International Journal of Communication Networks and Information Security (IJCNIS) Vol. 3, No. 1, April 2011

Novel Adaptive QoS Provisioning in Heterogeneous Wireless Environment

Tomislav Shuminoski and Toni Janevski

Ss. Cyril and Methodius University, Faculty of Electrical Engineering and Information Technologies
Karpos 2 bb, 1000 Skopje, Macedonia
{tomish, tonij}@feit.ukim.edu.mk

***Abstract*:** In this paper we introduce novel concept for adaptive QoS provisioning for multimedia services in wireless/mobile networks. The concept is proven via simulation analysis in integrated environment with 3G and IEEE 802.11 networks. We introduce a new module that provides the best QoS and lower cost for a given service by using one or more wireless technologies at a given time. The performance of the algorithm is evaluated using simulation with multimode mobile stations. The analysis of this framework has shown overall better performances and QoS provisioning for different multimedia services in a variety of network conditions in heterogeneous wireless environment.

***Keywords*:** Adaptive QoS, Multimedia, Quality-of-Service (QoS).

1. Introduction

The next generation wireless mobile networks are expected to provide a broad range of multimedia services (voice, data and video) to mobile users, with ubiquitous mobility, enormous processing power of the mobile equipment, adaptive QoS support and an enormous spectrum of advanced capabilities. In the future mobile network, which is seen as user-centric concept instead of operator-centric as in 3G or service-centric concept as seen for 4G, the mobile user is on the top of all [1]. The terminals will have access to different wireless technologies at the same time and the terminal should be able to combine different flows from different technologies using adaptive QoS algorithms. Furthermore, each wireless network will be responsible for handling user-mobility, while the terminal will make the final choice among different wireless/mobile access network providers for a given service. In that context, QoS provisioning for wireless and mobile multimedia networks is becoming increasingly important objective, since it requires great thoughtfulness, scalability and thoroughfull analysis. Since radio bandwidth is one of the most precious resources in wireless systems, an efficient adaptive QoS framework is very important to guarantee QoS and to maximize radio resource utilization simultaneously. Moreover, the most significant QoS parameters in the existing wireless/mobile networks are the throughput, packet delivery ratio, call blocking probability, delay and jitter (especially when we use real-time services).

The analysis in this paper is focused on adaptive QoS provisioning for multimedia service (real-time and non-real-time services) over integrated UMTS and WLAN networks, in a loose coupling architecture, using novel dual-mode Mobile Equipment (ME) node with adaptive QoS module within.

Integration of the WLAN and UMTS networks has been intensively studied in the past years due to their complementary characteristics. The 3GPP has been continuously evolving to support multimedia services which require high data rates in cellular networks. Today, the UMTS network can support services with maximum data rate of several Mbps. On the other hand, the IEEE 802.11a and IEEE 802.11g can provide up to 54 Mb/s in 5GHz and 2.4GHz bands, respectively. Also, 802.11n can go up to several hundreds Mbps. However, WLAN is lacking support for user mobility and has significantly smaller coverage areas by access points (AP) when compared to base stations (NodeB or eNodeB in 3GPP networks). Such complimentary characteristics of these two popular technologies have stimulated research efforts to integrate 3G and WLAN networks so that mobile stations can choose the network that has better network quality when they are covered by both networks and can have continuous services when they roam in the integrated network environment. The hardware requirement for integrating UMTS and WLAN networks is to build dual-mode ME (which exists today) with adaptive QoS module inside (which is a novel framework that is not present nowadays), which has the capability of accessing both networks and choose the best connection according to QoS demands for the given service, and roam between the networks as many times as needed by using vertical handovers executed by the mobile terminal. The prerequisite for this is ME to have Service Level Agreements (SLA) with both networks, 3G and WLAN, where these networks can belong to different network providers.

Moreover, without loss of generality, this adaptive QoS provision framework can be used in any mobile and wireless IP multimedia networks. Hence, WLAN and 3G are chosen here for demonstration purposes as most widely spread wireless technologies today. Nowadays many types of mobile equipment (ME) have also a WLAN and Bluetooth interfaces, and in the near future many MEs will have Long Term Evolution (LTE) interfaces too, besides their UMTS, WLAN, WiMAX, Bluetooth, ZigBee etc. radio interfaces. However, when there are different wireless and mobile networks on one side, and single ME on the other, then consequently the user of that ME should have possibility to use all those technologies in the range using his/her personal settings in the ME, or this user can choose only one from all available technologies. For that purpose the Open Wireless Architecture (OWA) [2] is proposed to provide open baseband processing modules with open interface parameters for supporting different wireless communication standards. The main mobile phone design concept as well as protocol stack for this approach is introduced in [1].

The remainder of this article is structured as follows. Section II gives an overview of the most relevant research works in this field. Section III presents our ME adaptive QoS module. In Section IV we provide simulation results. Finally, the last Section V concludes this paper.

2. Related Works

The major goal in any wireless and mobile multimedia network is the high level of QoS provisioning for every given service. The interest for adaptive QoS provisioning is growing together with the tremendous grow of adaptive multimedia services in mobile communication networks, where it is possible to increase or decrease the bandwidth of individual ongoing flows. One adaptive QoS framework for Wireless Ad-hoc Networks, which dynamically adapts flows in response to observed changes based on user-supplied adaptation policy, is introduced in [3]. Mainly the adaptive QoS framework is based on adaptive policy-based routing strategy which adapts the flows across the mobile nodes every time when they move. This results it is focused only on some improvements in Wireless Ad-hoc and sensor network. Similar to previous work, in [4] is presented an adaptive QoS routing system that considers both channel allocation and clustering.set of fast routing algorithms that provide a diverse set of QoS guarantees to different applications in MANETs. This adaptive algorithm introduces a two level routing hierarchy that decomposes the routing computation into several lower complexity subproblems (hierarchical approach is necessary in a large wireless network due to the presence of interference). However, [3] and [4] have limited focuses of adaptive QoS algorithms only for MANET or sensor networks, which solve only several QoS problems.

Furthermore, in [5] is presented bandwidth adaptation algorithm which seeks for high level of QoS provisioning. Moreover, in [5] the bandwidth of an ongoing multimedia calls can be dynamically adjusted, with the Call Admission Control (CAC) algorithms. Call blocking probability, forced termination probability and call overload probability are the main QoS parameters on a call level. But in [5] only single class of adaptive multimedia networking has been investigated. Furthermore, in [6] is presented effective QoS provisioning for wireless adaptive multimedia with using a form of discounted reward reinforcement learning known as Q-learning. Proposed scheme in [6] considered the handoff dropping probability and average allocated bandwidth constraints simultaneously, in order to achieve optimal CAC and bandwidth allocation policies that can maximize network revenue and guarantee QoS constraints. Simulation results in [6] demonstrate that the given scheme is high effective. A step forward is made in [7] , where is proposed a generic adaptive reservation-based QoS model for the integrated cellular and WLAN networks. It uses an adaptation mechanism to support end-to-end QoS. The performance results shown in [7] reveal that the given adaptive QoS management scheme can considerably improve the system resource utilization and reduce the call blocking probability and handoff dropping probability of the integrated networks while still maintaining acceptable QoS to the end users. However, this adaptive QoS management shame modified only MAC layer CAC procedure with appropriate bandwidth adaptation algorithm (given in [7]) and satisfies limited number of QoS parameters (traffic load parameter, call blocking probability and handoff dropping probability).

On the other hand, when we focus on architectures for integrating WLAN/UMTS systems they can be grouped into two categories based on the independence between the two networks [8], tight coupling and loose coupling. The loose coupling architecture enables the two networks deployed independently, but it results in longer delays for signaling and vertical handovers. 3GPP has been working on standardization for integration of cellular 3GPP technologies and WLAN systems [9]. Furthermore, schemes for dual-mode ME node for UMTS/WLAN internetworking, have been proposed in [10] and [11], but without emphasized QoS issues. Similar on previous dual-mode UE node for UMTS/WLAN, in [12] is presented advanced one with implemented handover logic modules within. The dual-mode UE design includes a monitoring and reporting unit to determine the status of the interfaces and an interface selection unit to activate or deactivate the interfaces (UMTS and WLAN) for mobile handoff. The results indicate a smoother and seamless handoff process. The lack of this model is in focusing only in mobile HO processes and not implementing any adaptive QoS framework for improving the results of other QoS parameters.

Similar to our work in [13] the adaptive wireless end-to-end QoS algorithm is presented. That algorithm solves the main QoS problems (congestion, wireless medium, handovers, temporary disconnecting and ect.) within the Network Layer in Heterogeneous Networks. Also, in the simulation results in [13] ns-2 simulation environment is used. However, the lack of the adaptive QoS framework presented in [13] is the focus only in video streaming delivery (real-time services) over heterogeneous networks.

The main motivation that led us to the development of novel adaptive QoS module, which will provide intelligent high level of QoS in any wireless and mobile networks (including integrated UMTS/WLAN networks [14]), using every available technology at same time, is taken from [1]. In [1] is given the main 5G mobile phone concepts and moreover the needs for creating and implementing adaptive QoS management mechanisms have been introduced. To emphasize that in comparison with other related works, our adaptive QoS module is implemented on IP level. In our previous works (with the first version of our adaptive QoS module) we have presented early simulation results and analysis for adaptive QoS VoIP provisioning (real-tmine services) in integrated WLAN/UMTS networks [15] and also, adaptive QoS provisioning for non-real time services in heterogeneous wireless networks [16]. After improvements of our Adaptive QoS Module within the ME, we achieved even superior results then the previous one, and even better QoS provisioning in heterogeneous wireless networks. Furthermore, in the next section we elaborate the intelligence of our novel adaptive QoS module.

3. Adaptive QoS System Module

In Figure 1 we present our novel ME node, which is dual-mode UMTS/WLAN node, with Adaptive QoS module within IP layer. According to [1] and [2] physical and OWA define the wireless technology (i.e. OSI Layers 1 and 2). The network layer will be IP, but separation of this layer into two sublayers will be necessary. The first sublayer (Upper Network Layer) has one unified IP address within, and is nominated for routing as well as for creation of sockets to the upper application layer. The other sublayer (Lower Network Layer) may include several different IPv4 (or IPv6 addresses), one IP address for each of the radio interfaces, while each of these IP addresses will be mapped with unified IP address of the Upper Network Layer. In the middleware between the Upper and Lower network layers will be address translation module, which shall maintain and translate IP addresses from Upper network address (one IPv4 or IPv6) to different Lower network IP addresses (IPv4 or IPv6), and vice versa. Moreover, for 5G mobile terminals will be suitable to have Open Transport Protocol - OTP (transport layer in the clasical OSI model) that is possible to be downloaded and installed. Such MEs shall have the possibility to download (e.g., TCP, modifications and adaptation of TCP for the mobile and wireless networks, RTP, some new transport protocol and etc.) version which is targeted to a specific wireless technology installed at the base stations. Application layer in Fig.1 is the same like that from classical OSI model. More detail description for the all OSI layers in the 5G mobile terminal design is given in [1]. Furthermore, we briefly present our adaptive QoS framework in ME. The core of our work is development of novel adaptive QoS Module; we will refer to it as QoS-Cross-IP Module (QXIP), which is defined separately from each wireless technology (e.g. UMTS, WLAN, WiMAX, 3G-LTE, 4G, etc.). It is implemented on Upper Network Layer, which will be able to provide intelligent QoS management and routing over variety of network technologies. Moreover, the QXIP module is able to combine simultaneously several different traffic flows transmitted over the same or different wireless access channels, achieving higher throughput and optimally using the radio resources. All those functionalities and performances are programmed in C++ within the IP layer module class (and its subclasses) in ns-miracle 1.2.2 [17] simulator.

For the purpose of the QXIP, the ME must collect QoS parameters, such as delay, jitter, losses, bandwidth, reliability, Packer-Error-Ratio (PER), Signal-to-Noice-Ratio (SNR), Transmission Power (TP), etc., continuously, at given time intervals (all the time), by collecting the measurements data via cross-layer messages (special XMessage C++ class developet in ns-miracle 1.2.2 for cross-layer communication) from OSI layer 1 up to Lower Network layer, and then storing the data into two-dimensional matrix variable within the QXIP module. This two-dimensional matrix is a small QoS DB (database), which can be easy extended, in a more complex multi-dimensional matrix (more complex DB, which will save all other relevant parameters for any used mobile wireless technology). The first row of this matrix contains UMTS QoS parameters and second row contains the WLAN QoS parameters, appropriately. On the other hand, with one cross-layer message, for each send packet, the Type-Of-Service information (ToS field in IPv4 or DSCP field in IPv6) from Application Layer is collected (from the arrived packets), in order to implement packet scheduling priority, i.e. higher priority for real-time service packets. Before every downlink transmission of IP packet from QXIP down to UMTS or WLAN MAC modules, the QXIP module is doing service quality analysis by using the data stored in the QoS DB in the Upper Network Layer of ME for given time period in the past (e.g., seconds, minutes) in order to choose the best wireless connection upon required QoS.

Here, in our current implementation, we are testing only: ToS, SNR, PER and Transmission Power, which are collected from Application and OWA Layer (OSI Layer 1 and OSI Layer 2) via cross-layer messages (in ns-miracle 1.2.2 this C++ class is XMessage, which saves SNR, PER and Transmission Power parameters in privet variables). When the IP packet comes to the QXIP module, he always fist try to get admission (in downlink) to the WLAN whenever it is available (i.e. all tested WLAN parameters: SNR, PER and TP, are above their appropriate WLAN thresholds and moreover, the WLAN utility function in [10] (equation (8)), is satisfied). Second, if QXIP module doesn't get WLAN admission, it tries to get admission to the UMTS network (all tested UMTS parameters are above their appropriate UMTS thresholds and also the UMTS utility function given in [10] (equation (7)) is satisfied).

Finally, QXIP module sends the packet that comes from Upper Network Layer down to the chosen LL/MAC module or drops it in the case there is no admission to any of the given wireless mobile networks. However, every packet goes through packet priority scheduling, before it is passed to the above mentioned downlink procedure.

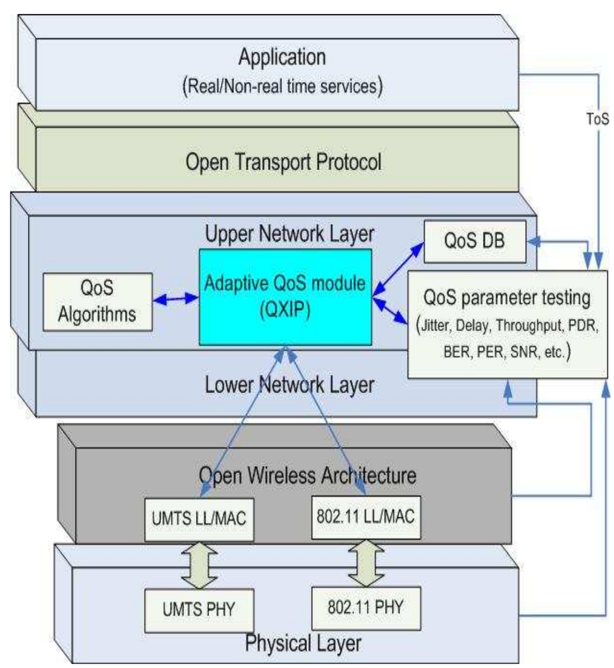

Figure 1. ME dual-mode Node with Adaptive QoS Module.

On the other hand, in uplink, all packets which are coming from all LL/MAC modules are received in Upper Network Layer, and send without any losses up, from QXIP module to Transport Layer. With those procedures different flow combining is done within the QXIP module.

4. Simulation Results and Analysis

In Figure 2 the simulation scenario is given, and as can be seen, two UMTS Node B and four WLAN Access Points are set. At the beginning of the simulation, the MEs are randomly scattered within the area of 560x560 m^2. For MEs physical mobility, we adopted the Gauss-Markov Mobility model [18] considering average speeds in the range of 2-23 m/s. The UMTS Node B 1 coordinates are: (0,0) and the UMTS Node B 2 coordinates are: (550,550); each of them are providing coverage for the MEs placed within a distance of about 520 m. On the other hand, WLAN AP 1 is placed at (160,160), WLAN AP 2 is placed at (370,370), WLAN AP 3 is placed at (0,550) and WLAN AP 4 is placed at (550,0). The WLAN coverage for the MEs placed within a distance of about 130 m. This simulation scenario is providing total network coverage for all MEs (WLAN or UMTS coverage, or both in the center of the simulation area). The multimedia traffic (Constant Bit Ratio and Variable Bit Ratio traffic) starts at the beginning of the simulation time. Until the end of the simulation time, part of this multimedia traffic flows between Internet through the gateway (GW), which is wired to UMTS Node Bs and 802.11 APs, to all MEs (e.g., VoIP, video-conference and/or web session) and another part of the traffic flows between MEs (e.g., one user sends some multimedia file, such as video, audio and/or data, to another user or group of users). The general parameters used in our simulation are summarized in Table 1.

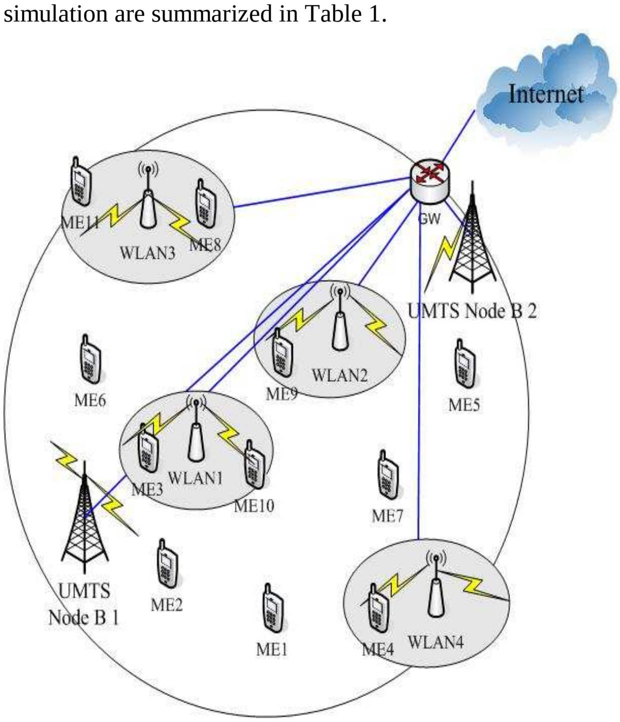

Figure 2. Simulation scenario for multimedia services.

Table 1. Simulation parameters

Parameters	Values
CBR packet size	160 Bytes
WLAN Data rate	1 Mbps
Physical header	192 bits
MAC header	224 bits
SIFS	10 µs
DIFS	50 µs
Traffic frame interarrivel time	4 seconds
CTS, ACK	112 bits + Phy header
WLAN_PER threshold	$7x10^{-11}$ W
UMTS_PER threshold	10^{-6} W
NodeB spreading factor	32
ME spreading factor	16
TCP packet size	500 Bytes

At the first case all MEs are dual-mode UMTS/WLAN, and are equipped with QXIP module. We use ns-miracle 1.2.2 [17] simulation environment for creating our dual-mode ME with two interfaces (one for UMTS network, another for WLAN network) and with QXIP module (presented in the previous section). Moreover we create novel cross-layer messaging class, for cross-layer communication between the modules. The performances in this case is shown with blue lines in Figures 3-10, and is compared with the simulation results in the cases when we have MEs without QXIP module, i.e., when we use only WLAN MEs (green line) or we use only UMTS MEs (pink line).

As we can obtain from Figure 3, the average throughput for our dual-mode ME with included QXIP module (i.e., QXIP_ME), achieves better throughput for every number of ME nodes, in comparison with the average throughput in the case of only WLAN MEs or only UMTS MEs. Moreover, our dual-mode MEs shows superior average throughput values over compared with the case with only UMTS MEs. On the other hand, the WLAN average throughput curve and the curve for our dual-mode ME with QXIP module, shows almost the same throughput. This statistical similarity is because of the fact that our dual-mode MEs with QXIP module within, move with mean speed of 2m/s and the probability some of them to pass through the WLAN areas is high. Consequently, they more often are connected on WLAN APs, using the higher WLAN throughput, and from time to time using UMTS access. Moreover, even at times when those two traffic flows are combined, WLAN traffic characteristics are dominant regarding the throughput. It is necessary to emphasize that in order to achieve more realistic values and results, in the simulation scenario, we have used background traffic in both networks up to 60% of their capacity.

Furthermore, as we see in Figure 4, the average Packet Delivery Ratio (PDR) values for the first case when we use QXIP dual-mode MEs are very balanced, i.e. our PDR values are somewhere between the PDRs from UMTS and WLAN MEs in case when we have few MEs (nodes), and have tendency at some points to reach UMTS ME PDR values. After we use more then 8 MEs in the simulation scenario, PDR values in our case (when we use QXIP dual-mode MEs) are better of the other two PDR values (UMTS PDR values and WLAN PDR values), so the QXIP gives better results in more saturated environment. Consequently, WLAN PDR values in any case are smaller in comparison with our QXIP PDR values and UMTS PDR values, due to the smaller network coverage area in the given simulation scenario. In that context, in Figure 5 are shown similar results for PDR values for all three cases. In this case number of MEs is set to 10, and the average velocity is 2 m/s. As it is shown, the PDR values for our QXIP dual-mode MEs have tendency to reach UMTS PDR values, and in some cases (e.g., at 20, 25 and 40 seconds, in Figure 5) QXIP PDR values are highest. Again we have balanced PDR values in our case.

Inn Figure 6 we present average throughput for different mean velocities (from 2 m/s, up to 23 m/s) of the MEs, when we have 10 MEs and simulation time of 20 seconds. First of all, it can be clearly noted that average throughputs when we used dual-mode QXIP MEs is superior than the average throughput values from the cases when we use only WLAN MEs or when we use only UMTS MEs, for any given average velocity ($\overline{v}$).

To emphasize that, when we using our dual-mode QXIP MEs, the average throughput curve has ascending trend due to the fact that with higher average speed of the MEs, there are more frequent handovers to the WLAN areas, and vice versa, and consequently it achieves higher average throughput. As it was elaborated before, similar statistics between QXIP and WLAN throughput curves remain. To emphasize that for higher velocity values, QXIP and WLAN throughput curves have descending trend, because at those speeds not all MEs have possibility to access WLAN APs (at higher user velocities there is no time for doing UMTS-WLAN vertical handovers).

Furthermore, in Figure 7 average jitter values as a function of velocity for two cases (when we use dual-mode QXIP MEs and when we use UMTS MEs) have been presented. In this scenario, the number of MEs is fixed on 10, and the duration of the simulation is 20 seconds. As we can see, for our case when we used dual-mode QXIP MEs, in comparison with the case when we use UMTS MEs, for any particular velocity, lover average jitter value has been achieved. For a lower velocity values, in comparison with the average jitter values of UMTS MEs, around two times lower average jitter values for our QXIP MEs are achieved. As the average ME velocity increase, those two curves converge, due to the fact that MEs access only UMTS network, practically flying over WLAN areas (no time for handovers, i.e. using WLAN network minimal).

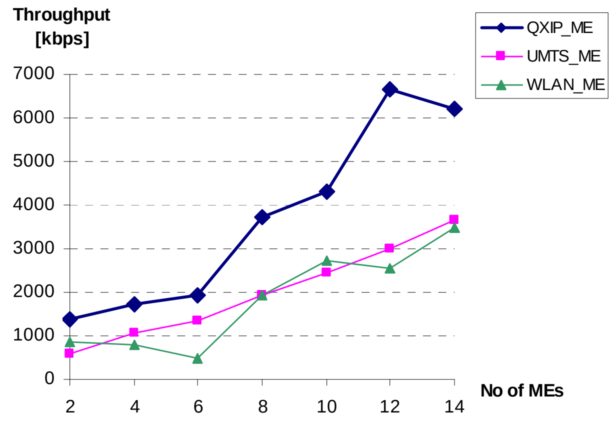

Figure 3. Average throughput vs. number of mobile nodes ($\overline{v}$ = 2m/s).

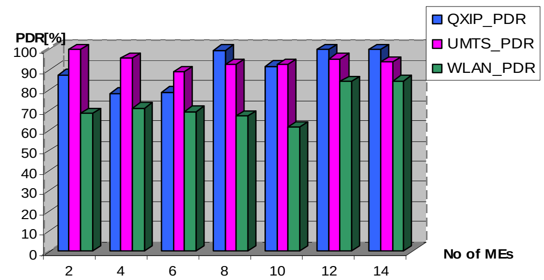

Figure 4. Average PDR vs. number of mobile nodes ($\overline{v}$ = 2m/s).

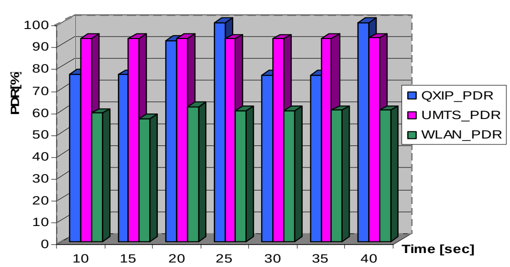

Figure 5. Average PDR vs. time (number of mobile nodes is 10 and $\overline{v}$ = 2m/s).

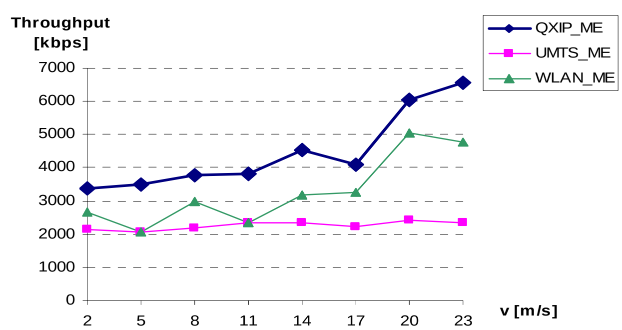

Figure 6. Average throughput vs. velocity (number of mobile nodes is 10, t_sim= 20 seconds).

In Figure 8 average jitter values for non-voice traffic as a function of simulation time for the same two cases are shown. As can be seen, in case where we use dual-mode UMTS/WLAN QXIP MEs, during whole simulation time, very balanced average jitter is achieved. Moreover, in comparison with UMTS jitter, all the time, QXIP jitter has significantly lower values.

Furthermore, in Figure 9, the average delays versus number of used MEs, for all three cases are presented. In this scenario, average velocity of MEs in the Gauss-Markov Mobility model is fixed on 2 m/s, simulation duration is 20 seconds and we change the number of MEs from 2 up to 14. As we can see, our dual-stack QXIP ME delay curve is between the curves for UMTS and WLAN cases, with lower values than the values of UMTS curve, and higher values compared with the values of the WLAN curve. By increasing the number of MEs the dual-stack QXIP MEs delay curve becomes very balanced, oscillating around its average value (in this case 900 ms). Due to the lower latency of WLAN network and because of the fact that we carefully managed the traffic load of the WLAN network (we set it to be maximum 50 %, in order to achieve satisfying level of QoS provisioning with this wireless technology), all WLAN MEs achieve lower latency values.

5. Conclusion

In this paper we have presented simulation results for the key Quality of Service parameters (throughput, jitter, delay and Packet Delivery Ratio), using the proposed novel adaptive QoS module and dual-mode UMTS/WLAN mobile terminals.

According to the simulation results, our proposed dual-stack UMTS/WLAN ME with adaptive QoS module performs fairly well, even in different network conditions regarding user mobility, background traffic load and number of nodes; achieving overall better performances in comparison with the cases when only WLAN or only UMTS MEs have been used. The results showed the performance gain with QXIP module in the dual network scenario, while it can be easily generalized in multi wireless networks scenario.

In our future work we are focusing on development of advanced QXIP module, by using additional network conditions as inputs for intelligent wireless access decisions. Moreover, we plan to add WiMAX and LTE interfaces in OWA Layer, and use more complex algorithm in QXIP module, together with more complex database. This advanced QXIP module should be able to choose the best wireless technology under given QoS requirements and time intervals, for best QoS satisfaction. Also, it can combine different traffic flows from/to different wireless and mobile networks, with aim of achieving superior QoS provisioning (i.e., maximal throughput, minimal delay and jitter, maximal PDR, minimal packet error, etc.). All given capabilities of our novel adaptive QoS framework, together with several others, are part of the future 5G mobile phone paradigm, which now exists only as a main concept.

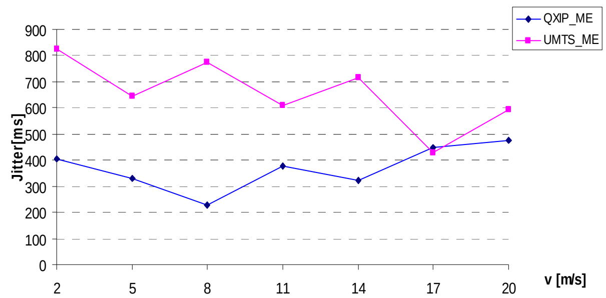

Figure 7. Average jitter vs. velocity (number of mobile nodes is 10, t_sim= 20 seconds).

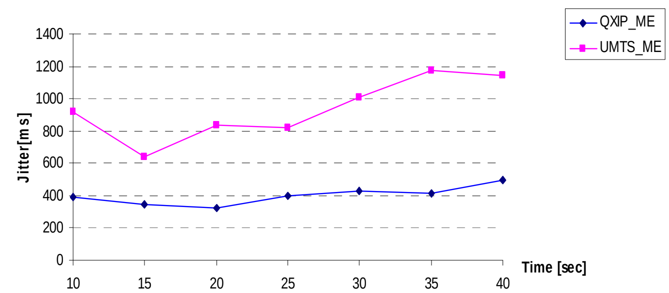

Figure 8. Average jitter vs. time (number of mobile nodes is 10, $\overline{v}$ = 2m/s).

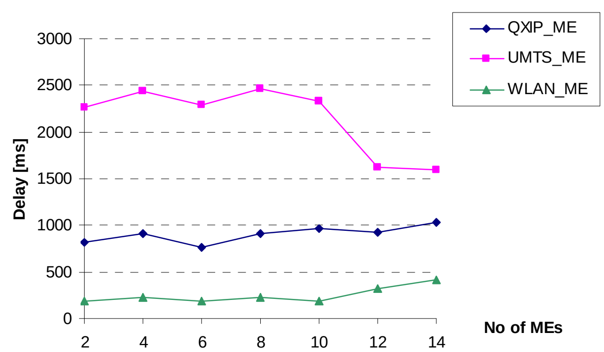

Figure 9. Average Delay vs.. number of mobile nodes ($\overline{v}$ = 2m/s).

References

[1] Toni Janevski, “5G Mobile Phone Concept” – CCNC conference in Las Vegas, 2009.

[2] Willie W. Lu, “An Open Baseband Processing Architecture for Future Mobile Terminals Design”, IEEE Wireless Communications, April 2008.

[3] Seoung-Bum Lee, "Adaptive Quality of Service for Wireless Ad hoc Networks", Ph.D. Thesis, Columbia University, 2006.

[4] Antonis Dimakis, Linhai He, John Musacchio, Hoi-Sheung Wilson So, Teresa Tung, Jean Walrand, "Adaptive Quality of Service for a Mobile Ad Hoc Network", Fifth IFIP-TC6 International Conference, pp.90-93, 2003.

[5] T. Kwon, Y. Choi, C. Bisdikian andM. Naghshineh, “QoS provisioning in wireless/mobile multimedia networks using an adaptive framework”, Wireless Networks 9, pp. 51–59, 2003.

[6] Yu Fei, Vincent W.S. Wong, Victor C.M. Leung, “Efficient QoS Provisioning for Adaptive Multimedia in Mobile Communication Networks by Reinforcement Learning”, Mobile Networks and Applications 11, pp. 101–110, 2006.

[7] Xin Gang Wang, Geyong Min, John E. Mellor, Khalid Al-begain, "An Adaptive QoS Management Scheme For Interworking Cellular and WLAN Networks", Computer Networks: The International Journal of Computer and Telecommunications Networking - Wireless IP through integration of wireless LAN and cellular networks,Volume 47 Issue 2, 4 February 2005.

[8] M. Buddhikot, G. Chandranmenon, S. Han, Y. W. Lee, S. Miller and L. Salgarelli, Integration of 802.11 and Third-Generation Wireless Data Networks, Proc. IEEE INFOCOM, Apr. 2003.

[9] 3GPP, Group Services and System Aspects; 3GPP Systems to Wireless Local Area Network (WLAN) Interworking; System Description (Release 6), TS 23.234, v. 6.2.0, Sept. 2004.

[10] Y. Zhou, Y. Rong, H.-A. Choi, J.-H. Kim, J. K. Sohn, and H. I. Choi,"A Dual-Mode Mobile Station Modules for WLAN/UMTS Internetworking Systems," Proc. OPNETWORK 2007, Washington, DC, August 27-31, 2007.

[11] Nicola Baldo, Federico Maguolo, Marco Miozzo, Michele Rossi, Michele Zorzi, ”Ns2-MIRACLE:a Modular Framework for Multi-Technology and Cross-Layer Support in Network Simulator 2”, NSTools ’07, October 22, 2007, Nantes, France.

[12] Abdul-Aziz Al-Helali, Ashraf Mahmoud, Talal Al-Kharobi, Tarek Sheltami, "Simulation Of a Novel Dual-Mode User Equipment Design For B3G Networks Using OPNET", Third International Conference on Modeling, Simulation and Applied Optimization Sharjah,U.A.E, January 20-22 2009.

[13] Ouldooz Baghban Karimi, Mahmood Fathy, "Adaptive end-to-end QoS for multimedia over heterogeneous wireless networks", Computers & Electrical Engineering (CEE) 36(1):45-55, 2010.

[14] Wei Song, Hai Jiang, Weihua Zhuang “Performance analysis of the WLAN-First scheme in Cellular/WLAN interworking”, IEEE transactions on wireless communications, Vol.6, Issue 5, pp.: 1932-1952, May, 2007.

[15] Tomislav Shuminoski, Toni Janevski, "Novel Adaptive VoIP QoS Provisioning In Integrated UMTS/WLAN Networks", ICEST 2010, Ohrid, Macedonia, 23-26 June, 2010.

[16] Shuminoski Tomislav, Janevski Toni, "Adaptive QoS Provisioning for Non-real Time Services in Heterogeneous Wireless Networks", TELFOR 2010, 18-th Telecommunications Forum, Belgrade, Serbia, November, 2010.

[17] Ns-MIRACLE:Multi InteRfAce Cross Layer Extension for ns-2, http://www.dei.unipd.it/wdyn/?sez_alias=ricerca/signet/tools/nsmiracle

[18] B. Liang and Z. Haas, “Predictive distance-based mobility management for PCS networks”, in Proceedings of IEEE Infocom, New York, NY, US, Mar. 1999.