Novel Adaptive QoS Framework for Integrated UMTS/WLAN Environment

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***Abstract* — Since Quality of Service (QoS) provisioning for multimedia traffic in integrated Wireless and Mobile Networks is becoming an increasingly important objective, in this paper we introduce a novel concept of an adaptive QoS cross-layer framework. The Adaptive QoS framework is proven via novel simulation results in integrated environment with UMTS and IEEE 802.11 networks. The aim of our novel framework is presenting a new module that shall provide the best QoS and lower cost for a given service using one or more wireless technologies in a given time. The analysis of simulation results has shown superior performances with a high level of QoS provisioning in a variety of network conditions. The performance of Adaptive QoS algorithm is evaluated using ns-miracle augmented with our dual-mode Mobile Equipments (MEs) and using statistical analysis.**

***Keywords* — Quality of Service (QoS), Mobile Networks, Multimedia, Wireless Networks.**

I. Introduction

NEXT generation mobile and wireless networks are promising to offer a huge spectrum of multimedia services to mobile users, with a variety of advanced capabilities, supported with a high level of QoS provision. The implementation of all advanced capabilities of those networks, such as ubiquitous mobility, enormous processing power of the mobile equipment, any-time and any-place paradigm, adaptive high-level QoS support, etc., requires great scalability and a thorough analysis. Since radio bandwidth is one of the most precious resources in wireless and mobile systems, an efficient adaptive QoS framework is very important to guarantee QoS provision for any given services and to maximize radio resource utilization simultaneously. In the next generation mobile and wireless network (beyond 4G), which is seen as a 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 mobile equipments will have access to different wireless technologies at the same time and they should be able to combine different flows from different technologies using adaptive QoS algorithms. Furthermore, each wireless and mobile heterogeneous network will be responsible for handling user-mobility, while the mobile terminal will make the final choice among different wireless and mobile access network providers for a given service. In that point, satisfied QoS provisioning for wireless and mobile multimedia networks is becoming an increasingly crucial target. Moreover, the analysis in this paper is focused on adaptive QoS provisioning for multimedia service over integrated UMTS and WLAN networks, in a loose-coupling architecture, using a novel advanced QoS Framework within dual-mode mobile equipment. This Adaptive QoS Framework has the capability of accessing both networks and chooses the best connection according to QoS requirements for the given service, and roams between the networks as many times as needed by using vertical handovers executed by the mobile equipment. The prerequisite for this is the mobile equipment 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.

In cases when multiple different wireless and mobile networks are available to a single mobile device, then it may have a possibility to use all radio access technologies in the range, or select a single one from available technologies. For that purpose we use the Open Wireless Architecture (OWA) [2] which provides open baseband processing modules with open interface parameters for supporting different wireless communication standards. However, the main mobile terminal design concept as well as protocol stack for this approach is introduced in [1].

The paper is organized as follows. Section II gives an overview of the most relevant research work in this field. Section III presents our system model with an adaptive QoS framework. Section IV provides simulation results. Finally, Section V concludes this paper.

II. Related Works

The major goal in nowadays and in the future wireless and mobile multimedia networks is providing a high level of QoS support for any given service. The interest in adaptive QoS provisioning is growing together with the tremendous development of multimedia services in mobile and wireless networks, where it is possible to increase or decrease the bandwidth of individual ongoing flows. One bandwidth adaptation algorithm which seeks for a high level of QoS provisioning, is presented in [3]. Also, in [3] the bandwidth of an ongoing multimedia call can be dynamically adjusted, with the Call Admission Control

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(CAC) algorithms. Call blocking probability, forced termination probability and call overload probability are the main QoS parameters on a call level that are a concern. But in [3] only a single class of adaptive multimedia networking has been investigated. Furthermore, [4] presents effective QoS provisioning for wireless adaptive multimedia with using a form of discounted reward reinforcement learning known as Q-learning. The scheme proposed in [4] considers 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 [4] demonstrate that the given scheme is highly effective. A step forward is made in [5], where authors propose a generic adaptive reservation-based QoS model for integrated cellular and WLAN networks. It uses an adaptation mechanism to support end-to-end QoS. The performance results shown in [5] 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 integrated networks while still maintaining an acceptable QoS to the end users. However, this adaptive QoS management scheme modifies only MAC layer CAC procedure with an appropriate bandwidth adaptation algorithm (given in [5]) and satisfies a limited number of QoS parameters (only: traffic load, call blocking probability and handoff dropping probability).

On the other hand, when we focus on architectures for integrated WLAN/UMTS systems they can be grouped into two categories based on the independence between the two networks [6], tight coupling and loose coupling. The loose coupling architecture enables the two networks to be deployed independently, but it results in poor QoS provisioning (longer delays for signaling and vertical handovers). 3GPP has been working on standardization for the integration of cellular 3GPP technologies and WLAN systems [7]. Furthermore, schemes for dual-mode mobile equipment for UMTS/WLAN interworking network have been proposed in [8] and [9], but without emphasized QoS issues. Similarly to a previous dual-mode ME node for UMTS/WLAN, in [10] is presented an 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 shortcoming of this model is in focusing only on mobile HO processes and not implementing any adaptive QoS framework for improving the results of other QoS parameters. Furthermore, in [11] the adaptive wireless end-to-end QoS algorithm is presented. That algorithm solves the main QoS problems (congestion, wireless medium, handovers, temporary disconnecting, etc.) within the Network Layer in Heterogeneous Networks. Also, in the simulation results in [11] an ns-2 simulation environment is used. However, the shortcoming of the adaptive QoS framework presented in [11] is the focus on only video streaming delivery (real-time services) over heterogeneous networks. The main motivation that has led us to develop a novel adaptive QoS framework in one module within ME, which will provide an intelligent high level of QoS in any wireless and mobile heterogeneous network (including integrated UMTS/WLAN networks [12]), using every available technology at the same time, is taken from [1]. In [1] is given the 5G mobile phone concept and, moreover, the needs for creating and implementing adaptive QoS management mechanisms have been introduced. We 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-time services) in integrated WLAN/UMTS networks [13] and also, adaptive QoS provisioning for non-real time services in heterogeneous wireless networks [14]. After improvements of our Adaptive QoS Framework in our Module within the ME, we have achieved even superior results than in the previous one, and even better QoS provisioning in heterogeneous wireless and mobile networks (published in [15] and [16]). Furthermore, we elaborate the intelligence of our novel adaptive QoS module, presenting novel results with improved statistical analysis.

III. System Model

In Fig. 1 is presented our system model, a novel ME node, which is a dual-mode UMTS/WLAN node, with an Adaptive QoS module within on IP layer. According to [1] and [2] a physical layer and OWA define the wireless technology, the network layer will be IP, but separation of this layer into two sublayers will be necessary; one subleayer for routing and another will be for each interface (different IPv4 addresses). For more details about all these layers, see [1]. Furthermore, our adaptive QoS framework in ME is presented briefly.

The core of our work is the development of a novel adaptive QoS Module; we call it QoS-Cross-IP Module (QXIP), defined separately from each wireless technology, which will be able to provide intelligent QoS management and routing over a variety of network technologies. The QoS parameters (such as delay, jitter, losses, bandwidth, reliability, Packer-Error-Ratio (PER), Signal-to-Noise-Ratio (SNR), Transmission Power (TP), Type of Service (ToS), etc.) are continuously, all the time, collected via cross-layer messages from Physical layer up to Application layer, and stored in a two-dimensional matrix within the QXIP module. The first row of this matrix contains UMTS QoS parameters and the second row contains the WLAN QoS parameters, appropriately.

Before every transmission of IP packet from QXIP down to UMTS or WLAN LL/MAC modules, the QXIP module is doing service quality testing (testing of collected QoS parameters) in order to choose the best wireless connection upon required QoS. Here, in our current implementation, we are testing only: ToS, SNR, PER and TP, which we have collected from Physical, OWA and Application layers via cross-layer messages. According to the performance analysis in [12], QXIP module always fist tries to get admission (in uplink) to the WLAN whenever it is available (i.e. all tested WLAN parameters: SNR, PER and TP, are above their appropriate WLAN thresholds, given in [8]).

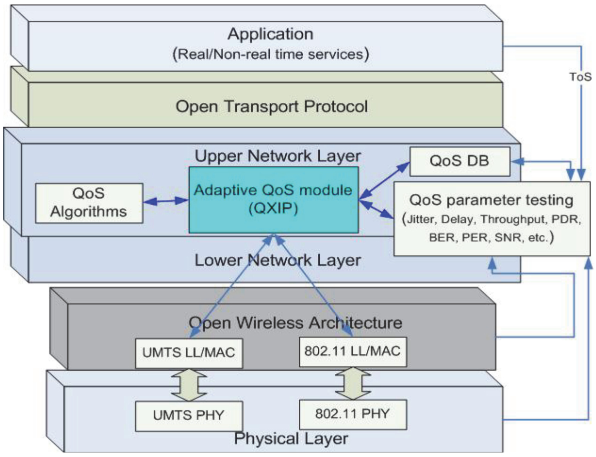

Fig. 1. ME with Adaptive QoS Module.

Second, if QXIP module doesn't get WLAN admission, it tries to get admission to UMTS network (all tested UMTS parameters are above their appropriate UMTS thresholds, given in [8]). Finally, QXIP module sends the packet that has come from the Upper Network Layer down to the chosen LL/MAC module or drops it if it doesn't find admission to any of those two networks. In a downlink, all packets from all OWA modules are received and sent up from QXIP to the Upper Network Layer, without dropping them.

IV. Simulation Results

Fig. 2 shows the simulation scenario. It consists of one UMTS Node B and one WLAN Access Point. At the beginning of simulation, the MEs are randomly scattered within the area of 500x500 m^2. For MEs physical mobility, we have adopted the Gauss-Markov Mobility model [17] considering average speeds in the range of 2-21 m/s. The UMTS Node B coordinates are (500, 500), and it is providing coverage for the MEs placed within a radius of about 520 m. On the other hand, WLAN AP is placed at (150,150), providing coverage for the MEs in a diameter around 130 m.

This simulation scenario is providing total network coverage for all MEs (WLAN and/or UMTS coverage). The multimedia traffic (Constant Bit Ratio and Variable Bit Ratio) starts at the beginning of the simulation time. Until the end of the simulation time, a part of this multimedia traffic flows between Internet via 4G core network, through the gateway (GW), which is wired to UMTS Node B and IEEE 802.11 AP, to all MEs (e.g., VoIP, video-conference, e-mail and web sessions) and another part of the traffic flows between MEs (e.g., one user sends some multimedia file, such as video, audio and data, to another user or group of users in the simulation area). The general parameters used in our simulation are summarized in Table I.

In the first case all MEs are dual-mode UMTS/WLAN, equipped with a QXIP module (presented in the previous section). We use an ns-miracle 1.2.2 for creating the proposed dual-mode ME with two interfaces (one for UMTS, another for WLAN network) and the implemented QXIP module. The performance outline in this case is shown in Figs. 3-8, in which it is compared with the simulation results for cases when there are MEs without QXIP module, i.e. only with a WLAN interface or with a UMTS interface.

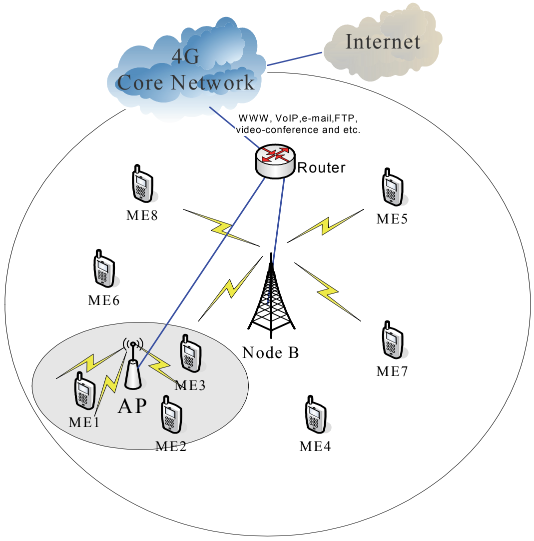

Fig. 2. Scenario for multimedia traffic.

Table 1: System parameters.

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

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.

As shown in Fig. 3, the average throughput for the dual-mode ME with included QXIP module within (QXIP_ME) achieves superior values in comparison with the average throughput obtained from the scenario with only WLAN MEs, or only UMTS MEs. However, this might be expected due to the fact that when MEs are moving at a mean speed of 2m/s (7.2 km/h), the probability of some of them to pass through the WLAN area is very high, consequently they are using more often both WLAN AP and UMTS access for the given services.

Furthermore, as shown in Fig. 4, average Packet Delivery Ratio (PDR) values for the first case when we use QXIP dual-mode MEs are very balanced, especially in cases when we use a higher number of MEs in the simulation area (i.e. more than 8 – the number of MEs). Moreover, our PDR values are somewhere between the PDRs from UMTS and WLAN MEs for all different numbers of MEs, and have a tendency at some points to reach UMTS PDR values (which are the highest due to the full UMTS network coverage).

In that context, in Fig. 5 are shown similar results for PDR values for all three cases. In this case the number of mobile terminals is set to 8, and the average velocity is 2 m/s (7.2 km/h). As it is shown, again, the PDR values for the QXIP dual-mode MEs have a tendency to reach UMTS PDR values, especially in some cases (e.g., at 25, 30 and 35 seconds, in Fig. 5). The balanced PDR values in the QXIP ME case are between the other two PDR values (of the cases when we use UMTS MEs or WLAN MEs). The reasons for the smallest PDR values in the third case, when we use WLAN ME, are arising from the smallest WLAN network coverage area used in our simulation scenario.

Furthermore, in Fig. 6 are presented autocorrelations of the values of delay for different mean velocities (2 m/s - 21 m/s, i.e. 7.2 km/h – 75.6 km/h). To emphasize that, the analyses of autocorrelation curves are giving very important statistical information about some random process (in this case about the average delay and jitter values). The autocorrelations of delay values for our QXIP MEs have an almost linear descending trend, positioned between the autocorrelations for UMTS and WLAN MEs. The faster decreasing slope of the UMTS autocorrelation curve and oscillations of WLAN ME curve correspond to the greater delay variance compared to the values obtained from the QXIP ME case. Moreover, the average delay for all velocities in our QXIP ME is 385,62 ms, and 1919,17 ms, 115,59 ms for UMTS MEs and WLAN MEs, respectively. All this indicates that in the case when we use dual-mode mobile terminals with QXIP module, we have steady delays, which is a step up regarding the performances when compared with the other two cases.

Similar results for the autocorrelation values of delay can be seen in Fig. 7, where the autocorrelations of the values of delay for different numbers of mobile terminals (from 2 up to 8 MEs) are presented for all three cases. In this simulation the average velocity of all used MEs is 2 m/s (i.e. 7.2 km/h).

The autocorrelations of delay values for our QXIP MEs for different numbers of mobile nodes (MEs) have a linear descending trend, between the autocorrelations for UMTS and WLAN MEs (that oscillates around QXIP autocorrelation curve). Again we have faster decreasing of the UMTS autocorrelation curve and oscillations of WLAN ME curve due to the same reasons as before. Moreover, the average delay for all MEs in our QXIP ME

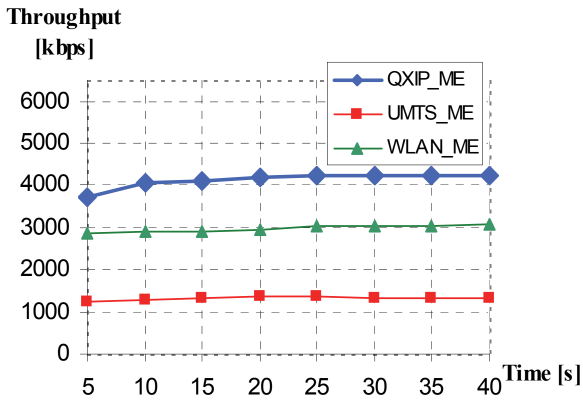

Fig. 3. Average throughput vs time ($\bar{v}$ =2m/s, NoNodes=8).

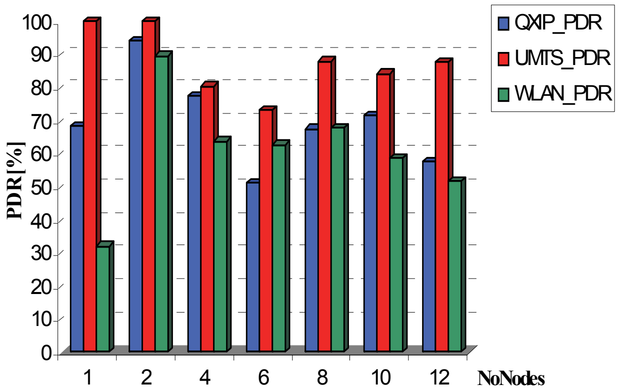

Fig. 4. Average PDR vs number of nodes ($\bar{v}$ =2m/s).

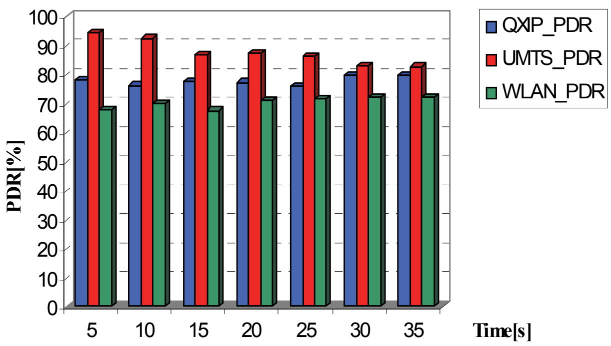

Fig. 5. Average PDR vs time ($\bar{v}$ =2m/s).

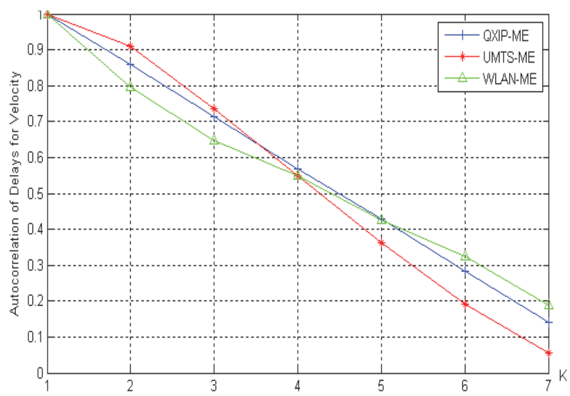

Fig. 6. Autocorrelation of Delay for $\bar{v} \in (2,3,...21 m/s)$.

is 406.80 ms, and 535.05 ms, 263.05 ms for UMTS MEs and WLAN MEs, respectively. The statistical analysis from the autocorrelation curves of the delay for different numbers of MEs show that in our QXIP MEs dual-mode case we have stable and balanced delays for any given number of mobile nodes, i.e. a better statistical outcome from the other two cases.

Furthermore, Fig. 8 shows average jitter values as a function of the number of MEs for any three cases that have been presented. In this scenario, the MEs mean velocity is 2 m/s. As we can see, for the case when we use dual-mode QXIP MEs, in comparison with the case when we use UMTS MEs, one may note that there are lower average jitter values, accompanied with constant curve trends. On the other hand we have higher average jitter values in comparison with the average jitter values of WLAN MEs, but this is so because of the fact that in WLAN technology we have a lower processing time, smaller coverage area, and have 60% (of the WLAN network capacity) background traffic. In the case with dual-mode QXIP MEs, the average jitter value is 55,25 ms, which is acceptable regarding all services, including real-time (e.g., Voice over IP-VoIP, streaming, etc.) and non-real-time services (e.g., web, e-mail, etc.).

In general, QXIP module provides statically better QoS provisioning in heterogeneous wireless and mobile networks scenario, which was demonstrated here by using the two currently most spread technologies, the WLAN (i.e., WiFi) and the UMTS.

V. Conclusion

This paper proposes a novel QoS framework for mobile devices in heterogeneous wireless and mobile environments. The proposed QoS module QXIP has been tested using several simulation scenarios, with the aim to obtain its statistical characteristics and to compare it with existing cases, when a single radio access technology is used by a single mobile terminal. The simulation results for the key QoS parameters (throughput, jitter, delay and PDR) are generated by using the novel adaptive QoS framework implemented in dual-mode UMTS/WLAN mobile terminals. According to the presented results, the proposed dual-stack UMTS/WLAN ME with an adaptive QoS module performs fairly well in different network conditions, achieving better performances in comparison with the cases when only WLAN or only UMTS MEs have been used.

The results have shown a performance gain with QXIP module in the dual network scenario, while it can easily be generalized to a multi wireless networks scenario, including any Next Generation mobile and wireless networks.

In our future work we will focus on the development of an advanced QXIP module, by using additional network conditions as inputs for intelligent wireless and mobile access decisions.

Moreover, we plan to add Mobile WiMAX and LTE/LTE-Advanced interfaces in the Open Wireless Access layer, and develop an advanced version of the QXIP module. This advanced QXIP module should be

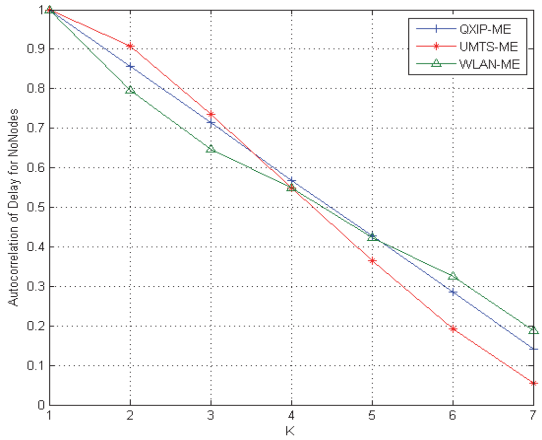

Fig. 7. Autocorrelation of Delay for Number of MEs=2-8.

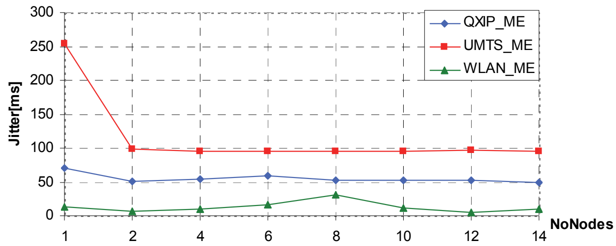

Fig. 8. Average jitter vs number of mobile terminals ($\bar{v}$ =2m/s).

able to choose the best radio access technology under given QoS requirements and time intervals, for best QoS satisfaction for any given service. Above all, it can combine different traffic flows from or to different wireless and mobile networks, with the aim of achieving superior QoS provisioning (i.e., maximal throughput, minimal delay and jitter, maximal PDR, minimal packet error, etc.) and maximal utilization of the available radio resources.

In that manner, the next logical step is wireless networks aggregation (on a network layer) which will provide a further increment in data rates using the available wireless and mobile technologies as well as future defined ones. Of course, for 5G there will also be new access schemes with higher spectrum utilization than in the existing 4G. However, radio network aggregation feature will provide a possibility to combine even newly proposed 5G wireless and mobile technologies with 4G technologies (LTE-Advanced and Mobile WiMAX 2.0, which provide layer-2 aggregation option), 3G technologies, as well as WLAN.

All described capabilities of our novel adaptive QoS framework, together with several others, are part of the future (5G) mobile terminal paradigm, which now exists only as a main concept.

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