

Quality of Service Mapping Over WiFi+WiMAX and WiFi+LTE Networks

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Abstract—In this paper we analyse two of the most widely used types of hybrid networks: WiFi + WiMAX and WiFi + LTE. For each of these networks we generate QoS mapping table, optimize the table for various practical scenarios and evaluate the performance of the constructed networks. The performance validation is based on detailed simulation and shows that each combination of hybrid network has its own specific advantages and constraints in terms of number of users, preference, coverage and applications. We analyse the obtained results and provide recommendations on how these results could be utilized when developing QoS requirements for future wireless broadband hybrid networks.

Index Terms—hybrid networks, LTE, QoS, Wi-Fi, WiMAX

I. INTRODUCTION

THE explosive growth in the number of services available in the internet community has made it impossible for individual network to support them. However all the existing wireless networks (2G/3G, LTE, WiFi, WiMAX, etc...) are designed to work separately, without consideration for connecting to each other. It should be highlighted here that practical networks should constitute of a heterogeneous [1] network architecture in which by definition requires cooperation of sub-networks in order to offer mobile users transparent services as shown in Fig.1.

Providing the required end-to-end quality of service (QoS) in hybrid networks is an arduous task due to the different bit rate, channel characteristics, bandwidth allocation, fault tolerant levels and handoff supports and methods implemented in each sub-network [2,3]. These differences can be outlined as following:

- Universal Mobile Telecommunication System (UMTS)/3G network provides wide coverage areas, full mobility, roaming and support for data traffic with variable bandwidth but for a relatively low data rates and at a high cost [4, 5].
- Wireless Local Area Networks (WLANs) provide higher data rate at lower cost, but only within a limited area [6].
- Worldwide Interoperability for Microwave Access Networks (WiMAX) coverage is up to 50km in radius with high data rates, good quality of service, seamless mobility both intra WiMAX network and inter networks of different

technologies and service providers [7].

- In Long Term Evolution (LTE) network, the amount of traffic per subscriber rises rapidly as multiple services such as the triple play services may be carried on multiple network domains, each with its own traffic pattern and QoS requirements [8].

In this paper we analyse the QoS parameters of different wireless networks, ‘combined’ to form a hybrid network aiming at providing optimized end-to-end QoS connection. The typical parameters that affect the end-to-end quality of service in an application are:

- throughput (how much data can be transferred from one location to another in a given amount of time);
- latency (measured time delay experienced in a system);
- delay (time taken for one packet to travel from point to point in network);
- packet loss (the amount of packets which were lost along the data path) [9].

However in this paper the analysis will focus only on the throughput performance as to validate the accuracy of the proposed architecture model.

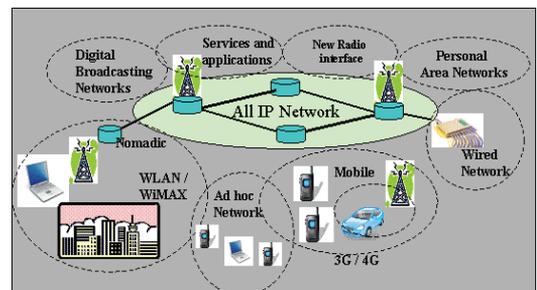


Figure 1: Hybrid Wireless Network Architecture [10]

The rest of this paper is organized as follows; section II provides a description of the QoS in various standards defining wireless broadband systems. Section III presents the proposed mapping of the end-to-end QoS parameters for two different hybrid networks, namely Wi-Fi + WiMAX and Wi-Fi + LTE. The simulation results are explained in section IV and finally section V concludes the paper.

II. QoS IN WIRELESS BROADBAND SYSTEMS

A. UMTS/3G

UMTS supports universal roaming with one cell covering up to several square kilometers and can be integrated with other networks for example WiFi and WiMAX. It is among the first 3G mobile systems which offer wireless wideband multimedia communications over the Internet Protocol (IP) [11-13]. To guarantee the end-to-end QoS in UMTS network, four classes of service were defined in UMTS. They are Conversational, Streaming, Interactive and Background classes as shown in Table 1. The main distinguishing factor among these classes is how delay sensitive the traffic is.

Table 1: UMTS QoS Classes [5]

| Traffic Class | Conversational | Streaming | Interactive | Background |
|-----------------------------|---|--|---|--|
| | Real Time | Real time | Best Effort | Best Effort |
| Fundamental characteristics | Preserve time relation (variation) between information entities of the stream. Conversational pattern (stringent and low delay). | Preserve time relation (variation) between information entities of the stream. | Request response pattern. Preserve payload content | Destination is not expecting the data within a certain time. Preserve payload content |
| Applications | Voice | Video streaming | Web browsing | Background download of emails |

Conversational and streaming classes are intended mainly to carry real-time traffic flows for example the video telephony. On the other hand Interactive and Background classes are meant mainly for the traditional Internet application such as email, WWW, Telnet, FTP and News. Conversational class is therefore meant for traffic that is critical to delay sensitive whereas Background class is meant for delay insensitive traffic class [14, 15].

B. WLAN

WLAN provides convenient to physically move around and remain connected to the internet over local network. The network can support data rates up to 54 Mbps at a range of about 30 to 300 meters [16, 17]. There are five main WLAN specifications: IEEE 802.11a, IEEE 802.11b, IEEE 802.11e, IEEE 802.11g and IEEE 802.11n. Among them, the most popular standard is IEEE 802.11b which is also known as Wireless Fidelity (Wi-Fi) [18]. To assure a consistent QoS mechanism in Wi-Fi network, the standard has categorized four priority classes which are the voice, video, best effort and background as illustrated in Table 2 below. These QoS classes assure a consistent QoS mechanism across wired and wireless networks [19].

Table 2: Wi-Fi QoS Classes [20]

| QoS Classes | Description | Application |
|----------------------------------|--|-------------|
| Real Time Polling Service (rtPS) | Bidirectional Voice calls with 64Kbps at 20ms. Talk spurt and silence spurt exponential with mean 0.35 seconds and 0.65 seconds. | Voice |
| | Downlink VBR stream with an average rate of 1Mbps and a peak rate of 5Mbps. | Video |
| Best Effort (BE) | Inter-page request time exponentially distributed of mean 15 seconds. | Web |
| | FTP download of a 20MB file | FTP |

C. WiMAX

WiMAX or the IEEE802.16 standard was designed for a wider range of wireless network connections with the speed of 15 Mbps in a 3 km cell coverage area [21, 22, 23]. The WiMAX protocol supports five different classes of service: Unsolicited Grant Service (UGS), Real-time Polling Service (rtPS), Extended Real-time Polling Service (ertPS), Non-real-time Polling Service (nrtPS) and Best Effort Service (BE). These WiMAX QoS classes are listed in Table 3.

Table 3: WiMAX QoS [24]

| QoS Classes | QoS Specifications | Applications |
|--|--|-------------------------------------|
| Unsolicited Grant Service (UGS) | Jitter tolerance Maximum latency tolerance Maximum sustained rate | VoIP |
| Real-time Polling Service (rtPS) | Traffic priority Maximum latency tolerance Minimum reserved rate Maximum sustained rate | Audio/Video Streaming |
| Extended Real-time Polling Service (ertPS) | Traffic priority Jitter tolerance Maximum latency tolerance Maximum reserved rate Maximum sustained rate | VoIP (VoIP with Activity Detection) |
| Non-real-time Polling Service (nrtPS) | Traffic priority Minimum reserved rate Maximum sustained rate | File Transfer Protocol |
| Best Effort Service (BE) | Traffic priority Maximum sustained rate | Data transfer, web browsing |

A) Unsolicited Grant Services (UGS): This service is designed to support real-time service flows such as Voice over IP (VoIP), or for applications where WiMAX is used to replace fixed lines such as E1 and T1. It offers fixed-size grants on a real-time periodic basis, which remove the overhead and latency and assure that grants are available to meet the flow's real-time needs.

B) Real-time Polling Service (rtPS): This service is designed to support real-time services such as MPEG video. It is also used for enterprise access services where guaranteed E1/T1 rates are needed but with the possibility of higher bursts if network capacity is available. It has a variable bit rate but with guaranteed minimums for data rate and delay.

C) Extended Real-time Polling Service (ertPS): This service is designed to support real-time services such as VoIP with silence suppression that have variable data rates but require guaranteed data rate and delay. One typical system in this QoS class is Skype.

D) Non-real-time Polling Service (nrtPS): This service is designed to support for services where a guaranteed bit rate is required but latency is not critical, such as FTP.

E) Best Effort Service (BE): This service is designed for Internet services such as email and web browsing that do not require a minimum service-level guarantee. Data packets are carried as space becomes available. In this QoS class, delays may be incurred and jitter is not a problem.

D. LTE and LTE-Advanced

LTE was developed by the 3rd Generation Partnership project (3GPP) with the association of the European Telecommunications Standards Institute (ETSI). LTE is a set of enhancements to the UMTS which was released in the 4th quarter of the year 2008 [25] while LTE-Advanced is an enhancement of LTE which was pronounced as 4G standard by ITU Telecommunication Standardization Sector (ITU-T) in 2010 [26]. LTE standards specify a bearer-level QoS model with a variety of Class of Service (CoS)/QoS mechanisms. In LTE QoS Model, each Evolved Packet System (EPS) bearer is associated with a QoS Class identifier (QCI) and an Allocation Retention Priority (ARP) [27]. EPS bearers can be classified into two categories which are the Guaranteed Bit Rate (GBR) bearers and Non-GBR bearers. For GBR bearers, resources are permanently allocated during a bearer's lifetime which means a certain bit rate is guaranteed. The suitable applications are Voice over Internet Protocol (VoIP) and real-time video. Whereas for Non-GBR bearers, there is no guarantee for resource availability and it is used for web browsing and file transfer applications [28]. There are nine level of QCI in the LTE QoS as described in Table 4. Each level of QCI is assigned to a different priority and applications. The benefits of LTE network with QoS include the priority handling, dedicated bandwidth, controlled latency, controlled jitter and improved loss characteristics [29].

Table 4: LTE QoS [30]

| Resource Type | Service | | Example Service |
|-----------------------------------|---------|----------|--|
| | QCI | Priority | |
| Guaranteed Bit Rate (GBR) | 1 | 2 | Conversational voice |
| | 2 | 4 | Conversational video (live streaming) |
| | 3 | 3 | Real time gaming |
| | 4 | 5 | Non-conversational video (buffered streaming) |
| Non-Guaranteed Bit Rate (Non-GBR) | 5 | 1 | IMS signaling |
| | 6 | 6 | Video (Buffered Streaming) TCP-based (e.g www, e-mail, chat, ftp, p2p file sharing, progressive video) |
| | 7 | 7 | Voice, Video (Live Streaming), Interactive Gaming |
| | 8 | 8 | Video (Buffered Streaming) TCP-based (e.g www, e-mail, chat, ftp, p2p file sharing, progressive video) |
| | 9 | 9 | |

III. MAPPING OF QoS CLASSES

A massive deployment of numerous wireless broadband access networks was carried out globally over the last decade. While each of the developed networks has well defined advantages, independent operation of these networks results in certain drawbacks [31, 32]. In order to achieve the maximum benefit from the existing infrastructure, convergence of the networks is no more an option. However, such proposal will not be successful without developing and providing the much needed end-to-end quality of service for the existing service classes across the proposed network architecture. The general solution to this problem represents complex analytical and practical task as all possible network architectures need to be analyzed for all possible end-user cases. While this is the overall target of our research, in this paper, we start by developing and analyzing two practical cases i.e. WiFi+WiMAX hybrid network and WiFi+LTE hybrid network.

A. QoS mapping for WiFi+WiMAX network

Figure 2 shows the diagram of the hybrid WiFi+WiMAX network. In this figure we consider the most generic case when up to M WiFi users could be connected to any of the N WiMAX client premises equipment (CPE). Such an architecture cover a wide range of applications, from basic internet browsing to environmental monitoring to healthcare and security [33, 34].

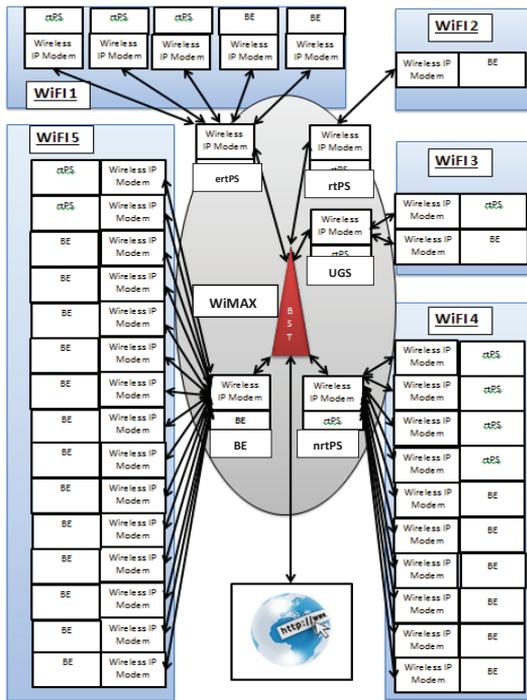


Figure 2: Hybrid WiFi + WiMAX network

Table 5 shows the proposed end-to-end QoS mapping in the above defined WiFi+WiMAX network. This mapping will be used in the analysis in the next section to ensure its ability to carry the required QoS.

Table 5: Mapping of Wi-Fi to WiMAX QoS Classes

| | Application Examples | Wi-Fi QoS Classes | WiMAX QoS Classes |
|----------------------------|--|----------------------------------|--|
| Real Time Applications | VoIP & Video conference Services | Real Time Polling Service (rtPS) | Unsolicited Grant Service (UGS) |
| | Multimedia Streaming, Multiparty Gaming Services | | Real-time Polling Service (rtPS) Extended Real-time Polling Service (ertPS) |
| Non-Real Time Applications | Web browsing, File Transfer Services | Best Effort Service (BE) | Non-real-time Polling Service (nrtPS) |
| | MMS & Email Services | | Best Effort Service (BE) |

B. QoS mapping for Wi-Fi + LTE network

Figure 3 shows the hybrid network architecture consisting of Wi-Fi and LTE networks. This configuration is similar to the previous Wi-Fi + WiMAX scenario in which in this case there are 5 users in the LTE that are connected to 5 different Wi-Fi scenarios.

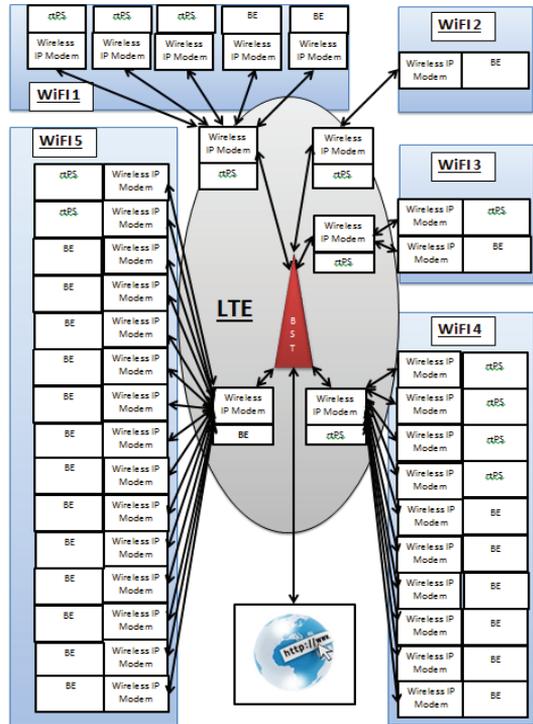


Figure 3: Hybrid WiFi+LTE network

Table 6 shows the proposed mapping for end-to-end QoS in WiFi+LTE Network. This mapping will be tested in the next section to ensure its ability to carry the required QoS.

Table 6: Mapping of Wi-Fi to LTE QoS Classes

| Resource Type | Application Examples | Wi-Fi Network QoS Classes | Resource Type | LTE Network | |
|------------------------|--|----------------------------------|--------------------------|-----------------|----------|
| | | | | LTE QoS Classes | Priority |
| Real Time Applications | VoIP & Video conference Services Multimedia | Real Time Polling Service (rtPS) | Guarantee Bit Rate (GBR) | rtPS1 | 2 & 3 |
| | | | | rtPS2 | 4 & 5 |

| | | | | | |
|----------------------------|---------------------------------------|--------------------------|----------------------------------|--------------------------|-------------|
| | Streaming, Multiparty Gaming Services | | | | |
| Non-Real Time Applications | Web browsing, File Transfer Services | Best Effort Service (BE) | Non-Guarantee Bit Rate (Non-GBR) | Best Effort Service (BE) | 1,7,6,8 & 9 |
| | MMS & Email Services | | | | |

IV. SIMULATION

Numerous simulations representing various scenarios and different QoS mapping with reference to Table 5 and Table 6 were conducted using the Network Simulator 2 (NS2) and Network Simulator 3 (NS3) simulation tools. Only downlink results are shown for discussion.

4.1 Confirming the Correctness of the Developed Models

To ensure that individual network model is able to perform accordingly and hence ensuring the hybrid model will follow suit, we first run the simulation based on the individual Wi-Fi, WiMAX and LTE model. The results are as shown in A, B and C below.

A. Wi-Fi network

For Wi-Fi network, we used the following standard parameters: bandwidth 20 MHz, data rate per stream 65 Mbps and overhead is assumed to be 18%. Figure 4 shows the downlink throughput for real-time Packet Services (rtPS) QoS for one user in the Wi-Fi network while Figure 5 shows the downlink throughput for best effort (BE) QoS for one user in the Wi-Fi network. Based on these two figures, it can be seen that the throughput distribution for the BE QoS exceeds the rtPS QoS. This is anticipated because by virtue of BE it will occupy the remaining of the bandwidth and hence we conclude that this model working correctly.

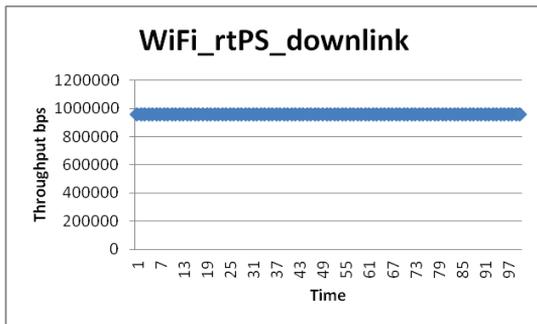


Figure 4: Throughput for real-time Packet Services (rtPS) QoS for one user in Wi-Fi network

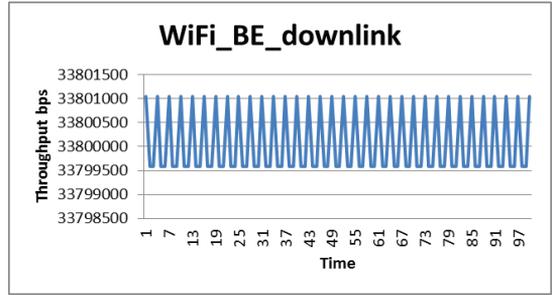


Figure 5: Throughput for Best Effort (BE) QoS for one user in Wi-Fi network

B. WiMAX network

For WiMAX network, IEEE 802.16e standard is used with the following parameters: bandwidth 10 MHz, throughput 50Mbps and overhead assumption 18%.

Figure 6 shows the downlink throughput for 5 users with different QoS level in the WiMAX network in which BE QoS has the highest throughput. This phenomenon can be explained by the fact that for such a low number of users in the network, all resources are equally distributed among the users hence outperforming performance of other (higher) levels of QoS.

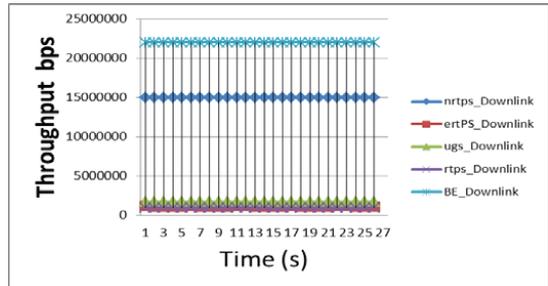


Figure 6: Total throughput distributions for between 5 users depends of user's QoS in WiMAX network

C. LTE network

For the LTE network, we used the following parameters: bandwidth 10 MHz, subcarriers per LTE symbol 600, data rate (64 QAM) 50.8 Mbps, each subcarrier carries 6 bit, LTE symbol duration 10ms and overhead assumption 18%.

The total bandwidth allocated for each rtPS QoS user is 5 Mbps. Figure 7 and Figure 8 show the downlink throughput for real-time Packet Services (rtPS) QoS and best effort (BE) QoS for one user in the LTE network respectively. As anticipated BE will occupy the bandwidth that is not in use by others.

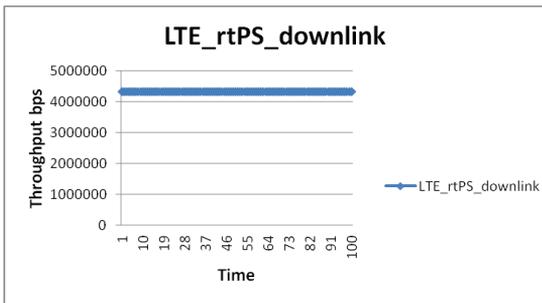


Figure 7: Throughput for real-time Packet Services (rtPS) QoS for one user in LTE network

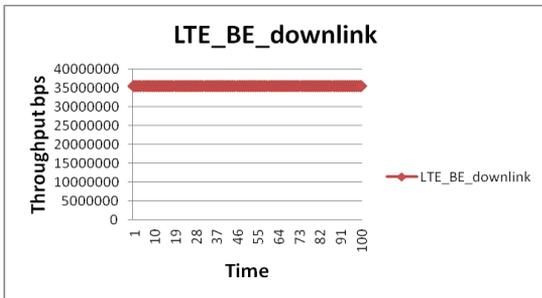


Figure 8: Throughput for Best Effort (BE) QoS for one user in LTE network

4.2 Hybrid networks for Wi-Fi + WiMAX and Wi-Fi +LTE

For the evaluation of the developed QoS mapping in WiFi+WiMAX and WiFi+LTE networks, the number of users is increased to the level when it affects the overall throughput and latency in the network.

A. Hybrid network for WiFi+WiMAX

The first hybrid network (WiFi+WiMAX) contains 5 users in WiMAX network with 5 different scenarios in the WiFi network as illustrated in Figure 2. The topology illustrates the downlink processing in which data or information from the base station is transmitted to the users in the WiMAX network. In this situation these users can also function as a switch that acts as a hybrid connection with the Wi-Fi network or users. As shown in Figure 6 above, the total bandwidth for all users in the WiMAX network is 40 Mbps which is around 22 Mbps allocated for BE QoS users, 15 Mbps for nrtPS QoS users, and 3 Mbps for all the other remaining WiMAX QoS users. Therefore in this analysis, the discussion will only focus on the BE and nrtPS QoS in WiMAX network which are WiFi4 and WiFi5 scenarios.

WiFi 4 Scenario

In this scenario, total number of users in Wi-Fi network are 10 where 4 users are with the rtPS QoS and 6 users are with the BE QoS. All of them are connected to the nrtPS QoS in the

WiMAX network. From the results obtained, it shows that users with BE QoS in the Wi-Fi network outstrip the users with the rtPS QoS in the same network. The throughput for each BE Wi-Fi user is around 1.25 Mbps compared with 963.5 kbps for the rtPS Wi-Fi user as shown in Figure 9 and 10.

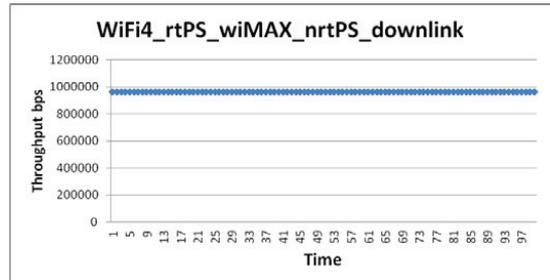


Figure 9: Throughput for real-time Packet Services (rtPS) QoS in Wi-Fi and non-real-time Polling Service (nrtPS) QoS in WiMAX network

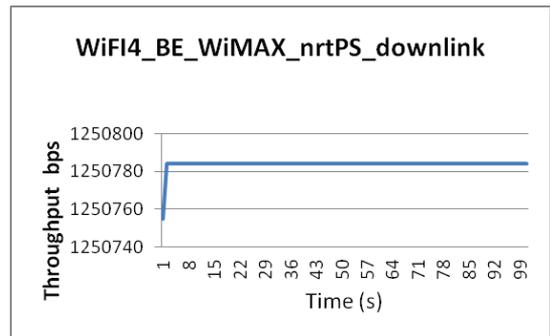


Figure 10: Throughput for Best Effort (BE) QoS in Wi-Fi and Non-real-time Polling Service (nrtPS) QoS in WiMAX network

WiFi 5 Scenario

In this case, the total number of users in Wi-Fi network is increased to 15. The number of users with the rtPS QoS in Wi-Fi network is 2 and the remaining 13 users are for the BE QoS. They are connected to the BE QoS in the WiMAX network. Once again the throughput for the BE QoS users in WiFi network were much greater which is around 1.37 Mbps compared with 963 kbps for the rtPS QoS users as illustrated in Figure 11 and 12 below. However if there are more BE QoS users, the throughput will reduce to less than the rtPS QoS user.

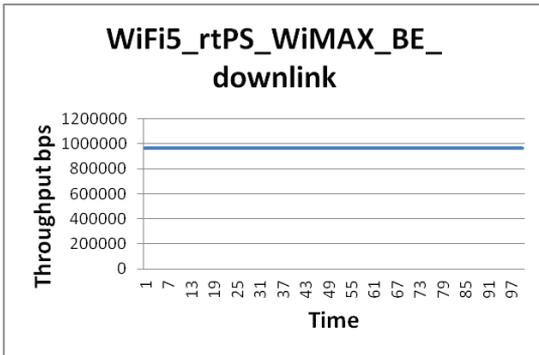


Figure 11: Throughput for real-time Packet Services (rtPS) QoS in Wi-Fi and Best Effort (BE) QoS in WiMAX network

rtPS QoS will occupy 1 Mbps throughput whereas the other 6 users with the BE QoS need to share the remaining 1 Mbps among themselves as shown in Figure 13 and 14.

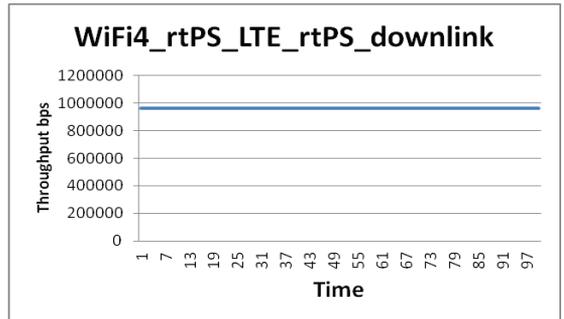


Figure 13: Throughput for real-time Packet Services (rtPS) QoS both for LTE and Wi-Fi network

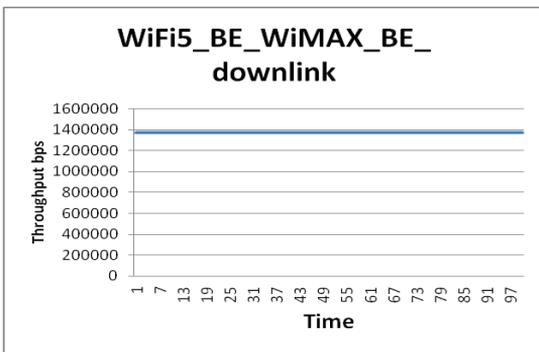


Figure 12: Throughput for Best Effort (BE) QoS both for Wi-Fi network and WiMAX network

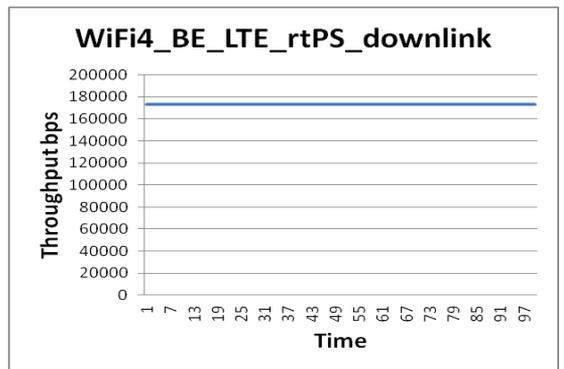


Figure 14: Throughput for Best Effort (BE) QoS in Wi-Fi and real-time Packet Services (rtPS) QoS in LTE network

B. Hybrid network for WiFi+ LTE

The second hybrid network (WiFi+LTE) caters for 5 users in LTE network with 5 different scenarios in the Wi-Fi network as shown in Figure 3. As in WiFi+WiMAX, the topology also illustrates the downlink processing in which data or information from the base station is transmitted to the users in the LTE network. For this simulation, the total bandwidth for each user with the rtPS QoS in LTE network is assumed to be around 5 Mbps and user with the BE QoS is 30.8 Mbps. Similar to WiFi+WiMAX above, our focus here is also on the worst case scenarios which are WiFi4 and WiFi5 scenarios.

WiFi 4 Scenario

This scenario is the same as WiFi4 scenario in WiFi+WiMAX hybrid model in which the total number of users in Wi-Fi network is 10 where 4 users are with the rtPS QoS and 6 users are with the BE QoS. All of them are connected to the rtPS QoS in the LTE network. It can be seen from the results obtained that users with rtPS QoS in the Wi-Fi network outperformed the users with the BE QoS in the same network. This is evident from the fact that each user with the

WiFi 5 Scenario

In this case, the total number of users in WiFi network is increased to 15. The number of users with the rtPS QoS in Wi-Fi network is 2 users and the remaining 13 users are for the BE QoS. All users are connected to the BE QoS in the LTE network in which total bandwidth given is around 30.8 Mbps. The results show that users with BE QoS in Wi-Fi network gain much higher throughput which is around 1.8 Mbps compared with 963 kbps for users with the rtPS QoS as evident from Figure 15 and Figure 16 and again it is attributed to the nature of best effort services.

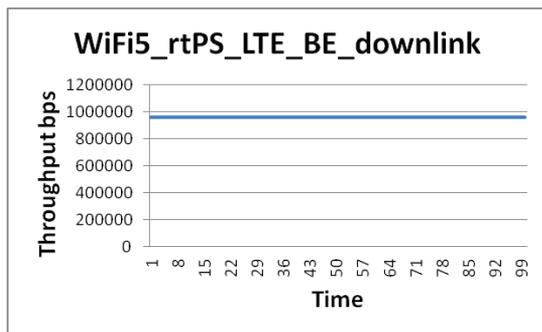


Figure 15: Throughput for real-time Packet Services (rtPS) QoS in Wi-Fi and Best Effort (BE) QoS in LTE network

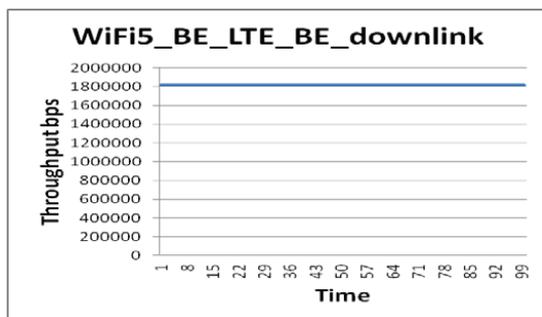


Figure 16: Throughput for Best Effort (BE) QoS both for LTE and Wi-Fi network

V. CONCLUSION AND FUTURE WORK

We have presented quality of service mapping for two of the most widely used cases of hybrid networks – WiFi+WiMAX and WiFi+LTE. Typically users or network providers will presume that rtPS QoS will give the very best throughput or performance compared with the BE QoS. This is due to the theoretical characteristic of the rtPS QoS which is designed to support real-time service flow. In contrast, BE QoS is designed for non-real-time applications where no service guarantees is provided and therefore control services on a best available basis.

Therefore, in order to accentuate the merit of the BE QoS, this paper investigated a variety of users' scenarios and validate them through simulations. Taking Figure 3 and WiFi4 and WiFi5 scenarios for example, the LTE network will intuitively decide to connect the WiFi users with the LTE rtPS QoS. This is to ensure that all the WiFi rtPS users will have the best and stable throughput. However this LTE rtPS switch/user can only manage to support up to 4 WiFi rtPS users or else there is no slot available for the WiFi BE user. Meanwhile if there is a large number of WiFi users, they have to be connected to the LTE BE QoS. This unique hybrid network can support up to more than 30 WiFi users where at this point the WiFi BE user's throughput is better than that of the WiFi rtPS user.

Hence, it can be concluded that although BE QoS is the cheapest pricing or probably the most unwanted QoS model, it still possesses satisfying network accomplishment. As for future work direction, we will investigate the elaborate combinations for the hybrid WiFi+WiMAX+LTE network and examine its performance.

REFERENCES

- [1] C.Sarraf, F.Ousta,N.Kamel,M.Z.Yusoff, " Quality of Service Mapping between UMTS, WiMAX an IP-based Network in Heterogeneous Wireless Networks", The 4th International Conference on Intelligent and Advanced Systems (ICIAS 2012), Kuala Lumpur Convention Centre, Malaysia.
- [2] C. Sarraf, F.Ousta."End-to-End Quality of Services Issues in 4G Mobile Networks", 12th WSEAS International Conference on Communications, Crete Island, Greece, July 23-25 2008.
- [3] M.S.Ryu, H.S.Park, S.C.Shin, "QoS Class Mapping over Heterogeneous Networks using Application Service Map", International Conference on Networking, ICNICONSMCL, 2006.
- [4] M.Rahnema, "UMTS Network Planning, Optimization, and Inter-Operation with GSM", Wiley & Sons, 2008.
- [5] R.Cuny, et al., "QoS Functions inCore and Backbone Networks", in QoS and QoE Management in UMTS Cellular System, ed., John Wiley, 2006.
- [6] A.Zvikhachevskaya, A.Marshall, G.Markarian, "IEEE 802.11 and its application for QoS Provisioning in Mobile Emergency". 13th World Congress "Internet in Medicine – MedNet. St.Petersburg, Russia, 2006.
- [7] R.K.Jha, Dr. U.D.Dalal SVNIT, "Location Based Resource Allocation in WiMAX and WLAN network", IEEE 2011.
- [8] A.Zvikhachevskaya, G.Markarian, L.Mihaylova, "QoS consideration for wireless telemedicine/e-health services" IEEE Wireless Communications and Networking Conference WCNC, Budapest, Hungary, 2009.
- [9] E.Mingozzi, G.Stea, M.A.Callejo_rodrguez, J.enriquez-Gabeiras, "End-to-End Quality of Service over Heterogeneous Networks", Computer Communications, Elsevier, 2008.
- [10] M.Kulkarni, "www.4G Wireless and international Mobile Telecommunication (IMT) Advanced", 2008.
- [11] M.Vranje, T.Svedek, S.R.Drlje, " The Use of NS-2 Simulator in Studying UMTS Performances", International Journal of Electrical and Computer Engineering Systems, Vol 1, Num 2, 2010.
- [12] L.Lenzen, et al., "Traffic Engineering in End-to-end Quality of Service over Heterogeneous Networks", Vol.1.1 ed. Springer, 2008.
- [13] J.Lee, S.H.S.Newaz, J.K.Choi, G.M.Lee, N.Crespi, "QoS Mapping over Hybrid Optical and Wireless Access Networks", First International Conference on Evolving Internet, 2009.
- [14] Noordin Kamarul and Markarian Garik "Providing QoS support through schedulling in WiMAX systems" International Journal of the Physical Sciences, 6 (16), pp. 4070-4081, 2011.
- [15] M.Galetzka, D.Roder, A.Finger, "Simulation of User-Perceived QoS in Hybrid Broadcast and Telecommunication Networks", IEEE 2006.
- [16] R.Chechi, D.R. Khanna, " QoS Support in Wi-Fi, WiMAX & UMTS Technologies", International Journal on Electronics & Communication Technology, 2011.
- [17] H.Attaulah, M.Y.Javed, "QoS based Vertical handover between UMTS, Wi-Fi and WiMAX Networks", Journal of Convergence Information Technology, Vol 4, Num 3, 2009.
- [18] G.Lampropoulos, et al., "A flexible UMTS/WLAN architecture for improved network performance", Wireless Pers. Communication, Vol.43, pp.889-906, 2007.
- [19] I.Paudel, F.Outay, B.Jouaber,"QoS-HAN:QoS Provisioning in Home Automated Networks Over IEEE 802.11n", IEEE 2012.
- [20] D.C.Mur, M.D.Gomonly, X.P.Costa, S.S.Ribes, "Leveraging 802.11n Frame Aggregation to enhance QoS and Power Consumption in Wi-Fi networks", Elsevier, 2011.
- [21] M.S.Murty, D.Veeraiah. A.S.Rao, "Performance Evaluation of Wi-Fi comparison with WiMAX Networks", International Journal of Distributed and Parallel Systems (IJDPS), Vol.3, No.1, Jan 2012.
- [22] Y.C-Lai, Y.H-Chen, "Design and Implementation an IEEE 802.16 Network Simulator for Performance Evaluation of Bandwidth Allocation

- Algorithms”, 11th IEEE International Conference on High Performance Computing and Communications, 2009.
- [23] WiMAX Forum, “WiMAX Pre-Release 8 3GPP Interworking”, Vol.WMF-T-37-008-R016v01 ed, WiMAX Forum, 2010.
- [24] D.G Stratogiannis, et al, “4G Wireless Networks: Architectures, QoS Support and Dynamic Resource Management,” Wireless Network Traffic and Quality of Service Support: Trends and Standards, Vol.1, T.Lagkas,et al., ed, Information Science References, 2010.
- [25] Stefan Parkvall, Erik Dahlman, Anders Furuskär, Ylva Jading, Magnus Olsson, Stefan Wänstedt, Kambiz Zangii, LTE-Advanced – Evolving LTE towards IMT-Advanced, Vehicular Technology Conference, 2008. VTC 2008-Fall. IEEE 68th 21-24 Sept. 2008 Page(s):1 — 5.
- [26] V.H.Muntean, M.Otoreanu, G.M.Muntean, “QoS Parameters Mapping for the E-learning Traffic Mix in LTE Network”, IEEE 2010.
- [27] M.Alasti, B.Neezad, C.J.Hui, R.Vannithamby, “Quality of Service in WiMAX and LTE Networks”, IEEE Communication Magazines, 2010.
- [28] JH.Pham, X.N.Vu, S.H.Hwang, “Service Class-Aided Scheduling for LTE”, International Conference on Advanced Communications Technology (ICTACT), South Korea, 2011.
- [29] L.Li and S.Shen, C.C.Y.Yang, “LTE CoS/QoS Harmonization Emulator”, International Conference on Cyber-Enabled Distributed Computing and Knowledge Discovery, 2011.
- [30] P.M.Bhagat, P.S.Halgaonkar, V.M.Wadhai, “Comparison of LTE and WiMAX on the Basis of Qualities”, International Journal of P2P Network Trends and Technology, Vol 1 Issues 3, 2011.
- [31] N.Moradpoor, G. Parr, S.McClean, B. Scotney, G. Owusu, “ Hybrid Optical and Wireless Technology Integrations for Next generations Broadband Access Networks”, IEEE International Workshop on Broadband Convergence Networks, 2011.
- [32] A.Sameh, S.Wagih, Q.Salama, “dealing with Quality of Service in Hybrid Wired-Wireless Networks”, Second International Conference on Network Applications, Protocols and Services, IEEE, 2010.
- [33] Wang, P., Marshall, A., Noordin, K. , Huo, X. & Markarian, G. Hybrid network combining PLC and IEEE802.16 for hospital environment In: Power Line Communications and Its Applications (ISPLC), IEEE International Symposium on. IEEE p. 267-272. 6 p. 2010
- [34] G Markarian, L Mihaylova, DV Tsitserov, A Zvikhachevskaya Video Distribution Techniques Over WiMAX Networks for m-Health Applications IEEE Transactions on Information Technology in Biomedicine, 16 (1), 24-30.

