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СОДРЖИНА

5G Mobile Networks: the User-side Approach

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***Abstract*:** In this paper we propose new design for network and protocols architectures of future 5G mobile networks. The proposed design is based on user-centric mobile environment with heterogeneous radio access technologies. In the proposed design the user terminal has possibility to change the Radio Access Technology - RAT based on certain criteria. For that purpose we split the network layer on two network sub-layers, lower and upper one. The lower one is network IP layer, providing identification of the wireless interface to the given mobile network, so there are different IP addresses for different RAT interfaces. The upper IP layer, so-called here virtual network layer provides identification of the network layer towards the applications in the mobile terminals, and there is only one IP address, so tunneling is used over different RATs towards the central tunnel endpoint called Policy Router, which establishes IP tunnels to the mobile terminal via different available RATs to the terminal. The selection of the RAT is performed by the mobile terminal using the proposed user agent for multi-criteria decision making based on the experience from the performance measurements of different RATs performed by the mobile terminal in the given time window in the past. We present results of simulation analysis of the proposed intelligent Mobile RAT selection algorithm on the user-side for scenario with two RAT technologies, one Wireless WAN and one Wireless LAN. The obtained results showed that the proposed algorithm is significantly better compared to the traditional approaches for RAT selection. Also, the proposed solution in fact provide possibility for throughput aggregation on the network layer, where we already have carrier aggregation on Layer 2 in 4G technologies such as LTE-Advanced.

Keywords: 5G, Heterogeneous Wireless Networks**,** Quality of Service (QoS), Policy Routing.

1. Introduction

Today we have different wireless and mobile technologies, which are mass deployed, such as 3G mobile networks (UMTS, cdma2000), LTE (Long Term Evolution), WiFi (IEEE 802.11 wireless networks), WiMAX (IEEE 802.16 wireless and mobile networks), as well as accompanying networks, such as sensor networks, or personal area networks (e.g., Bluetooth, ZigBee). Mobile terminals include variety of interfaces, including the GSM ones, which are based on old-fashioned circuit switching, the technology that is going into its last decade of existence. All wireless and mobile networks today are going towards all-IP principle, meaning all data and signaling will be transferred via IP (Internet Protocol) on network layer [1]. So, we may have different Radio Access Technologies (RATs) today and new RATs in the future (e.g., LTE-Advanced), but the common "thing" for all of them is IP, which is unifying technology. The 4G term is related to available bit-rates in the access link, i.e. more than 1 Gbps is set as condition by ITU for a technology to be marked as 4G. Also, all-IP is the characteristic of 4G in the access and in the core network part, there will be no circuit-switching as it existed in 3G systems, such as UMTS. On the other side there are a lot of efforts done for separation of transport stratum and service stratum in the concepts of Next Generation Networks (NGN), [2], [3]. Next generation of mobile and wireless networks will certainly need to fit within the NGN, because it is based on wireless and wired access possibilities, including all services and using all-IP concept. However, the main principle for NGN is complete separation in parallel between the transport part in the access and in the core networks from the service provisioning, i.e., from the service stratum. Since, the 4G is already at the "front door" of communication world, the next generation of mobile and wireless networks will be labeled 5G, if we continue the same pattern from the past two decades. We believe that the 5G approach will be user-centric approach [4], since the mobile terminals are becoming highly computationally capable devices which can support more complex functionalities for performing calculations, as well as bigger memory space and longer battery life in years will provide enough storage capability for control information. Then, in IP world, the main principle from the beginning was keeping simple network nodes and having smart end devices (e.g., computers), an approach completely different from the Public Old Telephone Systems (POTS). However, we need smart nodes on the networks side in all-IP concept as well, which should be used for negotiation with the user equipment premises (mobile terminals in the case of mobile networks) for providing necessary Quality of Service, as well as authentication, authorization, accounting and security functionalities.

In this paper we provide complete functional architecture for 5G mobile networks. The main assumption in our approach is that the user will have the possibility to access different RATs from single mobile device at the same time, which is reality even today. Then, we propose establishing new network nodes for policy-based routing between IP tunnels to mobile user via different RATs, which are placed in service stratum of the network. We have invented several solutions for making fully functional the proposed 5G network architecture.

The remainder of this article is structured as follows. Section 2 covers the models for interoperability in heterogeneous wireless environment. Section 3 presents the design of the network architecture for 5G mobile networks. In Section 4 we provide description of use-cases for the proposed 5G architecture. The proposed system for performance measurement in next generation wireless networks is given in Section 5. Finally, Section 6 concludes the paper.

2. Interoperability in Heterogeneous Wireless Environment

The challenge in the design of the terminals is connected to the management of trade between the flexibility of how to use the spectrum and needed space and power to given platform. New methods for partial reconfigurable offer design dimensions that allow the system to adapt to the opportunities and requirements of the terminals in a manner that shall maximize the spectral efficiency and also maximize the battery power [4]. As a result of growing level of acceptance of the wireless technologies in different fields, challenges and types of wireless systems associated with them are changing.

With the evolution of 3G/4G cellular systems defined by 3GPP, new architecture provides sophisticated control mechanisms that enable the central management of the operator's network in granular way with great precision and accuracy. In this context 3GPP introduced new methods for providing radio management (hierarchical management of resources) implemented in systems with a common radio resource management, a single radio resource management and in multiple-access radio resource management. In these hierarchical schemes, local resource managers of the various wireless technologies provide interaction with the central entity to perform a joint optimization of available resources. In parallel with the evolution of cellular data systems, we have evolution of WLAN, i.e., IEEE 802.11 networks. The 802.11 systems handovers between different AP from a common domain are based on a decision by the user. Large 802.11 networks show the emergence of problems in resource management in areas with a dense distribution of AP. The concept of unified wireless network architecture argues that the centralized management of data resources in 802.11 networks is necessary to achieve true scalability. WiFi networks were never intended for use as broadband wireless networks. On the other side, WiMAX is also IEEE standard, but with more control implemented in base station. The base station is responsible for fair distribution of available resources among users through the implementation of a centralized system for scheduling. The WiMAX handover functionalities are supported by each base station and the handover is done with their assistance, namely each serving base station helps the user to find their target base station from the list of candidates for base stations to switch.

Taking into consideration the existence of various wireless technologies evolve in parallel, the concept of emergence of heterogeneous networks is not new. In heterogeneous wireless networks the concept is "always best connected" (always associated with the best quality), aimed at client terminals, and is proposed in different researches. This approach leads to the emergence for vertical handover between different radio access technologies [5]. Based on different optimization techniques such as balancing the load on the network and/or maximizing battery life of the user terminal, it can change the access technology from one to another on a periodic basis or triggered by a given event. In order to perform controlled client assistance at the stage of vertical handover, IEEE created the 802.21 standard referred to as mechanism for exchanging messages between the client and the corresponding base station or AP below the network layer (which is IP in all these cases).

Reviewing the concept of heterogeneous networks inevitably raises the question of inter-working among the radio access technologies in a newly designed system, which will not demand changes in the RATs, but only introduction of control functionalities in the core networks. In terms of the user or user applications, heterogeneous system or a heterogeneous network is considered as a unified network [6] and access a single segment which will place the connection with the application servers in and out of operator’s network. To meet the relevant requirements of the user applications are generally considered two possible models for interoperability between building blocks of radio access technologies within the heterogeneous system. First one refers to a centralized operator access, while the second one defines the Internet model of interoperability. The first model involves introducing a certain level of integration between the radio access technology through which mobile access terminal, in this direction have been made different analysis and developed different standards that should define the levels of architecture connectivity for realizing vertical handover between different access technologies involved in the construction of heterogeneous domain, [5], [6]. The introduction of this model implies interoperability protocol interoperability of lower levels of communication in the field of radio access. The second model is called the Internet model, which represents a focus for further development in this paper and refers to providing continuity of customer service in case of independent radio access technologies available to the mobile terminal by connecting on the network level, [7]. In this case, interoperability between network technologies is done on the upper (network) protocol levels, i.e. at a level that is common to all access technologies for communication between user applications with the appropriate application servers.

The ultimate goal of both models for interoperability is the same and it is providing a transparent transfer of user information between client applications and related application servers without impact on the diversity of access technologies in the communication process and providing continuity of user sessions in the communication process. The main difference between the two models concerns the way in providing interoperability. Apart from this difference, very important are vertical handover between access technologies and the conditions or circumstances which trigger handovers. The first method provides an integrated architecture of radio access technologies that builds heterogeneous network, and as such is applicable in cooperative networks or in networks where the radio access technologies are owned by the same operator or operators who have cooperation. In such networks are strictly defined rules for vertical handovers, mainly dictated by conditions in the radio access networks, or by the operator's preference, while user preferences are taken into cooperative architectures. The second method is more general and relates to interoperate regardless of the user’s operators, which provide access technology for the user equipment. In these methods, generally speaking, vertical handover is accomplished as a result of the conditions under which user applications see main qualitative parameters of service or experience to the user, [8].

The tendency of introducing heterogeneity in future wireless radio systems entails the implementation of different radio interfaces in the new terminals. Each radio access technology has its own radio resource management and they are well engineered for maximum utilization of available resources. Radio access technologies can ensure achievement of customer service in the access part. In most of the radio access technologies which have been made, the system makes adaptation of appropriate resources allocated according to the nature of the services. Considering these characteristics of radio access technologies and taking into account the heterogeneity of future wireless networks and the need for the user to ensure the best possible quality of its services for a satisfactory price certainly appears the need for parallel use of the variety of access technologies in order to realize the user requirements, [4]. The heterogeneity of these networks allows the user terminal to perform a selection of radio access technologies depending on given preferences, [9]. This choice provides better conditions for user applications.

3. Design of 5G Network Architecture

Figure 1 shows the system model that proposes design of network architecture for 5G mobile systems, which is all-IP based model for wireless and mobile networks interoperability. The system consists of a user terminal (which has a crucial role in the new architecture) and a number of independent, autonomous radio access technologies. Within each of the terminals, each of the radio access technologies is seen as the IP link to the outside Internet world. However, there should be different radio interface for each Radio Access Technology (RAT) in the mobile terminal. For an example, if we want to have access to four different RATs, we need to have four different access-specific interfaces in the mobile terminal, and to have all of them active at the same time, with aim to have this architecture to be functional.

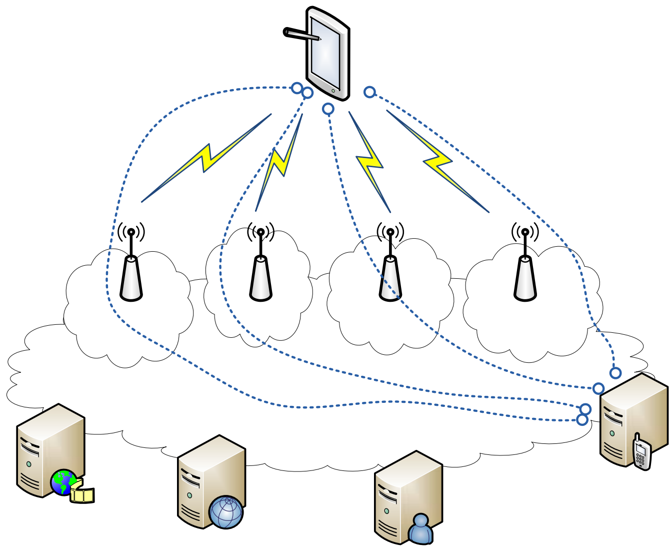

Figure 1. Functional architecture for 5G mobile networks

The first two OSI levels (data-link level and physical level) are defining the radio access technologies through which is provided access to the Internet with more or less QoS support mechanisms, which is further dependent upon the access technology (e.g., 3G and WiMAX have explicit QoS support, while WLAN has not). Then, over the OSI-1 and OSI-2 layers is the network layer, and this layer is IP (Internet Protocol) in today's communication world, either IPv4 or IPv6, regardless of the radio access technology. The purpose of IP is to ensure enough control data (in IP header) for proper routing of IP packets belonging to a certain application connections - sessions between client applications and servers somewhere on the Internet. Routing of packets should be carried out in accordance with established policies of the user. Application connections are realized between clients and servers in the Internet via sockets. Internet sockets are endpoints for data communication flows. Each socket of the web is a unified and unique combination of local IP address and appropriate local transport communications port, target IP address and target appropriate communication port, and type of transport protocol. Considering that, the establishment of communication from end to end between the client and server using the Internet protocol is necessary to raise the appropriate Internet socket uniquely determined by the application of the client and the server. This means that in case of interoperability between heterogeneous networks and for the vertical handover between the respective radio technologies, the local IP address and destination IP address should be fixed and unchanged. Fixing of these two parameters should ensure handover transparency to the Internet connection end-to-end, when there is a mobile user at least on one end of such connection. In order to preserve the proper layout of the packets and to reduce or prevent packets losses, routing to the target destination and vice versa should be uniquely and using the same path. Each radio access technology that is available to the user in achieving connectivity with the relevant radio access is presented with appropriate IP interface. Each IP interface in the terminal is characterized by its IP address and netmask and parameters associated with

5G termir

GPRS/EDGE 3G

the routing of IP packets across the network. In regular inter-system handover the change of access technology (i.e., vertical handover) would mean changing the local IP address. Then, change of any of the parameters of the socket means and change of the socket, that is, closing the socket and opening a new one. This means, ending the connection and starting e new one. This approach is not-flexible, and it is based on today's Internet communication.

In order to solve this deficiency we propose a new level that will take care of the abstraction levels of network access technologies to higher layers of the protocol stack. This layer is crucial in the new architecture.

To enable the functions of the applied transparency and control or direct routing of packets through the most appropriate radio access technology, in the proposed architecture we introduce a control system in the functional architecture of the networks, which works in complete coordination with the user terminal and provides a network abstraction functions and routing of packets based on defined policies. At the same time this control system is an essential element through which it can determine the quality of service for each transmission technology. He is on the Internet side of the proposed architecture, and as such represents an ideal system to test the qualitative characteristics of the access technologies, as well as to obtain a realistic picture regarding the quality that can be expected from applications of the user towards a given server in Internet (or peer). Protocol setup of the new levels within the existing protocol stack, which form the proposed architecture, is presented in Figure 2.

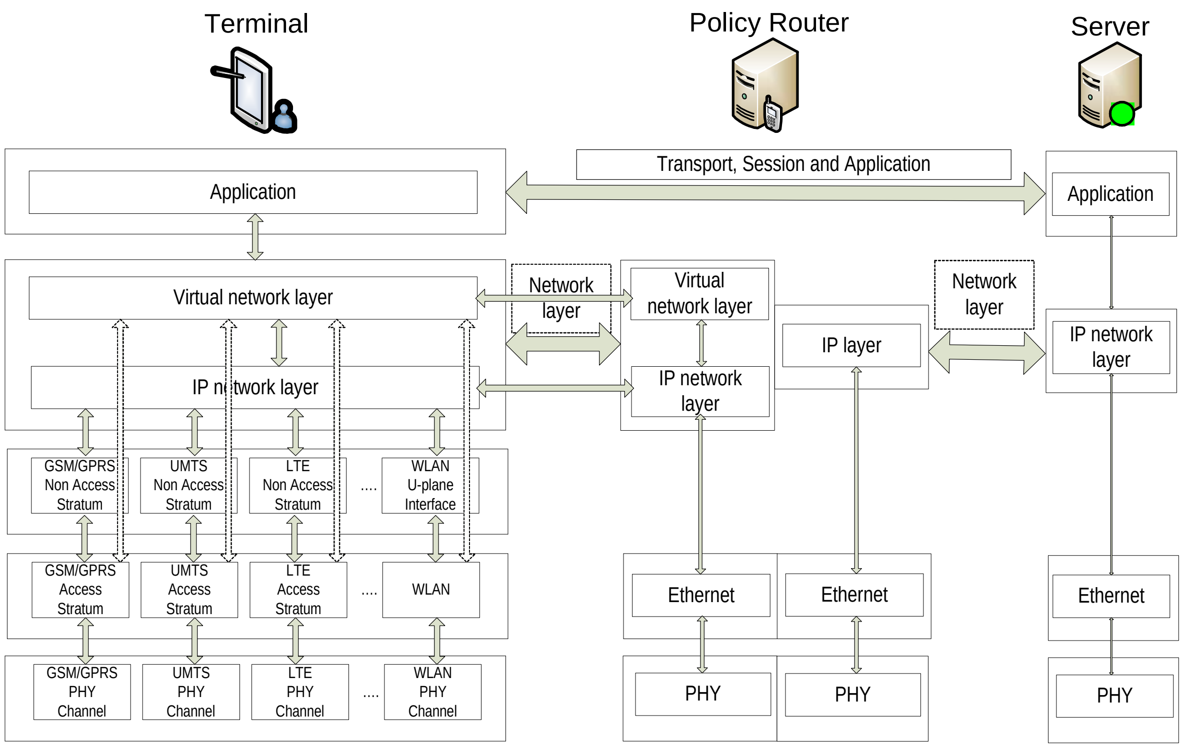

Figure 2. Protocol layout for the elements of the proposed architecture

The network abstraction level would be provided by creating IP tunnels over IP interfaces obtained by connection to the terminal via the access technologies available to the terminal (i.e., mobile user). In fact, the tunnels would be established between the user terminal and control system named here as Policy Router, which performs routing based on given policies. In this way the client side will create an appropriate number of tunnels connected to the number of radio access technologies, and the client will only set a local IP address which will be formed with sockets Internet communication of client applications with Internet servers. The way IP packets are routed through tunnels, or choosing the right tunnel, would be served by policies whose rules will be exchanged via the virtual network layer protocol. This way we achieve the required abstraction of the network to the client applications at the mobile terminal. The process of establishing a tunnel to the Policy Router, for routing based on the policies, are carried out immediately after the establishment of IP connectivity across the radio access technology, and it is initiated from the mobile terminal Virtual Network-level Protocol. Establishing tunnel connections as well as maintaining them represents basic functionality of the virtual network level (or network level of abstraction).

4. Network nodes

Heterogeneity of wireless networks enables the user terminal to perform a selection of access technologies depending on their preferences. This choice provides better conditions for user applications. The processes of achieving connectivity in new environments are strongly associated with the application process. Namely, the need of the user application to establish communication with the some application server usually ends by initiating a connection through the network level, i.e., network access to resources by the user terminal.

Considering that the functions of the virtual network layer in the proposed new architecture include many functions related to connectivity, security and continuity of the application sessions initiated by the user, the virtual network layer logically is divided into several cooperative software modules which perform different functionalities. Figure 3 given block-diagram of the software modules in the virtual network layer.

There are certain differences between client and server functions to a virtual network layer. On the client side there are five software modules that:

- RAT-CCSM (Radio Access Technology - Connection Control Software Module);
- MQPBR (Mobile Quality Policy Based Router);
- SPME (Security and Policy Management Entity);
- ITHC (Inter Tunnel Handover Control); and
- QoS / QoE CM (QoS and QoE Control Manager).

On the other side, the Policy Router includes four software modules as follows:

- MCCSM (Media Connection Control Software Module);
- CQPBR (Central Quality Policy Based Router);
- SPME (Security and Policy Management Entity);
- CPH (Client Profile Handler); and
- QoS / QoE CM (QoS and QoE Control Manager).

Each software module has determined position within the global architecture to provide the ultimate functionality that is providing interoperability in 5G heterogeneous systems. Providing functionality between software modules is done through precisely defined interfaces to other modules and with appropriate links between peer protocol modules on both sides of the architecture.

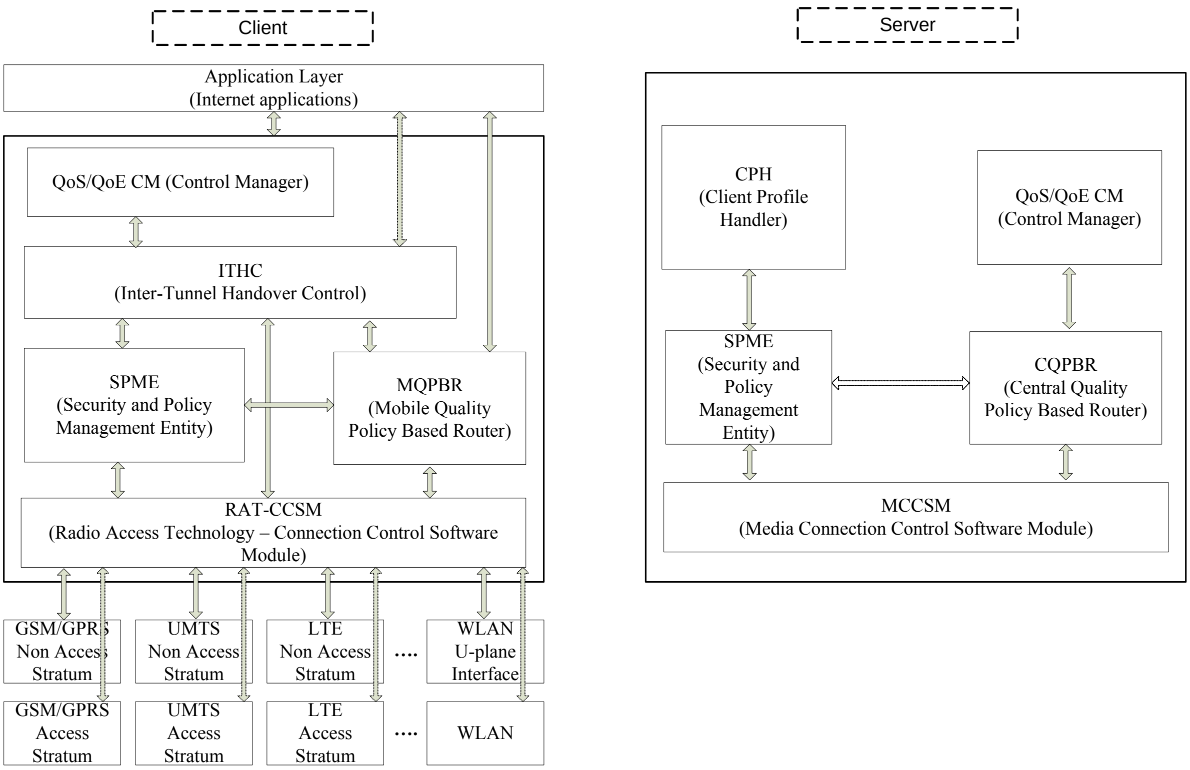

Figure 3. Software diagram of the proposed virtual network layer

As can be seen from the diagram in Figure 3 there are four common cooperative / coordination modules on different sides (client and server) that are interconnected. Hence, we may distinguish among four basic functionalities carried out by the virtual network layer.

First basic functionality of the virtual network layer is to provide a network abstraction. This functionality is related to the cooperative working together of the RAT-CCSM and MCCSM software modules that are designed to make masking of the IP level seen by each radio access technology. Besides this basic functionality, RAT-CCSM module at the client side is using API interfaces for access to the appropriate software modules from the lower levels of radio access technologies in order to provide additional information. This link is a way through which it receives information for improving connectivity of individual access technologies (e.g., generated PDP context with specified IP address, connection established with a given AP in WLAN networks and corresponding IP addresses, etc.) and the level of received signal of the corresponding radio access technology. In this way the software module has continuous information for the network and radio conditions in each radio access technology. Tunnels are formed between RAT-CCSM on the client side and MCCSM module in the Policy Router. RAT-CCSM module starts a process to establish a tunnel between the mobile client and the Policy Router (in particular, with the MCCSM module). The tunnel is formed through the established IP connectivity of the particular radio access technology. Source IP address of the tunnel is the IP address obtained by the establishment of IP connectivity via the given access technology, while destination IP address of the tunnel seeing in the uplink direction from the mobile side) is the loopback address of the software module of MCCSM Policy Router. RAT-CCSM software module performs continuous monitoring of the status of each radio access technology in terms of radio parameters (signal received level) and in terms of IP connectivity through the same network. The obtained information regarding the radio access technologies it forwards to another associated software module whose primary function is managing handover in the transmission of data between the established IP tunnels (the ITHC software module). The second link of this module refers to the routing module, where routing is based on policies determined on the offered Quality of Service. Their interaction results in defining the appropriate tunnel interfaces (corresponding to the tunnels created by the radio access technologies) within the routing table. The process of establishing the tunnel procedure begins with the authentication and authorization between the mobile client and the Policy Router, so the software module has a direct connection with SPME module for management of security mechanisms.

The second function is related to routing policies based on the determined Quality of Service offered by access technologies. This functionality is accomplished by cooperative working between MQPBR and CQPBR software components on the client and server sides. The mutual cooperation between these two modules is realized through the appropriate routing control protocol developed specifically for this purpose. Its goal is to provide proper prioritization of routes or routing rules via the tunnel interfaces within routing matrix / table. The changes are initiated and controlled by MQPBR client module in cooperation with the ITHC module. At the same time, the MQPBR software module on the client side presents the client IP address which is obtained in the phase of the authentication and authorization by the software module for that purpose - SPME. The actual determination of the client mobile IP address will be marked with McIP, where it is an IP address of the client in the heterogeneous network, which is generated by SPME software module and it is then given to the MQPBR client module. The communication of the upper protocol levels, such as the transport, session and application levels, is via McIP address of the user, which is seen as IP network address to them. The main feature of this software module, in comparison with other routing software components, is its ability to perform coordinated routing between the two software modules depending on the application that is initiated by the client. This would mean that routing table of this module expands and takes the form of three-dimensional routing matrix where for each initiated user application is defined priority for the tunneling interface.

The third function is associated with managing security procedures or security mechanisms and policies applied to users. RAT-CCSM module triggers corresponding module on the client side (SPME) in order to carry out proper user authentication and authorization for the same approval to create a tunnel through the appropriate technology. This process is accomplished through any “free” IP address obtained from a radio access technology towards a defined IP address of the server on the other side. In this case RAT-CCSM transparently forwards these packages directly to the network interfaces of the radio access technologies. After receiving the result of a process of authentication and authorization RAT-CCSM and MCCSM begin the process of establishment of an IP tunnel or reject the request. On the client side user terminal contains all the information in a local storage (in the mobile terminal) within the security software module, while the Policy Router stores the information for the mobile clients in an additional software module, referred to as CPH, which can be part of the same Policy Router (but, it is not mandatory). All information for each user of this architecture, the authentication parameters and policies, are stored in this database - CPH. Obtained policies and user parameters that describe a customer, which are obtained from other systems and stored in CPH module, and such data is then made available to RAT-CCSM module as well as MQPBR and CQPBR modules and the IHTC module. The RAT-CCSM module is allowed to establish a tunnel; the defined McIP address is announced to MQPBR and CQPBR modules, while to IHTC are announced other policies contained in the CHP that should help it in the process of handover decisions.

The fourth functionality is associated with the management mechanisms for measuring the parameters that define the Quality of Service and Experience in terms of user applications. This functionality is accomplished by cooperative working between the QoS / QoE module on the client side and QoS / QoE module on the server side. The purpose of this module in the mobile terminal (the client side) is to continuously measure the basic qualitative parameters of radio access technologies. Thus, the measured parameters give a realistic picture of the Quality of Service that can be expected from the radio access technologies, which in fact are on the path between the client and Policy Router. Measurements are carried out individually by each access technology. The results of these measurements are a direct input to the ITHC module for handover decisions between tunnels.

Fifth functionality of the network architecture is dedicated to the user only, and its location within the heterogeneous wireless network. This functionality is intended to ensure continuity of customer service while taking into account the qualitative requirements of the applications, the user, and the network, in a form of predefined policies or gained knowledge from the user services. This module on the user side is represented as ITHC software module and has a direct interaction with other software modules of the virtual network layer. Software Module continually processes data from RAT-CCSM software module (realized tunnels and signal reception level of each access technology). Also, it is directly associated with the QoS / QoE module, from which it receives information about the qualitative characteristics of each radio access technology used by the user. Then, with aim to decide which application will use which available radio access technology, it receives from the SPME the user policies as well as preferences of the user and the operator (that is the one that provides the functionalities of Policy Router). If there is a need of changes of the access technology for an ongoing session, this module is required to initiate the process of handover between tunnels connected with the relevant access technologies. The criteria under which it will begin the procedure of handover are part of the software module and its internal logic. The change of priorities for the routes for each application is performed by the module responsible for policy-based routing, i.e., the Policy Router on the network side.

6. Radio Access Technology Selector

In this section we provide description of a novel algorithm for radio networks selection in heterogeneous environment, which is created using biologically inspired algorithms. The algorithm consists of four building components as shown in Figure 4. First component or module is a set of parallel Fuzzy Logic (FL) controllers, which has as input the measurements data for different selection criteria, including user requirements, QoS requirements, service policies, as well as radio link conditions in different wireless technologies present in the user's area. The second module is multi-criteria decision mechanism algorithm, which uses as inputs the outputs of the FL controllers form the first module. Third module is Genetic Algorithm, which does optimization of weighting coefficients of different input criteria. That is, each criterion can have different weight, which depends upon the assumption of its impact on the best network selection process (i.e. the decision). The fourth module is Particle Swarm Optimization (PSO) [10], [11], mechanism which dynamically modifies the functions of FL controllers in the first module (shown in Figure 4).

This system is not limited only to access network selection, but it can be also used for solving other optimization problems as well. The proposed scheme in this paper is targeted for wireless networks selection in heterogeneous environment, so the decision as an outcome should select the best wireless network (among all present at the moment for a given user) or to rank in certain order all present radio access networks.

Initial phase of this scheme is data collection, by using measurement of the parameters of the Radio Access Networks (RAN). This process includes operator and user preferences. For instance, such measured parameters from each network are received signal power and signal to noise ration on link layer. Then, additional preferences can be service cost over a given RAN, which depends upon Service Level Agreements (SLA) between the user and each of the wireless networks. i.e., depends upon service policies.

The proposed scheme assumes that mobile terminal has enough processing power, memory capacity and battery support, so it can provide functionalities described above. Considering the Moore's law for computers, where we can today place mobile terminals as well, one may assume that near year 2020 mobile phones will have processing capabilities of today's power computers. So, the mobile phone can operate a database, do processing on given time intervals using measurements data from a given timeframe in the past.

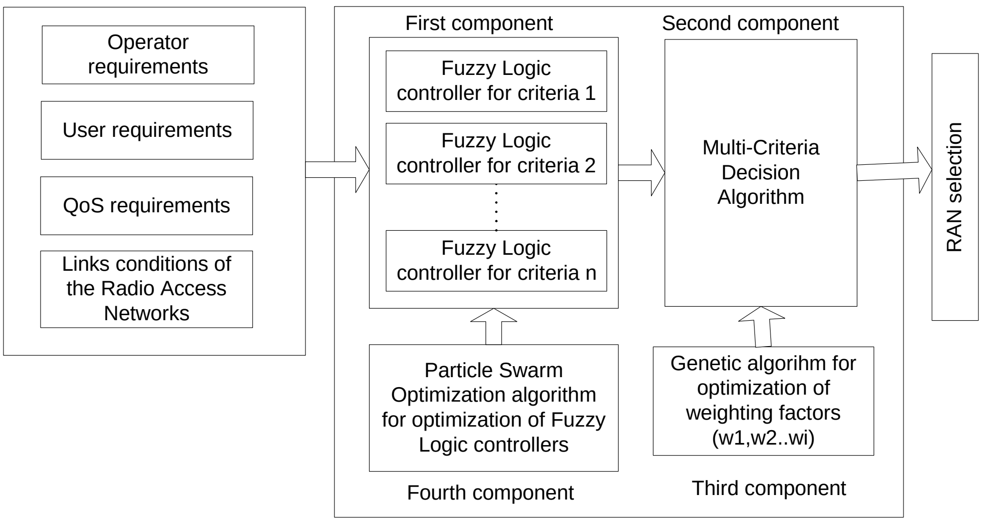

Figure 4. Radio Access Network selection scheme

Crucial part of selection mechanism in this terminal-controlled scenario is providing adequate data as an initial training sequence of Artificial Intelligence (AI) algorithms in the solving scheme. There are several possibilities to achieve this goal. Data can be provided by the network in a loosely-coupled scenario considering operator assisted terminal-controlled scenario, or by imposing training period in terminal itself considering pure terminal-controlled scenario. Never the less quantity of historical data that have to be included in the initial phase of training of AI algorithms must be determined.

In order to define the initial buffer size several simulations have been conducted with different size of initial buffer and comparative analysis has been made. As it can be seen on Figure 5, best buffer size can be defined in borders of 300- 400 historical intervals.

History intervals as shown on Figure 5 are time periods between subsequent measurements of the RATs parameters of the mobile terminals as well as the snapshot of user and service network demands in that period of time. They present most recent history of the user activity as well as user personal and user service demands from the network.

For the purpose of simulation analysis we have used the following mobility model, which provides randomness for user mobility. Each mobile terminal has velocity calculated according to the following:

$$v_i = v_{i-1} * C_v + \sqrt{1 - C_v^{\ 2}} * v_{mean} * N \ ; \tag{1}$$

where v_i is the user speed [m/s]. C_v is the correlation of the velocity between time steps. It depends on both a_{mean} that is the mean acceleration of the mobile user and v_{mean} which is mean velocity of mobile user. C_v is calculated as:

$$C_v = \left(\frac{-dt * a_{mean}}{v_{mean}} \right) \tag{2}$$

where N is Rayleigh distributed magnitude with mean 1 and a random direction. v_{mean} is the mean speed of mobiles. v_{mean} was set to 10 km/h and a_{mean} has been set to 1 km/h^2, which are typical values for urban environment. Figure 6 shows the users, in marked spots, over the simulated environment. Four types of services are considered in the simulation and they are equally distributed among the users, the voice calls, the low bit rate real-time video telephony, the high bit rate video, and the non-real-time data traffic.

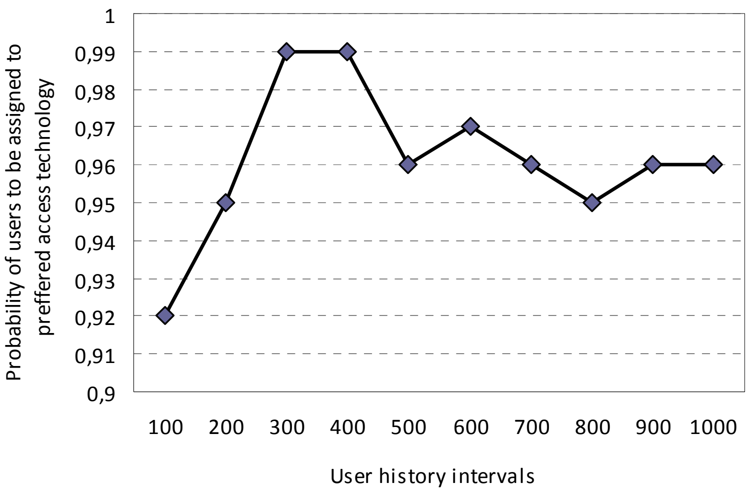

Figure 5. Initial buffer size dependency

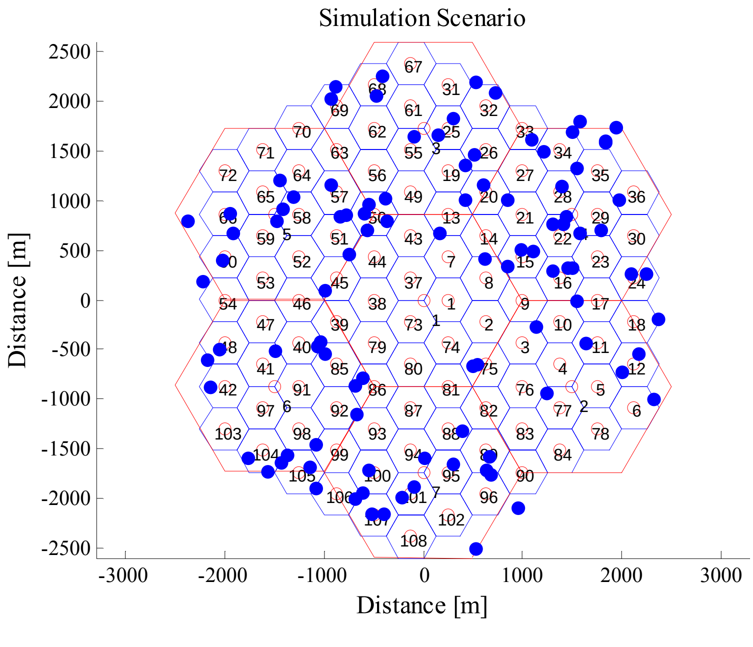

Figure 6. Simulation Scenario

Further we need to model the four types of services used in the simulation analysis in the following part of this paper. Each of the four service types is described and defined by requested bandwidth (in bps) and latency (in ms). First service type is defined with lower bandwidth (data rate) and lower latency, because it includes telephony services. The second service type is defined with the higher average data rate and relatively small latency, and it is targeted to video conferencing service. The third service type is video streaming, which requires higher bandwidth per connection, but can accommodate higher latencies compared to telephony. The last one, fourth service type, models non-real time services, such as web and email, and it is defined with fairly higher data rates (since these services use TCP, which consumes all available bandwidth end to end). All four service types, for the purpose of simulation analysis, are defined with the following pairs of values (bandwidth, latency), respectively:

$$[service\_latency\ (ms),\ service\_bandwith\ (kbps)]$$
$$\{[100, 64]; [200,128]; [400,256]; [800,512]\} \tag{3}$$

During the simulation for a given number of active users N, each user is randomly assigned to one of the four types of services defined above. For each service, the connection duration is modeled with the Poisson process. The mean holding time is set to 50 seconds, based on comparative measurements. For the purpose of simulation Fuzzy logic controllers were designed to fit the FL controller. During this design process a Particle Swarm Optimization (PSO) algorithm is used in order to optimize FLC, where membership function are tuned to the measured signal strengths and wanted user behavior. Considering that two RAT technologies (3G network and WLAN) are analyzed in the scenario we have two outputs from each FL controller. Outputs from the FL controller present so-called degree of membership of each RAT scaled to input variables regarding Fuzzy Logic rules.

In our simulations the PSO algorithm uses swarm size of 50 particles while maximum number of iteration is set to 50. Evaluation function is based on minimizing the mean square error (MSE) while comparing it to the expected predefined values. Expected values are defined as values taken from humanly decision that would be made if access network selection is done by human for every point in time and separately for each analyzed criteria [10]. Considering the evaluation done in section III, for Initial data buffer in the simulations we use range of 300 historical intervals. This means that in the scenario training period of 300 time slots (intervals) is imposed and initial data gather during this period are stored. These data are then used in GA for acquiring the first set of weights that will be imposed in the decision done using the multi-criteria approach. After this initial moment, in every other step, data from the buffer are constantly refreshed with new measured data. This is done in FIFO manner, first input data from training period are replaced and pushed out from the buffer, all other data are moved for one place backwards and on the last place newly measured data are placed. During this process buffer data size remains the same 300 historical measured data, so we have a certain time window for data collection in the mobile terminal, obtained from different present RATs (in this case, there are two RATs, i.e., 3G and WLAN).

Genetic Algorithm (GA) is used as optimization method for determination of appropriate values for weights of different criteria in multi-criteria decision making approach. The goal of the GA is to optimize the weights upon locations of the users and their demands to the network (which is dependent upon service type initiated by each user). With this approach, the GA can assign weighting coefficient to provide best user satisfaction. In our analysis we use 200 iterations, which is based on the fact that there is no improvement after successive 100 generations in most cases.

Taking into account the effects of different input parameters of the simulation as they were defined in the previous sections, such as the cost factor of access technologies from user point of view, and the factor of speed users and different number of offered services (service types defined by the appropriate bit rates and delays) was set up a simulation in which all user input parameters were randomly defined, each in a given value space. In addition, the users receive a random simulation values for the factor cost in the range of values from 1 to 10, and a random value for the velocity, in the range of values from 1 to 10 kmph. Then, several simulations have been performed for different number of mobile users, in the range from 100 to 1000 users, using the increment step of 100 users. This simulation scenario represents the best approximation of a realistic situation regarding the radio resource management in heterogeneous networks. The results of this algorithm have been compared with the following well-known algorithms for radio resource management (RRM), i.e., random RRM, service-based RRM and referent FGA.

The results are given in Figure 7, which gives the dependence of the user satisfaction, for a different number of users, when all input parameters were associated with users in random manner. The averaged results over the number of users are given in Figure 8. The user satisfaction means that a user is assigned to the RAT which gives optimum performance for the chosen user service, using the given constraints on RAT signal level, QoS, and service cost. The solution named M-RATS (Mobile-based Radio Access Technology Selector) uses Fuzzy controller and Genetic Algorithm with PSO (Particle Swarm Optimization) as described in the previous sections in this paper. Simulation results are given for different number of users, where users are randomly distributed within the given services area, which consists of WWAN and WLAN cells. Even with less users in the scenario (e.g., 100 or 200 users, as it can be seen from Figure 7), the M-RATS algorithm shows better behavior from well-known RRM techniques, including referent FGA, random-based RRM, and service-based RRM.

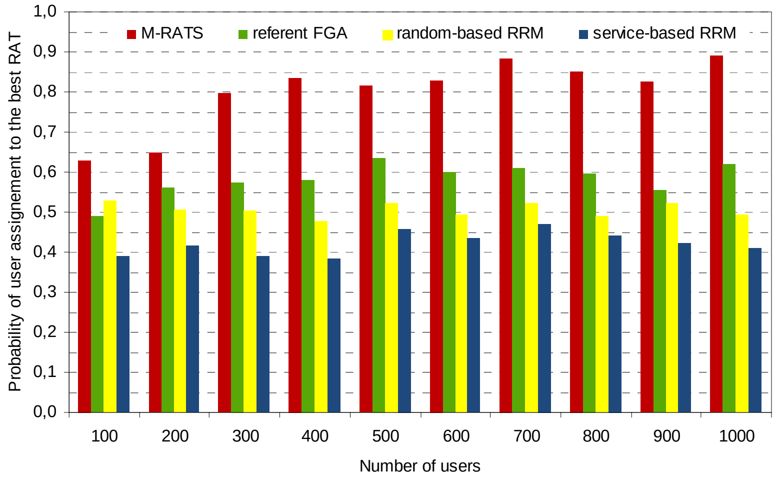

Figure 7. Probability for user access via preferred radio access technology (user satisfaction), using uniform random distribution of the input parameters to the algorithm

The results regarding the probability of assignment of users to the best RAT (which is subjective for each user) goes between 80 and 90% for all simulations with more than 300 users, because there are more user participants in the process.

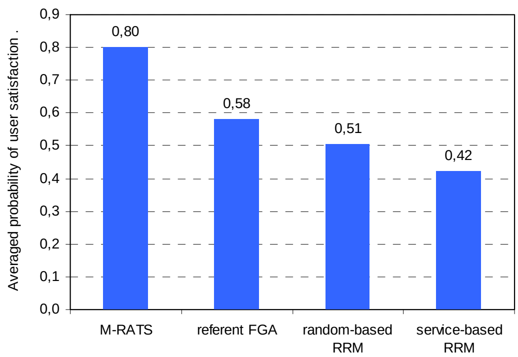

Figure 8. Average probabability for user satisfaction averaged over number of users

Most of the systems for selection of network access are based on one criterion. In contrast to such approaches, the proposed mechanism M-RATS is a multicriteria algorithm that seeks to satisfy different requirements or objectives set by various criteria. All previous algorithms do not address the roles of different sides in the selection process (users and network providers) and do not provide a complete solution that can be applied in heterogeneous networks. This is particularly important because of the nature of the network selection process in which both, the operators and the user, wants to control the network selection process and their roles in it should be strictly defined and in accordance with the degree of interdependence between different radio access technologies that consist the architecture of a heterogeneous network. Our approach allows defining the different roles of all parties in the decision-making in general terms that increase the satisfaction of them by the proposed final choice.

In heterogeneous wireless architectures consisted of wireless networks which are owned by different entities (i.e., network operators), the user should be able to control the RAT selection, assisted by network entities and the service stratum, which may belong to a third party. In loosely-coupled or tight-coupled architectures of heterogeneous networks owned by single operator, the RAT selection model can be implemented as a system which is divided into two modules, one set in the user terminal and another set on the network side as an integral part of the mechanism for joint radio resource management. The goal of the proposed mechanism, which is in fact the final choice of radio access technology, is done by direct interaction between the two modules.

7. Conclusion

The development of the mobile and wireless networks is going towards higher data rates and all-IP principle. Currently, there are many available radio access technologies, which provide possibility for IP-based communication on the network layer, as well as there is migration of all services in IP environment, including the traditional telephony and even television, besides the traditional Internet services, such as web and electronic mail as most used among the others. On the other side, mobile terminals are obtaining each year more processing power, more memory on board, and longer battery life for the same applications (services). It is expected that the initial Internet philosophy of keeping the network simple as possible, and giving more functionalities to the end nodes, will become reality in the future generation of mobile networks, here referred to as 5G.

In this paper we have defined completely novel network architecture for such 5G mobile networks. The architecture includes introduction of software agents in the mobile terminal, which will be used for communication with newly defined nodes called Policy Routers, which shall be placed in the core network. The Policy Router creates IP tunnels with the mobile terminal via each of the interfaces to different RATs available to the terminal. Based on the given policies, the change of the RAT, i.e., vertical handover, is executed via tunnel change by the Policy Router, and such change is based on the given policies regarding the Quality of Service and user preferences, as well as performance measurement obtained by the user equipment. Finally, the proposed RAT selector algorithm, based on genetic algorithms and particle-swarm optimization, provides highest probability of satisfied users regarding their requirements from the access network.

The proposed architecture for future 5G mobile networks can be implemented using components of the shelf (existing and standardized Internet technologies) and its implementation is transparent to the radio access technologies, which makes it possible solution for the next generation mobile and wireless networks.

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