International Journal of Grid Distribution Computing
Vol.7, No.6 (2014), pp.111-128
http://dx.doi.org/10.14257/ijgdc.2014.7.6.09

Advanced Mobile Terminal for Heterogeneous Wireless Networks

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Abstract

This manuscript introduces a novel design concept for advanced mobile terminals with radio network aggregation capability and enhanced Quality of Service (QoS) provisioning for various multimedia services in heterogeneous wireless and mobile networks. We establish a new module that provides the best QoS and lowest cost for any given multimedia service (voice, video and audio) by using simultaneously all available wireless and mobile networks for a given traffic flow. The performance of our proposal is evaluated using simulations with multimode mobile stations carrying multimedia traffic in heterogeneous environment with coexistence of multiple Radio Access Technologies, such as 3G, 4G as well as future 5G radio access networks. The analysis of the proposed framework for radio networks aggregation in advanced mobile terminals has shown overall better performances regarding the achievable throughput and multimedia access probability in heterogeneous wireless and mobile environment.

Keywords: *5G, Aggregation, Heterogeneous, Quality of Service, Radio Access Technology, Throughput, Wireless*

1. Introduction

The Information and Communication Technology (ICT) world is in tremendous growth and development. Especially that growth can be noticed in the heterogeneous wireless and mobile network technologies where is expecting to be provided a broad range of multimedia services (voice, data and video) to mobile users, with ubiquitous mobility, enormous processing power of the mobile equipment, advanced QoS support, as well as bigger memory space and longer battery life of mobile terminals, which will provide enough storage capability for control information and enormous spectrum for advanced capabilities. Currently we have operator-centric approach implemented in 3G mobile networks such as UMTS/HSPA, cdma2000, Mobile WiMAX 1.0 (IEEE 802.16e), and service-centric approach in 4G mobile networks, which are (according to the ITU IMT-Advanced umbrella): LTE-Advanced (LTE Release 10 and beyond) and Mobile WiMAX 2.0 (802.16m), [1, 2]. In the future mobile networks, the 5G, we are moving towards the user-centric concept [3, 4, 5, 6]. The user-centric approach is accepted as a basis for the work in the paper. In the future the mobile terminals will have access to different wireless technologies (through their different interfaces) at the same time and the terminal should be able to combine different flows from different technologies using advance QoS algorithms and control protocols.

On the other side, the existing wireless and mobile networks are going towards an all IP-based principle, which means that all data and signalling traffic will be transferred via IP

ISSN: 2005-4262 IJGDC

(Internet Protocol) on network layer. Different Radio Access Technologies (RATs) may exist together (older RATs, such as 3G UMTS, and newer RATs such as LTE-Advanced and Mobile WiMAX 2.0), however the common "thing" for all of them as a unifying technology is IP. That is the main reason why the main changes and improvements we are proposing in the network layer of the mobile terminal.

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 (different RATs) for a given service or traffic flow. 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 and mobile systems, an efficient QoS framework is very important to guarantee the required QoS and to maximize radio resource utilization simultaneously in all present wireless and mobile networks. We have used the throughput parameter as a performance metric. Moreover, the user throughput also defines the generations of the mobile network. For example, one condition by ITU for a given technology to be marked as 4G is higher aggregate throughput than 1 Gbit/s for low mobility scenarios and more than 100 Mbit/s for high mobility scenarios.

On the other hand, in a heterogeneous wireless network, with different multimedia traffic flows, each with different QoS requirements, achieving higher access probability of any given service is essential. In that manner, with limited available radio resources (bandwidth scarcity), increasing the throughput and maintaining high value of multimedia access probability, at the same time, is a great improvement due to the fact that system throughput and access probability are conflicting with each other.

The key goal of this paper is to propose a novel radio network aggregation technique for future 5G mobile networks by maximization of radio access throughput, with high level of QoS support and advanced QoS routing algorithm. Moreover, without loss of generality, the proposed advanced QoS routing framework and mobile terminal design can be used in any mobile and wireless IP multimedia networks, including existing RATs as well as future ones. Therefore, in our proposal we have not tied to any of existing RATs. However, 5G mobile terminal will not be attached to a single RAT, but to multiple RATs at the same time. Nowadays, smartphones have WLAN and Bluetooth interfaces, as well as several interfaces to 3GPP mobile networks (*e.g.*, GSM, UMTS, LTE). However, nowadays smartphones and other mobile devices use only one RAT at a given moment for a given flow. However, when there are different wireless and mobile networks on one side, and single mobile equipment on the other, then consequently the user of that mobile terminal should have possibility to use all available radio access technologies in the range using his/her personal settings in the mobile terminal, or this user can choose only subset of them (*e.g.*, one RAT, or two RATs). For that purpose the Open Wireless Architecture (OWA) [4] is proposed to provide open baseband processing modules with open interface parameters for supporting different wireless and mobile communication standards. The main mobile phone design concept as well as protocol stack for this approach is introduced in [3].

The remainder of this article is organized as follows. Section II gives an overview of the most relevant research works in this field. Section III presents our advanced mobile equipment with multi-interfaces. Section IV provides description of a novel algorithm for radio networks selection in heterogeneous wireless environment, which is created using biologically inspired algorithms. In Section V we provide simulation results. Finally, Section VI concludes this article.

2. Related Works

The main motivation and starting points for our Advanced Mobile Terminal framework could be found in [3-10]. Evermore, our framework and design of a novel mobile terminal is a next step from our previous works on adaptive QoS provisioning in heterogeneous wireless and mobile IP networks [11-13]. In those papers was introduced a novel adaptive QoS provisioning module that provides the best QoS and lower cost for a given multimedia service by using one or more wireless technologies at a given time. Nowadays the interest for adaptive QoS provisioning is continuing to grow together with the tremendous development of adaptive multimedia services in mobile and wireless communication networks, where it is possible to increase or decrease the bandwidth of individual ongoing flows. The performance of our adaptive QoS algorithm was evaluated using simulation with dual-mode UMTS/WLAN mobile equipments. The analysis of this concept and the simulation results for the key QoS parameters (throughput, jitter, delay and packet delivery ratio) has shown overall better performances and QoS provisioning for different multimedia services in a variety of network conditions in heterogeneous wireless and mobile environment. However, the drawback of such adaptive QoS framework is of its applicability to single RAT at a given time, even in the cases when it is probably the best connection for a given service flow. In that way, one step forward is made by using simultaneously all available wireless/mobile technologies at a same time by combining different flows from different technologies.

Furthermore, in [14] an adaptive multiple attribute vertical handoff decision algorithm is presented, which enables wireless access network selection at a mobile terminal using fuzzy logic concepts and a genetic algorithm. Similar concepts we used in our advanced QoS routing algorithm for advanced mobile terminals, but in this case for simultaneous access to different wireless network at the same time for a given multimedia service. The presented study in [14] proposes RAT selection algorithm by using the integrated wireless environment consisted of wireless wide area networks (WWANs) and wireless local area networks (WLANs). The proposed algorithm is a vertical handoff decision algorithm which is able to determine when a handoff is required, and selects the best RAT based on current network conditions, QoS requirements, mobile terminal conditions, user preferences, and service cost over different RATs.

Moreover, in [15] is presented effective QoS provisioning for wireless adaptive multimedia based on using a form of discounted reward reinforcement learning known as Q-learning. The proposed scheme in [15] considered the handoff dropping probability and average allocated bandwidth constraints simultaneously, in order to achieve optimal CAC (Call Admission Control) and bandwidth allocation policies that can maximize network revenue and guarantee QoS constraints. A step forward is made in [16], 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 [16] reveal that the given adaptive QoS management scheme can considerably improve the system resources utilization and reduce the call blocking probability and handoff dropping probability of the integrated wireless networks while still maintaining acceptable QoS to the end users. However, the adaptive QoS management scheme given in [16] has modified only MAC layer (in particular, the CAC procedure) with appropriate bandwidth adaptation algorithm and satisfies limited number of QoS parameters such as traffic load, call blocking probability and handoff dropping probability.Besides the discussed algorithms above, there are also many other works dealing with other advanced and novel mechanisms for selecting and accessing RATs. One of those mechanisms is presented in [17] where the mechanism for automated radio access network selection is introducing several novelties. The proposed mechanism enables terminals to build prioritized lists of target access networks independently for each of their active connections, and at the same time it aims to satisfy user preferences. Lastly, it operates with two decision-making points (mobile terminal and core network), splitting the complexity of the overall process and accessing the target RAT easier.

Another paper [18] is dealing with a network selection algorithm based on Fuzzy Multiple Attribute Decision Making. That algorithm considers the factors of Received Signal Strength (RSS), monetary cost, bandwidth, velocity and user preference. It defines a network selection function that measures the efficiency in the utilization of radio resources in given networks. Again, there is a selection of only one network.

The main base for developing our advanced QoS routing algorithm for our advanced mobile terminal can be found in [19]. The proposed general scheme is trying to solve the access network selection problem in the heterogeneous wireless network and has been used to present and design a general multicriteria software assistant that can consider the user, operator, and/or the QoS view points. Combined fuzzy logic (FL) and genetic algorithms (GAs) have been used to give the proposed scheme the required scalability, flexibility, and simplicity. The simulation results (as given in [19]) are showing that the proposed scheme and software assistant have better and more robust performance over the random-based selection.

On the other side, [20] presents a joint radio resource management strategy based on reinforcement learning mechanisms that control a fuzzy-neural algorithm to ensure certain QoS constraints. Three RATs, namely UMTS, GERAN and WLAN are considered as common available RATs for selection. The fuzzy logic allows for a very simple handling of the joint radio resource manager simply by activating a set of rules. Also, membership functions used in [20] are adaptive so that a desired performance only in terms of the probability of user satisfaction can be guaranteed.

In comparison with all related works, we must to emphasize that our advanced QoS routing module is implemented on IP level. In our previous papers (with the first version of our adaptive QoS module [11-13]) we have presented early simulation results and analysis for adaptive QoS provisioning for real-time and non-real-time services in integrated WLAN/UMTS networks and also in heterogeneous wireless networks. However, after improvements of our Adaptive QoS Module and developing of advanced QoS routing algorithm within the mobile terminal, which is able to combine different traffic flows from different technologies and in the same time to use several RATs, we achieved even superior results then the previous one, and even better QoS provisioning in heterogeneous wireless and mobile networks.

3. System Model

The main characteristics of our novel mobile terminal with incorporated advanced QoS routing algorithm are illustrated in Figure 1. As can be seen, our novel 5G oriented mobile equipment is multi-mode node, with several interfaces, each for different RAT. The advanced QoS routing algorithm is set within the advanced QoS routing module on IP layer. According to [3] and [4] physical and OWA define the wireless technology. Without doubts, the network layer will be IP, but separation of this layer into two sublayers will be necessary.

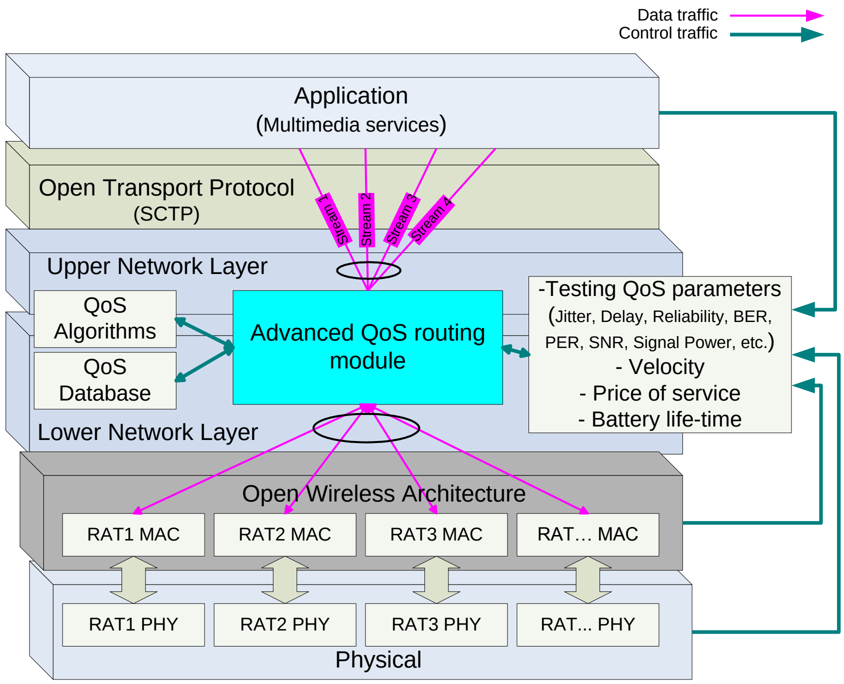


Figure 1. Advanced Mobile Equipment with Incorporated Advanced QoS Routing Algorithm

The Upper IP Network Layer has one unified IP address within, and is nominated for routing as well as for creation of sockets to the upper open transport layer and to the application layer. The other sub-layer, Lower IP 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 IP Network Layer. In the middleware between the Upper and Lower IP Network layers will be address translation module (included in the Advanced QoS routing module), which shall maintain and translate IP addresses from Upper IP Network address (one IPv4 or IPv6) to different Lower IP Network layer IP addresses (IPv4 or IPv6), and vice versa. Moreover, for 5G mobile terminals will be suitable to have Open Transport Protocol - OTP that is possible to be downloaded and installed. Such MTs shall have the possibility to download (*e.g.*, TCP, modifications and adaptation of TCP for the mobile and wireless networks, RTP, Stream Control Transmission Protocol - SCTP [21], some future transport protocol, *etc.*,) version which is targeted to a specific wireless and mobile technology installed at the base stations. From the standardized transport protocols, for the proposal in this paper the most convenient is SCTP, originally created for transfer is signaling data over IP networks, and currently it is used within the core part of 3G and 4G all-IP mobile networks (*e.g.*, between eNodeBs and gateways in 4G). The reason of implementing SCTP in OTP layer within our advanced mobile terminal lies in SCTP's attractive features such as multistreaming and multihoming. Moreover, SCTP is overcoming the limitations of TCP for transport of signaling messages over IP, the three-way handshake during the setup of connection (in SCTP there is a four-way handshake), *etc*. Mainly, in this article we used SCTP for multihoming, *i.e.*, for delivering different multimedia traffic over different RAT in the same time, after selecting the best RAT that is optimized to network conditions (accessibility), QoS requirements, mobile terminal conditions (the battery life-time), user preferences, and service cost over that RAT. With this we also have load balancing and we are trying to achieve the best QoS provisioning and highest throughput for any user. However, on the other end of the connection (in the multimedia server, or maybe some proxy control server) must be installed SCTP on its transport layer, in order to have successfully established SCTP association, as well as peer-to-peer communications.

Application layer in Figure 1 is the same like the one in classical OSI model. More detail description for the OSI layers in future 5G mobile terminal designs is given in [3], and [7-11]. Furthermore, we briefly present our advanced QoS routing framework in the mobile terminal presented in Figure 1.

The core of our work is development of novel adaptive QoS Module with adaptive QoS routing algorithm. We will refer to it as Advanced QoS-based User-centric Aggregation (AQUA), which is defined independently from different RATs (e.g. UMTS, WLAN, Mobile WiMAX, LTE, LTE-Advanced, *etc.*,). It is implemented between Upper and Lower IP Network Layer, which will be able to provide intelligent QoS management and routing over variety of RATs. Moreover, the AQUA module is able to combine simultaneously several different traffic flows from different multimedia services transmitted over the same or different RAT channels, achieving higher throughput, and optimally using the heterogeneous radio resources. For the functionalities of the AQUA, the mobile equipment must have mechanisms (which are out of the scope of this paper) to collect the following data (using different protocols at different protocol layers in the mobile terminal): user velocity information, battery life-time, price of service over any available RAT, and the QoS parameters (in RATs where it is applicable) such as possible delay, jitter, losses, available bandwidth, reliability, Packer-Error-Ratio (PER), Signal-to-Noice-Ratio (SNR), Transmission Power (TP), etc. This task is executed periodically at given time intervals (all the time while the multimedia application is going on). After collecting the above mentioned data they are stored in the QoS DB (database) into multi-dimensional matrix connected on the AQUA module. Further, the AQUA module is also connected to the QoS Algorithm database, where are located biologically inspired algorithms that are used in the AQUA process. More information and details for AQUA are elaborated in the next section.

Furthermore, after AQUA module executes its algorithm and gets the most adequate decision for routing, it sends the packet that comes from Upper IP Network Layer down to the appropriate Lower IP Network Layer interface, towards the chosen RAT LL/MAC module for a current service or drops it in the case there is no admission to any of the given RATs in the heterogeneous environment. However, every packet goes through packet priority scheduling, before it is passed to the above mentioned downlink procedure. This is the current procedure for only one packet for one service, but at the same time there are several packets which are coming from several different multimedia services (*i.e.*, one from voice, other from data, third from video-conference and *etc.*,) and which are simultaneously processed through AQUA module. These processes are demanding more processing power, parallel processing, memory capacity, battery life-time and *etc.*, but the future advanced mobile terminal is expecting to support all this mentioned (according to Moore’s law for development of computers devices).

On the other hand, in uplink, all packets which are coming from all RATs interfaces are received in Lower IP Network Layer, and sent from AQUA module to the Upper IP Network Layer, then sent to Open Transport Layer (*e.g.,* SCTP). Finally, all packets are delivered to the peer application. In the downlink direction, the Upper IP Network Layer is sending the application data (received from the application via the transport protocol) through the most appropriate RAT interface determined with AQUA logic.

4. AQUA Algorithm

In this section we provide description of our QoS algorithm for radio networks selection and routing in heterogeneous wireless environment, which is created using biologically inspired algorithms. The AQUA algorithm building components are shown in Figure 2. The data measurements for different selection criteria, including user requirements, QoS requirements, operator requirements, as well as radio link conditions in different RATs present in the user's moving area are inputs for the n sets of parallel criteria functions (CFs), one set per each RAT (from RAT 1 up to RAT n). One RAT CF is shaping and filtering the outputs from the previous four components into four interior threshold functions: the first is shaping the QoS parameters, the second is shaping the service price if the service stream is going over that RAT (which depends on Service Level Agreements between the user and each of the wireless and mobile networks), the third is shaping velocity support and the last is shaping the signal strength detected in mobile terminal from RAT base station(s). Any of those four threshold criteria functions is giving on its output only one value (as a real number within the limits of [0, 1]). The central component is Advanced QoS routing and selecting algorithm module, which as inputs uses: the outputs of the n sets of parallel criteria functions (CFs), four values from each RATs (4*n in total) and the output of the threshold CF for battery support (one value) which shapes and filtrates the outputs from the user's mobile battery life-time. This central component of AQUA algorithm is in continuous communication and interaction (connected permanently) with: the Generic Algorithm (GA) module, QoS algorithm module and the QoS database. GA module is doing the optimization of weighting coefficients of different input criteria for each RAT for a given multimedia service. That is, each criterion may have different weight that depends upon the assumption of its impact on the best RAT selection process (i.e. the decision). The reason for using GA for access network selection is justified by the fact that GA is proven to provide better results and to be more robust compared to random-based selection algorithms and other examined algorithms from this affiliation [19].

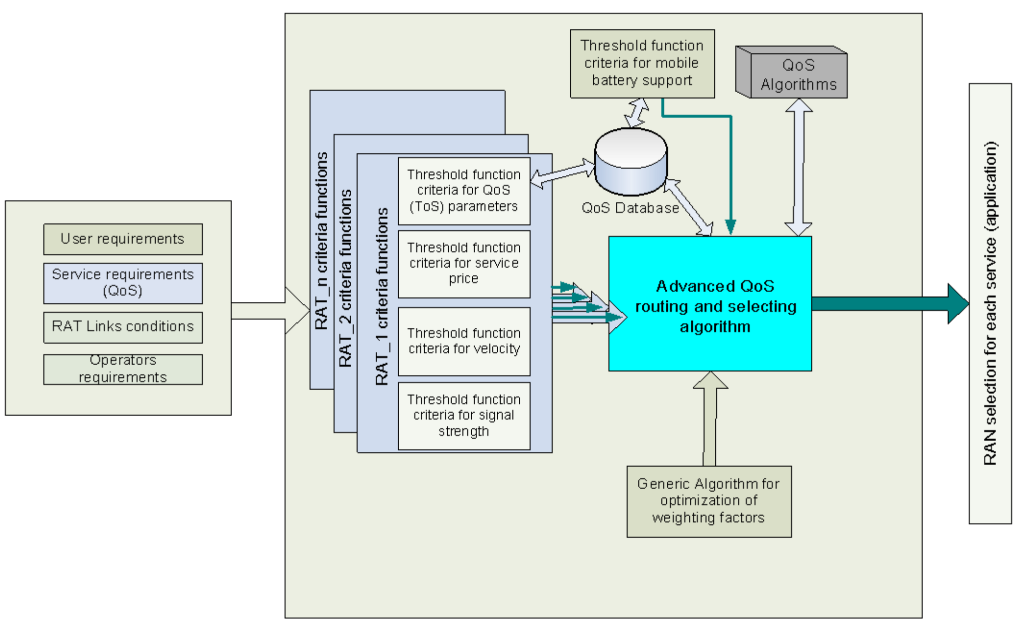


Figure 2. Advanced Quality of Service Routing and RAT Selection Algorithm

Furthermore, the QoS algorithm module is a database where the QoS algorithms for different RATs are implemented. In the QoS database is stored information for QoS parameters for all services, together with the measured data. Finally, the Advanced QoS routing and selecting algorithm module is targeted for the selection of wireless and mobile networks in heterogeneous environment, so the decision as an outcome should select the best RATs (among all present RATs at the moment for a given user and given service) and will rank them in certain order. The ranking order accrues from the ranking value that have each of the RAT ranking functions. If we calculate the inputs from the threshold CFs as a real numbers within the limits of [0, 1], then the RAT ranking functions can be calculated as follows:

$$RF_{RAT\_i} = \frac{QoSt_i * W_{QoS} + Ct_i * W_C + Vt_i * W_V + SSt_i * W_{SS} + Bt_i * W_B}{W_{QoS} + W_C + W_V + W_{SS} + W_B} \quad (1)$$

where $1 \le i \le n$ and $W_{QoS} + W_C + W_V + W_{SS} + W_B = 1$, (2)

where W_{QoS}, W_C, W_V, W_{SS}, W_B are assigned weight factors for the criteria functions of: QoS parameter, service price, velocity of the mobile terminal, signal strength and mobile terminal battery support, respectively. Those values of weight factors are assigned using a particular method of optimization, *i.e.*, genetic algorithms, where their value is obtained through the process of moving the genetic optimization algorithm to the pre-specified goal. On the other hand, after passing the four interior threshold functions for *i*-th RAT CF, the outputs (shaped values) from QoS parameters are $QoSt_i$, from service price are Ct_i, from velocity support are Vt_i, and from detected signals strength are SSt_i. The shaped output value of the threshold CF for battery support is Bt_i. So, the final step is selection of the best RAT for a given service.

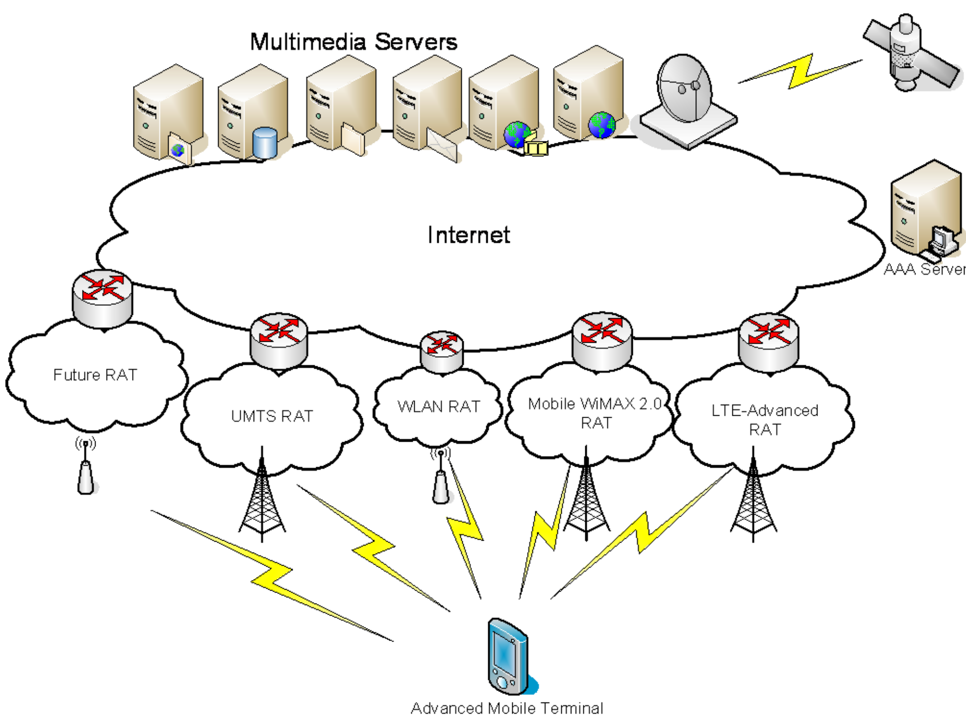


Figure 3. Illustration of a One Future 5G Scenario

Of course, there are no restrictions one RAT to serve several different multimedia services of one mobile terminal, or one service to go over several different RATs. Moreover, in Figure 3 is presented an example of a future 5G scenario according to our research view, where all five RATs are used from the advanced mobile terminal, by applying AQUA. As one can notice, for the proposed mobile terminal design there is no restrictions on number of concurrently used RATs.

5. Simulation Results and Analysis

In this section we show the obtained simulation results for average system throughput, as well as multimedia access probability values are presented for different network conditions. In Figure 4 is described simulation scenario, which consists of three RATs. Each RAT is represented with single base station with different radius of network coverage. All base stations (from all RATs) are positioned in the center of the simulation area, with coordinates (0, 0).

RAT1 has diameter of the coverage area of 5 km, RAT2 cell has radius of 3 km and RAT3 cell has radius of 250 m. Network capacity for the given three RATs is set to: RAT1_C = 307200 kbit/s, RAT2_C = 1048576 kbit/s, and RAT3_C = 614400 kbit/s. The values are reflecting the certain theoretical capacities for: LTE, IEEE 802.16m (Mobile WiMAX 2.0) and IEEE 802.11n RATs, appropriately.

At the beginning of the simulation, the mobile terminals (MTs) are randomly scattered within the area of 10x10 km2. For MTs physical mobility, we adopted the Gauss-Markov Mobility model [22] and [23] considering average speeds in the range of 50-220 km/h (v_{mean}), and providing high level of randomness for user mobility. In this 2-dimensional implementation of the Gauss-Markov model, each MT is assigned an initial velocity and direction, as well as an average velocity and direction. At set intervals of time, a new velocity and direction are calculated for each MT, which follow the new course until the next time step. This cycle repeats through the duration of the simulation.

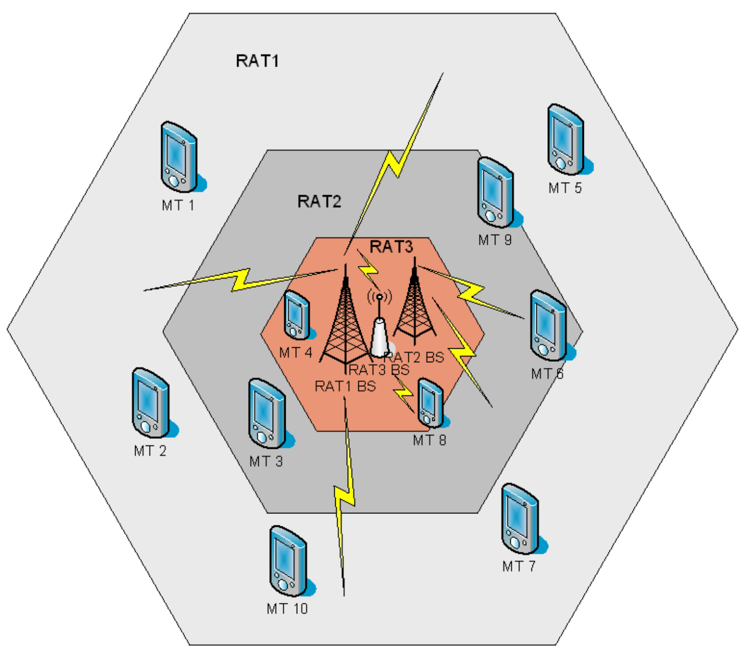


Figure 4. Illustration of the Simulation Scenario

The new velocity and direction parameters are calculated according to the following equations:

$$V_i = \mu * V_{i-1} + (1-\mu) * V_{mean} + \eta_{v_{i-1}} * \sqrt{1-\mu^2} \quad (3)$$

$$d_i = \mu * d_{i-1} + (1-\mu) * d_{mean} + 2\pi\eta_{d_{i-1}} * \sqrt{1-\mu^2} \quad (4)$$

where V_i is MT velocity (m/s) and the d_i is the MT direction parameter (in radians). Moreover, μ is a tuning parameter (if μ=0 the model becomes memoryless and totally random Gaussian, if μ=1 the model becomes predictable, *i.e.*, linear, and in such case *I* is loosing all randomness) while $\eta_{v_{i-1}}$ and $\eta_{d_{i-1}}$ are random variables from a Gaussian (normal) distribution, which are giving some randomness to the new velocity and direction parameter.

This simulation scenario provides total network coverage for all MTs (RAT1, RAT2 and RAT3 coverage, or minimum RAT1 coverage). The multimedia traffic flows (Constant Bit Ratio and Variable Bit Ratio traffic) are defining the type of services and their representation among the users in the system. The multimedia service model in the proposed form predicts the existence of three types of services that are defined by its required bit rate (bandwidths) and its starting time and duration. For the purpose of simulation analysis, all three service types are defined with the following pairs of values: [bit rate, starting time, duration], respectively given in the Table 1. The first service type is defined by a low bit rate (128 kbit/s) and small propagation time (Round Trip Time - RTT), very sensitive on delay and jitter and is used for handling of video conference. The second service type is defined by medium bit rate and low propagation time, it is jitter sensitive and is used for services such as video-streaming (256 kbit/s). To emphasize that the duration (the mean holding time) of this service is set to 50 seconds, based on comparative measurement. The third service type is defined with a high bit rate and can handle bigger time propagation and delays, but requiring no packet delivery error and is used for data services (web, ftp and email services with 512 kbit/s bit rates).

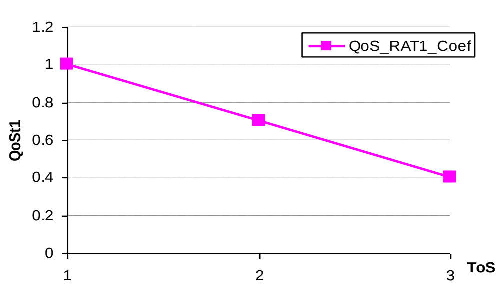
During the simulation for a given number of ordinary active mobile users N, each user is randomly assigned to one of the three types of services defined above. On the other side, when the users have advanced MT with AQUA module within, for each user are randomly assigned all three types of multimedia services (minimum two, maximum all three services). The traffic model reflects the process of creation and duration of user services. Its goal is to give a realistic picture of the user traffic throughput and the multimedia access probability within the simulation.

Table 1. Parametric Values for the Multimedia Services

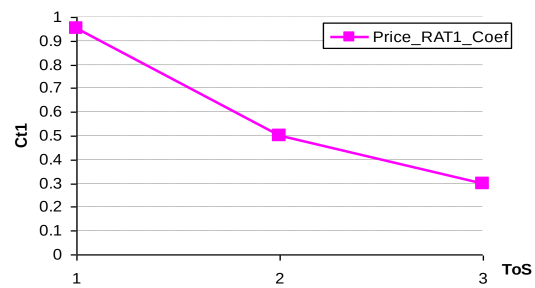
	Bit rate [kbit/s]	Starting time [s]	Duration [s]
Video conference	128	Poisson distributed with mean value 7 sec	End of simulation
Video-streaming service	256	Poisson distributed with mean value 6 sec	Poisson distributed with mean value 50 sec
Data service	512	Poisson distributed with mean value 6,5 sec	End of simulation

In the first case all MTs are enhanced with AQUA module. We use MATLAB (R2007b) simulation environment for creating our trial-mode MT with three interfaces (one for each RATs) and with AQUA module (presented in the previous section). Moreover we create: traffic models for the above mentioned types of services, models for mobility of users, RAT QoS control access mechanism, and communication scenario script. It is convenient to emphasize that in simulation of AQUA for the Genetic Algorithm module for optimization of weighting coefficients of different input criteria for each RAT we used the MATLAB function GA, which implements the genetic algorithm at the command line, that is used in an objective function to assign the weighting coefficient, to provide best QoS provisioning and optimal RATs selection for all services. In our analysis we use 100 iterations, which is based on the fact that there is no improvement after successive 50 generations in most cases. The mutation rate we set to 0.1, as the most suitable, and the population size chosen in our GAs has been set to 20. In our case, the number of individuals that are guaranteed to survive to the next generation has been set to 5 individuals (because of the five weighting factors).

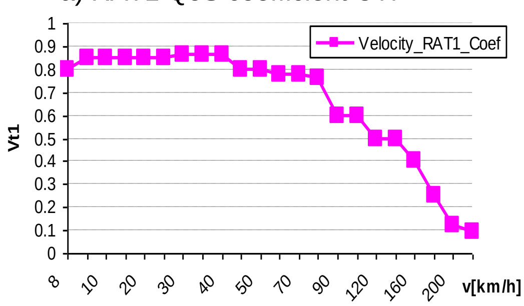
In our current implementation, the current criteria threshold functions (CTFs) which shapes the inputs of data measurement values, for all RATs are given in Figure 5. In Figures 5 a), b), d), e), h) and i) for ToS we set 1 for Video conference service, 2 for video-streaming service and 3 for data service. Moreover, in Figure 6 are given the two criteria threshold functions for detected signals strength (SSt_i) and the battery support coefficient (Bt_i) which are same for all different RATs, because it depends from the MT and its position in the simulated area.



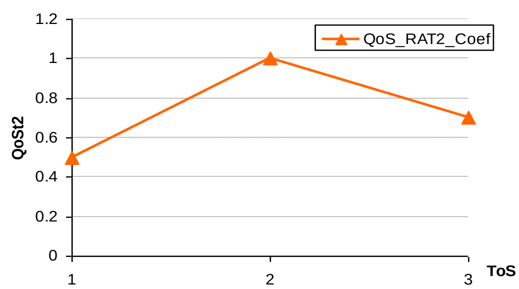
a) RAT1 QoS coefficient CTF



b) RAT1 price coefficient CTF

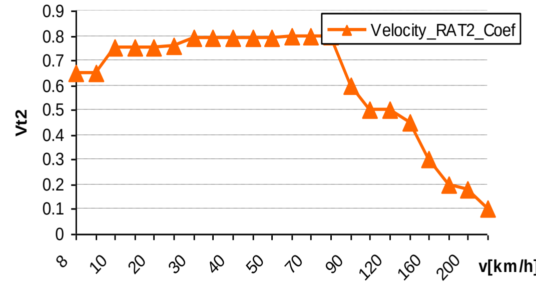


c) RAT1 velocity coefficient CTF

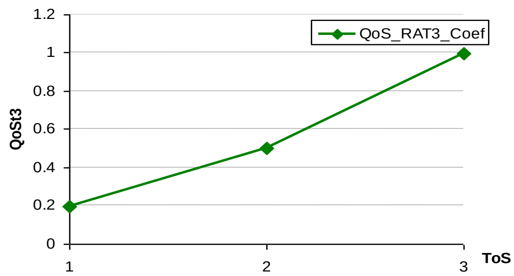


d) RAT2 QoS coefficient CTF

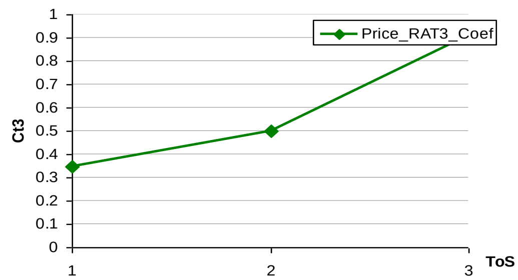
e) RAT2 price coefficient CTF



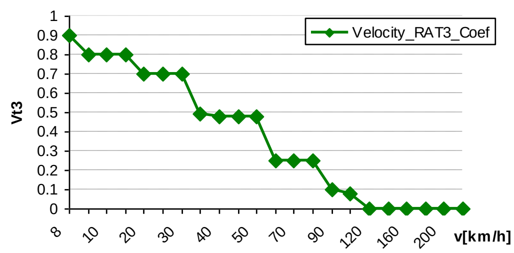
f) RAT2 velocity coefficient CTF



h) RAT3 QoS coefficient CTF

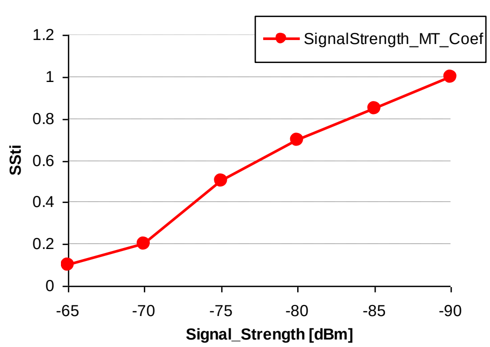


i) RAT2 price coefficient CTF

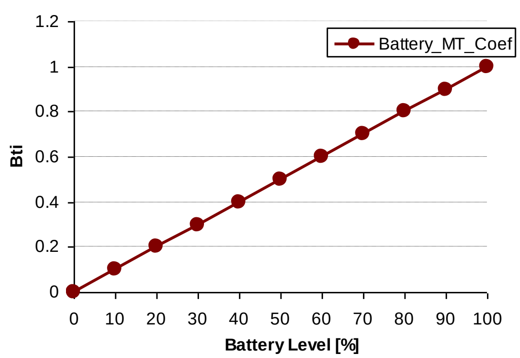


j) RAT3 velocity coefficient CTF

Figure 5. Criteria Threshold Functions for RAT1, RAT3 and RAT3



a) MT signal Strength coefficient CTF



b) MT battery coefficient CTF

Figure 6. Criteria Threshold Functions for Detected Signals Strength and Battery Support Coefficients

Furthermore, in Figure 7 the simulation analysis regarding the achievable throughputs are shown, which provides results on the average throughput versus number of MTs. The average velocity of the MTs is set on 50 km/h and the total simulation time is 50s. As can be noticed, the throughput for our Advanced MT (AMT), with included AQUA module, for any number of used MTs, is higher than the average throughput values in the case when we used only MTs that can access only RAT1 (R_RAT1_MT), or in the case when we use only MTs that access RAT2 (R_RAT2_MT) or RAT3 (R_RAT3_MT). As one can notice, until the saturation of all RATs the throughput for the Advanced MT (AMT) is increasing. For example, RAT1 is saturated around 160 users, but RAT2 and 3 have still capacities to admit more users, and then AMT throughput continues to increase with the increasing of the RAT3 throughput (up to 470 MTs where they saturated). The results are more or less expected due to the fact that when we used just a small number of MTs with mean speed of 50 km/h, there is enough capacity in all three RATs and the problems with congestion, losses and dropping users is visible until number of MTs goes above 150. However, for our case with ATMs, the congestion is avoided in many situations, and the dropping probability is smaller even for a higher number of users, due to the fact that ATMs are using all RATs at the same time (parallel usage of different RATs on network layer). Consequently other MTs which are using only one service per user, and only one RAT, are limited with the capacity provided by that particular RAT. So, using the radio networks aggregation in Advanced MTs we obtain an aggregate throughput which includes the throughputs of all available RATs to the MTs included in the simulation scenario.

Moreover, in Figure 8, the bit rate (R) during the simulation time for AMTs with AQUA module, achieve the highest values, in comparison with the average throughput values in other three cases. As can be noticed, in the beginning of the simulation (up to 4 seconds), we obtain almost equal average throughput values in our AMT case and in the other three cases (when only RAT1 MTs or RAT2 MTs or RAT3 MTs are used). This is due to the fact that when we used mean number of MTs (here we used only 500) with average velocity value of 50 km/h, the access probabilities of RAT1 and RAT2 MTs are very high at the beginning of the simulation, because those RATs have high coverage area and our AMTs are accessing all RATs by using the GA, so there can exist some imperceptible access losses.

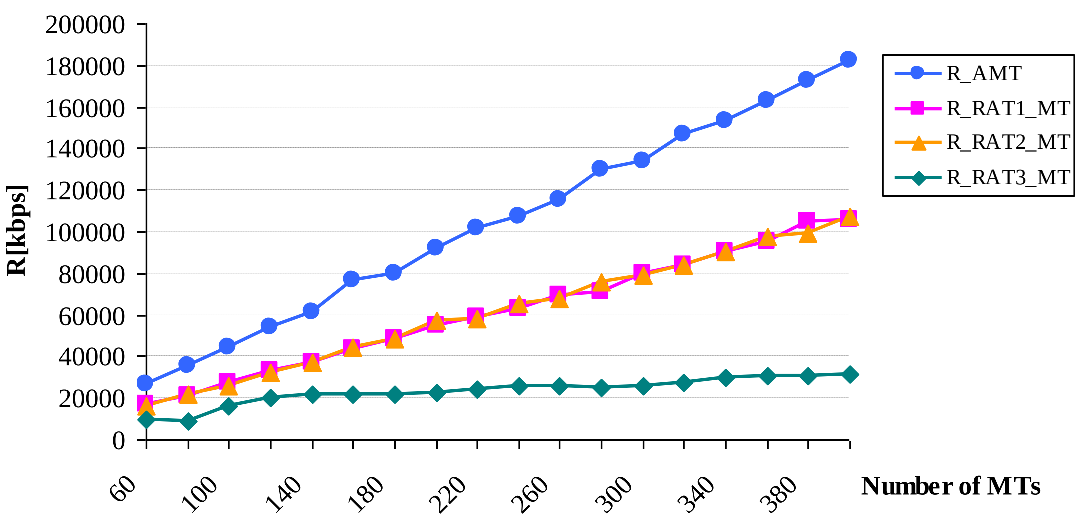


Figure 7. Average Throughput Versus Number of MTs

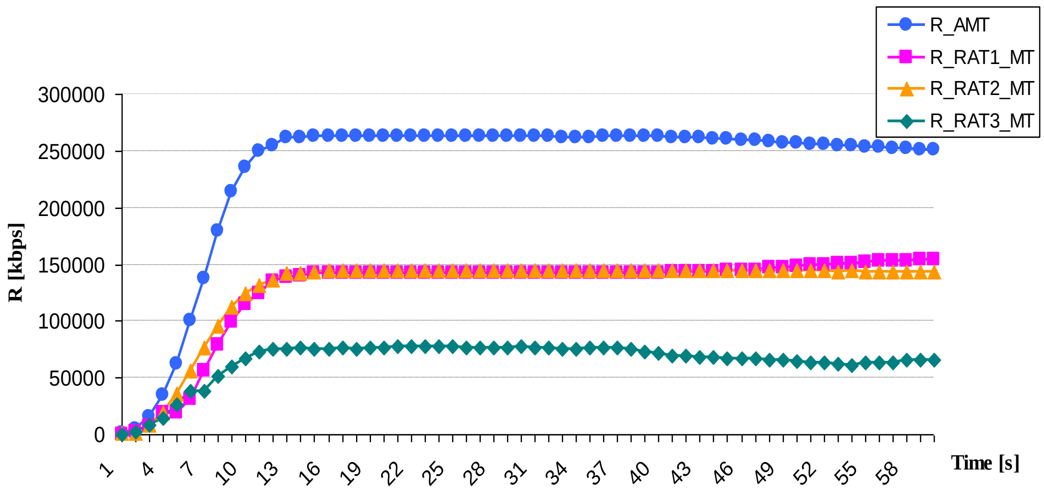


Figure 8. Average Throughput Versus Simulation Time for 500 MTs

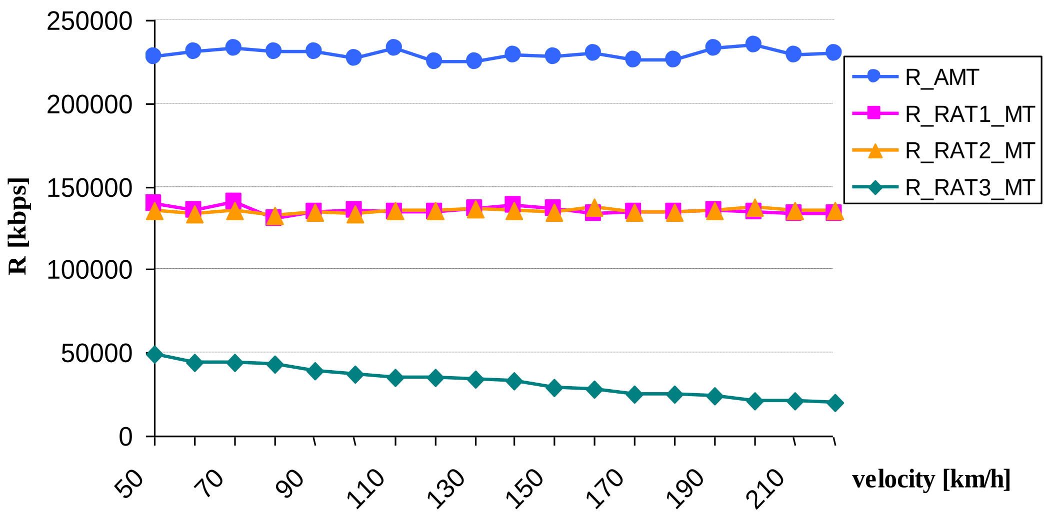


Figure 9. Average Throughput Versus Simulation Time for 500 MTs

But after the initial time period of the simulation (after the 13s) the results are converging towards the dominant throughput for AMTs, which is almost two time higher than cases with RAT1 and RAT2 MTs, and 70% more than throughputs in the case of RAT3 MTs.

Moreover, in Figure 9 is presented average throughput for different terminal velocity (50 - 220 km/h), when we have 500 MTs and simulation time of 60 seconds. First of all, it can be clearly concluded that the average throughputs of our case (R_AMT), for any given average velocity, shows superior values over compared average throughput values from the other three cases (RAT1, RAT2 and RAT3 MTs). However, all throughput curves have minimal deviation and generally have descending trend (*i.e.*, negative slope) because at those speeds all MTs have higher handover intensity which causes packet losses and low access probabilities.

Finally, in Figure 10 are presented the average multimedia access probability ratio (*Pm_acc*) values for different average speeds for all four cases considered in the simulation analyses. The multimedia access probability ratio is calculated with the following equation:

$$Pm\_acc = \gamma P_{acc\_VoIP} + \kappa P_{acc\_Video} + \delta P_{acc\_Data} \quad (5)$$

where the γ, κ and δ are multimedia shaping factors for access of Video conference, Video-streaming and Data services, respectively. They are real number within the range [0, 1] for a multimedia users with AMTs, and for ordinary users those factors are 0 if there is not started such a service, 1 if such a service is started.

Each of the service access probabilities are defined in standard definition:

$$P_{acc\_service\_i} = \frac{N_{user\_accessed\_service\_i}}{N_{user\_accessed\_service\_i} + N_{user\_not-accessed\_service\_i}} . \quad (6)$$

In this case number of MTs is set to 100 and the simulation time is 60 s. As it is shown, the average *Pm_acc* values for our AMTs for any average velocity values is highest in comparison with access probability ratio of RAT1, RAT2 and RAT3 MTs. In case of congested networks (when number of users is larger), the gain from the radio network aggregation regarding the multimedia access probability is reduced.

The highest Pm_acc values for our Advanced MTs with AQUA module within, together with the excellent properties of the throughput as given in Figures 7-9, prove the excellence of the proposed advanced MT solution in this article.

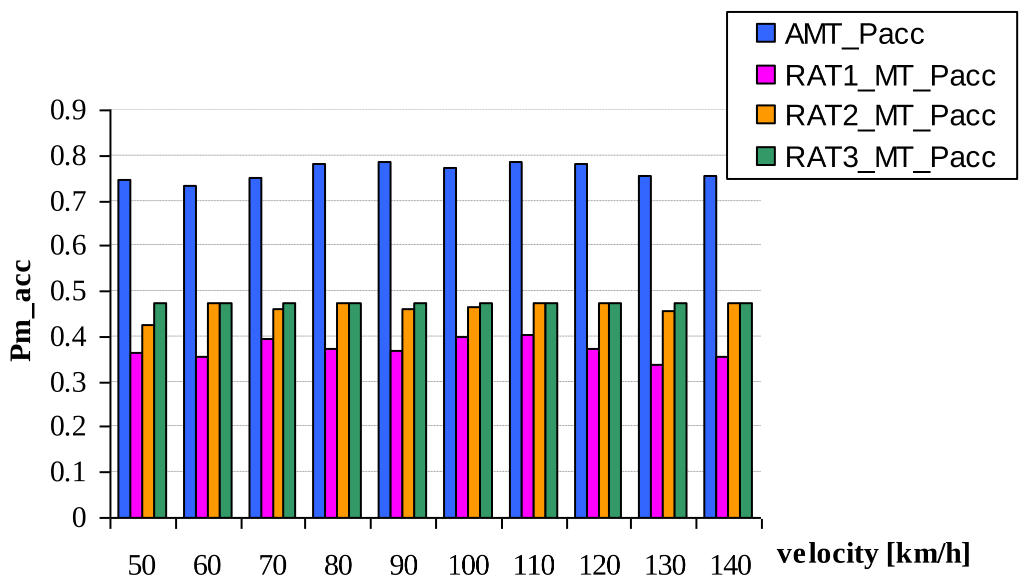


Figure 10. Average Multimedia Access Probability Versus Average Velocity for 100 MTs

6. Conclusion

In this article we have proposed a novel advanced mobile terminal design based on radio network aggregation in so-called Advanced Mobile Terminal (AMT), which probably will belong in the family of 5G terminal. The proposal is evaluated via simulation results for the key Quality of Service parameters in the analysis, throughput and multimedia access probability, in heterogeneous wireless environment.

According to the simulation results and analysis, our proposed Advanced Mobile Terminal with AQUA performs fairly well under a variety of network conditions. Consequently it provides highest level of multimedia access probability, throughput, highest number of satisfied users, with minimal cost per service and optimal utilisation of network resources.

The analysis showed that the performance gain with AQUA module in the AMT can be easily generalized in multi-interface heterogeneous mobile and wireless network scenario, including any present and future radio access technology.

In our future work we are focusing on upgrading of the advanced QoS routing module, by using additional network conditions as inputs for intelligent RAT decisions. The future AMT with AQUA module should be able to choose the best set of available wireless/mobile technologies under given QoS requirements. Also, it will be able to combine different streams over different RATs, with aim of achieving superior QoS provisioning (*i.e.*, maximal throughput, minimal delay and jitter, maximal multimedia access probability, minimal packet error, *etc.*).

Finally, one of the solutions for providing higher throughput in 4G mobile networks is carrier aggregation on MAC layer, thus providing possibility for usage up to five aggregated frequency carriers, each up to 20 MHz wide. The goal for such approach is providing the data rates that will satisfy IMT-Advanced requirements for 4G set by ITU (for example, data rates over 1 Gbit/s in the downlink, something that can not be achieved with single carrier of today). In that manner, the next logical step is radio networks aggregation which will provide further increment in the data rates using the available RATs as well as future defined ones. Of course, for 5G there will be also new access schemes with higher spectrum utilization than 4G. However, radio network aggregation feature, as proposed in this paper, provides possibility to combine even newly proposed 5G RATs with 4G RATs (LTE-Advanced and IEEE 802.16m), 3G RATs, as well as WiFi. Hence, we believe that the given proposal for advanced mobile terminals can be one of the feasible solutions for the future 5G mobile networks paradigm.

References

[1] M. Rahman and F. Mir, “Fourth generation (4G) mobile networks - features, technologies and issues”, 6th IEE International Conference on 3G Mobile Communication Technologies, UK, **(2005)**, pp. 1-5.

[2] J. M. Pereira, “Fourth generation: now, it is personal”, 11th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), London, UK, vol.2, **(2000)**, pp. 1009-1016.

[3] T. Janevski, “5G Mobile Phone Concept”, IEEE Consumer Communications and Networking Conference (CCNC) 2009, Las Vegas, USA, **(2009)** January.

[4] W. W. Lu, “An Open Baseband Processing Architecture for Future Mobile Terminals Design”, IEEE Wireless Communications, **(2008)** April.

[5] J. Noll and M. M. R. Chowdhury, “5G – Service Continuity in Heterogeneous Environments”, Wireless Personal Communications - DOI: 10.1007/s11277-010-0077-6, Published online: 31 July 2010.

[6] F. Tian and Z. Feng, “An information accuracy based mesh division mechanism for cognitive pilot channel”, IEEE 71st Vehicular Technology Conference, IEEE VTC 2010 - Spring, **(2010)** May.

[7] A. Tudzarov and T. Janevski, “Functional Architecture for 5G Mobile Networks”, International Journal of Advanced Science and Technology, vol. 32, pp. 65-78, **(2011)** July.

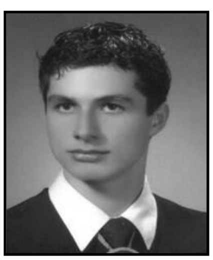
[8] A. Tudzarov and T. Janevski, “Design for 5G Mobile Network Architecture”, IJCNIS, vol. 3, no. 2, **(2011)**, pp. 112-123.

[9] A. Tudzarov and T. Janevski, “Protocols and Algorithms for the Next Generation 5G Mobile Systems”, Network Protocols and Algorithms, ISSN 1943-3581, vol. 3, no. 1, **(2011)** April 20, pp.94-114.

[10] A. Tudzarov and T. Janevski, “Efficient Radio Access Technology Selection for the Next Generation Wireless Networks”, International Journal of Research and Reviews in Next Generation Networks, vol. 1, no. 1, **(2011)** March, pp. 14-25.

[11] T. Shuminoski and T. Janevski, "Cross-Layer Adaptive QoS Provisioning for Next Generation Wireless Networks", International Journal of Research and Reviews in Next Generation Networks (IJRRNGN) 2011, ISSN: 2046-6897, London, United Kingdom, vol. 1, no. 1, **(2011)** March, pp. 7-13.
[12] T. Shuminoski and T. Janevski, "Adaptive Cross-layer QoS Framework for Multimedia Traffic in Heterogeneous UMTS/WLAN Networks", TELFOR 2011, 19-th Telecommunications Forum, Belgrade, Serbia, **(2011)** November 22-24.
[13] T. Shuminoski and T. Janevski, "Novel Adaptive QoS Provisioning in Heterogeneous Wireless Environment", International Journal of Communication Networks and Information Security 2011, ISSN: 2076-0930, vol. 3, no. 1, **(2011)** April, pp. 1-7.
[14] Y. Nkansah-Gyekye and J. I. Agbinya, "Vertical Handoff Decision Algorithm Based on Fuzzy Logic and Genetic Algorithm", SATNAC 7-10, **(2008)** September.
[15] Y. Fei, V. W. S. Wong and V. C. M. Leung, "Efficient QoS Provisioning for Adaptive Multimedia in Mobile Communication Networks by Reinforcement Learning", Mobile Networks and Applications, vol. 11, **(2006)**, pp. 101–110.
[16] X. Gang Wang, G. Min, J. E. Mellor and K. 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, vol. 47, no. 2, **(2005)** February 4.
[17] A. Kaloxylos, I. Modeas, F. Georgiadis and N. Passas, "Network Selection Algorithm for Heterogeneous Wireless Networks: from Design to Implementation", Network Protocol and Algorithms, ISSN 1943-3581, vol. 1, no. 2, **(2009)**, pp. 27-47.
[18] K. Radhika and A. Venugopal Reddy, "Network Selection in Heterogeneous Wireless Networks based on Fuzzy Multiple Criteria Decision Making", International Journal of Computer Applications (0975 – 8887), vol. 22, no. 1, **(2011)** May.
[19] M. Alkhawlani and A. Ayesh, "Access Network Selection Based on Fuzzy Logic and Genetic Algorithms", Advances in Artificial Intelligence, vol. 8, no. 1, **(2008)** January.
[20] L. Giupponi, "A novel joint radio resource management approach with reinforcement learning mechanisms", in Proceedings of the 24th IEEE International Performance, Computing, and Communications Conference (IPCCC '05), Phoenix, Arizona, USA, **(2005)** April, pp. 621–626.
[21] S. Fu and M. Atiquzzaman, "SCTP: State of the Art in Research, Products, and Technical Challenges", IEEE Communications Magazine, **(2004)** April, pp. 64-76.
[22] D. Broyler, A. Jabbar and J. P. G. Sterbenz, "Design and analysis of a 3-D gauss-markov mobility model for highly dynamic airborne networks", ITC '10, **(2010)**.

Authors



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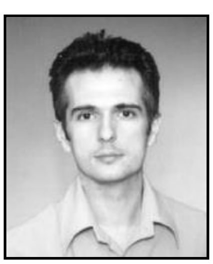

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