THE REPUBLIC OF TURKEY
BAHÇEŞEHİR UNIVERSITY

QUALITY OF EXPERIENCE-BASED (QOE-BASED) MOBILE DATA OFFLOADING IN HETEROGENOUS WIRELESS NETWORKS

Master Thesis

FAZIL AYKUT TÜZÜNKAN

İSTANBUL, 2014

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ABSTRACT

HANDOVER IN HETEROGENOUS WIRELESS NETWORKS BASED ON USER EXPERIENCE

Fazıl Aykut Tüzünkan

Computer Engineering

Thesis Supervisor: Assoc. Prof. Dr. Vehbi Çağrı Güngör

August 2014, 99 Pages

The increase on smartphone usage has brought the burden of data traffic with it. Operators are looking for cost-effective solutions to overcome the problem of 3G infrastructure for high contention traffic scenarios. Several schemes were offered to save the moment, and they brought some extra costs including deploying femtocell or WiMax, LTE, LTE-Advanced systems along with their expensive equipment. On the other hand, operators are expanding their networks with 802.11 technologies such that they can exploit the free-band communication including TV white space. Meaning the data traffic can handover between WLAN and UMTS/LTE-A interchangeably.

By using NS-2 simulator, we implemented IEEE 802.21 WG's Media Independent Handover (MIH) module by combining with Channel Quality Indicator (CQI) values collected from user equipment (UE) and observed a recovered throughput for both medium. We found that there is a tradeoff among energy efficiency, delay tolerance and cost.

Additionally, NS-3 simulator was utilized to exploit LTE developments such as carrier aggregation, joint usage of licenced and unlicenced spectrum includingTV white spaces and radio enviroment mapping.

Furthermore, in this study, we integrated a Quality of Experience (QoE) metric during real-time handover decision process so that with this type of collaborative solution, an operator will be unique in terms of user happiness and heterogeneous network management.

Keywords: Heterogeneous Wireless Networks (HWN), Mobile Data Offloading (MDO), Quality of Experience (QoE)

ÖZET

KABLOSUZ HETEROJEN AĞLARDAKİ SON KULLANICI BAZLI GEÇİŞLER

Fazıl Aykut Tüzünkan

Bilgisayar Mühendisliği

Tez Danışmanı: Doç. Dr. Vehbi Çağrı Güngör

Ağustos 2014, 99 Sayfa

Akıllı telefon kullanımında artış, veri trafiğinin yükünü artıran en önemli faktörler arasındadır. Operatörler yüksek trafik senaryolarındaki 3G altyapı sorunu aşmak için maliyeti düşük çözümler arıyorlar. Anı kurtarmak için bir çok çözüm getirildi bunlarında arasında femtocell kullanımı veya WiMax, LTE, LTE-Advanced altyapıları kurmak gösterilebilir fakat bunlar ekstra maliyet anlamına gelmektedir. Öte yandan, operatörler TV beyaz boşluk içeren serbest - bant iletişiminden yararlanabilir ayrıca zaten 802.11 teknolojileri ile alt yapı ağlarını genişleten operatörler bu ikisinden de etikili ve maliyeti düşük bir şekilde kullanabilir. Yani WLAN ve UMTS / LTE - A arasında geçişleri birbirleri arasında yapabilir.

NS - 2 simülatörü kullanarak, kullanıcı ekipmanından (UE) toplanan Kanal Kalite Göstergesi (CQI) değerleri ile IEEE 802.21 WG Medya Bağımsız Teslim (MIH) modülü simüle edildi ve gözle görülür bir hız artışı gözlemlendi kullanıcı başına. Bulgularımız arasında enerji verimliliği, gecikme toleransı ve maliyet arasında bir bağ olduğuydu.

Ayrıca, NS - 3 simülatörü taşıyıcı birleştirme, ortak lisanslı ve lisanssız spektrum (TV Beyaz Boşluk dahil) kullanımı ve radyo çevre haritalanması ile alakalı LTE geliştirmeleri için kullanılmıştır

Artı olarak, bu çalışmada, QoE kalite metriği de gerçek zamanlı geçişlerde entegre edilmiş bir paramateredir. Böylelikle işbirlikçi bir çözüm kullanıcı mutluluğu ve heterojen ağ yönetimi konusunda sunulmuştur.

Anahtar Kelimeler: Son Kullanıcı Tecrübesi, Heterojen Kablosuz Ağlar, WiFi Geçişleri

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ABBREVIATIONS

1G	:	First Generation Mobile Networks
2G	:	Second Generation Mobile Networks
3G	:	Third Generation Mobile Networks
3GPP	:	Third Generation Partnership Project
3GPP2	:	Third Generation Partnership Project 2
4G	:	Fourth Generation Mobile Networks
8PSK	:	8 Phase Shift Keying
AAA	:	Authentication, Authorization and Accounting
ABC	:	Always Best Connected
AGW	:	Access Gateway
AN	:	Access Network
ANDSF	:	Access Network Discovery and Selection Function
ANDSF-SN	:	ANDSF Server Name
AP	:	Access Point
ARP	:	Allocation and Retention Priority
BBERF	:	Bearer Binding and Event Reporting Function
BID	:	Binding Identification
BS	:	Base Station
BSS	:	Basic Service Set
BSSID	:	Basic Service Set Identification
BU	:	Binding Update
CAGR	:	Compound Annual Growth Rate
CAPEX	:	Capital Expense
CDF	:	Cumulative Distribution Function
CDMA	:	Code Division Multiple Access
CoA	:	Care-of Address
CS	:	Circuit Switched
DCH	:	Dedicated Channel
DL	:	Downlink
DM	:	Device Management

DPI	:	Deep Packet Inspection
DSCH	:	Downlink Shared Channel
DSL	:	Digital Subscriber Line
DSMIPv6	:	Dual-stack Mobile IPv6
DSSS	:	Direct-Sequence Spread Spectrum
EAP-AKA	:	Extensible Authentication and Key Agreement
EDGE	:	Enhance Data rates for GSM Evolution
eHRPD	:	evolved High Rate Packet Data
eNB	:	evolved NodeB
EPC	:	Evolved Packet Core
EPS	:	Evolved Packet System
ESS	:	Extended Service Set
ETSI	:	European Telecommunications Standards Institute
E-UTRAN	:	Evolved-Universal Mobile Telecommunications System
GGSN	:	Gateway GPRS Support Node
GPRS	:	General Packet Radio Service
GSM	:	Global System for Mobile communications
GTP	:	GPRS Tunneling Protocol
GW	:	Gateway
HA	:	Home Agent
H-ANDSF	:	Home-ANDSF
HLR	:	Home Location Register
HNP	:	Home Network Prefix
HO	:	Handover
HoA	:	Home Address
H-PCRF	:	Home PCRF
HPLMN	:	Home Public Land Mobile Network
HRPD	:	High Rate Packet Data
HSDPA	:	High Speed Downlink Packet Access
HS-DSCH	:	High Speed Downlink Shared Channel
HSGW	:	HRPD Serving Gateway
HSPA	:	High Speed Packet Access

HSS	:	Home Subscriber Server
HSUPA	:	High-speed Uplink Packet Access
HTTP	:	Hypertext Transfer Protocol
IBSS	:	Independent Basic Service Set
IEEE	:	Institute of Electrical and Electronics Engineers
IETF	:	Internet Engineering Task Force
IFOM	:	IP Flow Mobility
IKE	:	Internet Key Exchange
IMT-MC	:	International Mobile Telecommunications – Multi-Carrier
IP	:	Internet Protocol
IP-CAN	:	IP Connectivity Access Network
IPMS	:	IP Mobility Mode Selection
IRC	:	Interference Rejection Combining
ISI	:	Inter Symbol Interference
ISMP	:	Inter-System Mobility Policy
ISRP	:	Inter-System Routing Policy
ITU	:	International Telecommunication Union
I-WLAN	:	Interworking-WLAN
LAN	:	Local Area Network
LIPA	:	Local IP Address
LMA	:	Local Mobility Anchor
LPN	:	Low Power Node
LTE	:	Long Term Evolution
M2M	:	Machine-to-Machine
MAC	:	Media Access Control
MAG	:	Mobility Access Gateway
MAN	:	Metropolitan Area Network
MAP	:	Mobile Application Part
MAPCON	:	Multiple Access PDN Connectivity
MBR	:	Maximum Bit Rate
MCC	:	Mobile Country Code
MIMO	:	Multiple-Input and Multiple-Output

MIP	:	Mobile IP
MIPv4	:	Mobile IPv4
MIPv6	:	Mobile IPv6
MME	:	Mobility Management Entity
MMTel	:	Multimedia Telephony
MN	:	Mobile Node
MNC	:	Mobile Network Code
MO	:	Management Object
MRC	:	Maximum Ratio Combining
MS	:	Mobile Station
NAI	:	Network Access Identifier
NAP	:	Network Access Provider
NGMN	:	Next Generation Mobile Networks
NMT	:	Nordic Mobile Telephony
Non-GBR	:	Non-Guaranteed Bit Rate
NSP	:	Network Service Provider
OFDMA	:	Orthogonal Frequency Division Multiple Access
OMA	:	Open Mobile Alliance
OPEX	:	Operational Expense
PBA	:	Proxy Binding Acknowledgment
PBU	:	Proxy Binding Update
PCC	:	Policy and Charging Control
PCEF	:	Policy and Charging Enforcement Function
PCO	:	Protocol Configuration Option
PCRF	:	Policy and Charging Rules Function
PDA	:	Personal Digital Assistant
PDN	:	Packet Data Network
PDN GW	:	Packet Data Network Gateway
PLMN	:	Public Land Mobile Network
PMIP	:	Proxy Mobile IP
PMIPv6	:	Proxy Mobile IPv6

PS	:	Packet Switched
QoE	:	Quality of Experience
QoS	:	Quality of Service
QPSK	:	Quadrature Phase Shift Keying
SINR	:	Signal to Interference-plus-Noise Ratio
SIP	:	Session Initiation Protocol
SIPTO	:	Selected IP Traffic Offload
SNR	:	Signal-to-Noise Ratio
SPI	:	Security Parameter Index
SS	:	Subscriber Station
SSID	:	Service Set Identifier
TACS	:	Total Access Communication System
TCP	:	Transmission Control Protocol
TDD	:	Time Division Duplex
TDMA	:	Time Division Multiple Access
TFT	:	Traffic Flow Template
TOS	:	Type of Service
TR	:	Technical Report
TS	:	Technical Specification
TTI	:	Transmission Time Interval
UDP	:	User Datagram Protocol
UE	:	User Equipment
UL	:	Uplink
UMTS	:	Universal Mobile Telecommunications System
VHO	:	Vertical Handover
VNI	:	Visual Network Index
VoIP	:	Voice Over IP
VPLMN	:	Visited Public Land Mobile Network
VPN	:	Virtual Private Network
WCDMA	:	Wideband Code Division Multiple Access
WiFi	:	Wireless Fidelity

1. THESIS INTRODUCTION AND SUMMARY

This chapter presents a summary of the thesis work, and will provide a further insight about the need of WiFi offloading to overcome the exponentially growing mobile data traffic. 3GPP's 3G-UMTS and 4G-LTE Advanced technologies have been examined to propose optimized network architecture and multiple attribute decision making algorithms has been enhanced as a mathematical model. Mobile operators with the current proposal will have a cost-effective and pragmatic solution.

1.1 INTRODUCTION

Mobile data traffic has soared drastically in the past few years. The paramount reasons for this are the increasing smartphone usage, several voice and data campaigns, and the trend of watching video streams from different sources including IPTV and online video databases. It is anticipated that the increased interest for data connectivity is likely to put a burden on network capacity in near future. Operators are thus looking for cost-effective solutions to overcome the capacity bottlenecks in 3G infrastructures likely to emerge in high contention traffic scenarios. Several schemes have been offered so far, mostly consisting of temporary solutions to "save the day". They are likely to induce new costs resulting from femtocell or WiMAX, LTE, LTE-Advanced systems deployment.

However, operators realize that such options provide short-term relief only and they require that the target users stay in the operators own network. A more comprehensive solution that addresses real-world user behaviour i.e. that supports network roaming – both in vertical and horizontal directions- , and allows users to receive and enjoy quality services from their operator regardless of their location and choice of network access.

Such a solution becomes viable through the use of 802.11 technologies, as operators are already expanding their networks with 802.11 technologies such that they can exploit the free-band communication. It is reasonable to expect that the data traffic should be able to offload to operator based WiFi networks, implying vertical handovers between WLAN and 3GPP (UMTS, LTE, LTE-Advanced) technologies.

The objective of this work is to investigate the handover solutions in heterogenous networks and point out the metrics and factors influencing data offloading and related open research issues to the research community. To this extent, in NS-2 MIH functionality as utilized as presented by IEEE 802.21 WG to monitor access networks and to perform a seamless handover execution and a multiple attribute decision making (MADM) algorithm has been implemented in MATLAB based on QoE metrics during the decision making phase.

In summary, the following major contributions have been made:

i. User preference as a QoE metric during handover decision making has been integrated into the developed MADM algorithm.

ii. Handover execution has been handled not only based on link-quality including QoS values but also based on subjective measures.

iii. Network traffic of the heterogeneous wireless networks (HWNs) has been improved and managed based on user experience. Upon request, the complete simulation data will be made available. This would help the research community develop novel handover algorithms for HWNs.

iv. Two multi-users multiple attribute decision making (MADM) algorithms based on QoE metrics have been developed.

Furthermore, in NS-3 3GPP’s LTE and LTE-Advanced enhancenments such as multiple-input and multiple-output (MIMO) and radio environment map (REM) has been harnessed to simulate WiFi offloading for Release 8 and above.

1.1.1 Wireless Access Network Technologies

In this section an overview of the 3GPP technologies will be presented and in Table 1.1 key metrics will be highlighted.

Table 1.1: Comparison of Access Network Technologies

Technology	Family	Radio Technology	Downstream (Mbits/s)	Upstream (Mbits/s)
GSM	ETSI	TDMA/FDMA	1.6	0.5
UMTS-TDD	UMTS/3GSM	CDMA/TDD	16	16
UMTS W-CDMA HSDPA+HSUPA	UMTS/3GSM	CDMA/FDD CDMA/FDD MIMO	0.384 14.4	0.384 5.76
HSPA+	3GPP	CDMA/FDD MIMO	21 42 84 672	5.8 11.5 22 168
LTE	3GPP	OFDMA/MIMO/SCFDMA	100 Cat3 150 Cat4 300 Cat5 (in20 MHz FDD)	50 Cat3/4 75 Cat5 (in 20 MHz FDD)
WLAN	802.11 (n)	OFDM/MIMO	300 (using 4x4 configuration in 20 MHz bandwidth) or 600 (using 4x4 configuration in 40 MHz bandwidth)	300 (using 4x4 configuration in 20 MHz bandwidth) or 600 (using 4x4 configuration in 40 MHz bandwidth)
White-Fi	802.11 (af)	OFDM/MIMO	426.7 568.9	426.7 568.9

Source: Master Thesis, The Performance of WiFi Offload in LTE Networks, Desta Hagos, 2012.

A. GSM

With GSM (Global System for Mobile Telecommunications), circuit-switched network logic has been adapted into air interface. By ETSI (European Telecommunications Standards Institute) GSM was described as second generation or 2G digital network.

GSM was designated to be utilized across Europe; however, now GSM is utilized all over the world. GSM took place of the 1G analogue systems like NMT (Nordic Mobile Telephony) and TACS (Total Access Communication System), and as is considered as second generation.

In Europe, GSM utilizes licensed spectrum of 900 and 1800 Mhz bands; however, 850 and 1900 MHz are utilized in Canada and the United States. Both indoor and outdoor usage is possible for GSM.

As a medium access technology, GSM utilizes TDMA (Time Division Multiple Access) technology in the air interface in order to harness a single frequency among candidate users.

The system appoints timeslots in particular sequence to each user harnessing one common frequency. Users are determined with their SIM (Subscriber Identity Module)-a detachable smart card including the user's subscription information. With this specialty, user could switch their mobile equipment easily. With he help of clearinghouses and roaming deals among operators, subscribers also could use their phone in different countries.

The GSM standard was swelled in course of time to contain the first circuit switched data transportation, later packet switch data transportaion with GPRS (General Packet Radio Service). With EDGE (Enhanced Data rates for GSM Evolution), packet data relaying was speeded up and 2.5G was achieved. As a digital mobile phone technology EDGE was presented and with the help of it, data transmission rates was enhanced as a backward-compatible extension of GSM.

Only access network devices needed to be upgraded otherwise core network equipments remained same. EDGE utilizes 8 phase shift keying (8PSK) as coding scheme which allows for data rates of 59.2 kb/s per time slot. EDGE utilizes the coding scheme to the quality of the radio channel as in GPRS.[1]

[1] 3GNewsroom.com (2003-11-29). "3G Glossary – UTRA". [accessed 13 May 2014].

B. UMTS

Universal Mobile Telecommunications System (UMTS) is considred as third generation system and developed by 3GPP (3rd Generation Partnership Project) to enhance GSM networks. UMTS utilizes wideband code division multiple accesses (WCDMA) medium access technology to provide better spectral efficiency and bandwidth to operators where a pair of 5 MHz-wide channels typically is used for transmission in FDD mode. Spread-spectrum technology is utilized to spread the code allowing multiple users to to employ the same air channel where each transmitter is assigned a spreading code. [1]

UMTS includes the following networks: Radio Access Network UTRAN (UMTS Terrestrial Radio Access Network), the authentication of users via SIM cards (Subscriber Identity Module) and the Core Network (Mobile Application Part, or MAP). Plenty of channel types subsist and categorizes into physical channels, transport channels and logical channels. Limited volume of data may be transmitted utilizing a contention based uplink channel (Random Access Channel, RACH) or a common downlink channel (Forward Access Channel, FACH). Unlimited volume of date are relayed harnessing a dedicated channel (DCH) in both uplink and downlink directions. Today many user equipments could provide service for both UMTS and GSM together.

3GPP later developed HSDPA/HSUPA (High-speed Downlink Packet Access/High-speed Uplink Packet Access). With that technology, throughput could achieve 14.4 Mbps in the downlink direction and 5.76 Mbps in the uplink direction and end-to-end delays around 25 ms. In the past RNC was used to implement scheduling and with HSDPA/HSUPA, this task has been implemented in NodeB allowing faster scheduling results.

C. LTE

As a last wireless data communicaiton technology, 3GPP developed Long Term Evolution (LTE).It was introduced in release 8 of 3GPP.[2] LTE utilizes OFDMA (Orthogonal Frequency-Division Multiple Access) instead of the WCDMA of UMTS

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[2] 3GPP LTE Encyclopedia, “An Introduction to LTE”, Internet: http://sites.google.com/site/lteencyclopedia/home , March 2010. [accessed 13 May 2014].

for downlink and uses SC-FDMA (Single-carrier FDMA) for the uplink communication. Additionally, LTE utilizes MIMO (multiple-input, multiple-output) antenna scheme. LTE has been enhanced and reached up to Release 13.

In LTE, spectrum flexibility has been considered considerably.[3]For LTE, a broad group of frequency bands are anticipated to be utilized including the TV White Space band allowing for broad coverage or indoor usage. With the introduction of Release 10, 3GPP presented a true 4G specifications as ITU suggested. For this reason, LTE Release 10 is called as LTE Advanced, but it actually does not bring any new technology at all, it is just said for Releases 10 and later.A lot of development has been performed for Releases 10 and later. With these capabilites, LTE operators could provide higher data rates to their subscribers, and would assure user experience as their customer wanted. Release 12 contains heterogeneous network enhancements along with carrier aggregation and MIMO developments.

1.1.2 Market Penetration

By the end of 2013, mobile subscriptions are anticipated to arrive 7.4 billion; globally penetration of mobile is quickly reaching to the 100 percent mark. Broadband networks are growing substantially. Cisco's research anticipates that there are more than 1 billion HSPA subscriptions.

In the early 2014, LTE subscriptions corresponded to 130 millions subscriptions. With the progressing enhancements, LTE penetration will chiefly reach at a CAGR of 53 percent in the course of 6 years. LTE subscriptions will finally correspond to 2.4 Billion subscriptions in 2020. Currently U.S, far-east wireless network operators are pioneering LTE connections with a market share of 75 percent, since they adopted the technology earlier than their competitors. [4]

[3] Motorola, “"Long Term Evolution (LTE): A Technical Overview", http://www.motorola.com/web/Business/Solutions/Industry%20Solutions/Service%20Providers /Wireless%20Operators/LTE/_Document/Static%20Files/6834_MotDoc_New.pdf, October

[4] White Paper, http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white_paper_c11-520862.html [accessed 13 May 2014].

1.1.3 Mobile Data Traffic Trend

a. Worldwide wireless data traffic increased 81 percent in 2013. At the end of 2013 worldwide wireless data traffic extended to 1.5 exabytes a month, at the end of 2012 which was 820 petabytes a month.

b. In 2013, wireless data traffic was almost 17 times the size of the worldwide Internet in 2000. One exabyte of data traffic transmitted the worldwide Internet in 2000, and in 2013 wireless networks relayed almost 18 exabytes of traffic.

c. Wireless video traffic outreached 50 percent in 2012.

d. Half a billion wireless devices and connections were introduced in 2013. Worldwide wireless equipments and subscriptions in 2013 reached to 6.9 billion, in 2012 which was 6.4 billion. Smartphones constitutes 76 percent of that increase.

e. Worldwide, smartphones and other smart equipments describe 21 percent of the all wireless devices and subscriptions in 2013, they constitute 88 percent of the wireless data traffic. In 2013, smart equipment produced 29 times more traffic than a non-smart device.

f. In 2013, fourth-generation (4G) equipments produced 14.4 times more data traffic than non-4G devices. Eventhough 4G subscriptions constitute only 2.8 percent of wireless connections currently, this traffic already consitutes 30 percent of the worldwide data traffic.

Globally wireless data traffic is anticipated to reach to 15.9 exabytes a month by 2018, almost an 11-fold growth. Wireless data traffic will increase to a CAGR of 61 percent from 2013 until 2018.

The North America and Asia Pacific regions will consitute nearly two-thirds of worldwide wireless traffic by 2018, as shown in Figure 1-2. Africa and Middle East will possess the highest CAGR of 70 percent, growing 14-fold in the estimated timeframe. Central and Eastern Europe would experience the second highest CAGR of 68 percent, growing 13-fold in the estimated timeframe. The emerging markets such as Latin America and Asia Pacific would experience CAGRs of 67 percent and 66 percent respectively.

1.1.4 WLAN Technologies

The IEEE introduced the first version of the Wireless LAN (WLAN) standard 802.11 in 1997 allowing LAN services over the radio spectrum. IEEE 802.11 is a group of standards for utilizing WLAN (Wireless Local Area Network) for computers to communicate in the unlicensed bands at the 2.4 3.6 and 5 GHz spectrum bands respectively. WLAN was formed and developed by the IEEE LAN/MAN standards committee (IEEE 802). Furthermore, mobile network operators along with Wireless Internet Service Providers (WISPs) generally install 802.11-based wireless access points where the data trafic is high and demands for high throughputs are ubiquitous. The primary release of the standard utilized direct-sequence spread spectrum (DSSS) and frequency-hopping spread spectrum (FHSS) as physical layer technologies. They operated at 1 Mbits/s or 2 Mbits/s. The 802.11 a, g, and n amendments then utilized orthogonal frequency division multiplexing (OFDM) scheme, while the 802.11b amendment utilized DSSS. Additionally, the 802.11n amendment enables utilization of 4 multiple-input multiple-output (MIMO) streams.

New capabilites have been introduced to the IEEE 802.11 standard by developments to the base standard. Maximumthroughputs are as following: 54 Mb/s for 802.11a/g, 11 Mb/s for 802.11b, and 150 Mb/s for 802.11n. Generally these maximum rates cannot be experienced by users but only half of it. Delays are generally in the range of milliseconds. IEEE 802.11could be used both indoor and outdoor andcould be deployed for both instances.

A. 802.11af

IEEE 802.11af is called as White-Fi or Super Wi-Fi. It is a wireless and mobile communication standard based on the 802.11 amendments, enabling wireless local area network (WLAN) to operate in the VHF and UHF bands between 54 and 790 MHz corresponding to TV White space spectrum. This version was accepted in February 2014. Cognitive radio technology is utilized to relay on unused TV bands. This standard prevents the primary subscribers of the bands from interference; these users could be analog TV users, digitalTV users and wireless microphones.

Layer 1 which physical layer in 802.11af uses the orthogonal frequency division multiplexing (OFDM) scheme as specified in 802.11ac. The propagation path loss along with the power fading due to substances such as wall and concrete is lower in the UHF and VHF bands than in the 2.4 and 5 GHz bands, which improves the possible range with respect to 802.11 a/b/g/n/ac. The spectrum channels are 6 to 8 MHz wide; regulatory institution determines the range and the frequencies used. Maximum four channels may be aggregated in either one or two contiguous sets. MIMO could operate with up to four channels used for either space–time block code (STBC) or multi-user (MU-MIMO) mode.

The data rates of 26.7 Mbits/s per spatial channel could be reached for 6 and 7 Mhz channels, for 8 Mhz channels 35.6 Mbits/s data rates could be reached. Four spatial streams and four bonded channel represents the peak data rate of 426.7 Mbit/s in 6 and 7 MHz channels and 568.9 Mbit/s for 8 MHz channels. 802.11af reaches up to 5km range for a wireless local area connection.[5][6][7]

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[5] Lekomtcev, Demain; Maršálek, Roman (June 2012). "Comparison of 802.11af and 802.22 standards – physical layer and cognitive functionality". Retrieved 2013-12-29.

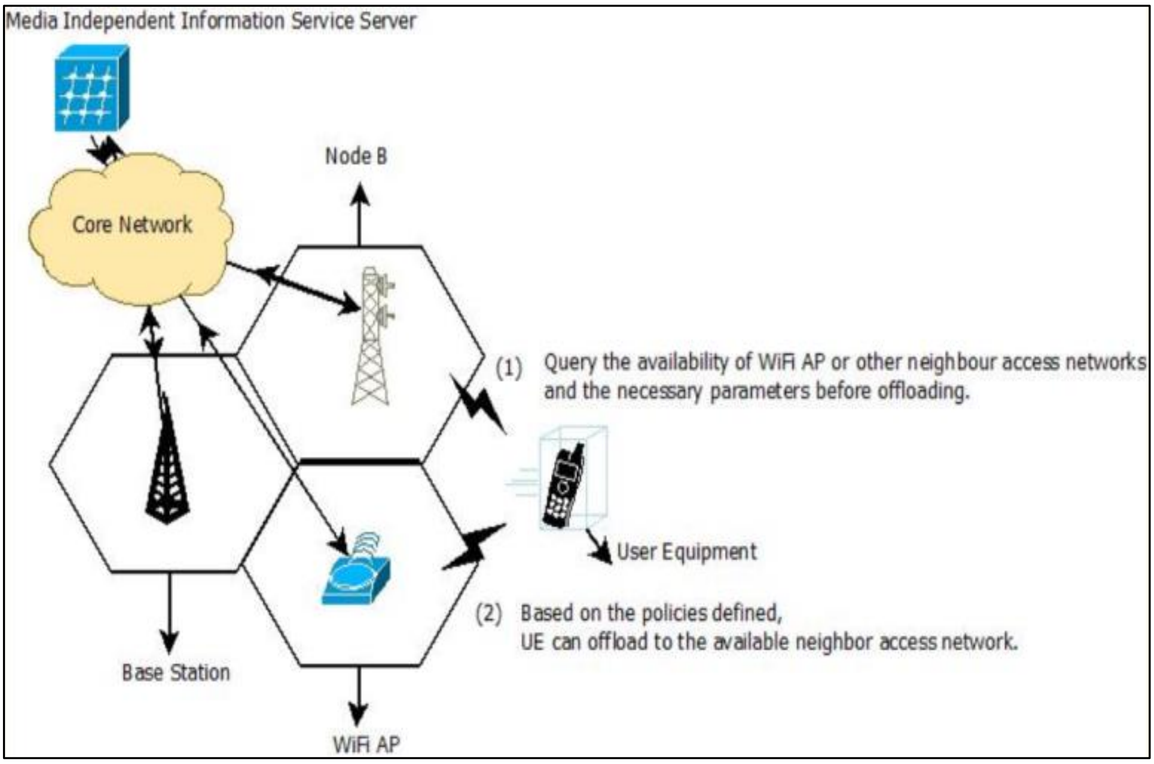
[6] Xiaojun Feng; Qian Zhang; Bo Li (2011). "Enabling Co-channel Coexistence of 802.22 and 802.11af Systems in TV White Spaces". Hong Kong University of Science and Technology. Retrieved 2014-01-19.

[7] Flores, Adriana B.; Guerra, Ryan E.; Knightly, Edward W.; Ecclesine, Peter; Pandey, Santosh (October 2013). "IEEE 802.11af: A Standard for TV White Space Spectrum Sharing". IEEE. Retrieved 2013-12-29.

1.2 THESIS CONCEPTUAL FRAMEWORK

This section represents the theoretical framework of the thesis. Figure 1.1 depicts a network where core network is connected to LTE-Advanced, UMTS and WLAN access networks. With this type of solution, operator could harness the most efficient interworking scheme.

Figure 1.1: A MIIS adapted handover solution



Source: The figure was done by Fazıl Aykut Tuzunkan.

As it will be presented latter in this report, the EPC architecture has been designated enabling
interworking with any access technologies creating a ubiquitous way of handling access to a PDN regardless of the access network technology utilized.[8] This clearly means that, for instance, user euqipments's IP address allocation, access to common IMS services along with network capabilites like security, user subscription, policy checking, billing,

[8] Magnus Olsson et al (2009). SAE and the Evolved Packet Core: Driving the Mobile Broadband Revolution. Academic Press, UK.

and VPN connections can be done without considering the access network technology used which could mobile or fixed network.

As a use case, a UE could be in a mall and all three access network, namel LTE, UMTS and WLAN, could be available in the area. In that case, based on the policies defined for the user, the mobile data could be offloaded from the originating access netowrk to target WLAN network.

1.3 THESIS ORGANIZATION

This thesis work consists of seven chapters. Chapter one provides an introduction and summary to the work. Chapter two explains keypoints of the interworking 3GPP and non-3GPP technologies. In chapter three, a modified seamless data offloading architecture schemes are discussed; furthermore, three modified multi-user multiple attribute decision making algorithms are presented. Chapter four provides the QoE models and assumptions made. Chapter five discusses the performance resultsof the simulations. In chapter six, a seamless offload model is proposed for integrated LTE/UMTS and WLAN networks. Finally, chapter seven concludes the thesis work and discusses about the future work.

1.4 WIFI OFFLOAD

The increase on smartphone usage has brought the burden of data traffic with it. Operators are looking for cost-effective solutions to overcome the problem of 3G infrastructure for high contention traffic scenarios. Several schemes were offered to save the moment, and they brought some extra costs including deploying femtocell or WiMax, LTE, LTE-Advanced systems along with their expensive equipment. On the other hand, operators are expanding their networks with 802.11 technologies such that they can exploit the free-band communication. Meaning the data traffic can handover between WLAN and UMTS interchangeably.

1.5 SUMMARY

The main purpose of this work is to present some viable solutions to switch between 3GPP data networks and WiFi networks. The QoE (Quality-of-Experience)-based innovative data offloading strategy is also introduced and evaluated in terms of peak signal-to-noise ratio, mean opinion score and communication delay. In this thesis, IEEE 802.21 MIH functionality and radio environment mapping has been feeded to some MADM algorithms developed to make a handover with high QoE.

The 3G/4G WiFi Seamless Offload solution not only offers seamless offload of best-effort data from 3G/4G, but also offers a 3GPP operator controlled and service-based selection of 3G/4G or WiFi access networks. Because, offloading is seen and defined to be an operator's action in which an operator decides who, when and how its own subscribers are offloaded. It includes also possibility to on-load selected subscribers back to the original network.

2. MOBILITY AND RADIO ACCESS NETWORK MANAGEMENT

This chapter explains the details of the radio resource management and mobility factors during an offloading.

2.1 INTRODUCTION

Heterogeneous Wireless Networks or WiFi integrated cellular networks could be optimized by user-centric models, network-centric models or collaborative schemes. Even though user-centric models are easier to implement than collaborative and network-centric-models, for the overall performance and complexity-wise of the both networks (3GPP and non-3GPP), the network-centric models provide the most efficient solutions. Collaborative solutions, on the other hand, introduce a little bit complexity; however, in return, offers a drastic performance difference with respect to network-centric solutions.

The common functions that need to be considered for offloading or handover mechanisms among different radio technologies are: Resource Monitoring including network discovery, decision making including network selection and decision enforcement.[9] [10]

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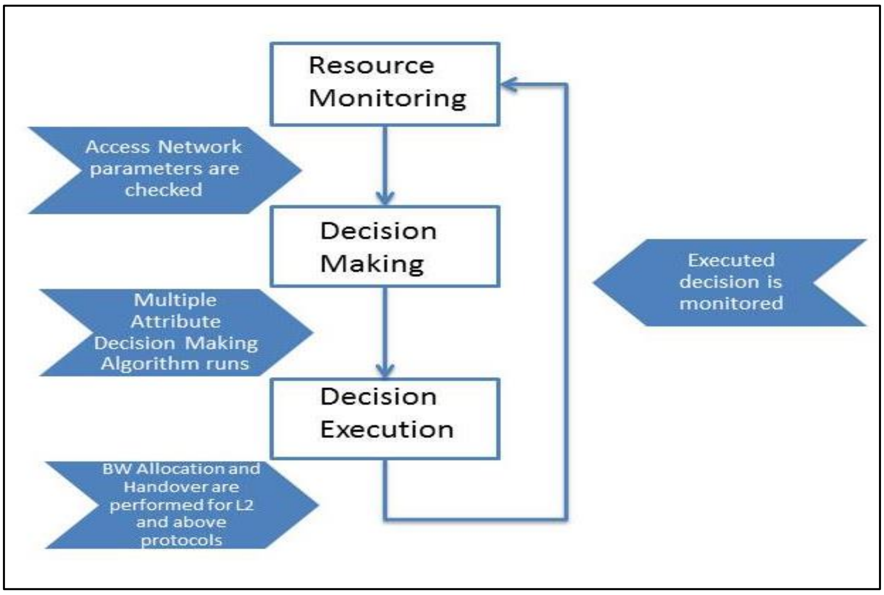
[9] K. Piamrat, A. Ksentini, J.Bonnin, C. Viho, Radio resource management in emerging heterogeneous wireless networks, Computer Communications, Volume 34, Issue 9, 15 June 2011, Pages 1066-1076, ISSN 0140-3664, 10.1016/j.comcom.2010.02.015.

[10] X. Gang Wang, G. Min, J. E. Mellor, K. Al-Begain, L. Guan, An adaptive QoS framework for integrated cellular and WLAN networks, Computer Networks, Volume 47, Issue 2, 4 February 2005, Pages 167-183, ISSN 1389-1286, 10.1016/j.comnet.2004.07.003.

Figure 2.1: A generic approach for resource management



Source: The figure was done by Fazıl Aykut Tuzunkan

Resource monitoring helps decision maker to identify and discover the access networks along with a QoS and/or QoE mechanism when a user changes its location. The decision maker could be user-equipment (UE) or network, meaning either each cell will broadcast its connection information to UEs or UE will retrieve the cell information from both 3GPP and non-3GPP networks. In 4G networks, access network discovery could be controlled by Evolved Packet Core (EPC) along with access network discovery and selection function (ANDSF). However, 3G networks are missing such a core system and require either an additional device or an additive functionality to the existing serving nodes in the infrastructure or a user-centric approach. 3GPP or trusted/untrusted non-3GPP (WiFi) networks could be discovered and monitored by this functionality.

As for decision making functionality, UE or Mobile Network Operator (MNO) selects the access networks by considering probabilistic demands ideally.

Network related, terminal related, user related and application related metrics need to be considered pertaining to vertical handover decision. However, the paramount elements amongst them are the user-related ones as access network alters, users should approve the changes such as throughput, energy consumption of the terminal, security etc. of the suggested network. Otherwise, it would infringe on their right to privacy because for the very same application an adult's decision would differ from that of a young person, for instance, security-wise an adult might not prefer to watch videos through WEP or WPA on WiFi networks but EAP-SIM on 3GPP network. Maybe this choice could be trivial for a young person and actually he would prefer a free communication band, but considering rising security challenges of today's world, operators need to pay importance on the subject for each subscriber. We can classify the handoff decision criterias as below:

a. Network-related: Coverage, bandwidth, latency, link quality (CQI), BER (Bit Error Rate), cost, security level.

b. Terminal-related: Speed of the user, energy consumption.

c. User-related: User profile (i.e. student or businessman) and preferences (i.e. Cost or security).

d. Service-related: Service capabilities, QoS, QoE, security grade.[11]

The handover decision algorithm's purpose is picking an access network for a specific service that can meet up with goals depends on some criterias (for example cost, improved RSS, higher MOS, optimized bandwidth, low latency and jitter, high reliability and long battery life) and considering the favored access network of the subscriber. Some techniques used for network-centric solutions such as stochastic programming, game theory and utility function could be performed in this respect.

Stochastic linear programming obtains maximum allocation in each network by using probabilities related to allocation, underutilization, and rejection in HWNs. Game theory takes advantage of the bankruptcy game, and efficient bandwidth allocation and admission control algorithms are developed by utilizing available bandwidth in each network. In utility function, operator prioritizes users and classifies services to allocate bandwidth for the users.[12] [13] [14]

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[11] Hadiji, F.; Zarai, F.; Kamoun, A., "Architecture of mobile node in heterogeneous networks," Communications and Information Technology (ICCIT), 2012 International Conference on , vol., no., pp.260,264, 26-28 June 2012.

[12] A. Taha, H. Hassanein, H. Mouftah, On robust allocation policies in wireless heterogeneous networks, in: First International Conference on Quality of Service in Heterogeneous Wired/Wireless Networks, 2004. QSHINE 2004, 18–20 October 2004, pp. 198–205.

In client-centric solutions, analytical hierarchy process helps ranking the networks based on QoS by checking user's preferences and network attributes. Consumer surplus is an economical model, and could be used to find the network benefits the best-generally used for non-real-time traffic. In profit function, the difference between bandwidth gain and handoff cost for each network is computed, and the most appropriate network is found. [15] [16] [17]

As for the collaborative models, fuzzy logic controller ranks the candidate networks based on the user's selection criteria, network data rate and SNR. In objective function, user's RSS, network's queue delay and policy such as cost are fed as input parameters, and the function provides the allocation of services to APs and terminals. [18] [19] [20] Lastly, in TOPSIS, the best path for flow distribution on multi-homed end-hosts is computed. Also, network's QoS (delay, jitter, and BER), user's traffic class and most importantly QoE are checked.

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[13] D. Niyato, E. Hossain, A Cooperative game framework for bandwidth allocation in 4G heterogeneous wireless networks, in: IEEE International Conference on Communications, 2006. ICC'06, vol. 9, June 2006, pp. 4357–4362.

[14] X. Yang, J. Bigham, L. Cuthbert, Resource management for service providers in heterogeneous wireless networks, in: IEEE Wireless Communications and Networking Conference 2005, vol. 3, 13–17 March 2005, pp. 1305–1310.

[15] Q. Song, A. Jamalipour, A network selection mechanism for next generation networks, in: IEEE International Conference on Communications, 2005. ICC'2005, vol. 2, 16–20 May 2005, pp. 1418–1422.

[16] O. Ormond, P. Perry, J. Murphy, Network selection decision in wireless heterogeneous networks, in: IEEE 16th International Symposium on Personal, Indoor and Mobile Radio Communications, 2005. PIMRC 2005, vol. 4, 11–14 September 2005, pp. 2680–2684.

[17] X. Liu, V.O.K. Li, P. Zhang, Joint radio resource management through vertical handoffs in 4G networks, in: IEEE Global Telecommunications Conference, 2006. GLOBECOM'06, November 2006, pp. 1–5.

[18] A. Wilson, A. Lenaghan, R. Malyan, Optimising wireless access network selection to maintain QoS in heterogeneous wireless environments, Wireless Personal Multimedia Communications 2005. WPMC'05, 18–22 September 2005.

[19] G. Koundourakis, D. Axiotis, M. Theologou, Network-based access selection in composite radio environments, in: IEEE Wireless Communications and Networking Conference, 2007. WCNC'2007, 11–15 March 2007, pp. 3877– 3883.

[20] A. Ben Nacef, N. Montavont, A generic end-host mechanism for path selection and flow distribution, in: IEEE 19th International Symposium on Personal, Indoor and Mobile Radio Communications PIMRC, 2008, pp. 1–5.

2.2 KEY HIGHLIGHTS OF THE INTERWORKING 3GPP ACCESS AND NON-3GPP ACCESS TECHNOLOGIES

This section considers the interworking subject in terms of policy control, charging, and some additional benefits.

2.2.1 Unified Policy Control

Wi-Fi trusted access or 3GPP access policy control is anchored on GGSN, so operators can achieve unified policy. That's to say WLAN access can reuse traffic management, for example day pass solution, suburb package solution. And WLAN access can reuse solutions to enhance user experience and achieve unified user experience as 3GPP access, for example achieve bill shock prevention in WLAN access mode. Since service anchor point is GGSN, so we can reuse the legacy PCRF, and no need to build PCC in WLAN network.

2.2.2 Unified Charging

In trusted WLAN access PS solution, charging is anchored on GGSN, this architecture can reuse the legacy BOSS and OCS to save investment. And also can reuse the flexible billing policy, can achieve offline and online charging, achieve flow based charging, including volume based, time based and event based content charging. Since GGSN support carrier-grade charging, this makes precise charging possible. For GGSN cut traffic of walled-garden service from common traffic package.

2.2.3 Business Successes from Vertical Handove Solutions

Wi-Fi offload solution will lead operators to business success:

1. Offload PS traffic to low cost WLAN network, release 3GPP PS network expansion pressure.

2. High bandwidth, seamless services bring better experience to end user, which can increase the stickiness of end user and attract more subscribers.

3. Bring up end users high-bandwidth services consumption habit, market more high bandwidth VAS services, to get more profit.

2.3 IEEE 802.21 AND SECURITY

Some other problems related to user-centric models are: a device would connect at Layer 2, but not at network layer. Also, UEs would connect one of APs available based only on signal strength, and end-up with wrong assignment such as application class or QoS requirement are not met. Adding the increasing number of interfaces such as WiMax, WiFi and cellular network, the burden of UE would extend to cover multiple interfaces.

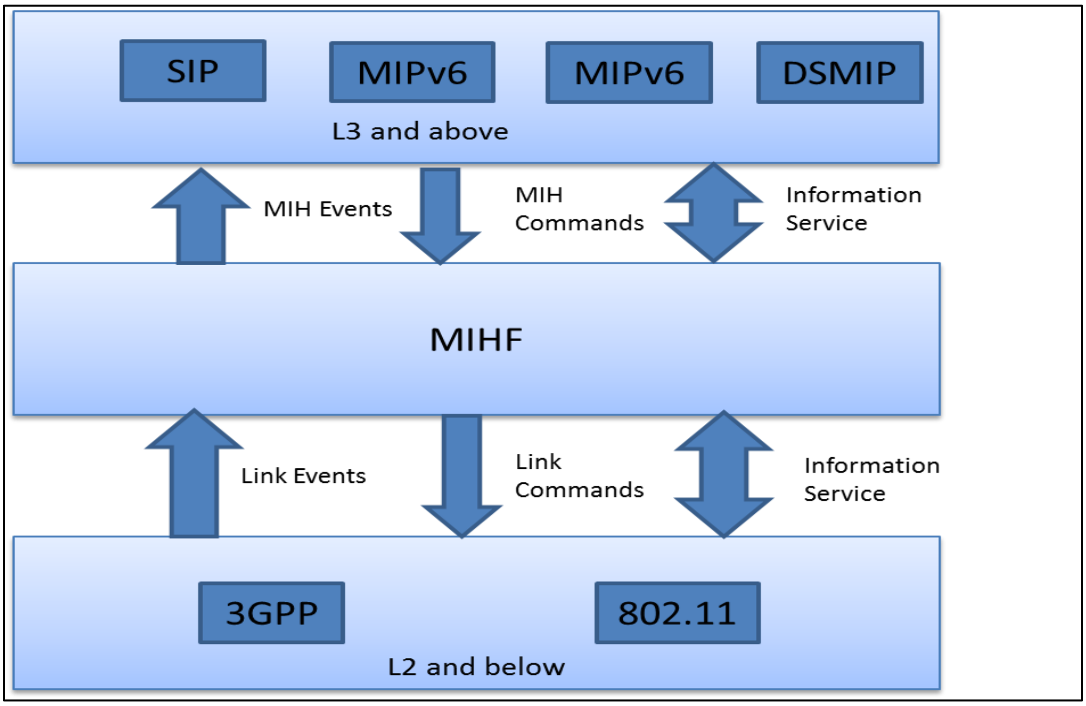
IEEE 802.21 WG was formed to overcome the diversity in the handover mechanisms and to eliminate user-centric methods' drawbacks, and therefore, a common MIHF (Media Independent Handover Function) was introduced. MIHF is an abstraction layer between layer 2 and layer 3. All interfaces on L2 (cellular, WiMax, LTE, WiFi) could communicate with MIHF, and MIHF could transmit the necessary messages to L3 and above such as SIP, MIPv4, MIPv6 or HIP. [21]

In IEEE 802.21 framework, there are several factors to determine the handover decision including application class, QoS, service continuity, network discovery and selection, security, energy management, and handover policy.

MIHF defines three services: Media Independent Event Service (MIES), Media Independent Command Service (MICS), and Media Independent Information Service (MIIS). MIES provides information concerning the link characteristics and status. MICS helps the user to manage and control the handovers and mobility. MIIS informs user regarding the neighboring networks and their capabilities. Command Service requests could be originated either from the local client or from a remote network element. In Fig. 2.2, MIHF architecture is showed.

[21] Dutta, A., et al.: Seamless Handover across Heterogeneous Networks - An IEEE802.21 Centric Approach. In: IEEE WPMC (2006)

Figure 2.2: MIHF Architecture



Source: The figure was done by Fazil Aykut Tuzunkan.

It was observed that the handoff delay and packet loss occur during the client's movement, IP address assignment procedure with DHCP server of the target network, and mobility binding update with both new and old network access points.

Basically, what IEEE 802.21 does is to put an information server to the network so that proactively user could obtain security, policy and IP assignment messages with the target networks, helping the handover process drastically with respect to handoff delay and packet loss. IEEE 802.11u implements 802.21 WG's MIH functionality, and provides a seamless VHO solution. The following section will describe IEEE 802.11u amendment.

2.3.1 IEEE 802.11u and Hotspot 2.0

For seamless WLAN handover and authentication, Hotspot 2.0 technology utlizes 802.11u as a building block so that wireless subscribers will be freely roamed amont the networks they are in without any other requirements.

Hotspot 2.0 technology allows users to speed up and automate their everday network selection, connecting and authentication steps, and this easiness comes with the 802.11 amendment.

WFA’s primary goal is to focus on vendor certification, while the WBA is focusing on a collection of network operators’ interest regarding interoperability. The Next Generation Hotspot programme of WBA describes interworking necessities for cable, hotspot, and 3G/4G wireless network operators. This programme contains enhancements of complete operator guide and a test environment to ease migration to Next Generation Access Points.

Due to the growth of data traffic on mobile networks and demand for wireless operators to handover this data traffic to WLAN networks, Hotspot 2.0 and Next Generation Acess Points (HotSpots) are globally considered as chief parts to upspeeding the adoption of WLAN as a joint technology to high-mobility wideband mobile options.

The amounts of WLAN access points are anticipated to almost triple by 2015 with some 1.2 million places Wi-Fi established. It is estimated that utilization will succeed suit, growing from almost 4 billion subscribers in 2010 to 120 billion subscribers by 2015. It is these subscribers and streams where 802.11u will come into the play to relieve the operators.

Based on the IEEE 802.11u specifications, the goal of the interworking methods discussed cosntitute:

i. Network discovery and selection: The seamless discovery of preferred access networks through the advertisement of network type, roaming agreement support and location information.

ii. Quality of service: This supplies a correlation among differentiated services code point (DSCP) markers to radio interface priority on a per-equipment basis, thus easing end-to-end quality of service.

iii. Emergency services: Alarm and events will be generated based on the alarm level and severity. [22]

As soon as 802.11u-capable equipment enters into frequency range of one or more access points, it would obtain the beacons of the access points (APs). If the APs provide 802.11u service, these beacons will show support for the standard. 802.11u utilizes a generic advertisement service to provide MAC later transmission of the advertisement protocol's frame between wireless equipment and a server in the core network of the operator before authentication completes.

An important component within 802.11u is the usage of the Access Network Query Protocol (ANQP). ANQP is considered as a query and response protocol utilized between the access network and a wireless device to learn a number of parameters such as the supported network authentication types supported, location name, roaming deals in place, data rates of the backhaul channels, common port numbers that are open.

By using this information, the mobile equipment checks its own credentials to acquire the list of roaming partners with which it will be able to make a connection. Then the list of roaming partners obtained from AP is compared with the one kept in the equipment and a successful authentication is achieved accordingly.

2.3.2 IEEE 802.11u Feature Summary

i. Network discovery and selection (NDS)

Generic Advertisement Service (GAS) along with Access Network Query Protocol (ANQP) and the Interworking element delivers insignificant support for network selection.

ii. Generalized QoS L3 $\rightarrow$ L2 mapping.

iii. Service Provider (aka SSPN) Interface.

iv. Support for emergency services including Emergency Alert Service (EAS).

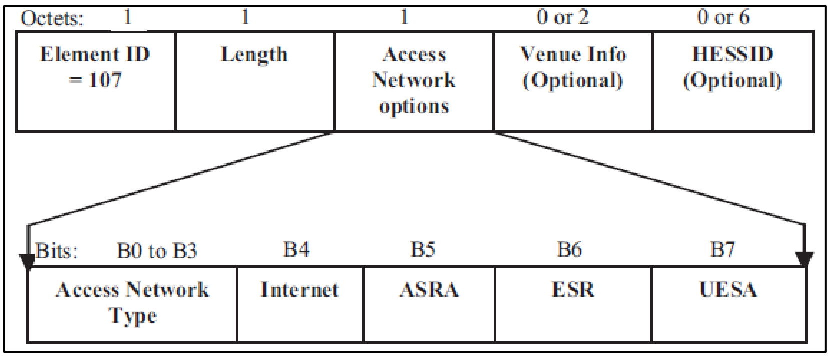
[22] IEEE 802.11u, http://standards.ieee.org/findstds/standard/802.11u-2011.html [accessed 13May 2014]

v. Standardized SAP for higher-layer mobility management protocols (only for client devices). [23]

2.3.3 IEEE 802.11u Interworking Information Element

Figure 2.3 shows the format of interworking information element. Its Element ID is 107. [24]It contains information about the interworking service capabilities of a WLAN network. The value of length field is equal to 1 plus sum of lengths of each optional field. As shown in Figure 2.3, the Access Network Options field is one octet long and further contains the information about the network. The most significant four bits (B0 to B3) advertise the type of access network from one of the following: Private, guest, chargeable and free networks. Bit B4 advertise whether the network provides connectivity to the internet or not. Bit B5 (ASRA: Additional Step required for Access) advertise that further step is required for accessing the network. Bit B6 and B7 advertise about the reachability of emergency services. The venue info field advertises the information about the place where the AP is present. The values it can contain are drawn from the International Building Code's Use and Occupancy Classifications. Fig. 2.3 represents bit-wise expression of the interworking IE.

Figure 2.3: Interworking Information Element



Source: Nokia, Technology Platforms, 2007.

[23] Dave Stephenson Wireless Networking Business Unit Strategic Initiatives and CTO Office February 27, 2012
[24] IEEE standard 802.11u , "Part 11: wireless LAN medium access control (MAC) and physical layer (PHY) specifications – amendment 9 interworking with external networks", 2011.

2.3.4 EAP-Based Authentication

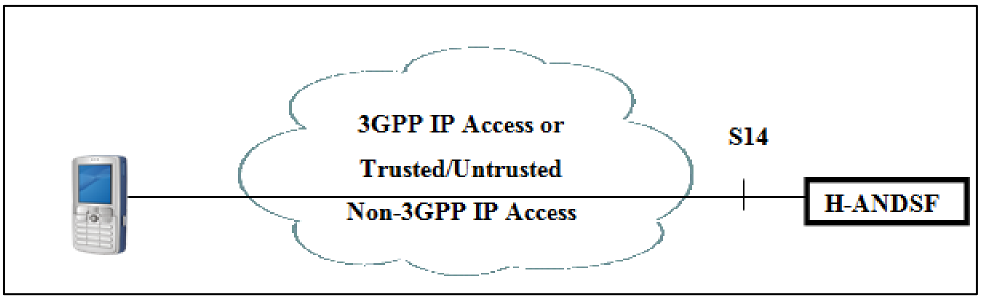
EAP-based authentication uses EAP and IEEE 802.1x to provide Layer 2 authentication for subscribers accessing the network with EAP-capable devices. For actual authentication, multiple credentials can be used, depending on the capability of the device.

Devices with SIM cards encapsulate the SIM application information exchange into the EAP message, and these are proxied by the AAA server to the home-location register (HLR) for authentication. EAP-SIM (RFC 4186) or EAP-Authentication and Key Agreement (EAP-AKA; RFC 4187) standards are used for the encapsulation, depending on the type of SIM card utilized and the HLR capabilities. Obviously, this method requires interconnection between the AAA server and the HLR or home-subscriber server (HSS).[25]

2.4 ACCESS NETWORK DISCOVERY AND SELECTION

UE should handoff to (while in active mode) or re-select (while in idle mode) as it is specified in TS 23.402. [26]

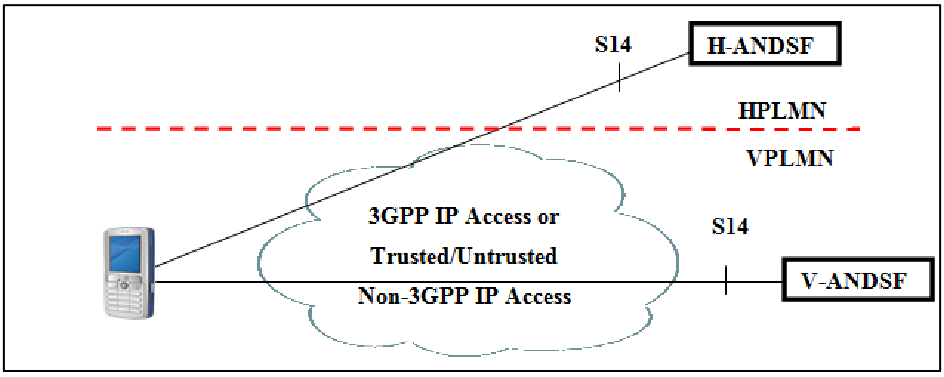
Figure 2.4: Non-Roaming Architecture for ANDSF



Source: Master Thesis, The Performance of WiFi Offload in LTE Networks, Desta Hagos, 2012.

[25] Cisco, Architecture for Mobile Data Offload over Wi-Fi Access Networks, White Paper, 2011
[26] 3GPP TS 23.402 V10.3.0, "Architecture Enhancements for Non-3GPP Accesses (Release 10)", March 2011.

Figure 2.5: Roaming Architecture for ANDSF



Source: Master Thesis, The Performance of WiFi Offload in LTE Networks, Desta Hagos, 2012.

As we can see it from Figure 2.4 and 2.5 depicted above, an ANDSF element placed in the home PLMN of a user equipment is called as the H-ANDSF for the corresponding UE, on the other hand an ANDSF element placed in the visited PLMN of a user equipment is referred to as the V-ANDSF for this UE.

2.4.1 ANDSF Discovery

Access-network specific information and inter-system mobility policies are provided by ANDSF to the user equipment and help the UE with executing the inter-system handoff. User quipment could provide this information either by using home operator or dynamically by ANDSF device over S14 interface which is described in TS24.302 and TS23.402.[27] According to [27] and [28] in non-roaming scenario, the H-ANDSF is detected by utilizing the DHCP Server function the Domain Name Service function. H-ANDSF address could also be delivered to the user equipment. New DHCPv4 and DHCPv6 options to allow the UE to detect ANDSF entities in an IP network are defined in IETF RFC 6153.[28] As it is defined in an earlier division of this chapter, the ANDSF answers UE requests for access network discovery information (which is called the pull mode operation) and it could also start data transfer to the user equipment (which is

[27] 3GPP TS 24.302 V10.3.1: "Access to the 3GPP Evolved Packet Core (EPC) via non-3GPP access networks; Stage 3 (Release 10)", April 2011.
[28] IETF RFC 6153: “DHCPv4 and DHCPv6 Options for Access Network Discover and Selection Function (ANDSF) Discovery”, February 2011.

called the push mode operation), based on network thresholds or as a consequence of prior communication with the user equipment.

As a multi-interface UE makes a connection to the CN by using various access networks, two criteria need to be considered. First of all, the UE is supposed to detect the available access networks without consuming so much battery power due to constant scanning messages. To solve this problem, network needs to push this information-available target access networks towards user equipment based on the UE location. Secondly, an appropriate access network needs to be picked for the UE that delivers good service performance. The target access network is selected without collaborating with end-user so that the selection will benefit network operator and will be beneficial for a good service delivery. However, an operator could provide some policies and restrictions which could be specific to users or devices used. Another thing that needs to be considered is to fairly balance the load among the target access networks.

2.4.2 Advantages of ANDSF

When a user equipment moves across the different wireless access network, it has to detect other available radio technologies in its region, which could possibly be opt for the currently used spectrum. For instance, a user equipment utilizing 3GPP spectrum such as 2G or 3G/4G needs to detect and discover as WiFi access becomes available and potentially activate a handoff to WiFi if this is more beneficial to the user or operator policies. When a user changes connection to another network leaving the range of the service of its current serving access network, handoff is supposed to be triggered seamlessly such that ongoing applications and services are not interrupted. The handoff operation demands switching the interfaces within a UE and it also engages seamless configuration of the supporting acess networks after discovery of the cell. Release-8 of 3GPP has specified the ANDSF framework through which the network operator can provide inter-system mobility policies. It is a 3GPP approach to date for governing handovering between 3GPP and non-3GPP access networks. As it is presented earlier in this report, the goal of the ANDSF is to help user equipments to discover access networks in their region and to deliver rules (policies) to prioritize and control connections to all system. As we know, the user equipment (UE) can discover target access networks in the range with no help from the network by periodically executing a spectrum scanning in the background. But this approach brings some problems as below:

i. Energy consumption can grow considerably, especially while user demands fast discovery.
ii. The information detected and discovered regarding the adjacent cells is bounded.
iii. The user equipment is supposed to have two different interfaces one for scanning and one for the current communiciation.
iv. Long delay from that a terminal enters a region where handover would be beneficial until the blind scanning discovers the available access.

This brings the requirement for network-based access network discovery and this is the main reason why ANDSF is one algorithm evaluated in this thesis work. In addition to the previously stated benefits, ANDSF features the following advantages:

i. Discovering information about neighboring networks.
ii. Dynamic construction of the database, information repository function.
iii. Deciding what information to gather and deliver to mobiles.
iv. Includes validity conditions to the information provided (i.e. indicate whether the provided information policies are valid or not).

The ANDSF MO (Access Network Discover and Selection Function Management Object) is utilized to govern the inter-system mobility policies along with access network discovery information kept in a user equipment providing configuration and provisioning of that information retrieved from an ANDSF.[29] The ISRP (Inter-system Routing Policy) information made up of a set of one or more Inter-System Routing Policies. Every Inter-System Routing Policy rule includes flag on load balancing for mobile devices that are provisioned for IFOM (IP Flow Mobility), MAPCON (Multi

[29] 3GPP TS 24.312 V10.3.0: "Access Network Discovery and Selection Function (ANDSF) Management Object (MO) (Release 10)", June 2011.

Access PDN Connectivity) or non-seamless WLAN offload. As it is defined in TS 23.402, ANDSF is basically a server that enables the UE to be retrieved with relevant attributes for access network discovery and intersystem mobility policy. The ANDSF server remotely sets parameters through a Management Object (MO) having hierarchical tree architecture defined in OMA DM as it is shown in the next figures.[30] The management object contains corresponding attributes for intersystem mobility policy- and access network discovery information which could be governed by the ANDSF. The functional and service necessities for the access network discovery and selection are defined in TS 23.402 and in TS 22.278 respectively.[31] More information about the ANDSF MO parameters can be found in TS 22.011.[32]

2.4.3 ANDSF Assisted Handover

In network-assisted handovers, network has a list of candidate access networks for the same and different spectrum technologies which can serve the user. The same idea can be carried out for adjacent network cell discovery in the joint 3GPP/non-3GPP network, because all legacy 2G/3G or 4G cells are developed to multicast or broadcast information regarding adjacent WLAN cells and vice versa. In the case of WiFi and LTE (or different technologies 2G/3G etc) there must be two interfaces, at least until software defined radio appears. In addition to this, when the user equipment contains a single receiver, then we have to ensure that the radio signal received from adjacent cells is evaluated without losing any packet from the serving cell. To make sure this, measurement for a user equipment needs to be scheduled by the base station serving.

As an alternative to this solution, if we need to decrase the changes of legacy spectrum networks, the adjacent cell information can not be broadcasted on spectrum channels but instead could be obtained by the user equipment (UE) from a specific entity in the system. This entity has already been defined by 3GPP to facilitate discovery of non-3GPP access network points, and is called the access network discovery and selection function (ANDSF).

[30] OMA-ERELD-DM-V1_2: "Enabler Release Definition for OMA Device Management".
[31] 3GPP TS 22.278 V11.3.0: "Service requirements for the Evolved Packet System (EPS) (Release 11)", June 2011.
[32] 3GPP TS 22.011 V10.3.0: “Service accessibility", March 2011.

2.5 CLIENT AND NETWORK MOBILITY PROTOCOLS

2.5.1 Client-based Mobility

In the evolved 3GPP core network EPS, client-based mobility support (DSMIPv6-based [33]) is supplied via the S2c interface for both trusted non-3GPP and untrusted non-3GPP access technologies. In both cases, the Packet Data Network Gateway acts as the Home Agent (HA). The IETF RFC 4877[34] is utilized in order to secure DSMIPv6 signalling and specifications of the security aspects are detailed in 3GPP TS 33.402. The first action the UE needs to execute for DSMIPv6 primary attachment is the discovery of the entity which is considered as the HA. The UE can find out the IP addresses of the HA by utilizing one of the following ways[35]:

i. Via attachment operation for 3GPP access network or trusted non-3GPP access network based on provisioned options;
ii. Via DNS;
iii. Via DHCPv6;
iv. Via IKEv2 during setupping tunnel to ePDG as for un-trusted non-3GPP access networks.

For this reason, the user equipment executes an IKEv2 exchange with the home agent before verifying the mobility tunnel as defined above.

2.5.1.1 Mobile SCTP

To reduce handoff delay and increase throughput performance, SCTP's multi-homing capability along with dynamic address reconfiguration (DAR) extension could be implemented in HWNs. SCTP based handoff solutions does not require any additional devices such as Registrar server as does SIP or MIP solutions. Mobile SCTP delivers an

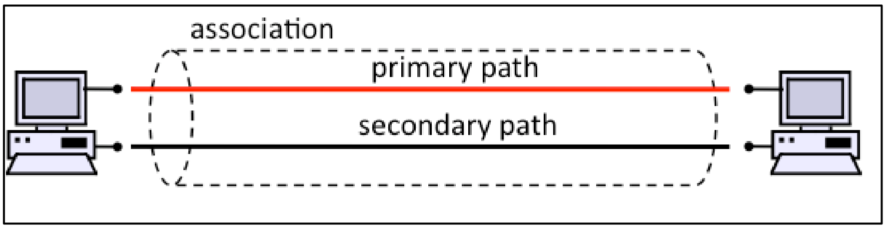
[33] IETF RFC 5555: Network Working Group, “Mobile IPv6 Support for Dual Stack Hosts and Routers”, June 2009.
[34] IETF RFC 4877: Network Working Group, "Mobile IPv6 Operation with IKEv2 and the Revised IPsec Architecture", April 2007.
[35] 3GPP TS 24.303 V10.2.0: "Mobility management based on Dual-Stack Mobile IPv6; Stage 3 (Release 10)", March 2011.

tandemly soft offloading scheme for mobility management. Consequently, SCTP scheme presents a network independent solution that operator or service providers prefer.[36]

Compared with application layer handoff solutions, SCTP-based mobility solution has the below advantages:

1. Only end-points need to exchange modified routing tables with each other.
2. Simultaneous utilizaition of any type of access routers is supported.
3. No new or modified component is required in the existing operator network.

Figure 2.6: Multihoming support in SCTP



Source: A New Method to Support UMTS/WLAN Vertical, 2004

The general necessities for SCTP to provide seamless vertical handover are:

1. Both mobile client (MC) and fixed server or correspondent node (FS) needs to be equipped with Mobile-SCTP implementation, for instance, SCTP with DAR extension;
2. Dual-mode support of 3GPP and non-3GPP at the data link and physical layers of the UE;
3. Issues on AAA, user authentication and QoS provisioning because of modifications.

One disadvantage of the Mobile SCTP is that if 3GPP and non-3GPP do not utilize the same AAA database, functions such as billing, security and customer management will be problematic.

[36] Li Ma; Yu, F.; Leung, V. C M; Randhawa, T., "A new method to support UMTS/WLAN vertical handover using SCTP," Wireless Communications, IEEE , vol.11, no.4, pp.44,51, Aug. 2004

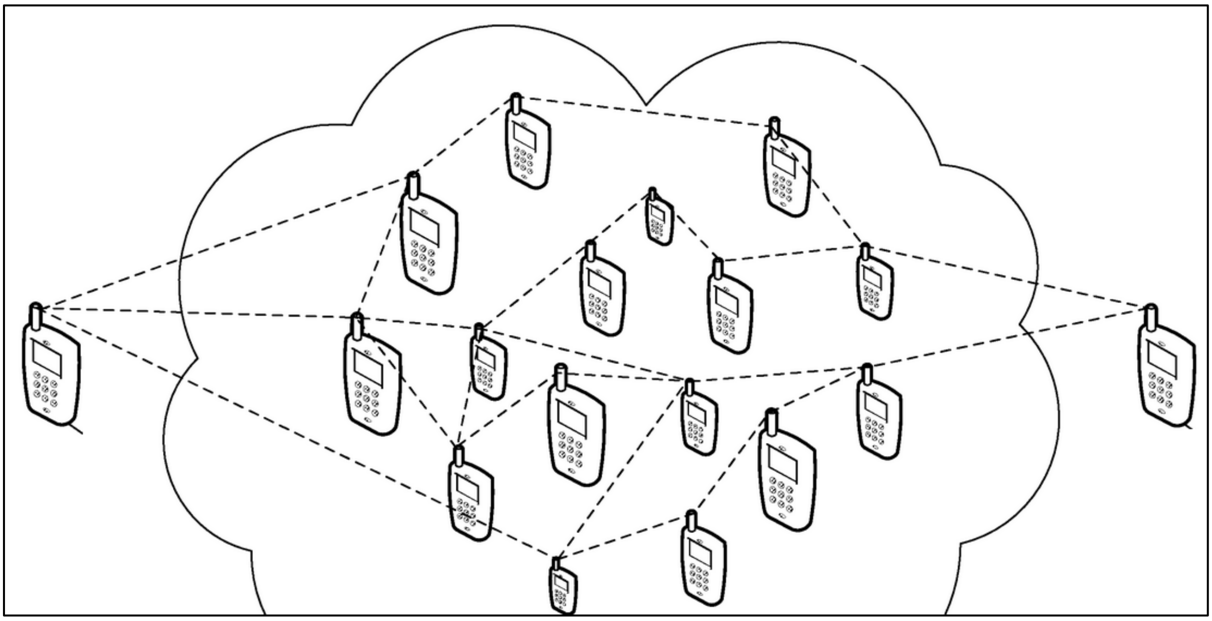
2.5.2 Network-based Mobility

The introduction of the EPC allows network operators to install and run one shared all-IP core network for 3GPP radio access technologies (E-UTRAN, UTRAN, and GERAN), along with other wireline and mobile access networks (e.g., WIMAX, WLAN, and DSL), supplying the network operator with a shared set of services and capabilities troughout the networks. The fundamental necessity of the EPC is to supply seamless mobility at the network layer as the user moves between access networks. As it is defined in RFC 5213, network-based mobility mechanism allows IP mobility for a machine host without requiring joining in any mobility-related signaling. The network's responsibility is governing IP mobility on behalf of the host. This means that the mobile nodes in the network are responsible for following the movements of the nodes.

2.6 OPPORTUNISTIC NETWORKS

By searching other peers who has the necessary requested data, the system fetches the users with the data. Due to the heterogeneity of access functions and the locality of information, while user equipments fail to access network by using their connections, they could demand to retrieve data from peers in their vicinity, who either have the data cached, or possess network access and so that they could download and upload the data among them. In Fig. 2.7, an opportunistic netwrok is depicted. UEs transmit data packets amonst them in order to lessen the infrastructure's heavy load.

Figure 2.7: A general opportunistic network



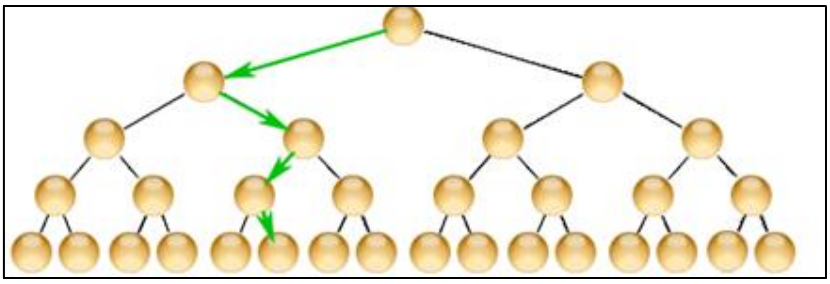
Source: Patent, Health-related opportunistic networking, 2012

2.6.1 Opportunistic Communication Handover Pull-Based Algorithms for Delay Tolerant Systems

Greedy

Whenever the information dissemination is a submodular function, then we can exploit the algorithm. User mobility knowledge is required to apply Greedy algorithm which may not be available at the very beginning. The algorithm can be utilized to find either the most active users or the users whose propogation channels are the strongest. [37]

Figure 2.8: Greedy Algorithm on the local optimum



Source: Devarticles, Greedy Strategy as an Algorithm Technique, 2008

Heuristic

This algorithm gives us a approximate solution in case no or inexpensive analytical model exists. By using this algorithm, user mobility pattern could be approximated.

Random

Since the aim for opportunistic communication is to select the best target set of users, by doing so is the least effective among other algorithms, but still better than nothing. Basically, this algorithm selects some random target-users.

Blind Global Promotion(Where multi-hopping is not an option)

After seperating the nodes based on neigberhood (global or hood), based on the attributes in social network theory including betweenness centrality, degree centrality, closeness centrality, and page rank, this algoritm ranks the nodes. It picks up the top-ranked nodes which are not yet promoted until the network coverage is completed.[38]

Greedy Global Promotion (Where multi-hopping is not an option)

After seperating the nodes based on neigberhood (global or hood), based on the attributes in social network theory including betweenness centrality, degree centrality,

[37] B. Han, P. Hui, V. Kumar, M. Marathe, J. Shao, A. Srinivasan, Mobile data offloading through opportunistic communications and social participation, IEEE Transactions on Mobile Computing (2011).
[38] A. Boc. Vip delegation: Enabling vips to offload data in wireless social mobile networks. 2011.

closeness centrality, and page rank, this algoritm ranks the nodes. Then, it begins with promoting to target-set the top-ranked node. After this preferment, the nodes which are covered by this target-set are listed and ranking on the left nodes are computed again. Then, the process is repeated until the network coverage is completed. [39]

Betweenness centrality: Measuring the number of occurrences of an entity in the shortest-path between pairs of others nodes. That is, it decides “bridge nodes” that, with their movement, operate as connectors between node groups.

Degree Centrality: Ranking nodes based on the number of their direct ties (i.e., adjacent neighbors) in the graph. It presents the most popular nodes, also called hubs in social network theory, possible used to exchange information.

Closeness Centrality: Ranking higher nodes with lower multi-hop distance to other nodes of the graph. It describes “independent nodes” that do not depend on others as transmitters or relayers of messages because of their closeness to other nodes.

Page Rank: The well known Google’s ranking algorithm, computes the likelihood of nodes in having important friends in a social graph.

Blind Hood Promotion(Where multi-hopping is not an option)

It behaves exactly as the equivalent Global algorithm, but covers only local nodes.

Greedy Hood Promotion(Where multi-hopping is not an option)

It behaves exactly as the equivalent Global algorithm, but covers only local nodes.

Approximation Algorithm

For scenarios where data lifetime is shorter, then this algorithm is applicable. The algorithm approximates the objective function where data lifetime is the major concern.[40]

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[39] Xin Gang Wang, Geyong Min, John E. Mellor, Khalid Al-Begain, Lin Guan, An adaptive QoS framework for integrated cellular and WLAN networks, Computer Networks, Volume 47, Issue 2, 4 February 2005, Pages 167-183, ISSN 1389-1286, 10.1016/j.comnet.2004.07.003.

[40] Y. Li, G. Su, P. Hui, D. Jin, L. Su, and L. Zeng, Multiple Mobile Data Offloading Through Delay Tolerant Networks In Proceeding in 6th ACM International Workshop on Challenged Networks (CHANTS 2011), Las Vegas, USA, September 2011

Optimal Storage Allocation Algorithm

For homegenous assumptions such as constant buffer size of helpers, constant data size and low-mobility, this algorithm could be applied. This algrith exploits Greedy algorithm for the homogeneous scenarios.

HotZone Algorithm

It harnesses delay tolerance and demands to retrieve information when users are close to WLAN access points; it is helped by estimations performed by the operator. [41]

MixZone Algorithm

The algorithm exploits opportunistic, ad hoc transfers between users, and is helped by estimations made by the wireless operator. The advantage is energy efficiency compared to a regular greedy algorithm.

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[41] N. Ristanovic, J. Boudec, Augustin Chaintreau, Vijay Erramilli: Energy Efficient Offloading of 3G Networks. MASS 2011: 202-211

Table 2.1: Comparison of existing opportunistic algorithms

	Mobilitywise (Vehicular or Human)	Delay Tolerancy	Scale (Large or Small Area)	Mobile Data Heterogeneousity (Life Time and Size)	Storage of Offloading Helpers	Energy Efficiency
Greedy with heuristic	Good	Yes	Both	Small Data Size	Not Considered	Medium
Heuristic	Medium	Yes	Both	Small Data Size	Not Considered	Medium
Random	Better than no algorithm applied	Yes	Depends on the randomness	Small Data Size	Not considered	Medium
Greedy Global with page rank	Good	Yes	Large	Large Data Size	Not considered	Good
Blind Global	Bad	Yes	Large	Large Data Size	Not considered	Good
Greedy Hood with page rank	Good	Yes	Small	Large Data Size	Not considered	Good
Blind Hood	Bad	Yes	Small	Large Data Size	Not considered	Good
Approxi-mation	Good	Yes	Both	Low Lifetime Data	Considered	Good
Optimal Storage Allocation	Bad	Yes	Both	Homogenous	Considered	Bad
Push-and-Track	Very Good	No	Both	Very Heterogeneous	Not Considered	Bad
Wiffler(Not algorithm)	Vehicular	Yes	Both	Not considered	Not considered	Bad
HotZone	Both	Yes	Small Area	Not considered	Not considered	Good
Mixzone	Both	Yes	Both	Not considered	Notconsidered	Very Good

Source: The table was done by Fazil Aykut Tuzunkan.

2.7 CARRIER AGGREGATION AND SPECTRUM MANAGEMENT

2.7.1 Spectrum Management

Due to the shift from analog to digital TV, a valuable spectrum band has been opened. Radio interface is a very paramount element for growing economic activities through broadband services. So by governing this new opening with the instruction of the regulatory esthablishments, new unlicensed bands could ne utilized for users benefit or these spectrum bands could go for some actions to be licensed and to be used by wireless network operators.

2.7.2 TV White Space

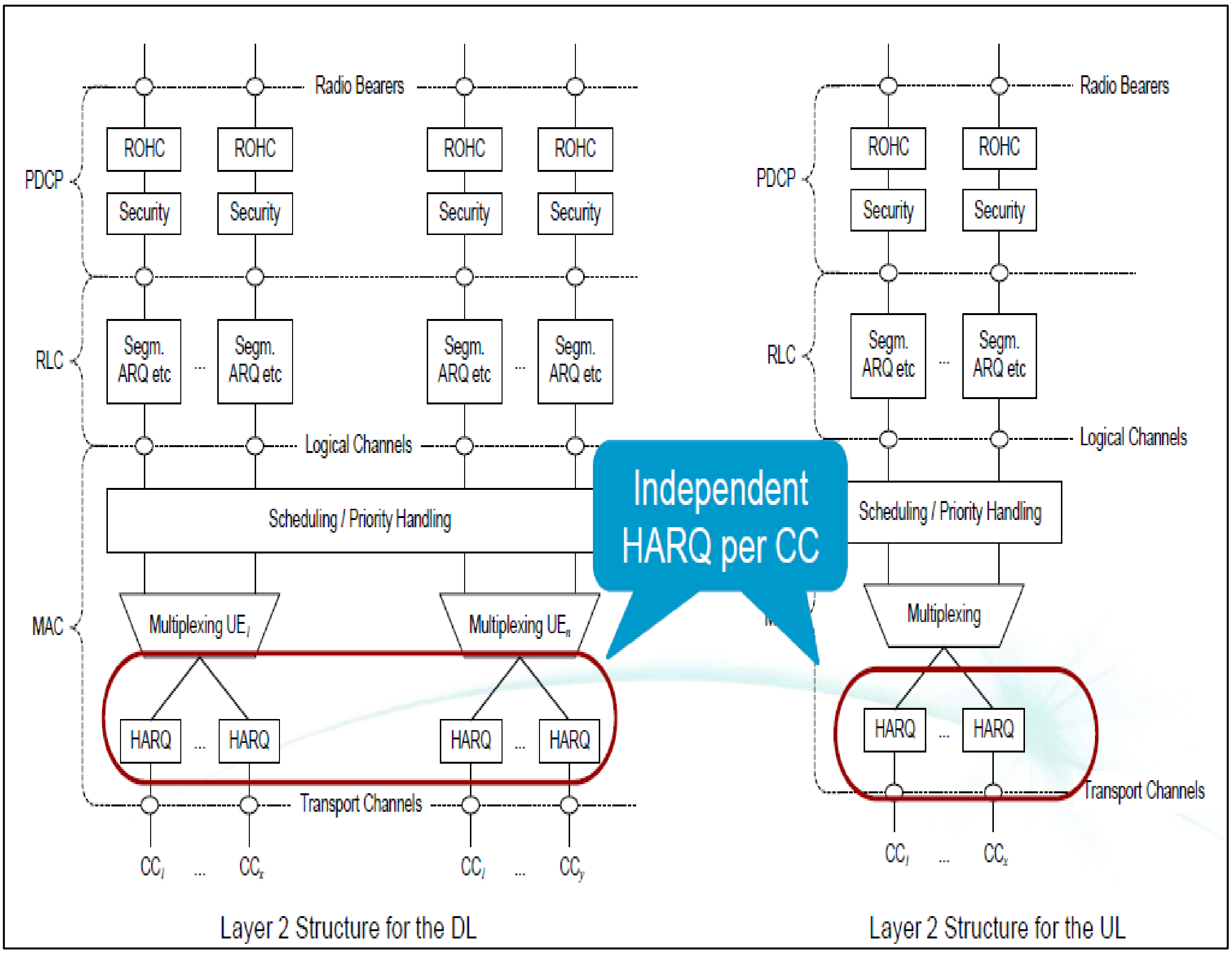
By taking advantage of this newly introduced spectrum, LTE deployments could go faster. Developing access network capabilities with existing devices will be preferred over a new deployment operator-wise. With the help of this TV White space, new users will be introduced and in return will cause opening up new markets that were not possible in the past.

One of the key capabilities of LTE is its adaptibility for deployment in bandwidths ranging from 1.4 MHz to 20MHz. Furthermore, it can work in all 3GPP spectrum band in paired and unpaired allocations. The performance of LTE is actually due to the multiple band usage or carrier aggregation. By using this feature, operators feel more flexible in terms of user allocation across heterogeneous networks. To increase network capacity, LTE usage along with carrier aggregation where TV White space is used would be a strategic move for the operators.

2.7.3 Carrier Aggregation and Types

Carrier aggregation provides the means to enable wider transmission bandwidths not previously supported in 3GPP Release 8 or 9. Carrier aggregation enables expansion of efficient bandwidth provided to a mobile terminal through simultaneous usage of spectrum resources throughout multiple carriers; the multiple carriers are aggregated to form an overall larger bandwidth.

Figure 2.9: Carrier Aggregation MAC layer



Source: Sprint, LTE Advanced - Carrier Aggregation, White Paper, 2013.

Carrier aggregation extends the maximum transmission bandwidth, up to 100 MHz, by aggregating up to five LTE carriers – also known as component carriers (CCs).

i. Lack of sufficient contiguous spectrum forces use of carrier aggregation to meet peak data rate targets:

a. 1 Gbps in the downlink and 500 Mbps in the uplink.

ii. Motivation:

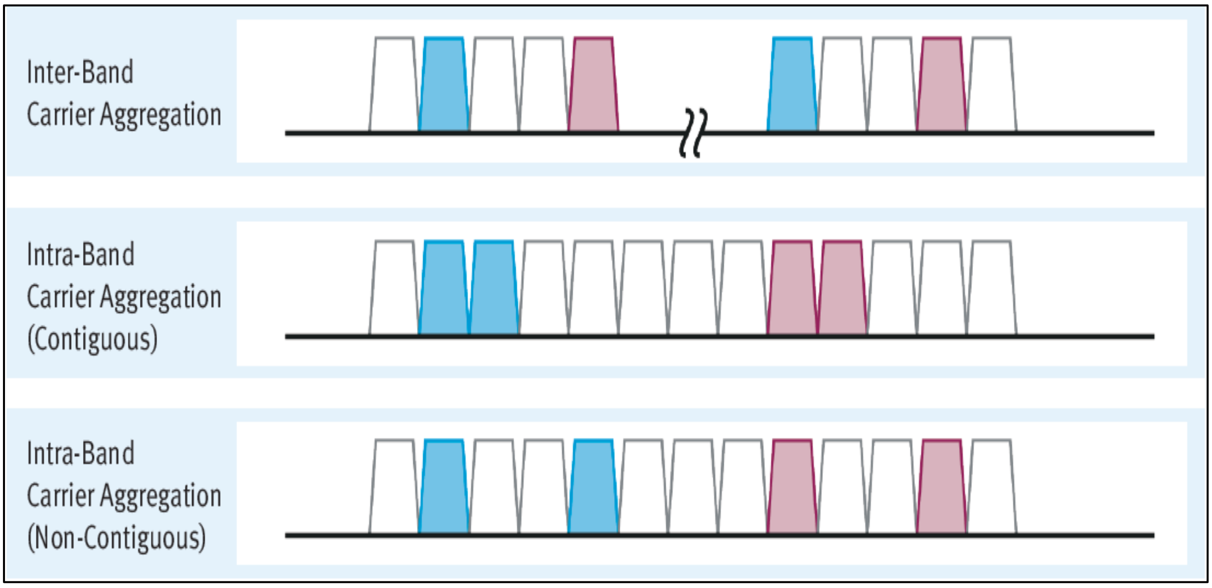
a. Achieve wide bandwidth transmissions.

b. Facilitate efficient use of fragmented spectrum.

c. Efficient interference management for control channels in heterogeneous networks.

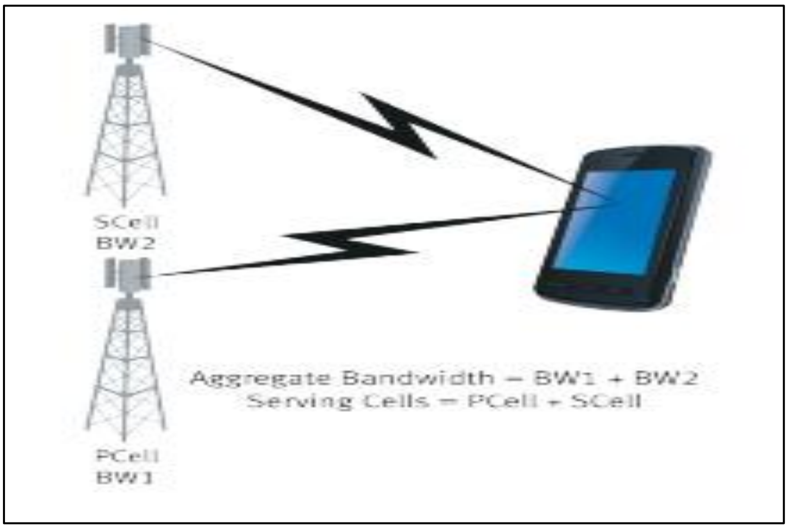
Three types of carrier aggregation are defined: inter-band aggregation, contiguous intra-band aggregation and non-contiguous intra-band aggregation.

Figure 2.10: Carrier Aggregation Types



Source: Sprint, LTE Advanced - Carrier Aggregation, White Paper, 2013.

Figure 2.11: Conceptual CA model



Source: Sprint, LTE Advanced - Carrier Aggregation, White Paper, 2013.

i. PCell: The primary cell where the UE establishes the RRC connection and where PUCCH is used.

ii. SCell: Secondary cell(s) that the UE could be monitoring for downlink assignment and using to transmit uplink data.

iii. The serving cell(s): The PCell and one or more SCells, if configured for a UE supporting carrier aggregation.

iv. Aggregated channel bandwidth: The cumulative channel bandwidth for all the carriers.

v. Cross-carrier scheduling: Scheduling information for a SCell is transmitted over PDCCH of the Pcell.

2.8 MULTIPLE ATTRIBUTE DECISION MAKING ALGORITHM USED

2.8.1 TOPSIS

In this thesis, TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) was utilized, due to its easy implementation, as a way of selecting the best target network for a given user's video application. The decision to use this algorithm was made based on the other multiple attribute decision making (MADM) algoritms' performance comparison results. By using this algorithm, we trigger the MIH events such as connect-link or disconnect-link to execute the handover seamlessly. For this purpose, first, we created a decision matrix:

$$A_{ij} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix}$$

In A_{ij} matrix (i-row, j-column), n refers to decision points such as link quality, MOS of the target network for the given application, user preference (cost security), and m refers to the target networks which are UMTS or WLAN. In second step, we formed a normalized decision matrix by using the following equation:

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^{m} a_{kj}^2}} \qquad (2.1)$$

We obtained the R matrix:

$$R_{ij} = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ r_{m1} & r_{m2} & \dots & r_{mn} \end{bmatrix}$$

Then, we created a weigted normalized decision matrix by multiplying each column of the matrix by corresponding weight w_i where $\sum_{i=1}^{n} w_i = 1$ by using the following equation:

$$v_i = w_i * r_i \qquad (2.2)$$

TOPSIS method assumes that each evaluation factor has a monotonically increasing or decreasing tendency. Next, we formed the positive (A^*) and negative (A^-) solutions by using the following formula:

$$A^* = \left\{ (\max_i v_{ij} \middle| j \in J), (\min_i v_{ij} \middle| j \in J^{'} \right\} \qquad (2.3)$$

$$A^- = \left\{ (\min_i v_{ij} \middle| j \in J), (\max_i v_{ij} \middle| j \in J^{'} \right\} \qquad (2.4)$$

For both formula, J refers to benefit (max), and J' refers to lost (min).
For both solution set, the number of evaluation factor consists of m elements.

We ended up with the respective sets of $A^* = \{v_1^*, v_2^*, ..., v_n^*\}$ and $A^- = \{v_1^-, v_2^-, ..., v_n^-\}$

Then we calculated the Euclidean distance S_i^* of each alternative a_i from the positive point and S_i^- of each alternative a_i from the negative point A^-. Both positive and negative set consists of the the number of evaluation factor, that is, m elements. The calculations are shown respectively as below:

$$S_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2} \tag{2.5}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \tag{2.6}$$

In the next step, we calculated the relative similarity of the alternatives from the positive and negative point which is done in the following manner:

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \tag{2.7}$$

where $0 \le C_i^* \le 1$

If C_i is close to value 1 the solution is closer to ideal.

3. SEAMLESS MOBILE DATA OFFLOADING

3.1 INTRODUCTION

The increase on smartphone usage has brought the burden of data traffic with it. Operators are looking for cost-effective solutions to overcome the problem of 3G infrastructure for high contention traffic scenarios. Several schemes were offered to save the moment, and they brought some extra costs, including deploying femtocell or WiMax, LTE, LTE-Advanced systems along with their expensive equipment. On the other hand, operators are expanding their networks with 802.11 technologies such that they can exploit the free-band communication.

At this point, mobile data offloading provides a solution with real business value. Significant cost reductions and improvement of the operator's reach to its customers gives a competitive edge to it. In this study, we will evaluate and simulate collaborative type of mobile data offloading scheme for real-time network (RTN) systems. In this scenario, we will develop a seamless offload scheme between 3GPP and WLAN networks for real-time packet traffic. This solution would carry heterogeneous mobile broadband networks' fundamental identifiers such as application targets, user's mobility and usage characteristics, network capacity and density, network management, terminal's power state, network congestion status, physical channel parameters to a mathematical plane.

With this model, by taking into account the base protocol functions such as access, error and congestion control, network and channel capacity, data transmission latency and reliability parameters will be improved based on the upper and lower limits of them. The scenario will allow us to contribute to the following points:

1. User preference as a Quality of Experience (QoE) metric during handover decision making will be integrated into the developed multiple attribute decision making (MADM) algorithm.

2. Handover execution will be handled not only based on link-quality including quality of Service (QoS) values, but also based on subjective measures.

3. Network traffic of the heterogeneous wireless networks (HWNs) will be improved and managed based on user experience.

3.2 ARCHITECTURE AND IP FLOW MOBILITY

3.2.1 Network Requirements

LTE has been designed to be an all-IP and support only packet-switched services thereby providing seamless IP connectivity between heterogeneous access networks without any interruption to the UE's application during mobility and service. One way to achieve seamlessness is by utilizing DSMIPv6 which was defined in 3GPP which enables seamless handoffs which are optimized and permits make-before-break connections for a robust user experience. We have also seen that EPS[7] makes use of the concept of EPS bearers, which are an IP flow with pre-defined QoS support mechanism between the PDN GW and the UE, to route IP traffic to/from a gateway in the PDN GW to the UE.

1. Based on the 3GPP standard [42] the following architectural requirements and assumptions are briefly discussed.
2. Multi access PDN connectivity and IP flow mobility should be probable for both EPS and interworking wireless local area network (I-WLAN) mobility architectures.
3. Minimum effects to the current functionality and to the access networks.
4. It would also be possible for a multi-radio UE that is able to simultaneously connect to a given PDN connection via several access networks to actuate individual service data flows from one radio access technology to another in a seamless scheme (i.e. without unnecessary disturbance of the user experience).
5. It would be probable for EPS/I-WLAN mobility to deliver simultaneous access to a single PDN by using different access networks.

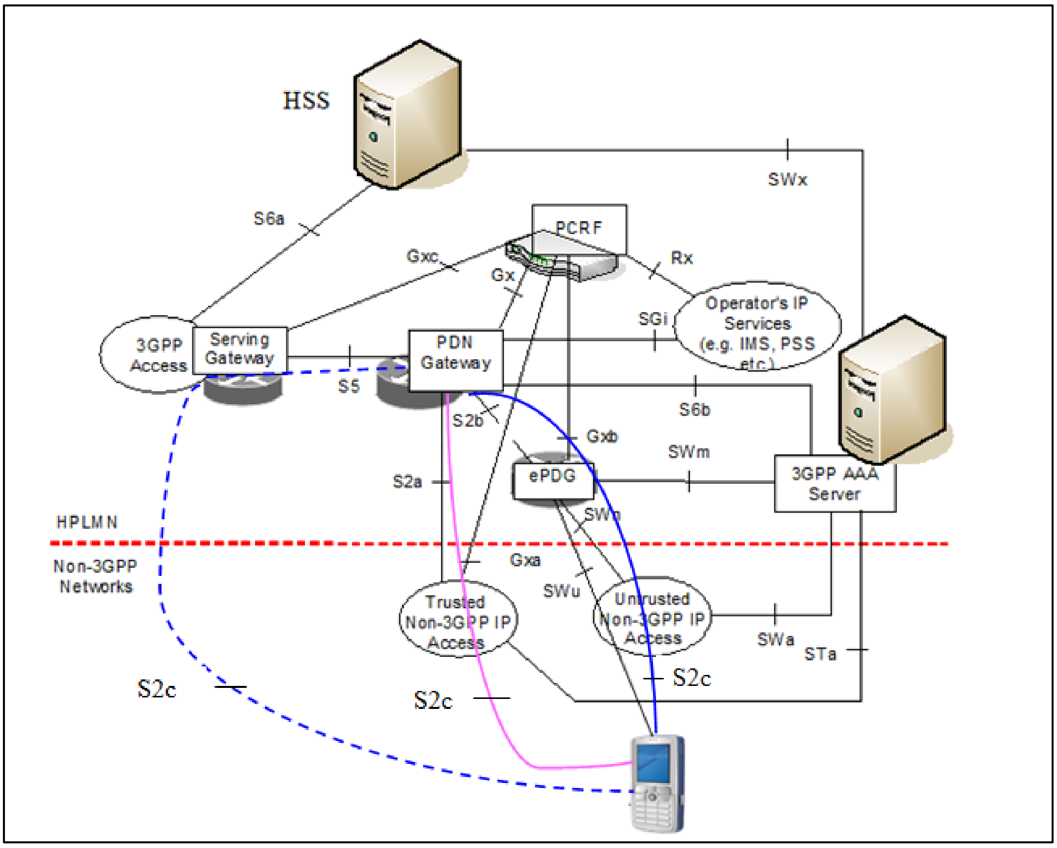
[42] 3GPP TS 23.861 V1.3.0: "Multiple access PDN connectivity and IP flow mobility (Release 9)", September 2009.

6. For accesses under the management of the operator, it should be possible for the network to detach the UE from the current ANs through which the UE simultaneously accesses the EPC.

Figure 3.1 presents the baseline scheme for multi access IP flow mobility and PDN connectivity when EPS is deployed in the non-roaming architecture in Release 8 EPS, where the Serving Gateway (SGW) is the default switch for the MT in 3GPP access technology. The Access Gateway behaves as the Serving Gateway for trusted non-3GPP access technologies. WiMAX could be an example of trusted non-3GPP access technology, where the Access Service Network Gateway defined by the WiMAX Forum behaves as the S-GW. For untrusted non-3GPP access, for example public WiFi could be given, the ePDG behaves as the S-GW, because it needs usage of an IPSec between the MT and the 3GPP network in order to deliver appropriate security mechanism reasonable to 3GPP mobile operator.[43] The main role of the PDN GW is to behave as anchor point for all the uplink and downlink traffic to/from the mobile node.

[43] 3GPP TS 33.234 V11.0.0, “3G Security; Wireless Local Area Network (WLAN) interworking security (Release 11)”, March 2011.

Figure 3.1: Non-roaming Architecture within EPS using S5, S2c



Source: Master Thesis, The Performance of WiFi Offload in LTE Networks, Desta Hagos, 2012.

As we can see it from Figure 3.1, the S5 and S2c interfaces, when EPS is deployed in the nonroaming case and a roaming case respectively, among the Serving GWs and the PDN GWs would be based on the network-centric mobility protocols (both GTP and PMIPv6. S2a is the interface which delivers the user plane with corresponding mobility and control support between the PDN GW and the trusted non-3GPP IP access (the ASN-GW when it comes to the WiMAX access' context) and S2b is the interface which provides the user plane with related control and mobility support between the ePDG and PDN GW. GTP or PMIPv6 are supported by both S2a and S2b interfaces. For PMIPv6, the PDN GW incorporates the LMA functionality and the Serving GW incorporates the Mobile Access Gateway functionality. The user plane with corresponding mobility and control support between the UE and the PDN GW is provided by S2c interface and it is established upon the DSMIPv6 protocol, where the PDN GW utilizes the functionality of a home agent. In release-8, the client-centric 3GPP/WLAN mobility scheme was detailed based on DSMIPv6, where the client is in communication with a home agent in the system to exchange connection information regarding non-3GPP access which could be by using binding updates. In addition to the DSMIPv6 support, TS 23.402 contains inter-technology mobility features by utilizing the 3GPP network-centric GTP and extensions of the IETF network-centric PMIPv6 protocols.

3.2.2 IFOM (IP Flow Mobility)

Even though the specification contained a study of network-based (PMIPv6) alternatives, the client-based (DSMIPv6) solution was considered more complete and was accordingly defined in TS 23.261.[44] Current work item discussions in Release-11 and IETF are going on to answer the network-centric schemes for MAPIM along with systems for IP subflow mobility, for example, the schemes which are being investigated for MCTP (Multi-path TCP) in IETF Internet Draft.[45]

As the title suggests, what is behind IP flow mobility in a wireless data communication is that

allowing for selective movement of IP flow between different access networks supporting different access technologies. An IP Flow contains a set of IP packets that are relayed back and forth between two entities and that correspond a provided flow definition. In Release-8 EPS and I-WLAN mobility architecture, the modularity of access network connectivity and inter-system mobility is for each PDN connection-wise, i.e. the UE cannot access the same PDN connection via multiple interfaces. This means the MT cannot handle mobility of each IP flow in a PDN connection in a seprate manner, and therefore when offloading from one network to another, it needs to carry all the IP flows in a PDN connection together. As a result of this, the following Table 3-1 shows the basic required enhancements, and latter in this same section will be described the required enhancements to have a PDN connection level inter-system mobility.

---

[44] 3GPP TS 23.261 V10.1.0: "IP Flow Mobility and seamless Wireless Local Area Network (WLAN) offload; Stage 2 (Release 10)", September 2010.

[45] IETF Internet Draft, draft-ietf-mptcp-multiaddressed-04, “TCP extensions for Multipath Operation with Multiple Addresses”, July 2011.

Table 3.1: Release 8 EPS and I-WLAN mobility basic required enhancements

	Rel-8 system	System with IP Flow mobility
Inter-system mobility	Per UE	Per IP flows within PDN connection
PCC logic & IP-CAN specific PCC signalling	Per IP-CAN	Per IP flows within IP-CAN
ANDSF Inter System Mobility policies	Per UE	Per IP flow classes within UE

Source: Master Thesis, The Performance of WiFi Offload in LTE Networks, Desta Hagos, 2012.

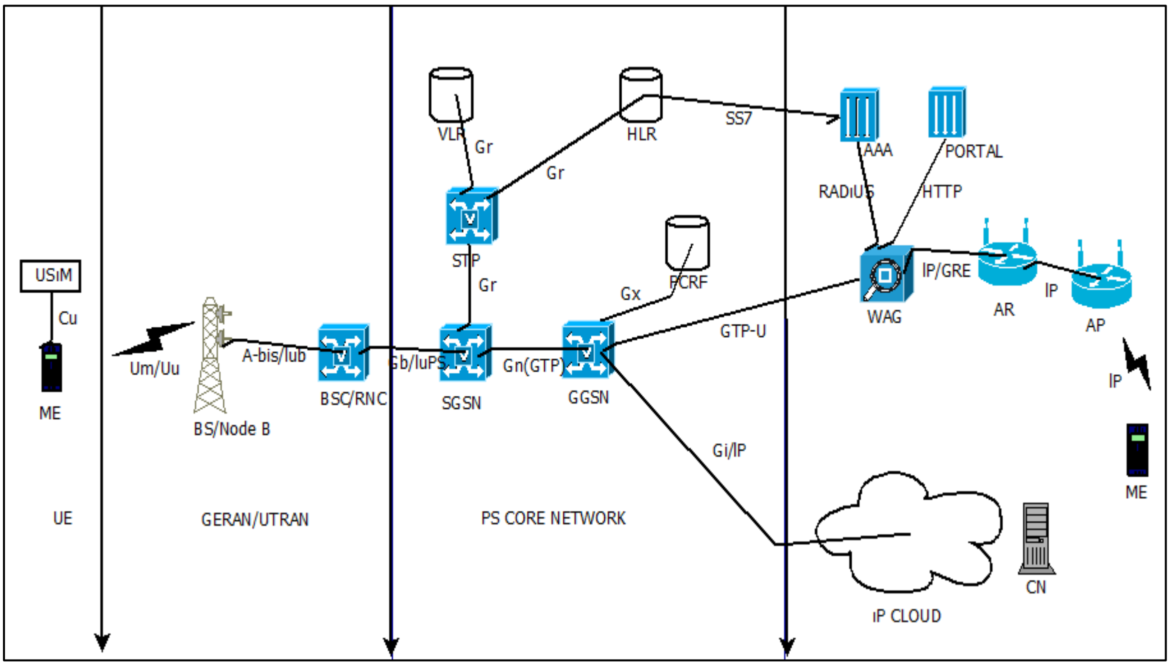
IP flow mobility represents the idea of handling IP flows separately in a PDN connection. The UE may simultaneously connect to different IP flows through different access interfaces. IP flow mobility details that the mobility of a PDN connection is treated per IP flow. The access interfaces the MT can stay at the same time connected with could contain 3GPP RAT, like GERAN (GSM EDGE Radio Access Network), UTRAN or E-UTRAN, and only one non-3GPP access system, such as WiFi or WiMAX. That is, that in a single PDN connection the below duties are supported:

a. Establishment of PDN connections over multiple accesses. This means that, the UE opens a new PDN connection on an access that was previously not used or on one of the accesses it is already simultaneously connected with.
b. Selective removal of IP flows from the PDN Connection. In this case, the UE moves selectively traffic related with one access network to another network and disconnects form one access.
c. Selective transfer of IP flows between accesses. This is a case where, at the time of inter-system handover the UE transfers a subset of the currently active PDN connections from the source to the destination address.
d. Transfer of all PDN connections (IP flows) out of a certain access system. This is a case where the UE moves all the active PDN connections from the source to target access, e.g. in case the UE goes out of the coverage of the source access.

3.3 USE CASES

3.3.1 Use case 1

Figure 3.2: Standard WiFi Offloading Architecture

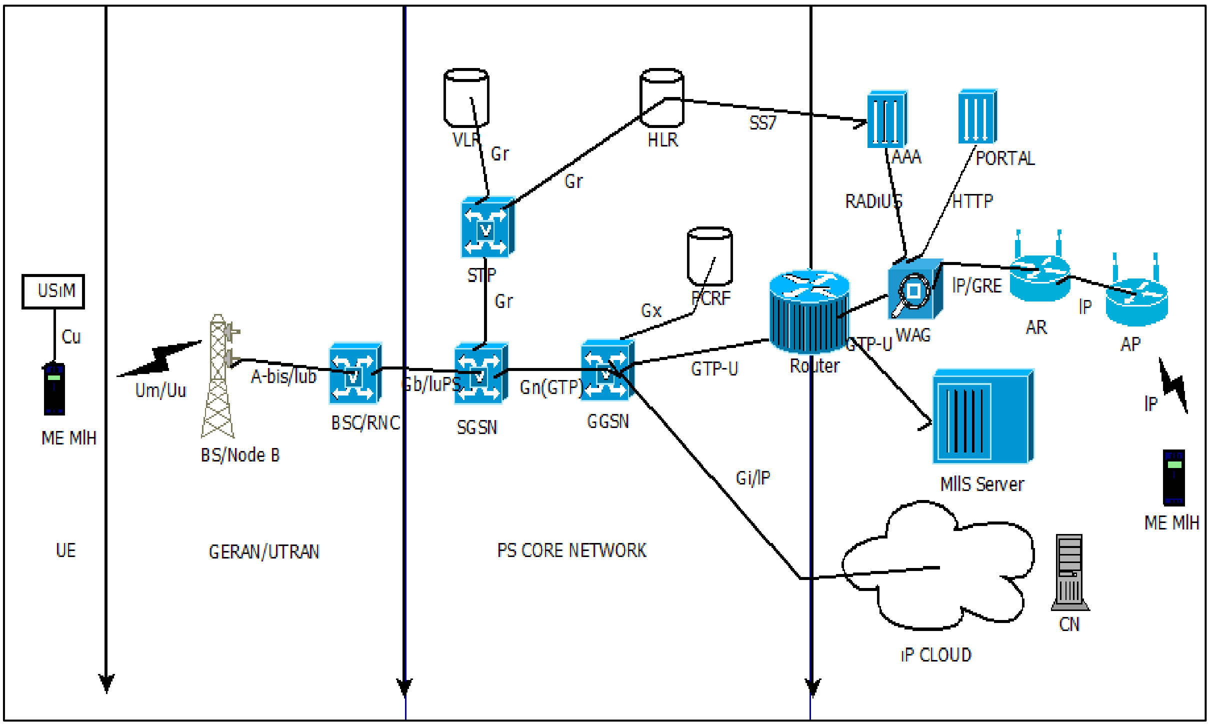


Source: The figure was done by Fazil Aykut Tuzunkan.

Fig. 3.2 above demonstrates a common solution for operators which want to offload their data traffic from UMTS to WLAN and vice versa. By modifying PCRF (Policy Charging and Ruling Function) and adding a WAG (Wireless Access Gateway), an easy offloading could be achieved with lots of drawbacks regarding handover time and quality. To eliminate such problems, IEEE 802.21 WG’s proposed a solution that could be modified and applied to a network.

3.3.2 Use case 2

Figure 3.3: IEE 802.21 in I-WLAN network architecture



Source: The figure was done by Fazil Aykut Tuzunkan.

In the above architecture- Fig. 3.3, we integrate a MIIS server that keeps the information of governed networks and supplies the adjacent network information to a MT. By doing so, UE can request available AP/BS info faster, and can attach itself to the preferred agent prior to breaking with the old one. The IEEE 802.21 standard describes MIH_Get_Information offer and answer messages for MIIS. If a MIH user produces a MIH_GET_Information offer message to obtain information from the MIIS server, the UE's MIHF module relays the message to that of the MIIS server and awaits for a answer from the server. After receiving a MIH_GET_Information offer, the MIIS server acquires the requested data from its internal database and produces a MIH_GET_Information answer message. Then, the MIIS server transmits the answer message to the UE.

3.4 ENHANCED TOPSIS ALGORITHMS FOR MULTI-USER SCENARIOS

3.4.1 Assumptions

There are N users each connected to a technology WLAN or UMTS/LTE at iteration 0. Each user observes the corresponding feature values of MOS, PSNR, CQI, QoS, .. etc. for each technology.

3.4.2 Sequential Update (Gauss-Seidel scheme)

All users x1, . . . , xN are updating sequentially, one after the other via the TOPSIS algorithm;

For iteration =1,..,T

For each user=1,2,...N

i. Run TOPSIS and update the feature values (channel utilization, etc).
ii. Decide appropriate technology (WLAN or UMTS).

End

End

3.4.3 Simultaneous Update (Jacobi Scheme)

All users x1, . . . , xN are updating simultaneously, via the TOPSIS algorithm

For iteration =1,..,T

For each user=1,2,...N

i. Run TOPSIS and DO NOT update the feature values (channel utilization, etc).

ii. Decide appropriate technology (WLAN or UMTS).

End

End

3.4.4 Random Update

All users x1, . . . , xN are updating in a totally asynchronous way, via the TOPSIS algorithm.

For iteration =1,..,T

Select a random user from 1,2,...N

i. Run TOPSIS and update the feature values (channel utilization, etc).

ii. Decide appropriate technology (WLAN or UMTS).

End

End

3.4.5 Developed Algorithms

In this study, we used TOPSIS as our core algorithm, due to its easy implementation, as a way of selecting the best target network for a given user's video application. The decision to use this algorithm was made based on the other multiple attribute decision making (MADM) algorithms' performance comparison results. In [17], four different MADM algorithms (MEW, SAW, GRA, TOPSIS) were evaluated and it was concluded that they all performed very similar.

First algorithm developed is a Multi-user TOPSIS with max-min fairness characteristic where channnel utilization parameter is of the utmost importance for the 3GPP network to balance the channel allocations. With this type of multi user algorithm the total system benefit is considered.

Second algorithm developed is a Multi-user TOPSIS algorithm with First Come First Served characteristic where subsriber density in the 3GPP network is of the utmost importance. With this type of algorithm user's benefits are considered up to a point where users reach to a pre-defined density threshold for a base station in 3GPP access network.

We then compare the aforementioned algorithms with single user TOPSIS. With single use TOPSIS, only user benefits are considered and the total system performance is neglected.

For video streaming, channel utilization and MOS of service should be of utmost importance and therefore the weight coefficients are distributed accordingly in Table X. For the purpose of comparison, the same weights are assigned to attributes for the differenct algorithms. Assignment of weights could be initiated by either user or operator or collaboratively. The table 3.2 as an example was used to rank access networks.

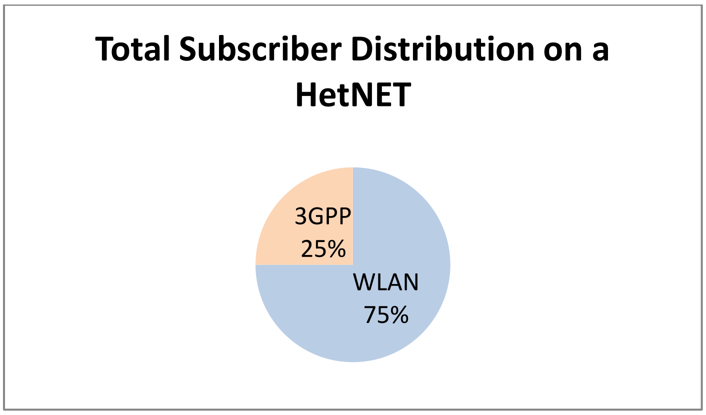
Table 3.2: Network Selection Criterias for Video Streaming

Parameters	**Rank**	**Weight**
MOS	**2**	**0.25**
QoS	**3**	**0.1**
Energy	**5**	**0.05**
Channel Utilization	**1**	**0.5**
Delay	**4**	**0.1**

Source: The table was done by Fazil Aykut Tuzunkan.

To compare algorithms we created an environment where four users are in intersection area between 3GPP and WLAN networks and their respective parameter values are same. With Multi-user TOPSIS max-min fairness algorithm, total subscriber distribution on a HetNET comprising 3GPP and WLAN access networks is shown in Figure 3.4.

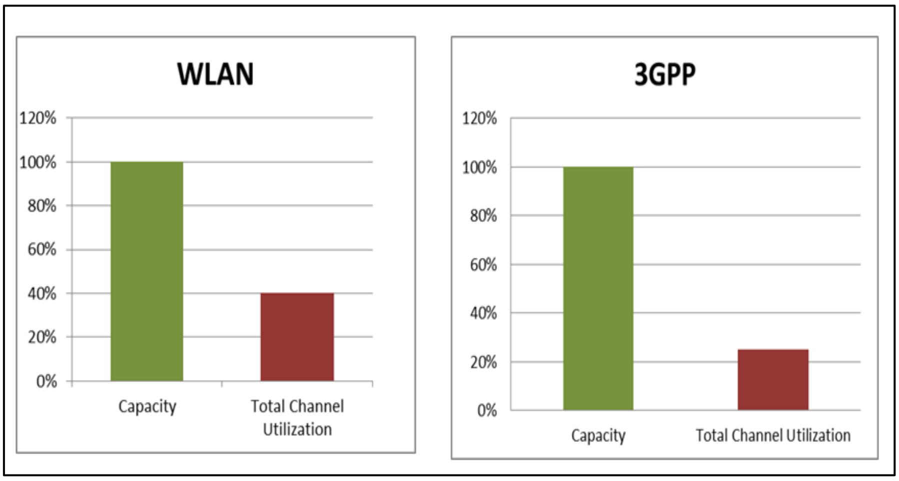
Figure 3.4: Subscriber Distribution for MTMMF



Source: The figure was done by Fazil Aykut Tuzunkan

Accordingly, the channel utilizations are shown in Figure 3.5. The important thing to notice is access network capacity of the corresponding technologies. For users who are in intersection area, for example, WLAN access network capacity would exceed that of 3GPP. Therefore, we cannot assume as if there is only one total system capacity even though their corresponding core network is converged.

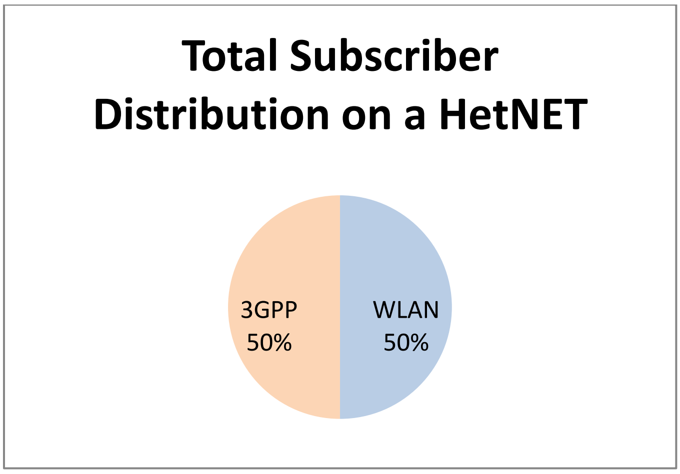
Figure 3.5: MTMMF Total Channel Utilization



Source: The figure was done by Fazil Aykut Tuzunkan.

By using the multi-user TOPSIS First Come First Served algorithm, the distribution has been equally divided as shown in Figure 3.6. Please note that by using this algorithm users were able to take advantage of QoE parameters such as MOS until user density reaches up to the half of the total subscriber number.

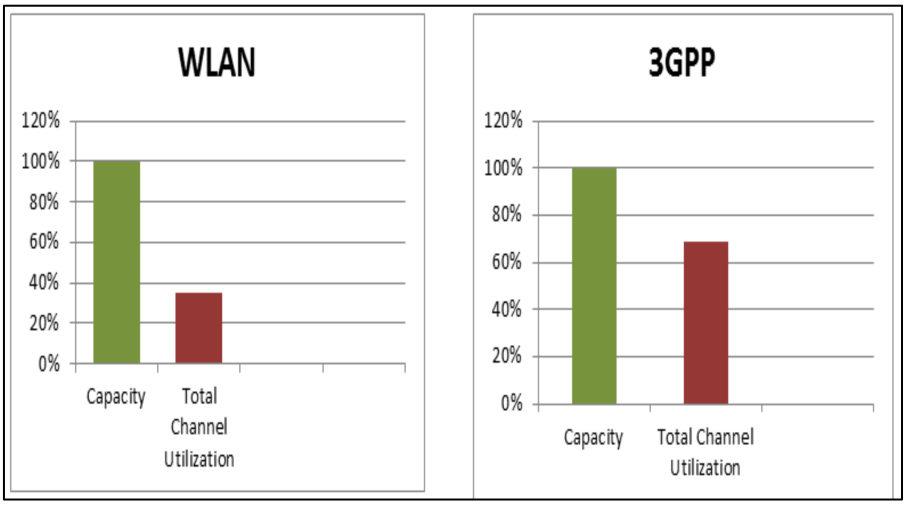
Figure 3.6: Subscriber Distribution for MTFCFS



Source: The figure was done by Fazil Aykut Tuzunkan.

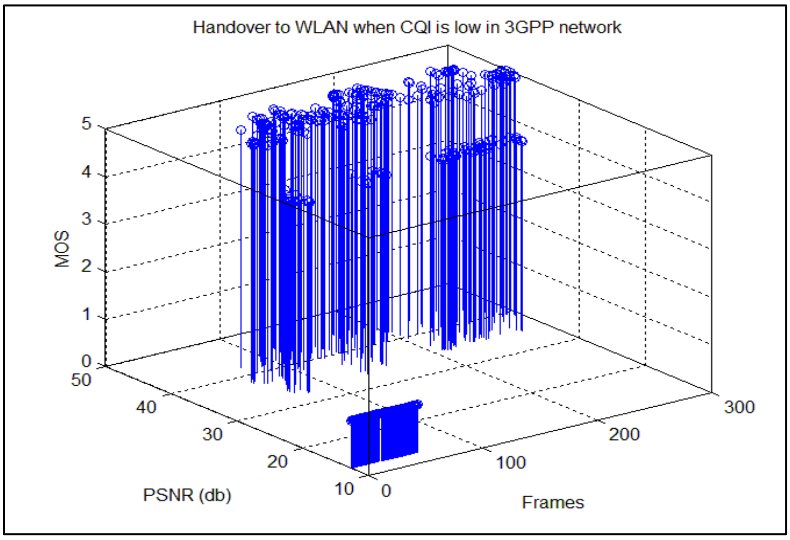
The total channel utilization percentages when MTFCFS algorithm is applied are shown in Figure 3.7. We see that 3GPP total channel utilization increased thus not only total channel utilization but also total MOS of the total system optimized as shown in Figure 3.8.

Figure 3.7: MTFCFS Total Channel Utilization



Source: The figure was done by Fazil Aykut Tuzunkan.

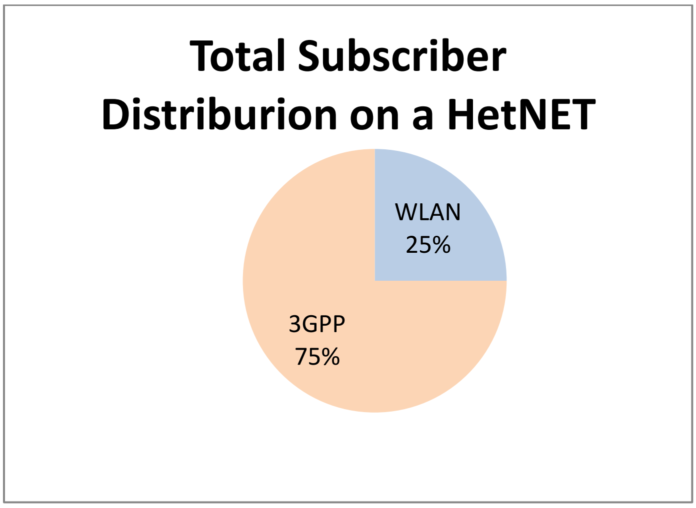
Figure 3.8: Handover to WLAN when MOS is low in 3GPP network



Source: The figure was done by Fazil Aykut Tuzunkan.

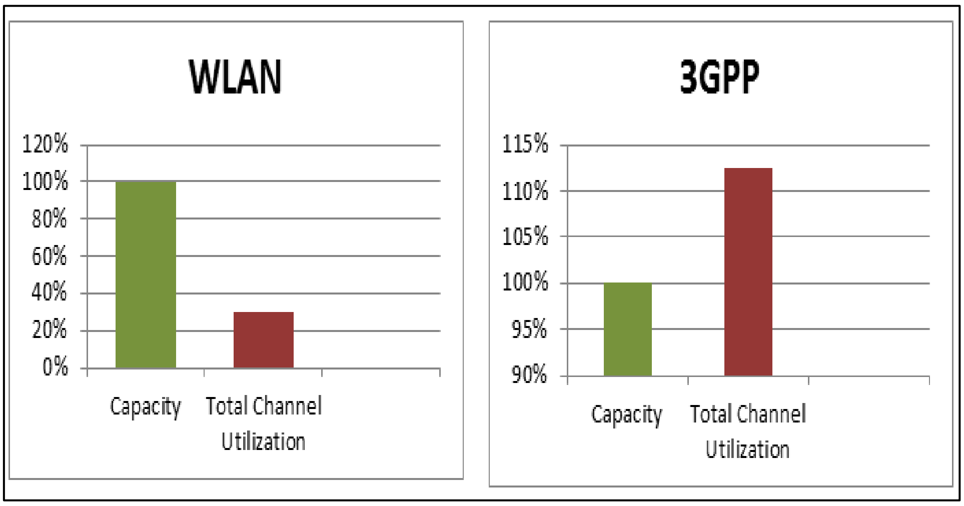
Finally, single user TOPSIS algorithm is applied, meaning only user benefit will be checked and total channel utilization will be ignored. The important thing to notice is QoE will be high with this type of algorithm but due to overallocation in one access network after the decisions are executed, users will suffer from either ping-pong effect or real-time network changes. Figure 3.9 shows total subscriber distribution and Figure 3.10 show the total channel utilization respectively.

Figure 3.9: Subscriber Distribution for SUT



Source: The figure was done by Fazil Aykut Tuzunkan.

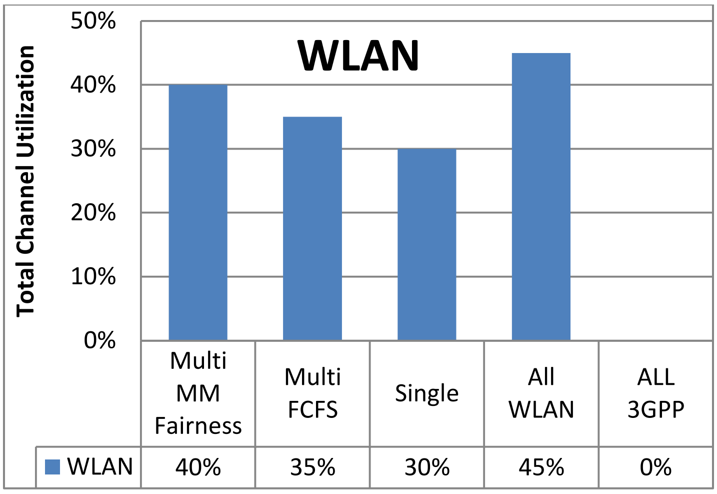
Figure 3.10: SUT Total Channel Utilization



Source: The figure was done by Fazil Aykut Tuzunkan.

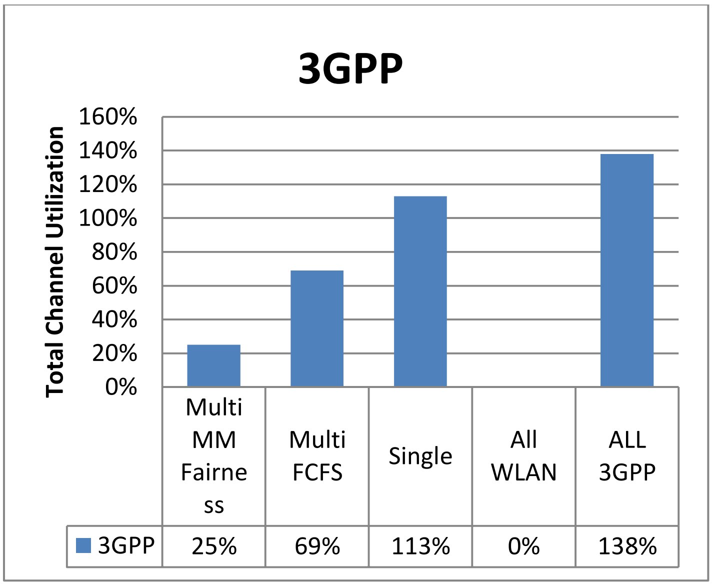
Lastly, in terms of total channel utilization we compare all the algorithms with each other as well as the cases where there is no algorithm implemented and users are free to choose any access network they desire. For a healty comparison, we utilized the exaclty same paramater values and weights provided.

Figure 3.11: Algorithms' comparison in terms of total CU of WLAN



Source: The figure was done by Fazil Aykut Tuzunkan.

Figure 3.12: Algorithms' comparison in terms of total CU of 3GPP



Source: The figure was done by Fazil Aykut Tuzunkan.

It is clearly seen that with single user TOPSIS algorithm and/or random assignments of users could lead to a high channel utilization consequently would decrease MOS substantially for the corresponding access networks. However with multi-user TOPSIS algorithms, load balance and MOS are optimized between 3GPP and WLAN access networks, in return, total QoE among subscribers would increase. From operator point of view, multi-user TOPSIS max-min fairness algorithm works best in terms of channel utilization or load balancing, however with this type of scheme QoE experienced by users would be slightly lower than the second algorithm implemented which is multi user TOPSIS First Come First Served. Single user TOPSIS works for user's benefit only and would cause for operator's network to be overloaded and to provide degraded services.

4. MODELS AND ASSUMPTIONS

4.1 NETWORK SIMULATORS

For this thesis work, in NS-2 MIH functionality as utilized as presented by IEEE 802.21 WG to monitor access networks and to perform a seamless handover execution and a multiple attribute decision making (MADM) algorithm has been implemented in MATLAB based on QoE metrics during the decision making phase.

Furthermore, in NS-3 3GPP's LTE and LTE-Advanced enhancenments such as multiple-input and multiple-output (MIMO) and radio environment map (REM) has been harnessed to simulate WiFi offloading for Release 8 and above.

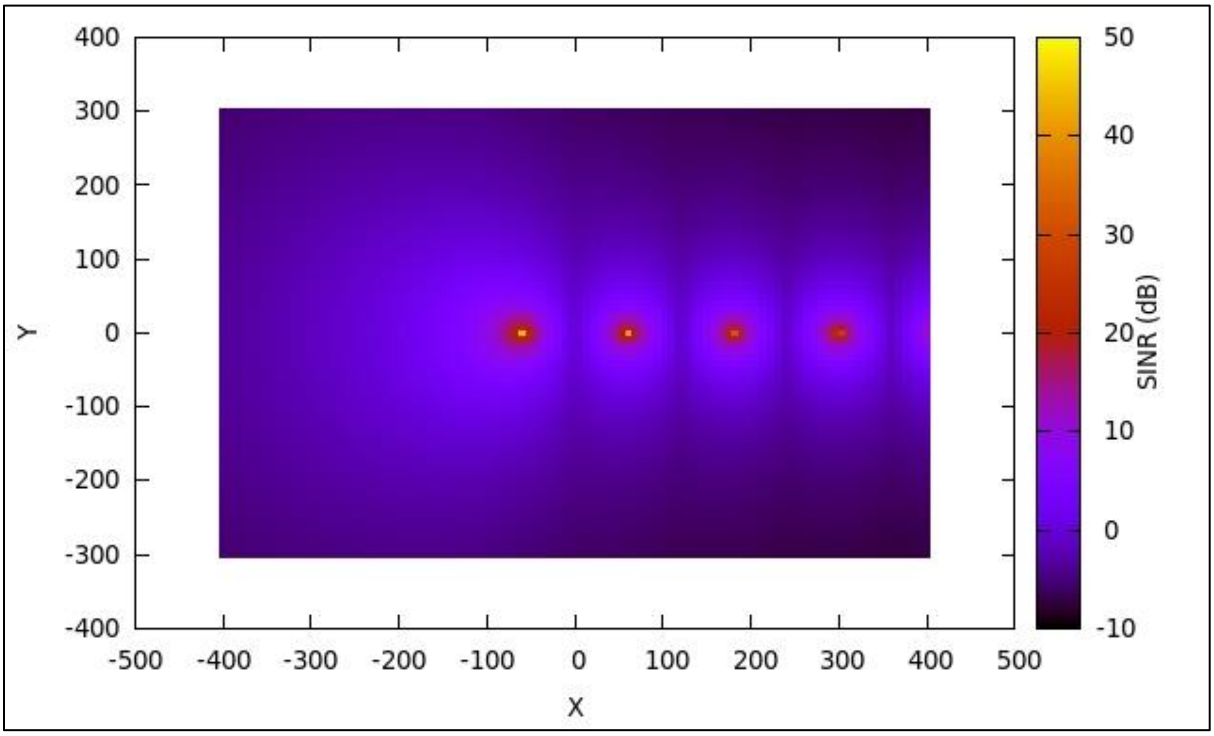
4.2 RADIO ENVIRONMENT MAP

i. REM is an information server and stores the radio environment parameters such as spectrum band states, policies regarding the bands, node positioning, coverage area and geographical features.

ii. TV white space and unlicensed bands are monitored; meaning it could be used for handover optimization or interference monitoring among nodes.

iii. REM could be utilized to determine the hotspots in return load sharing mechanisms would be invoked in network.

Figure 4.1: Simulated REM Model in NS3



Source: The figure was done by Fazil Aykut Tuzunkan.

4.3 SIMULATION PARAMETERS

4.3.1 Propagation: Fading, Channel Models

In this thesis work, the simulation parameters were chosen based on the allowed simualtion environment. The parameters could be seen as below in Table 4.1:

Table 4.1: Simulation Parameters

Scenario aspect	Description
Title	Data Offloading in Heterogeneous Wireless Networks
Network topology	HetNet (overlay of macro cells and small cells)
Radio Access Technology (-ies)	UMTS, LTE AND WLAN
Nature of small cells	Wi-Fi APs
Environment	Shopping center OR University campus OR Train station OR Offices OR Homes/flats
Context	Indoor
Inter-site distance	500 meters for macro-to-macro
	20 meters for small cell-to-small cell
	100 meters for macro-to-small cell
Frequency deployment strategy	Separate frequency deployment
Frequency bands	3GPP licensed bands AND Wi-Fi unlicensed bands (2.4G or 5G)
Density of small cells	Dense
Backhaul	Ideal backhaul between small cells
	Ideal backhaul between small cells and macro cells
	Ideal backhaul for all other interfaces
Mobility model	The percentage of cell-edge users is 10%. The coverage area radius dth is chosen 250m to find the APs for the cell-edge users.
Traffic model	Background traffic : Poisson arrivals
Services	The availability of flat-rate voice and data bundles, and higher demand for entertainment services like YouTube, Apple's iTunes and service such video streaming from Television Networks.
Number of transmit/receive antennas (for MIMO schemes)	1x1
KPIs, metrics involved	(a) Application end to end delay (s) (b) Data received (Kbps): (c) Packet Loss (%): (d) Throughput (Kbps): (e) MOS Value (Mean Opinion Score) : (f) Routing Traffic received (Kbps): (g) Jitter (s) :
Description of the problem to be solved (target) and proposed method for solution	The main purpose of this scenario is to find out a smart way to switch between 3GPP data networks and WiFi networks. For this report, we will be evaluating a client based offloading implementation and a QoE (Quality of

	Experience)-based innovative data offloading strategy
Evaluation method	Ex: Analytical AND System level simulations

Source: The table was done by Fazil Aykut Tuzunkan.

4.4 EVALUATION METHODOLOGY FOR VIDEO TRANSMISSION

For our simulation, we used NS 2.29 simulator integrated with EURANE, NIST and EVALVID packages to evaluate the video performances in a heterogeneous network during a handover execution where the TOPSIS algorithm results were utilized. Decision parameters of TOPSIS are as follows:

i. **MOS:** Mean Opinion Score is considered as a subjective measure. Currently, it is more often used to refer to one or another objective approximation of subjective MOS. Although all "MOS" metrics are intended to quantify QoE performance and they all look very similar (values between one and five with one or two decimal places), the various metrics are not directly comparable to one another. ITU P.800 and P.830 define the MOS scale as showed in Table 4.2.

ii. **PSNR (dB):** The peak signal-to-noise ratio is used as an objective measurement of the restored image quality. PSNR is most commonly used to measure the quality of reconstruction of lossy compression codecs which is in our case MPEG-4.

$$PSNR = 20\log\frac{Vpeak}{MSE} \qquad (4.1)$$

Vpeak = $2^k - 1$ where k is equal to number of bits per pixel (luminance component). MSE is mean squared error.

iii. **CQI:** Channel quality indicator is reported by UE and is calculated using BLER and SNR values. It is a vital parameter to estimate the UMTS air interface quality. The UE type that is assumed in the simulator is 3GPP UE category 1 to 6. In our simulation, the highest CQI value was accepted as 22. However, it varies between 1 and 22.

iv. **QoS:** Quality of service level of the access point (AP) is utilized in the algorithm to determine the link-quality of WiFi network. Voice = Platinum = 6, Video = Gold = 5, Best Effort = Silver = 3, Background = Bronze = 1.

v. **Security Policy used in WiFi network:** WPA or WPA2 cannot be used for a seamless solution. EAP-SIM is required to do so.

vi. **Channel Utilization:** It is a WiFi network parameter, and is monitored for a stable traffic level and to prevent under or over utilization.

vii. **Client SNR:** Signal-to-noise ratio is a critical and widely used metric to obtain the experienced WiFi quality per user.

viii. **User Preference:** For a businessman security and quality level could be extremely important whereas for a student the cost is of the utmost importance.

Table 4.2: ITU-R Quality and Impairment Scale

Scale Impairment	Quality	Impairment
5	Excellent	Imperceptible
4	Good	Perceptible, but not annoying
3	Fair	Slightly annoying
2	Poor	Annoying
1	Bad	Very annoying

Source: The table was done by Fazil Aykut Tuzunkan.

QoE assessment could be performed with subjective tests with humans, but by using this scheme we cannot make a handover execution in real-time, other approaches to the problem of QoE assessment includes utilizing objective testing to predict the MOS value of a service.

These solutions need original signals (for real time applications e.g., ITU-T objective measurement standards like PESQ (P.862), E-model (G.107) etc.) and are computationally complex [16-17]. Therefore, we calculated the PSNR frame by frame and map it to the corresponding MOS value as in Table 4.3.

Table 4.3: PSNR to MOS mapping

PSNR [dB]	**MOS**
> 37	5 (Excellent)
31 - 37	4 (Good)
25 - 31	3 (Fair)
20 - 25	2 (Poor)
< 20	1 (Bad)

Source: The table was done by Fazil Aykut Tuzunkan.

4.5 CENTRALIZED CONTENT-BASED MULTI-USER TOPSIS ALGORITHM

This is similar to a brute force approach. Assume that we list all the selections of technologies in row of D matrix, i.e. if we have two technologies, UMTS, WLAN and two users, U1,U2 then there are 4 possibilities.

I. UMTS, UMTS

II. UMTS, WLAN

III. WLAN, UMTS

IV. WLAN, WLAN

Then on the y-axis there are features such as

A. Total QoS,
B. Total Delay,
C. Total Energy,
D. Content Type (text, picture, video).

$$D = \begin{array}{c} \\ I \\ II \\ III \\ IV \end{array} \overset{\begin{array}{cccc} A & B & C & D \end{array}}{\begin{bmatrix} \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \end{bmatrix}}$$

Run TOPSIS over the matrix D and decide on the appropriate possibility (I, II, III or IV)

5. NUMERICAL RESULTS

5.1 PERFORMANCE RESULTS

When simulating our heterogeneous network in tight-coupling architecture, we used a case where a video is downloaded in the beginning. Our user was connected to an UMTS/LTE network and in this network throughput was 45Kb/s which is not even acceptable for voice networks since 64Kb is used for bearer payload whereas 16Kb needs to be used for signaling purposes in each direction, making a total of 80Kb/s at least for a good quality voice traffic. Considering our traffic, video requires a lot more throughput for an acceptable communication. As a result, we obtained the following frames in Figure 5.1.

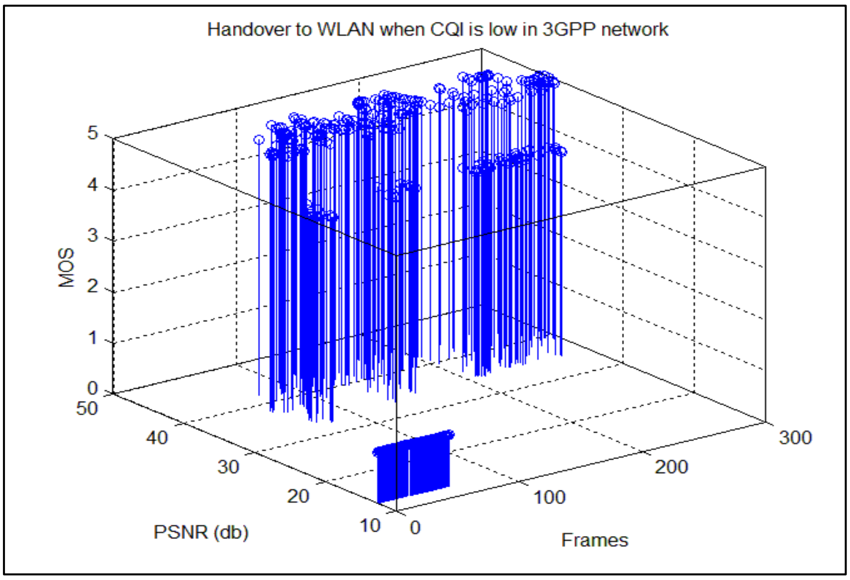
Figure 5.1: (a) Transmitted Common Intermediate Format (CIF) 352x288 MPEG-4 XviD (b) Received CIF 352x288 MPEG-4 XviD

(a) (b)

Source: The figure was done by Fazil Aykut Tuzunkan.

One UE's speed was 1m/s, and after 2 seconds where video is transmitted with a rate of 30fps, the MIH module discovered the WLAN network and requested the target WLAN network's metrics regarding QoS (jitter, delay, packet loss) and also user preference such as security (i.e. EAP-SIM or WPE) along with MOS. Based on the TOPSIS algorithm, user was attached to the target WLAN network by using MIH functionality at frame of 60. Between frames 60 and 300, user experienced MOS values between four and five. You can find the graphical representation of the scenario in Figure 5.2.

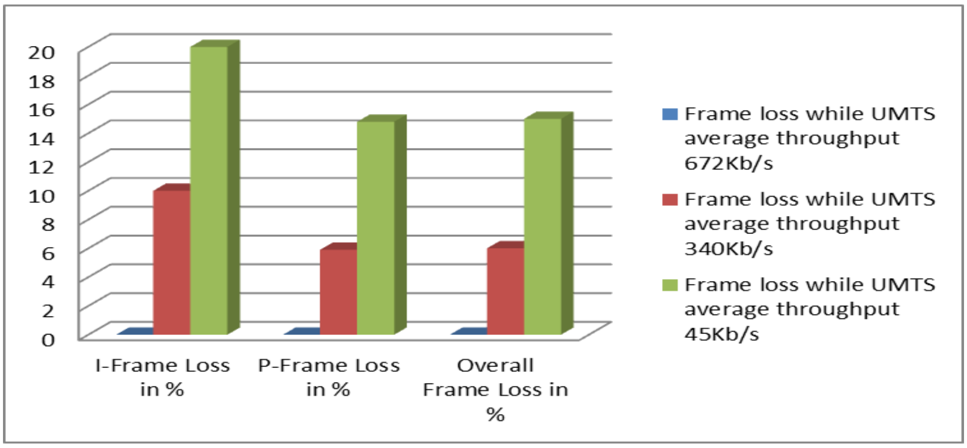
Figure 5.2: Handover to WLAN when CQI is low in 3GPP network



Source: The figure was done by Fazil Aykut Tuzunkan.

Furthermore, we calculated the packet loss rates in percentage for the same scenario while user experiences different throughput rates in UMTS/LTE network. The loss rates were measured to check the impact of an UMTS network before the handover execution and the impact of these losses for the full transmission. Our encoded video is composed of two distinctly different types of frames; Intracoded (I) frames, predictive (P) frames with a group of pictures (GOP) length of 30 frames with no B-frames. The frame losses are shown in Figure 5.3.

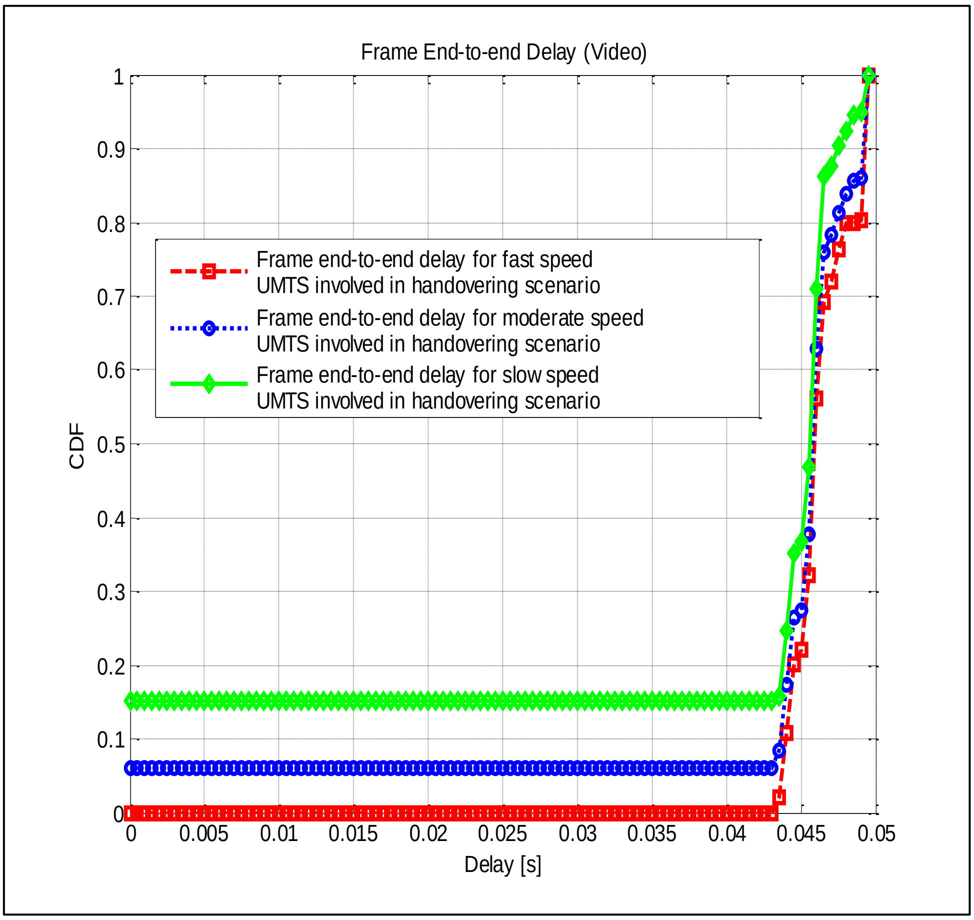
Figure 5.3: Impact of the frame losses due to UMTS network on the full transmission



Source: The figure was done by Fazil Aykut Tuzunkan.

Cumulative distribution function (CDF) of the delay has been presented for all aforementioned average throughput rates in Figure 5.4. Lost frames acquire a delay of 0. Thus, the start of the CDF-lines is the percentage of lost frames.

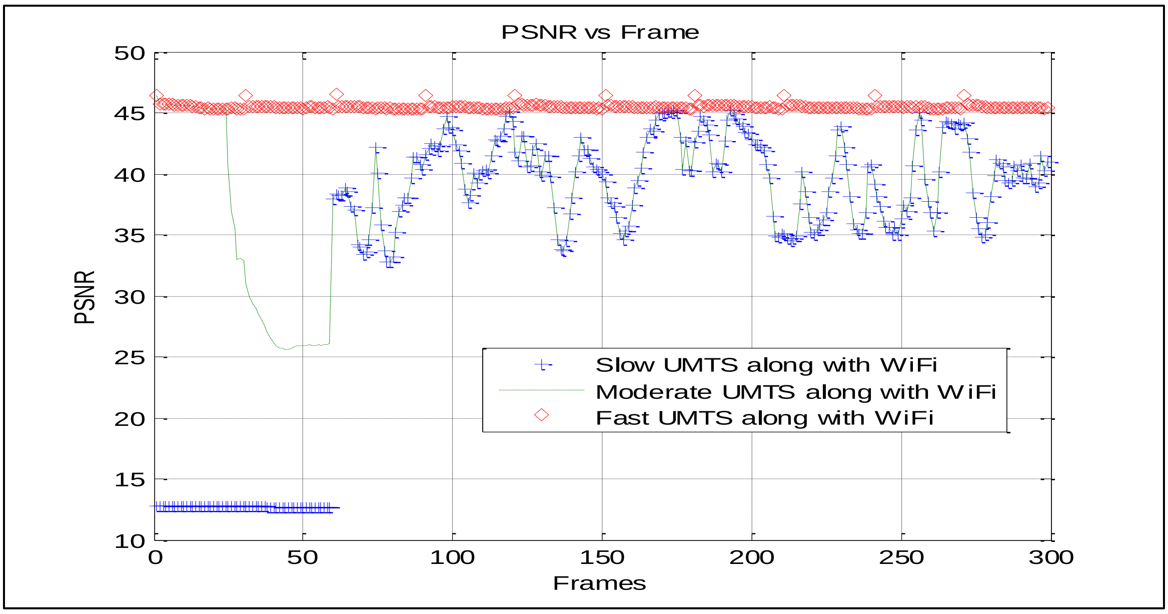
Figure 5.4: Frame End-to-end Delay



Source: The figure was done by Fazil Aykut Tuzunkan.

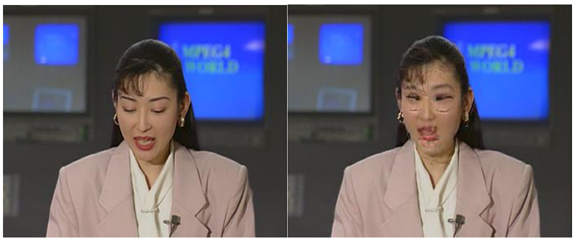
PSNR vs Frames is presented in Figure 5.5. In Figure 5.6, we compared the received frame of 59 for the three different PSNR obtained just before the handover executed to WiFi. In our three scenarios, WiFi traffic started after frame 60, and WiFi metrics in terms of QoS were always superior to UMTS/LTE; also, user preferred high MOS value with low cost.

Figure 5.5: PSNR vs Frames

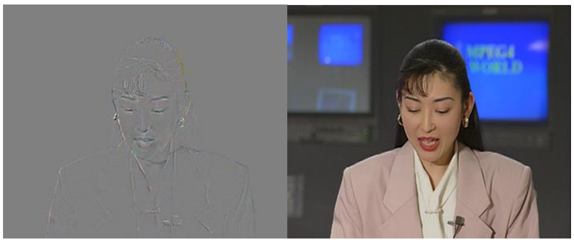


Source: The figure was done by Fazil Aykut Tuzunkan.

Figure 5.6: (a) Received CIF resolution frame in MPEG-4 XviD for fast UMTS – PSNR:45.39dB (b) Received CIF resolution frame in MPEG-4 XviD for moderate UMTS – PSNR:26.14dB (c) Received CIF resolution frame in MPEG-4 XviD for slow UMTS – PSNR:12.74dB (d) Transmitted original CIF resoluton frame in MPEG-4 XviD



(a) **(b)**



(c) **(d)**

Source: The figure was done by Fazil Aykut Tuzunkan.

Same scenario has been simulated in NS-3 for LTE networks and the similar results have been obtained in Fig. 5.7 when LTE eNB is congested. Since the MOS and PSNR values are so crucial for the end-user, operators need to offload the traffic to WiFi.

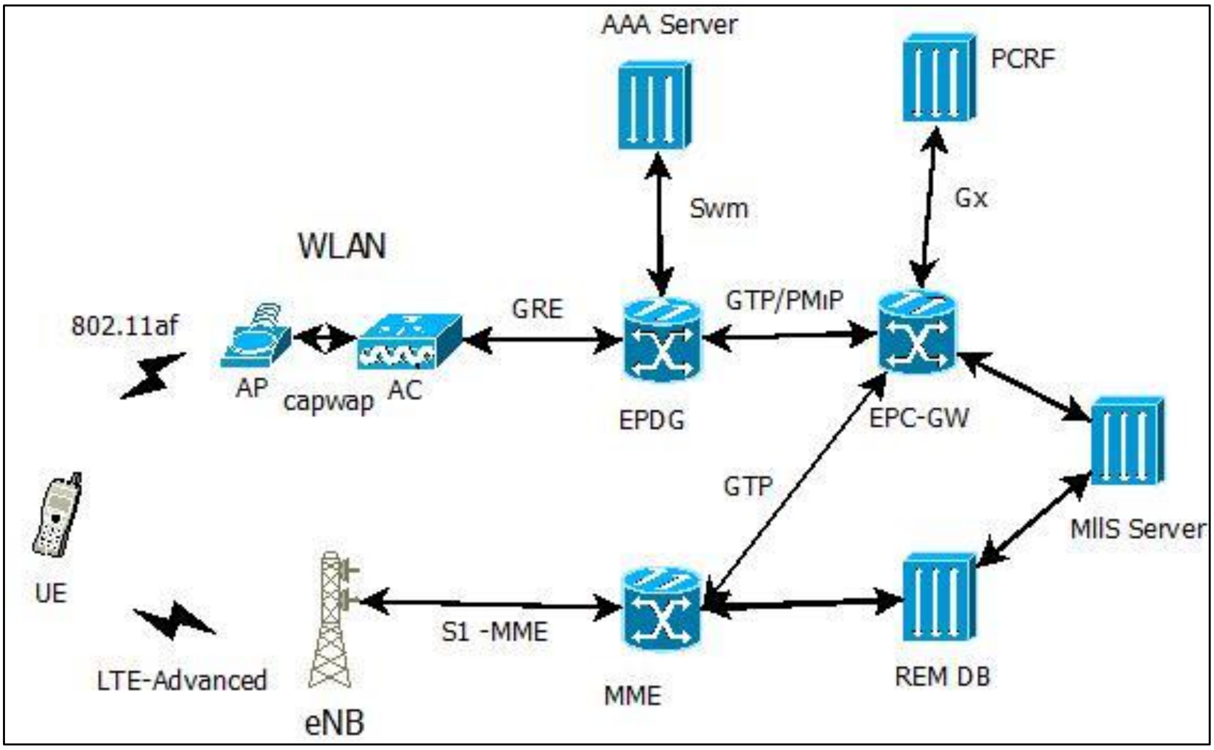
Figure 5.7: (a) Transmitted Common Intermediate Format (CIF) 352x288 MPEG-4 XviD (b) Received CIF 352x288 MPEG-4 XviD- PSNR: 29.13dB

(a) (b)

Source: The figure was done by Fazil Aykut Tuzunkan.

6. PROPOSAL

Figure 6.1: Proposed Handover Architecture



Source: The figure was done by Fazil Aykut Tuzunkan.

In the above architecture, a REM DB has been added to feed the MIIS server with the spectrum related parameters. These paramaters are as following:

i. Spectrum Band States retrieved from REM database.

ii. Spectrum band policies retrieved from REM database.

iii. Coverage area of the cell retireved from REM database.

To sum up, for a seamless offload we are utilizing both MIIS Server to facilitate the MIH functionality and REM DB to make the handover decision to increase user happiness and operator benefits.

7. CONCLUSION

Due to the data traffic volume growth of smartphone users every year, operators need to either evolve their both wireline and wireless networks; for instance, from UMTS to LTE, or offload the traffic to an existing WLAN network as a less costly solution. In this study, the interaction between a 3G/4G network and a WLAN network to make a seamless offload was analyzed and simulated. The 802.21 MIH module allowed us to handover on both layer 2 and layer 3, thus, we had almost seamless handover solution, but to make it even better, we used CQI values obtained from UEs so that the handover could occur based on the policies and/or QoE agreements between users and operators such as a high MOS value.

In this study, two novel multi-user TOPSIS algorithms were developed to compare the load balancing among access networks based on decision making phase's outcome of a handover process. It was concluded that MADM algorithms considering single user parameters affects operators' access networks badly in terms of load balancing. To overcome this situation, multi-user MADM algorithm usage is essential so that QoE could be high enough for a higher percent of subscribers. QoE includes both terminal end applications' behavior such as the used codec for the transmission and container and the network traffic health.

All in all, the major contributions have been made are as following:

i. User preference as a QoE metric during handover decision making has been integrated into the developed MADM algorithm.

ii. Handover execution has been handled not only based on link-quality including QoS values but also based on subjective measures.

iii. Network traffic of the heterogeneous wireless networks (HWNs) has been improved and managed based on user experience. Upon request, the complete simulation data will be made available. This would help the research community develop novel handover algorithms for HWNs.

iv. Two multi-user multiple attribute decision making (MADM) algorithms based on QoE metrics have been developed.

QoE include both terminal end applications' behavior such as the used codec for the transmission and container and the network traffic health. In this report, we only focused on the network improvement and user preferences such as cost or security, and considered the HWN where UMTS/LTE and WLAN are coupled. Based on the results, we achieved a high MOS value during the video transmission and better user experience.

The main drawback that could be taken into account is the power consumption caused by the neighbor discovery (ND) module. In this solution, the periodical router advertisement (RA) and router solicitation (RS) messages would eat up the limited battery power, but this needs to be tested as a future work.

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