Stage 5: If any network meets both conditions of omit, then the network is removed as a decisive step in the selection process.

In the proposed approach, network selection is mainly in association with the forgetting the undesirable networks from the decision matrix. A second or alternative approach can be introduced, in which the significant part of vertical handoff process is given to element of weighting for parameters. The following stages aim to explain this approach in clear terms for both types of voice also or data connections separately.

The second approach:

In the second approach, in voice connection, weights of packet delay and packet jitter are considered as the important role in minimizing of the decision matrix. This approach is implemented through the following steps.

Stage 1: Selecting the minimum of value of Packet Delay (PD) and that of Packet Jitter (PJ) parameters.

$$w_{min} = \min(w_{PD}, w_{PJ}) \qquad (5\text{-}12)$$

Stage 2: If $\left(\frac{w_{min}}{wj}\right)_{j\in N} \geq X_{th}$, then that specific parameter is eliminated from the decision matrix.

Stage 3: The weight by removing parameter is then divided equally into other parameter weights for satisfying $\sum_{j=1}^{N} w_j = 1$.

Steps for data connection

For data connection, network profile must meet the requirement of the user. So, the available bandwidth is considered as a parameter which helps to reduce the size of decision matrix. Hence, following steps help us to reach to the aims (formulas were adapted from [67]).

The first approach:

Stage 1: Selecting and setting the maximum value of the available bandwidth (parameter 1) for all networks.

$$x_{1_{max}} = max_{i\in M}[x_{i1}] \qquad (5\text{-}13)$$

Stage 2: If $\left(\frac{x_{1max}}{x_{i1}}\right)_{i\in M} \geq X_{th}$, , then that specific network candidate for elimination.

Stage 3: Selecting the maximum value of the total bandwidth and setting it (parameter 2) in the networks.

$$x_{2_{max}} = max_{i\in M}[x_{i2}] \qquad (5\text{-}14)$$

Stage 4: If $\left(\frac{x_{2max}}{x_{i2}}\right)_{i\in M} \geq X_{th}$, then that specific network gets omitted from the available networks.

Stage 5: If a network meets both conditions of omit, then the network is definitely removed from the list of networks available for the selection process.

Same as voice connection, in the second approach the weight of the available bit rate and total bit rate are applied according to the below steps to reduce the size of decision matrix.

The second approach:

Stage 1: Selecting a minimum of the value of the Available bandwidth and Total bandwidth parameters.

$$w_{\min} = \min(w_{AB}, w_{TB}) \quad (5\text{-}15)$$

Stage 2: If $\left(\frac{w_{\min}}{w_j}\right)_{j \in N} \geq X_{th}$, then that specific parameter is omitted from the decision matrix.

Stage 3: the weight of the removed parameter should then be divided equally to other parameter weights for fulfilling the formula $\sum_{j=1}^{N} w_j = 1$. (5-16)

4.5. Simulation of the proposed procedure

Matlab simulator is used for simulation of access network procedures in the present study. As discussed before, in this thesis two of the most important factors are focused as decreasing both the delay processing and the quantity of the extra handoffs. These two important decreases can also have the benefit of avoiding the ping-pong effect. The results show that processing delay is a very important element to acquire proper QOS and fulfil the demands of the users.

For calculation of processing delay, tic toc method in MATLAB is used. In order to show processing delay of the methods, approximately 5000 times of output with input decision matrix were averaged with random amounts. The decision point is a point that multiple criteria algorithms can select the network (whether the new network or the previous one). It is important to note that matrix values are chosen randomly through the use of the instrument of MATLAB simulator. Thus, two sets of scenarios are considered in this regard. Both scenarios are possible. In the first scenario, the network profile and service profiles play the most important role in access network selection through omitting some access networks which does not meet the user requirement. In the next approach, service profile and network profiles are considered for elimination of related attributes which does not fulfil the requirement set for quality of services from the decision matrix (it is illustrated in the Figures as conventional and reduced).

For simulation, I considered four functions for simulating the two scenarios (omitting the parameters and omitting the networks explained in the section 4.4) with two selection algorithms (SAW, TOPSIS, SAW_Reduced_w (which stand for network selection in the second scenario), Net_Sel_SAW_Reduced (which stand for network selection in the first scenario), Net_Sel_TOPSIS_Reduced (which stand for network selection in the first scenario for topsis), Net_Sel_TOPSIS_Reduced_w (which stand for network selection in the second scenario for topsis). (see appendix).

In order to deal with the weighting issue properly, three solutions are offered. Firstly, through flat weighting, all the parameters get the same weight. The second way offers high weighting to packet delay and packet jitter, which is working well for voice connection. In this solution, the rest of the weight that remains is divided between the other parameters. In the third solution, high weighting is given to access bandwidth and total bandwidth because of their priority (%70 more and the rest is divided between the other parameters. This weighting allotment is most suitable for data connection than for other purposes. The above weighting in MATLAB is simulated as the input of the w in which w is defined based on the above discussion. The w can be selected as the Application_case for values 1 or 2 or 3 (1 stand for flat weighting, 2 stands for voice connection and 3 stands for data connection).

As discussed previously, MADM would be employed for access network selection. While MADM is a problem solving approach that determines what to select from among a finite number of alternatives, other access network selection algorithms exist that are also based on MADM such as MEW, GRA, ELECTRC, WMC and VIKOR. In using the MADM, the present study would focus on SAW and TOPSIS as two algorithms for handover, as MADM gives the priority to access networks based on their parameters. TOPSIS selects those alternatives which seem to be closest to the ideal solution and farthest from the inverse of ideal solution, which is called negative ideal alternatives. The definition of these alternatives can be summarized as below:

Ideal alternatives are the one which have the best attributes or values (maximum benefits while minimum cost attributes).

Negative ideal alternatives are the ones which have the worst attribute values (minimum benefit attributes and maximum cost attributes, for that matter).

As a first step, nominated networks are prioritized based on their attributes. M is the number of networks and N is the number of attributes. In a decision matrix, x_{ij} is an array of related matrices which indicates the measurement of j_{th} parameter of i_{th} network as is shown in the decision matrix below:

$$\begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \qquad (5\text{-}17)$$

It should also be emphasized that weighting the values to our attributes are based on the preferences of the users in the sample explained above. For this purpose, it is considered essential to make the traffic classes limited and in line with the context-aware elements of the users. wj is weight of j_{th} decision-making parameter that is revealed by the requested traffic. In the formula, the sum of weights in all parts should be equal to 1.

$$\sum_{j=1}^{N} w_j = 1 \qquad (5\text{-}18)$$

Network selection parameters are comprised of two sides of cost and benefit parameters. Clearly, the favourable parameters are named as benefit parameters, while any unfavourable aspect of the issue from the user perspective can be considered under cost parameters. Then, the result is that the larger benefit parameters, the better while it can dubbed in other words, the smaller cost parameters, the better. All this equation from the user perspective should be taken into account.

As discussed before, three different access networks are used for simulation WiMAX (IEEE 802.11), UMTS (3GPP) and WLAN (802.16). In all, there are six access networks (2 access from each kind of access) for simulation alphabetically are UMTS1, UMTS2, WLAN1, WLAN2, WiMAX1 and WiMAX2. Parameters of the access networks which were considered were not only the Available Bandwidth (Mbps), but also Total Bandwidth (Mbps). It also accommodated the packet delay (ms), packet jitter (ms), packet loss in each 1 million packet per the cost of byte.

4.6. Analysis of simulation results

In this section, first of all, processing delay and unwanted handover are going to be delineated. Processing delay is a time interval between the decision matrix entrances until the access network selected by two algorithms (SAW& TOPSIS). When the number of handover exceed from a margin, the effect of Ping-Pong become worse. A result of extra handoff is that the user cannot camp on the proper access network.

In this section, the results of the proposed scenarios are illustrated using MATLAB. It is clear that these two items play important roles in QoS provisioning for the end user. The final aim is found to be achievable by reducing the size of decision matrix.

There are two methods where simulation has taken place, as presented in detail previously in this chapter. As delivery of the best access network that fulfil the required QoS is our aim for access network selection, the first step access network which do not provide the minimum requirements for user satisfaction will be ignored. For this reason, using the ANDSF tree, according to the user profile, network profile and service profile some of the access networks will be ignored. In the next step, we consider two margins for two kinds of traffic (voice and data traffic). This kind of decision-making, which is based on the user and service profiles, can be called context-ware access network selection. Also, in the simulation, two approaches are integrated together, and results are illustrated in the below Figures.

Considering the Figure 4.3, 4.4, 4.5 and 4.6 applying our proposed algorithms reduced the processing delay considerably which this reduction in TOPSIS algorithms is clearer because TOPSIS algorithms has more computing process in comparison with SAW . processing delay is a very complex issue in computation processing, as it is dynamically change by each QoS parameters and computing process (as an example CPU of the computer can effect this).

The results of processing delay analysis can be listed in below:

a) TOPSIS processing delay is more than SAW
b) The reduction in processing delay in TOPSIS is more visible
c) Proposed approach 2 has more effects on reducing the processing delay in TOPSIS
d) The second proposed method has more effect in reducing the number of handovers in voice case
e) The second method implementation has less effect on data connection
f) A mechanism managed with reduced internal signaling has high priority.

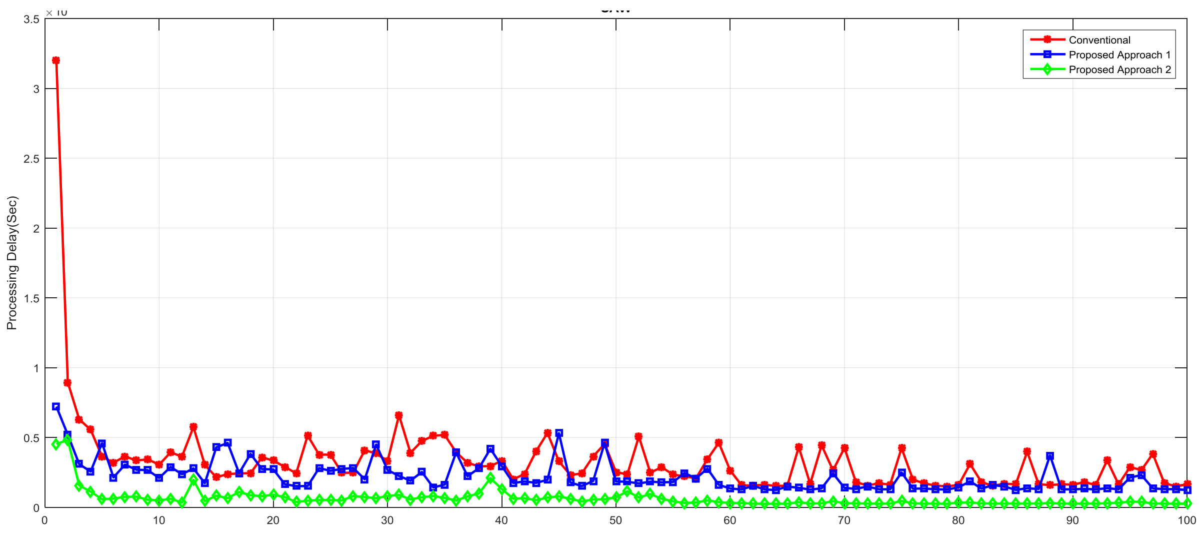

Figure 4.3: Processing delay comparison using SAW algorithm in voice connection

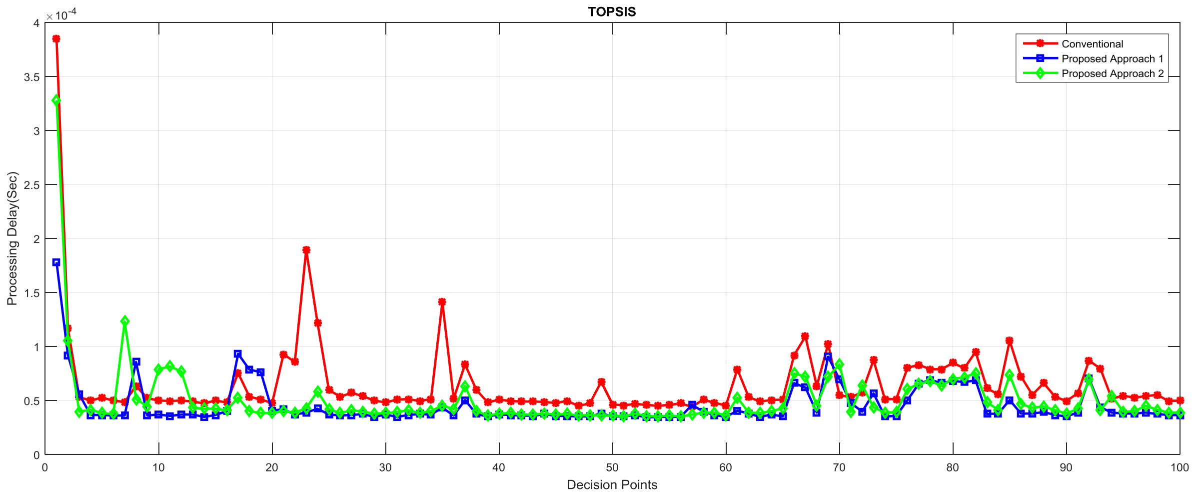

Figure 4.4 :Processing delay comparison using TOPSIS algorithm in voice

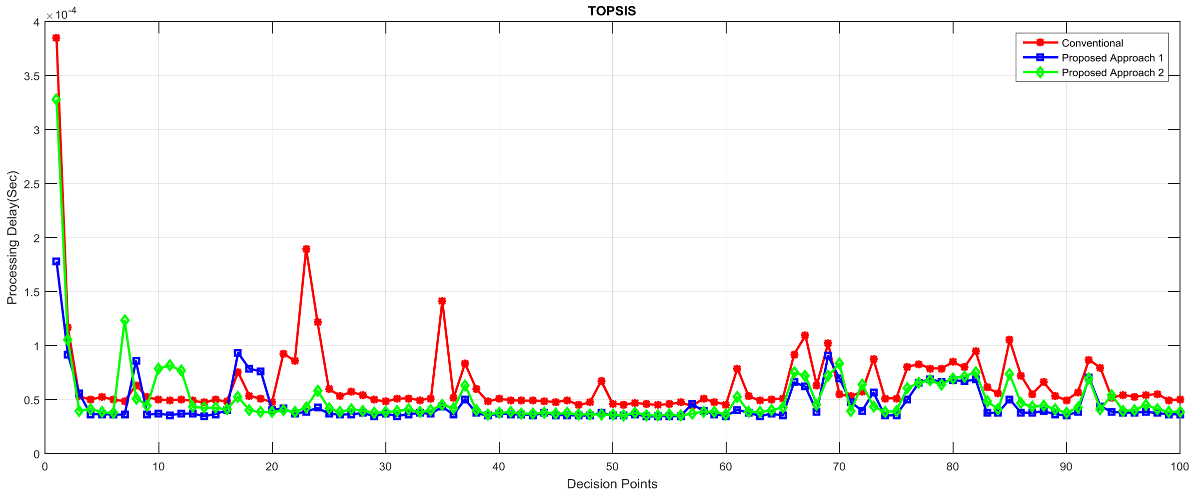

Figure 4.5: Processing delay comparison using SAW algorithm in data connection

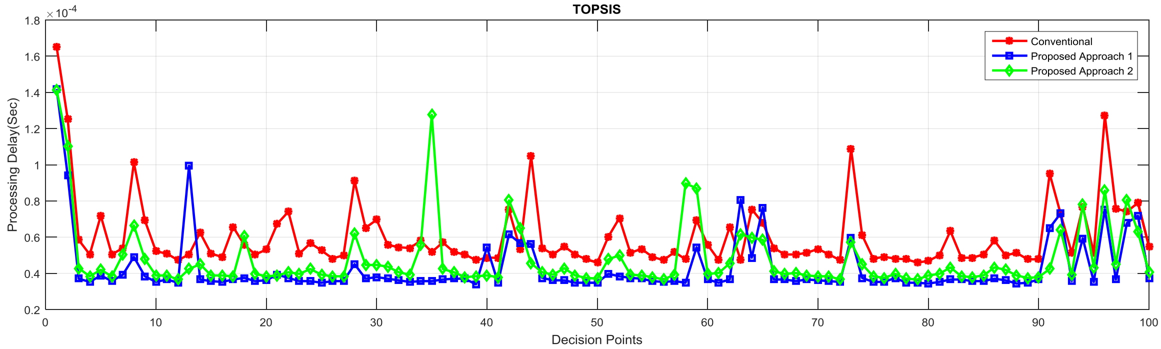

Figure 4.6: Processing delay comparison using TOPSIS algorithm in data connection

The next issue is considering on the sum of vertical handoff events in the course of selecting the desired network. From the perspective of the first and second method, the extra and the undesired vertical handoff of 100 points is considerable, as shown by Table 4.3, for clarifying the effects of the methods to reduce the number of extra handovers.

	Conventional method	**First method**	**Second method**
The number of handoff in voice using SAW	74	70	45
The number of handoff in voice using TOPSIS	73	72	56
The number of handoff in data using SAW	65	64	2
The number of handoff in data using TOPSIS	64	65	64

Table 4.3: the result of 2nd proposed scenario

Considering what the above table shows (Table 4.3); in case of voice connection; the proposed method leads to reduction in the number of handoffs. As, in data connection the bandwidth parameter is approximately fixed, and the reduction in number of handoff is not clear.

Decision point is considered as a point that multiple criteria algorithms would begin to choose the network (new or previous network). According to the Figure 4.7 and Figure 4.8, it is completely clear that using second proposed method reduces the number of handoff. The figures that follow through are self-explanatory based on the information discussed here and show the results of simulation.

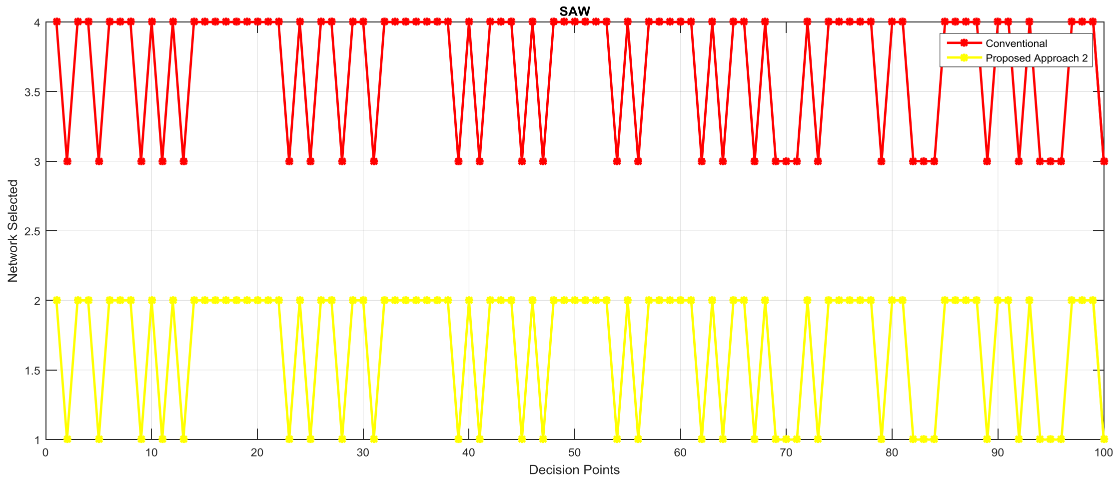

Figure 4.7: The number of handover comparison in voice connection using SAW algorithms in second approach

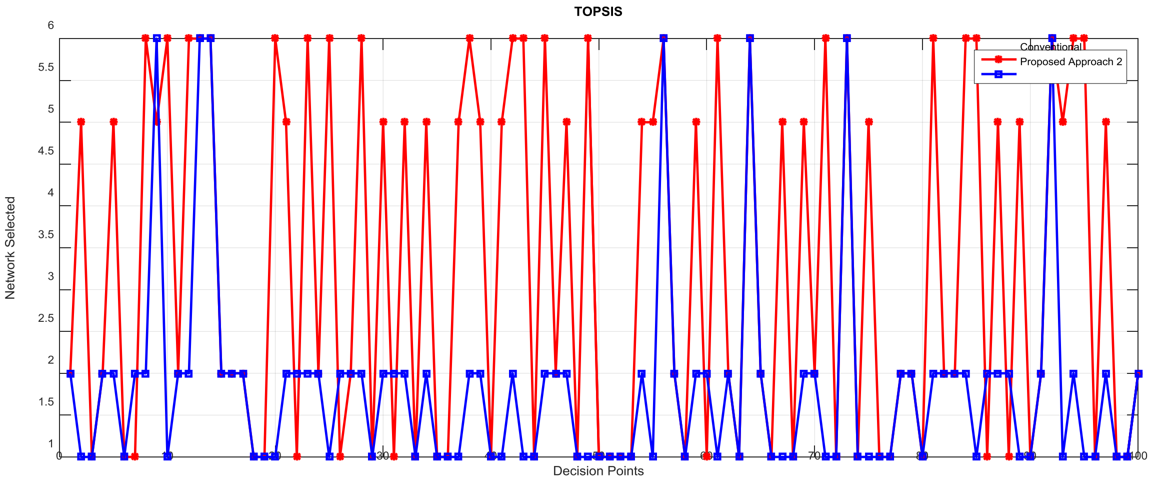

Figure 4.8: *The number of handover comparison in voice connection using TOPSIS algorithms in second approach*

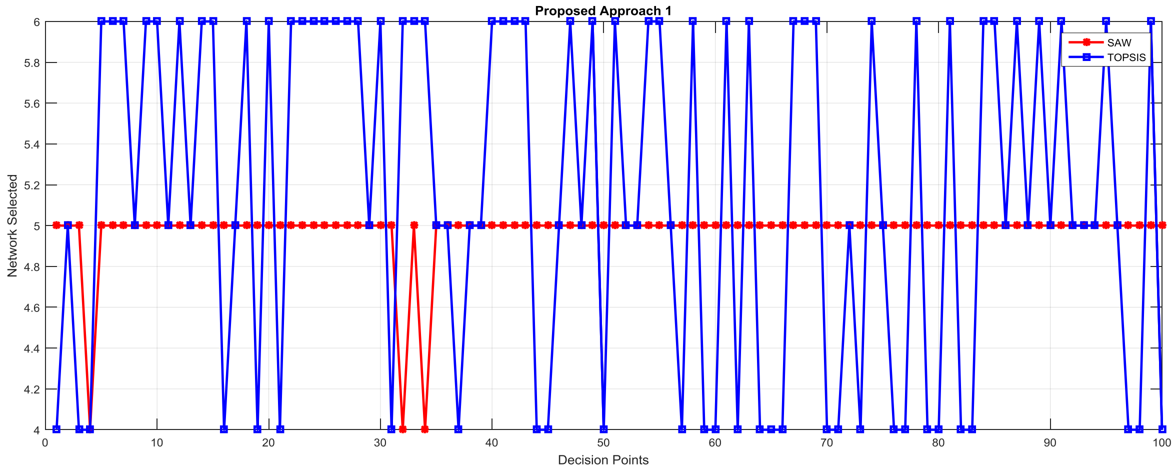

Figure 4.9: Comparison between SAW and TOPSIS algorithms using first proposed scenario in voice scenario

Figure 4.9 shows that, SAW algorithm in reducing the number of handover is more successful than TOPSIS algorithm.

The result of the simulation shows in the following numbered points:

1. In voice scenario, in first approach the size of decision matrix reduced from 6*6 to 4*6
2. In data scenario, in first approach the size of decision matrix reduced from 6*6 to 3*6
3. In voice scenario, in second approach the size of decision matrix reduced from 6*6 to 6*2
4. In data scenario, in second approach the size of decision matrix reduced from 6*6 to 6*2

Finally, it should be added that in voice connection and data connection, reducing the size of matrix using weighting (second approach) has more effect on reduction of the number of handover. The reduction in the number of handover in data connection using SAW is totally more successful in reducing the number of handover. For evaluating the processing delay, SAW algorithm is most successful than TOPSIS, as the second algorithm is more complex.

4.7. Discussion

The present research has focused on proposing and evaluating different frameworks for access network selection and dynamic service delivery. In order to evaluate the proposed algorithm, different factors such as delay and number of handovers were taken into account. Three different profiles have been defined to classify various contexts such as user-profile, network profile and service profile.

As described in chapter 2, there are some studies based on simulation research which have been done in access network selection with its different stages. The process of handover includes four stages which can be subdivided to context collection, context selection, decision making and finally the execution stage.

It is known from studies explained previously that two important standards which help in access network selection are called ANDSF and MIH which enable seamless VHO between different types of technologies. ANDSF provides some fixed rules to the UE in the special context, but there are various research projects which have been done in applying ANDSF in other extra roles.

Paper [56] applies ANDSF to assist in network discovery process. It claims that the proposed novel method avoids unnecessary energy consumption for network scanning. The above-said paper has used a new context parameter (query distance) which is considered to decide on the time to initiate network scanning process. The query distance is the average distance between UE and the closest WLAN AP which is the decision point for network scanning. The current research, however, considers three parameters (detection delay, delay and energy consumption rate) for evaluation of the proposed architecture. Considerable reduction in the evaluation parameters is the result of the proposed method.

There are similarities and differences between the findings of this study and a relevant paper. Paper [69] uses ANDSF in different ways in which the PCRF, during the access selection, sends a message to the ANDSF which contains information on the QoS parameters, location and time of the UE. In the next step, the ANDSF makes a decision based on the PCRF information. The mentioned paper considers decrement in delay (ms) in resource reservation process as the goal. Similar to the project of , paper [11], the ANDSF stores the possible session profiles to the IMSI of the UE. In case of handover, the second session profile is requested by the PCRF to be applied in the network.

In this thesis, evaluation parameters of the proposed algorithms are defined twofold, processing delay and extra handover. The processing delay is defined as the duration of time between the inputting of decision matrix into SAW and TOPSIS and its output decisions. The number of extra handovers is then dealt with in this project through the reduction of access networks into choosing one best access point and opting out of the rest quickly. If this is not considered, as usually with other previous research which only sufficed their decision to time of delay, the subscriber cannot camp on one access network in those situations. The present research has successfully simulated both solutions in a complementary manner. The development over the previous research [67] where ANDSF rules were not implemented is also worth noting. The attention paid to the proper implementation of ANDSF rules in the current study largely reduces the decision matrix and plainly facilitates a timely decision making (ANDSF MOs' are not simulated in this thesis).

Moreover, ANDSF-related research dealing with context-aware handover issues in the research literature have generally focused on the decision part without making it clear where these contexts come from. However, in the current project, the interfaces were explained in detail and the assumptions are expressed and the origins of contexts were made clear.

After all, this dissertation is based on a research that goes beyond what most research has conducted in terms of standards and their extensions. Most previous research has focused on fulfilling the standard rules while this project has also extended the assumption for transferring the momentary information from PCRF towards ANDSF.

In this dissertation the ability for the user or other mobile entities to communicate with the service provider is discussed. As the second subject, the possibility of service provider's profile adaptation with network context changes which is affected by the network selection mechanism was also discussed.

In this research, different information such as user context, service related context and network related context which are collected from various part of network managed in order to help in access network selection process. Generally in decision making procedure, different methods are used such as MADM which explained before in detail.

In this project, there is some innovations listed below:

a) Collected context from network (including static and dynamic) are categorised in three groups and map to the ANDSF MOs
b) Fixed ANDSF rules (provided by the operator) is used to omit networks which doesn't meet the requirement or they are not valid.
c) In parallel ANDSF play another rule in order to save the second reserved resources in order to adopt the services to the context changes (because of handover).

d) When decision matrix is made, two approaches are introduced to reduce the size of decision matrix (it is possible with defining a threshold and eliminate the context which does not meet the threshold)

The above contributions lead to reduce the processing delay and the number of handover. MATLAB simulator helps me in order to evaluate the results which are explained in chapter 4 in detail.

Chapter 5

5. Conclusion

With the emergence of heterogeneous networks, delivery of different services over different access network has been made possible. The aim of the future massive mobile network is to enable efficient communication to a high number of subscribers over heterogeneous access networks based on the requirement of different services and applications.

It is expected that the number of subscribers becomes doubled every year in order to match and deliver different services for various tastes. Considering this possibility, service delivery need to be adopted with the momentary network condition. It means that services must have different parameters in different networks. There is a requirement of enabling extra function into the architecture enabling high level of adaptation.

In fact, there is an essential requirement for an enabler in the core network to reduce the operational costs through the adaptation of the resources available for delivery of the required service. The enabler includes network selection and service adaptation together. Considering above aims, there are some limitations in core network which makes the implementation more difficult.

Firstly, the amount of internal communication signalling must be reduced. Currently, there is different signalling for service initiation and adaptation after context changes events in the network such as handover event. As service adaptation require more internal negotiation, introducing a mechanism in which internal signalling will be reduced and managed has high priority.

Heterogeneous environments which contain WiFi, 3G microcells, Piccocell and Femtocell QoS and QoE, are affected by various mechanisms such as service adaptation and efficient network selection. Both mentioned mechanisms need sufficient information from the users, network and the services. This type of information is called contexts.

Considering user preferences, service requirements and network context for limiting the access network collection can optimize the network selection process.

In this dissertation the ability for the user or other mobile entities to communicate with other network entity will be discussed. The result of the negotiation between the ANDSF client/server with other network entity leads to transmit the complementary context.

Collected context from different entity make 3 different profiles (user, network and service) which can play an important role in optimised access network selection and service adaptation. With an increase in the number of subscribers, delivery of various services for various tastes is required in heterogeneous access network in this situation; service delivery needs to be adapted with the momentary network conditions in which services need to have different parameters in different networks. Service adaptation is the possibility of service provider's profile adaptation with network context changes which is affected by the network selection mechanism. The solution is applying ANDSF as a 3GPP standard with some extension in order to collect different context.

Despite the previous research that has been conducted in service adaptation and network selection separately, this project contextualizes the user preferences in both areas simultaneously. A unique server and database centre will be defined for negotiation with the service provider in order to exchange the user preferences. Also, such a server, when introduced, can help network selection and offloading based on the user and network profiles. This solution reduces the amount of signalling for negotiation between user and service providers. Implementing such a technique makes the system sensitive to context or so called context-aware. Before delving deeper into the implementation of such a context-aware solution, a general overview of the service adaptation and network selection is necessary, which makes up the following section.

In all, the significance of the issue lies in the fact that user experience is the key point to the success of the future communications industry. Access to requested services with the right price and at the right time is important to encourage service usage. Users avoid services which they think as expensive service and they try to use services with reasonable value. They prefer to use advantage of the choice and diversity of the access networks available in their current location to have service with requested QoS, and reasonable price which delivered continually. In today telecommunication world, the business and technology models are changed. Access network selection is very important in order to deliver required service with requested criteria's. Thus, Access network selection should be a more intelligent process affected by different context. Gathered context either from network or user side need to play role in decision making procedure. This thesis presents research challenges in context-aware access network selection procedure.

In sum, this current research provided a response for the following questions raised to address the proposed architecture and scenario.

1-What are the aspects of context-based access network selection in heterogeneous network? (In terms of different profiles)

2- How can the delivered service be adapted to the changes of the context? (user contexts and network contexts)

3-How can the contexts be translated and transferred into an appropriate entity? (What is the requirement of transferring the context, which entities in LTE/EPC network have which kind of information?)

4-what are the related context and profiles in the access network selection process?

5-Based on the data collected from the user and network context sources, which algorithms are used in order to select the most proper access?

Further noteworthy point is that all above questions had to be addressed when introducing the proposed architecture. Yet, answering the above question was not possible without dealing with its own challenges first. For instance, the challenges included addressing the complexity of decision making process, context collection from different layers of the network and introducing a method to process collected raw context in order to be used in access network selection process. Ideally, decision is made by decision maker which is informed about network, service and user context with acceptable accuracy. However, decision making process is often such a complex procedure that a multi-stage process should happen and solve the problems such as lack of some essential information in due time or imperfectly gathered context. Uncertainty of gathered information is indeed one of the most challenging issues in decision making process. Yet, that is the way it is in real life, rather than ideal models.

Further, the nature of mobile communication is dynamic, so the collected context is always changing because of various reasons and sometimes beyond any predictive power. There are also both dynamic and static inputs with temporal dependency for decision makers which also increase the complexity of decision-making process.

Considering all this, implementing context-aware access network selection and service adaptation still leads to reduction of the amount of internal communication signalling to different service providers. This is so, just as the trajectory for the present research consists of a few consecutive steps, to be recapped here again. First of all, analysing the relevant concepts underlying the research as well as reviewing the works that have been done previously, a step that led to raising an issue which is not given sufficient attention and defining a timely research question. Second step, the insights were used in making a hypothesis in order to address the issue raised. In the third step, the hypothesis underwent testing, and eventually it was shown to be based on a valid theory. The phases explained, sums up the actions in order to achieve the study aims.

5.1. Directions for Further Research

Suggestions for further research can take different directions, detailed in this section. One direction is in the area of attributes, and the other is trialling other possible applications. Still other can be in continuation of researching the proposed scenario. Furthermore, research can take direction of other relevant standards to be used and finally in the area of policy-making. Details begin with attributes and finish with policy. In this project, a few of the most significant attributes from the defined profiles were used for simulation of providing two services (voice and data), while it can be suggested that the further research can use other attributes from the profiles to consider in the algorithm in the decision matrix.

Applications in all fields are growing very fast. In my theses, the gap of designing a client application can be sense. As described in previous sections, input data enters into the decision making algorithms (TOPSIS, SAW) in order to select the best access networks. In this project our focus was on two important issues, 1- how to collect and transfer the context (user profile, network profile and service profile) 2- how to select the best access network based on the input data. Algorithms usually runs in the handset of the users. For this reason, there are some projects have been conducted on designing an application for access network selection as a client on the user handset.

In continuation of researching the proposed scenario, ANDSF is responsible to provide some information (explained before) to the end user. ANDSF server is responsible to collect this information and transfer to the ANDSF client over S14 interface. ANDSF client installed in user handset can include other information such as provided MAP, HSS information in order to make a better decision. Although there was large evolution in the first proposed ANDSF, but it is still in an initial stage of standard.

In the standard, there was only minimal interface defined to the mobile device. There is no connection to other entities is standardized yet. Also, the information of the ANDSF is not dynamic and it has not any information about current backhaul traffic. So, it is expected to have some extension related to the ANDSF and it is related interface to the other devices. Also, due to the ongoing growth of the femtocells, ANDSF is not quite capable to collect information related to the femtocells. ANDSF currently has not any information about subscription profiles and coverage maps. Currently, there are some suggestions which introduce application clients including coverage map in order to make better access network decision. It can thus be a viable research suggestion. Proving such information to the ANDSF client leads to reduction in the amount of information exchanging between entities. After all, such research can further lead to ways of reduction of the required processing in the mobile device.

A further avenue of further research can be the case of policy-making. In other words, a dynamic ANDSF can have dynamic policy generator which generate policies based on the triggers and on the information received from the other entities. In case of service adaptation, TDF can play vital rule, as it is act as middle for transferring the service profiles to the PCRF (as a dynamic policy generator). TDF can reports detection information such as service flow information to the PCRF and then PCRF force the new rules to be applied in PCEF.

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Appendix: simulation data

sample MATLAB programming (Main, call decision, TOPSIS algorithm)

```
//Main
clc
clear variables
format short
Count1 = 1:100;
Net_Sel_SAW=zeros(length(Count1),1);
Net_Sel_TOPSIS=zeros(length(Count1),1);
Net_Sel_SAW_Reduced=zeros(length(Count1),1);
Net_Sel_TOPSIS_Reduced=zeros(length(Count1),1);
Net_Sel_SAW_Reduced_w=zeros(length(Count1),1);
Net_Sel_TOPSIS_Reduced_w=zeros(length(Count1),1);
threshold = 2;

%========================= << Initialization >> ==========================%
interval_UMTS_Avai_BW = 0.1:0.1:2;
interval_WLAN1_Avai_BW = 1:0.1:11;
interval_WLAN2_Avai_BW = 1:0.1:54;
interval_WiMax_Avai_BW = 1:0.1:60;

interval_UMTS_PD = 25:1:50;
%interval_UMTS_PD = 75:1:85;
interval_WLAN1_PD = 100:1:150;
%interval_WLAN1_PD = 75:1:85;
interval_WLAN2_PD = 60:1:150;
%interval_WLAN2_PD = 75:1:85;
interval_WiMax_PD = 60:1:100;
%interval_WiMax_PD = 75:1:85;

interval_UMTS_PJ = 5:1:10;
interval_WLAN1_PJ = 10:1:20;
interval_WLAN2_PJ = 10:1:20;
interval_WiMax_PJ = 3:1:10;

interval_PL = 20:1:80;
Application_case = 2; %1.Equal  2.Voice  3.Data
Count = 1;
jj=1;
while Count <= 100
    %=====================<< Weighting >>=====================
    switch Application_case
        case 1
            w = 1/6 * ones(1,6);
        case 2
            w(3) = 0.35;   w(4) = 0.35;   w(1:2) = ((0.3)/4) * ones(2,1); w(5:6) = ((0.3)/4) * ones(2,1);
        case 3
            w(1) = 0.35;   w(2) = 0.35;   w(3:6) = ((0.3)/4) * ones(4,1);
    end
    %===================<< Decision Matrix >>===================
    x = Call_Decision_rand(interval_UMTS_Avai_BW,interval_WLAN1_Avai_BW,interval_WLAN2_Avai_BW,...
```

```
interval_WiMax_Avai_BW,interval_UMTS_PD,interval_WLAN1_PD,interval_WLAN2_PD,...
interval_WiMax_PD,interval_UMTS_PJ,interval_WLAN1_PJ,interval_WLAN2_PJ,...
            interval_WiMax_PJ,interval_PL);
        [x_R,dec_vec]    = Call_Decision_Reduced(x,threshold,Application_case);
        [x_R_w,dec_vec1] = Call_Decision_Reduced_parameter(x,w,threshold,Application_case);
        [x_R_c,dec_vec2] = Call_Decision_Reduced_parameter(x_R,w,threshold,Application_case);
        %================================ << SAW >> ===============================%
        Approach_Selection =0; % Conventional Approach
        tic
        bb_SAW     = call_SAW(x,w,Approach_Selection,Application_case);
        t_0_SAW(jj) = toc;
        Net_Sel_SAW(jj) = bb_SAW;
        %==================================================
        Approach_Selection = 1; % Network Selection Approach
        tic
        bb_SAW_Reduced     = call_SAW(x_R,w,Approach_Selection,Application_case);
        t_1_SAW(jj) = toc;
        counter = 0;
        for i = 1:6
            if dec_vec(i) == 1
                counter = counter + 1;
            end
            if counter == bb_SAW_Reduced
                Net_Sel_SAW_Reduced(jj) = i;
            end
        end
        %=====================================================
        Approach_Selection = 2; % Parameter Selection Approach
        w1 = w(:,find(dec_vec1));
        w1 = w1 + (1-sum(w1))/length(w1);
        tic
        bb_SAW_Reduced_0     = call_SAW(x_R_w,w1,Approach_Selection,Application_case);
        t_2_SAW(jj) = toc;
        Net_Sel_SAW_Reduced_w(jj) = bb_SAW_Reduced_0;
        %===================================================


        %============================= << TOPSIS >> ==============================%
        Approach_Selection =0; % Conventional Approach
        tic
        bb_TOPSIS = call_TOPSIS(x,w,Approach_Selection,Application_case);
        t_0_TOPSIS(jj) = toc;
        Net_Sel_TOPSIS(jj) = bb_TOPSIS;
        %=================================
```

```
    Approach_Selection =1; % Network Selection Approach
    tic
    bb_TOPSIS_Reduced = call_TOPSIS(x_R,w,Approach_Selection,Application_case);
    t_1_TOPSIS(jj) = toc;
    counter = 0;
    for i = 1:6
        if dec_vec(i) == 1
            counter = counter + 1;
        end
        if counter == bb_TOPSIS_Reduced
            Net_Sel_TOPSIS_Reduced(jj) = i;
        end
    end
    %=================================
    Approach_Selection =2; % Parameter Selection Approach
    tic
    bb_TOPSIS_Reduced = call_TOPSIS(x_R_w,w1,Approach_Selection,Application_case);
    t_2_TOPSIS(jj) = toc;
    Net_Sel_TOPSIS_Reduced_w(jj) = bb_TOPSIS_Reduced;
    %==================================================

%============================= << Plots >> ==================================%
% Figure 1: Conventional SAW and Proposed approach 1
figure
plot(Count1,Net_Sel_SAW,'-*r','linewidth',2)
grid on
hold on
plot(Count1,Net_Sel_SAW_Reduced,'-sb','linewidth',2)
ylabel('Network Selected')
xlabel('Decision Points')
legend('Conventional','Proposed Approach 1')
title('SAW')

% Figure 2: Conventional SAW and Proposed approach 2
figure
plot(Count1,Net_Sel_SAW,'-*r','linewidth',2)
grid on
hold on
plot(Count1,Net_Sel_SAW_Reduced_w,'-sb','linewidth',2)
ylabel('Network Selected')
xlabel('Decision Points')
legend('Conventional','Proposed Approach 2')
title('SAW')

%==========================
% Figure 4: Conventional TOPSIS and Proposed approach 1
figure
plot(Count1,Net_Sel_TOPSIS,'-*r','linewidth',2)
grid on
hold on
```

```
plot(Count1,Net_Sel_TOPSIS_Reduced,'-sb','linewidth',2)
ylabel('Network Selected')
xlabel('Decision Points')
legend('Conventional','Proposed Approach 1')
title('TOPSIS')
% Figure 5: Conventional TOPSIS and Proposed approach 2
figure
plot(Count1,Net_Sel_TOPSIS,'-*r','linewidth',2)
grid on
hold on
plot(Count1,Net_Sel_TOPSIS_Reduced_w,'-sb','linewidth',2)
ylabel('Network Selected')
xlabel('Decision Points')
legend('Conventional','Proposed Approach 2')
title('TOPSIS')

% Figure 6: Conventional TOPSIS
figure
plot(Count1,Net_Sel_TOPSIS,'-*r','linewidth',2)
grid on
hold on
plot(Count1,Net_Sel_TOPSIS_Reduced_c,'-sb','linewidth',2)
ylabel('Network Selected')
xlabel('Decision Points')
legend('Conventional','Combined Proposed Approach 1 & 2')
title('TOPSIS')

% Figure 7: Proposed Approach 1
figure
plot(Count1,Net_Sel_SAW_Reduced,'-*r','linewidth',2)
grid on
hold on
plot(Count1,Net_Sel_TOPSIS_Reduced,'-sb','linewidth',2)
xlabel('Decision Points')
ylabel('Network Selected')
legend('SAW','TOPSIS')
title('Proposed Approach 1')
% Figure 8: Proposed Approach 2
figure
plot(Count1,Net_Sel_SAW_Reduced_w,'-*r','linewidth',2)
grid on
hold on
plot(Count1,Net_Sel_TOPSIS_Reduced_w,'-sb','linewidth',2)
xlabel('Decision Points')
ylabel('Network Selected')
title('Proposed Approach 2')
legend('SAW','TOPSIS')
title('Proposed Approach 2')
%========================================
% Figure 9: Processing delay SAW
figure
plot(Count1,t_0_SAW,'-*r','linewidth',2)
grid on
```

```
hold on
plot(Count1,t_1_SAW,'-sb','linewidth',2)
hold on
plot(Count1,t_2_SAW,'-dg','linewidth',2)
%hold on
%plot(Count1,t_3_SAW,'-+y','linewidth',2)
xlabel('Decision Points')
ylabel('Processing Delay(Sec)')
legend('Conventional','Proposed Approach 1','Proposed Approach 2')
title('SAW')
% Figure 10: Processing delay TOPSIS
figure
plot(Count1,t_0_TOPSIS,'-*r','linewidth',2)
grid on
hold on
plot(Count1,t_1_TOPSIS,'-sb','linewidth',2)
hold on
plot(Count1,t_2_TOPSIS,'-dg','linewidth',2)
%hold on
%plot(Count1,t_3_TOPSIS,'-+y','linewidth',2)
xlabel('Decision Points')
ylabel('Processing Delay(Sec)')
legend('Conventional','Proposed Approach 1','Proposed Approach 2')
title('TOPSIS')
```

//TOPIS

```
function Network_sel = call_TOPSIS(x,w,Approach_Selection,Application_case)
if (Approach_Selection == 0) || (Approach_Selection == 1)
    x = x';
    [m,n] = size(x);
    %============================== << TOPSIS >>
==============================%
    % Step 1: Construction of Normalized Decision Matrix
    R  = zeros(m,n);
    x0 = (x.*x);
    %x0 = (x.*x);
    x1 = sqrt(sum(x0));
    for j=1:n
        for i=1:m
            R(i,j)=x(i,j)/x1(1,j);
        end
    end
    %disp('TOPSIS; Normalized Decision Matrix:');
    %disp(R);

    % Step 2: Weighted Normalized Decision Matrix
    z  = zeros(m,n);
    for kk = 1:m
        z(kk,:)  = (w.*R(kk,:));
    end
    % Step 3:
    z_max = max(z);
    z_min = min(z);
    for j=1:n
        if (j==1)||(j==2)
            benefit_parameter = 1;
        else
```

```
            benefit_parameter = 0;
        end

        if (benefit_parameter == 1) % in shart dorost shavad
            A_positive (j) = z_max(j);
            A_negetive (j) = z_min(j);
        else
            A_positive (j) = z_min(j);
            A_negetive (j) = z_max(j);
        end

    end

    % Step 4: separation measure between the networks and the positive and
    % negative ideal networks

    p = zeros(m,n);
    for i=1:m
        for j=1:n
            p(i,j)=(A_positive(1,j) - z(i,j))^2;
        end
    end
    d1=sqrt(sum(p,2));  % Calculating S_i^+

    p = zeros(m,n);
    for i=1:m
        for j=1:n
            p(i,j)=(A_negetive(1,j) - z(i,j))^2;
        end
    end
    d2 = sqrt(sum(p,2));  % Calculating S_i^-

    % Step 5: Relative closeness to the ideal solution
    C  = d2./(d1+d2);  % Calculating C_i^*

    %disp('Relative closeness to the ideal solution:');
    %disp(C');

    % bb_TOPSIS is selected network index and aa_TOPSIS is the selected
network
    % relative closeness to the ideal solution
    [aa_TOPSIS bb_TOPSIS] = max(C);

    Network_sel = bb_TOPSIS;
elseif Approach_Selection == 2
    x = x';
    [m,n] = size(x);
    %============================== << TOPSIS >>
================================%
    % Step 1: Construction of Normalized Decision Matrix
    R  = zeros(m,n);
    x0 = (x.*x);
    %x0 = (x.*x);
    x1 = sqrt(sum(x0));
    for j=1:n
        for i=1:m
            R(i,j)=x(i,j)/x1(1,j);
        end
    end
```

```
%disp('TOPSIS; Normalized Decision Matrix:');
%disp(R);

% Step 2: Weighted Normalized Decision Matrix
z  = zeros(m,n);
for kk = 1:m
    z(kk,:)  = (w.*R(kk,:));
end
% Step 3:
z_max = max(z);
z_min = min(z);
for j=1:n
    if Application_case == 1
        if (j==1)||(j==2)
        benefit_parameter = 1;
    else
        benefit_parameter = 0;
    end

    if (benefit_parameter == 1)
        A_positive (j) = z_max(j);
        A_negetive (j) = z_min(j);
    else
        A_positive (j) = z_min(j);
        A_negetive (j) = z_max(j);
    end
    elseif Application_case == 2
        A_positive (j) = z_min(j);
        A_negetive (j) = z_max(j);
    elseif Application_case == 3
        A_positive (j) = z_max(j);
        A_negetive (j) = z_min(j);
    end
end

% Step 4: separation measure between the networks and the positive and
% negative ideal networks

p = zeros(m,n);
for i=1:m
    for j=1:n
        p(i,j)=(A_positive(1,j) - z(i,j))^2;
    end
end
d1=sqrt(sum(p,2));  % Calculating S_i^+

p = zeros(m,n);
for i=1:m
    for j=1:n
        p(i,j)=(A_negetive(1,j) - z(i,j))^2;
    end
end
d2 = sqrt(sum(p,2));  % Calculating S_i^-

% Step 5: Relative closeness to the ideal solution
C  = d2./(d1+d2);  % Calculating C_i^*

%disp('Relative closeness to the ideal solution:');
%disp(C');
```

```
    % bb_TOPSIS is selected network index and aa_TOPSIS is the selected
network
    % relative closeness to the ideal solution
    [aa_TOPSIS bb_TOPSIS] = max(C);

    Network_sel = bb_TOPSIS;
end
end


 function [x] =
Call_Decision_rand(interval_UMTS_Avai_BW,interval_WLAN1_Avai_BW,interval_WL
AN2_Avai_BW,...

interval_WiMax_Avai_BW,interval_UMTS_PD,interval_WLAN1_PD,interval_WLAN2_PD
,...

interval_WiMax_PD,interval_UMTS_PJ,interval_WLAN1_PJ,interval_WLAN2_PJ,...
    interval_WiMax_PJ,interval_PL)


[m_UMTS_Avai_BW n_UMTS_Avai_BW] = size(interval_UMTS_Avai_BW);
[m_WLAN1_Avai_BW n_WLAN1_Avai_BW] = size(interval_WLAN1_Avai_BW);
[m_WLAN2_Avai_BW n_WLAN2_Avai_BW] = size(interval_WLAN2_Avai_BW);
[m_WiMax_Avai_BW n_WiMax_Avai_BW] = size(interval_WiMax_Avai_BW);
[m_UMTS_PD n_UMTS_PD] = size(interval_UMTS_PD);
[m_WLAN1_PD n_WLAN1_PD] = size(interval_WLAN1_PD);
[m_WLAN2_PD n_WLAN2_PD] = size(interval_WLAN2_PD);
[m_WiMax_PD n_WiMax_PD] = size(interval_WiMax_PD);
[m_UMTS_PJ n_UMTS_PJ] = size(interval_UMTS_PJ);
[m_WLAN1_PJ n_WLAN1_PJ] = size(interval_WLAN1_PJ);
[m_WLAN2_PJ n_WLAN2_PJ] = size(interval_WLAN2_PJ);
[m_WiMax_PJ n_WiMax_PJ] = size(interval_WiMax_PJ);
[m_PL n_PL] = size(interval_PL);

Decision_UMTS1_Avai_BW =
interval_UMTS_Avai_BW(1,randi(n_UMTS_Avai_BW,1,1));
Decision_UMTS2_Avai_BW =
interval_UMTS_Avai_BW(1,randi(n_UMTS_Avai_BW,1,1));
Decision_WLAN1_Avai_BW =
interval_WLAN1_Avai_BW(1,randi(n_WLAN1_Avai_BW,1,1));
Decision_WLAN2_Avai_BW =
interval_WLAN2_Avai_BW(1,randi(n_WLAN2_Avai_BW,1,1));
Decision_WiMax1_Avai_BW =
interval_WiMax_Avai_BW(1,randi(n_WiMax_Avai_BW,1,1));
Decision_WiMax2_Avai_BW =
interval_WiMax_Avai_BW(1,randi(n_WiMax_Avai_BW,1,1));
Decision_UMTS1_PD     = interval_UMTS_PD(1,randi(n_UMTS_PD,1,1));
Decision_UMTS2_PD     = interval_UMTS_PD(1,randi(n_UMTS_PD,1,1));
Decision_WLAN1_PD     = interval_WLAN1_PD(1,randi(n_WLAN1_PD,1,1));
Decision_WLAN2_PD     = interval_WLAN2_PD(1,randi(n_WLAN2_PD,1,1));
Decision_WiMax1_PD    = interval_WiMax_PD(1,randi(n_WiMax_PD,1,1));
Decision_WiMax2_PD    = interval_WiMax_PD(1,randi(n_WiMax_PD,1,1));
Decision_UMTS1_PJ     = interval_UMTS_PJ(1,randi(n_UMTS_PJ,1,1));
Decision_UMTS2_PJ     = interval_UMTS_PJ(1,randi(n_UMTS_PJ,1,1));
Decision_WLAN1_PJ     = interval_WLAN1_PJ(1,randi(n_WLAN1_PJ,1,1));
Decision_WLAN2_PJ     = interval_WLAN2_PJ(1,randi(n_WLAN2_PJ,1,1));
Decision_WiMax1_PJ    = interval_WiMax_PJ(1,randi(n_WiMax_PJ,1,1));
Decision_WiMax2_PJ    = interval_WiMax_PJ(1,randi(n_WiMax_PJ,1,1));
Decision_UMTS1_PL     = interval_PL(1,randi(n_PL,1,1));
```

```
Decision_UMTS2_PL    = interval_PL(1,randi(n_PL,1,1));
Decision_WLAN1_PL    = interval_PL(1,randi(n_PL,1,1));
Decision_WLAN2_PL    = interval_PL(1,randi(n_PL,1,1));
Decision_WiMax1_PL   = interval_PL(1,randi(n_PL,1,1));
Decision_WiMax2_PL   = interval_PL(1,randi(n_PL,1,1));
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Decision Matrix
x = [Decision_UMTS1_Avai_BW Decision_UMTS2_Avai_BW Decision_WLAN1_Avai_BW
Decision_WLAN2_Avai_BW Decision_WiMax1_Avai_BW Decision_WiMax2_Avai_BW;
    2 2 11 54 60 60;
    Decision_UMTS1_PD Decision_UMTS2_PD Decision_WLAN1_PD Decision_WLAN2_PD
Decision_WiMax1_PD Decision_WiMax2_PD;
    Decision_UMTS1_PJ Decision_UMTS2_PJ Decision_WLAN1_PJ Decision_WLAN2_PJ
Decision_WiMax1_PJ Decision_WiMax2_PJ;
    Decision_UMTS1_PL Decision_UMTS2_PL Decision_WLAN1_PL Decision_WLAN2_PL
Decision_WiMax1_PL Decision_WiMax2_PL;
    0.6 0.8 0.1 0.05 0.5 0.4];
```