Functional Architecture for 5G Mobile Networks

Aleksandar Tudzarov [1)] and Toni Janevski [2)]
[1)] *T-Mobile Macedonia, Orce Nikolov bb, 1000 Skopje, Macedonia*
Email: aleksandar.tudzarov@telekom.mk
[2)] *Ss. Cyril and Methodius University, Faculty of Electrical Engineering and Information Technologies, Karpos 2 bb, 1000 Skopje, Macedonia*
E-mail: tonij@feit.ukim.edu.mk

Abstract

In this paper we propose novel network architecture for next generation 5G mobile networks. The proposed architecture is based on user-centric mobile concept in heterogeneous wireless environment. The implementation of the proposed architecture is performed in the service stratum, while the radio access technologies belong to the transport stratum regarding the Next Generation Networks approach. In the proposed architecture the mobile terminal has the possibility to change the Radio Access Technology - RAT based on certain user criteria. For the purpose of transparent change of the RATs by the mobile terminal, we introduce so-called Policy-Router as a new node in the core network, 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 user agent for multi-criteria decision making, which is using the newly defined QoS policy-based routing procedure.

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. Finally, Section 5 concludes the paper. 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. Heterogeneous Wireless Networks Interoperability

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.

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].

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 Mobile 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.

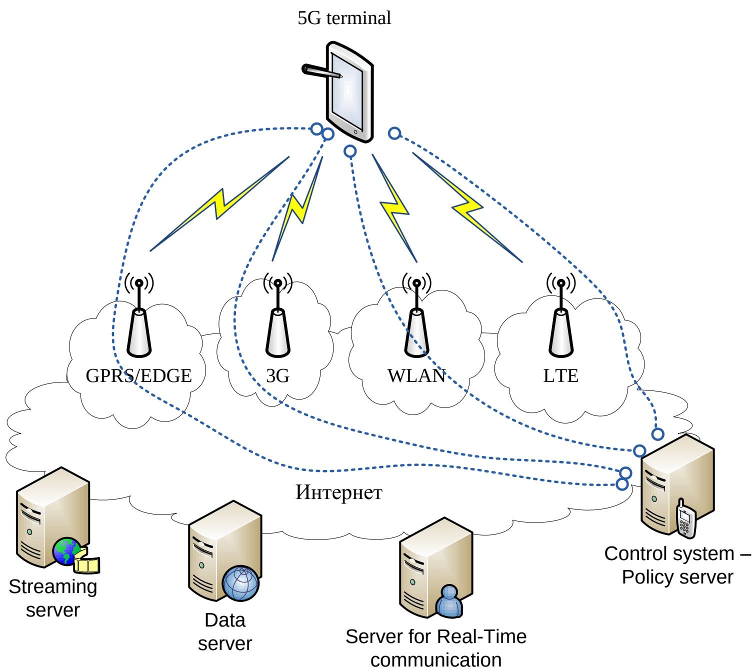

Figure 1 Functional Architecture for 5G Mobile Networks

The first two OSI levels (data-link and physical levels) 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.

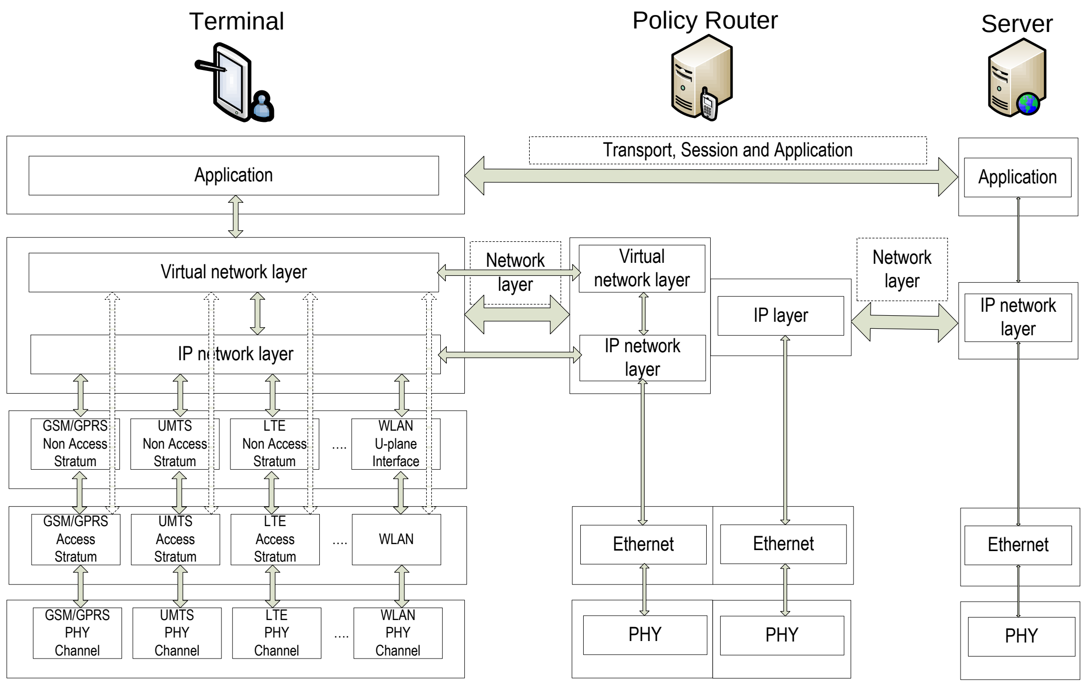

Figure 2 Protocol Layout for the Elements of the Proposed Architecture

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 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.

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. Functional Entities and Functionalities in the Proposed Network Architecture

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.

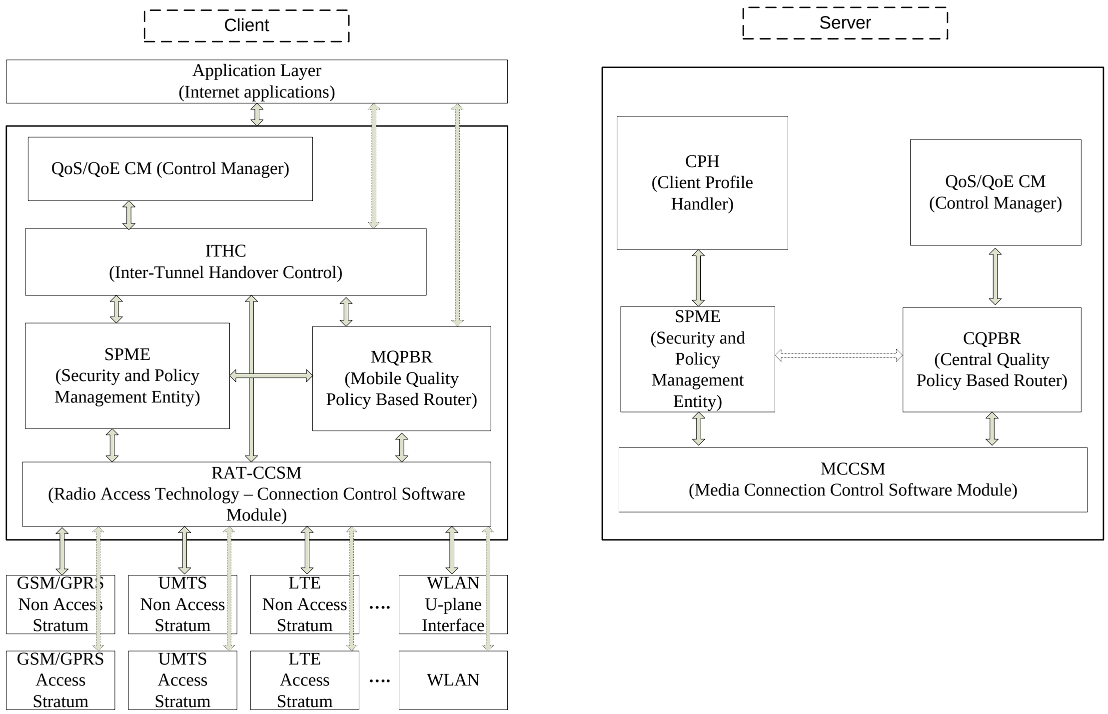

Figure 3 Software Diagram of the Proposed Virtual Network Layer

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.

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 [9]. 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.

5. QoS Functional Architecture based on Performance Measurements

Next Generation Networks (NGN) consists of support functionalities for data transport, and control transport, as well as functionalities for support of services and applications. The measurement of traffic is a basic control activity in order to provide Quality of Service, [10]. So, performance measurement is an intrinsic component in NGN, and it is usually performed at edge (border) network nodes, in access, core and transit networks. Also, it can be performed by the mobile terminals in the wireless environment, and here this is very important to create mobile user assisted probing of the RAT performances, [11], [12].

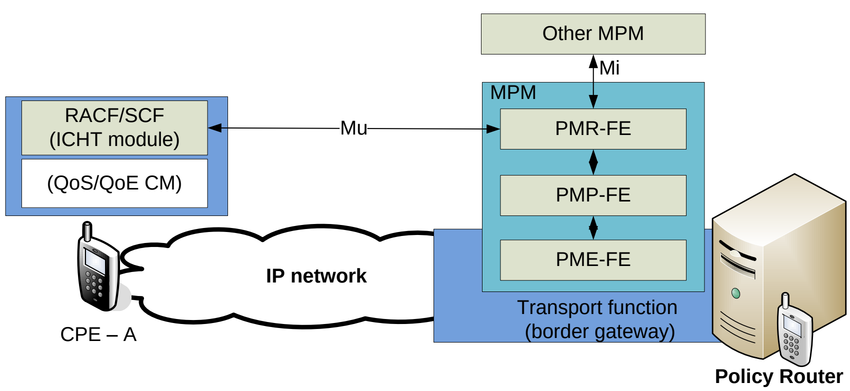

Figure 4 Network Performance Measurements Using RTP / RTCP and RTCP Extension

Figure 4 presents also detailed view of the general architecture for Management for Performance Measurements (MPM) in NGN, with added functionalities on the side of the mobile terminal (CPE – Customer Premises Equipment).

The network architecture consists of the following entities:

- Performance Measurement Execution Functional Entity (PME-FE) is an entity to perform performance measurements. PME-FE is responsible for three groups of functionalities: performance measurements, process measurements and single configuration entity conducting the measurements;

- Performance Measurement Processing Functional Entity (PMP-FE) is an entity for processing the measurements. PMP-FE is responsible for two groups of functions: processing of measurements and configuration of measurement tests across the network architecture. Functions for processing of measurements include collecting measurement reports, their analysis, aggregation as well as analysis of measurements in cyclical periods; and
- Performance Measurement Reporting Functional Entity (PMR-FE) is an entity reporting the performed performance measurements.

Most of the sessions of multimedia services over IP based networks are using RTP (Real-time Transport Protocol). RTCP (Real-time Transport Control Protocol) is accompanying the RTP protocol to transmit the feedback from receiver to sender's RTP side.

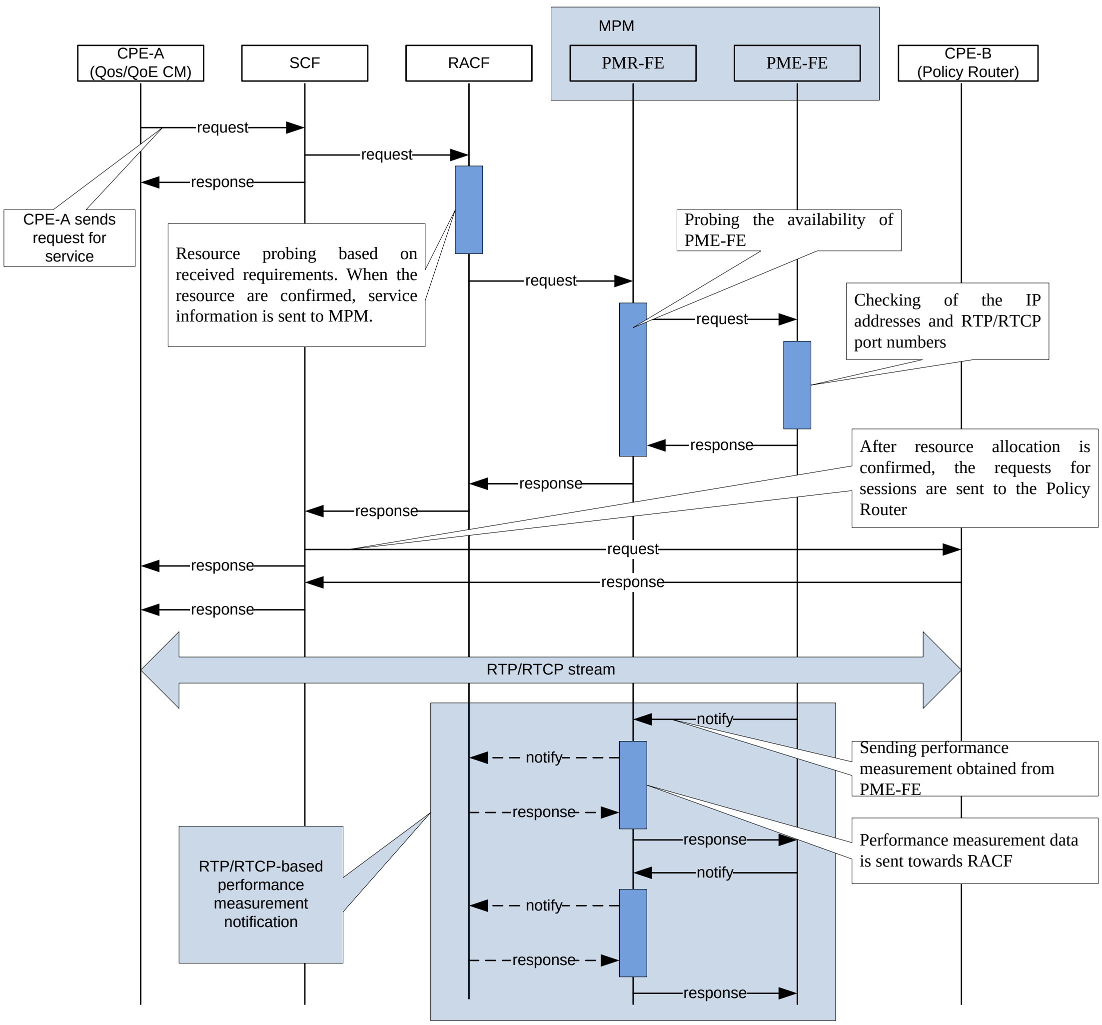

Figure 5 RTP / RTCP-Based Diagram for Performance Measurements

The idea is to perform continuous performance measurements by the customer premises equipment (CPE) without introducing additional probing systems and this to be used towards the management of the performance as an aid in decision-making on resource allocation in next generation networks, respectively, and thus directly affect the provisioning of the required QoS for each of the realized services that customers use. Figure 4 shows the possible configuration for performance measurements using RTP / RTCP. On this Figure is presented Mu interface to Resource and Admission Control Function (RACF), which is an essential part of the process of decision-making performance in the allocation of resources. In the proposed architecture in this paper the interface for measurement data is between the QoS / QoE CM software module and software module for control of handovers between wireless technologies (ITHC).

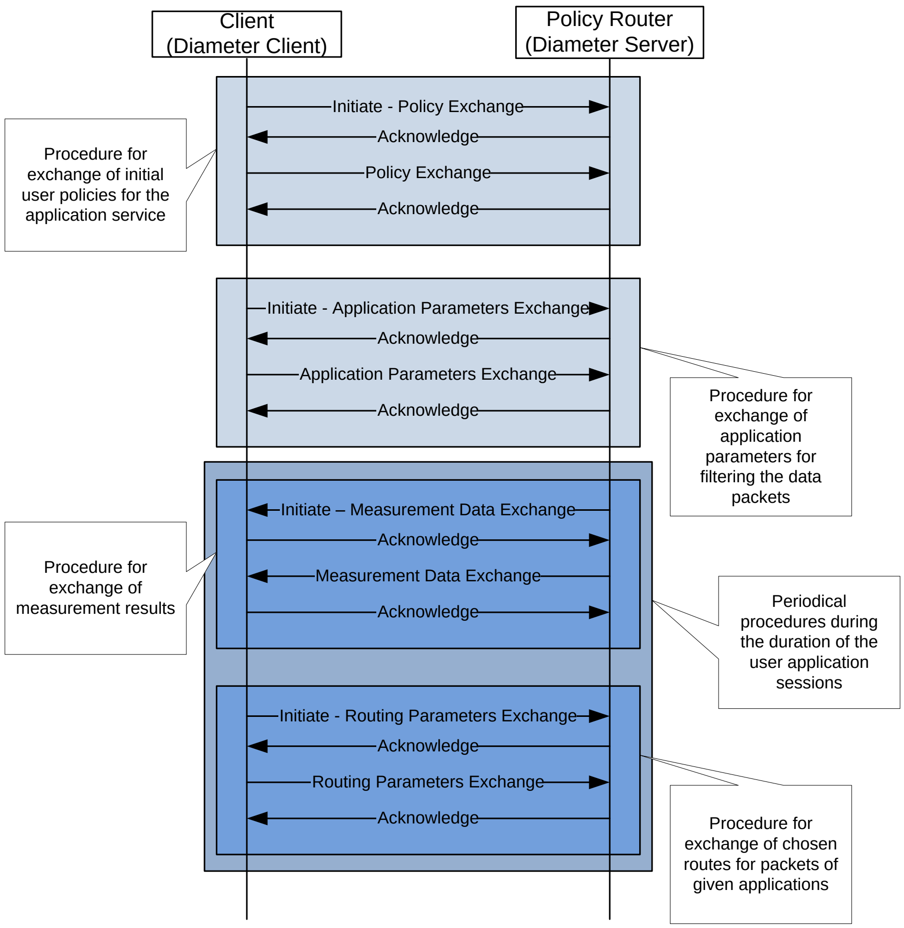

Figure 6 QoSPRO – Information Exchange in the Proposed Architecture

The procedure for notifications based on qualitative performance measurements obtained by RTP / RTCP-based scheme is shown in Figure 5.

The necessity of setting a new protocol for the exchange of network parameters between the two sides of the network architecture (policy client and router) is perceived by the parameters and scope of information to be exchanged.

For proper operation of the process for control and routing of packets there are required the following four key functionalities:

- Exchange of initial policies for technologies and user requirements;

- Exchange of the application characteristics for separation of the packets;
- Continuous periodic exchange of measurement information of the QoS parameters of each radio access technology, which is achieved through connection to the client with the IP world; and
- Exchange of information on selected set of routes for given applications (periodic exchange triggered by the ITHC module).

The idea of this protocol QoSPRO (Quality of Service Policy based ROuting) is to unite in itself all the essential and necessary parameters by which the exchange between the control and measurement entities, in particular between MQPBR and CQPBR software modules in the proposed architecture, would enable the mutual synchronization in order to achieve proper operation. Protocol procedures that should be supported by QoSPRO protocol are shown in Figure 6. Decisions for change of the radio access technology are executed on the mobile terminal (client) side, using the developed M-RATS algorithm [9], which uses key performance indicators as input parameters for proper decision for RAT choice.

All these information are intended to make the proper direction of the packets of user applications in order to achieve best quality and optimal routing. In the process of routing it is also important to introduce hysteresis in periodic review of the status of the RATs, to avoid the effect of ping-pong switching between them. The idea of using the DIAMETER as the basis of this protocol gives great flexibility and simplicity and yet makes it a powerful and expandable enough to meet also future requirements of the proposed architecture.

6. 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 via new defined procedure for that purpose in this paper, called Quality of Service Policy based ROuting (QoSPRO).

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 very likeable solution for the next generation mobile and wireless networks.

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Authors

Aleksandar Tudzarov is born in 1978 in Veles, Republic of Macedonia. He received his B.Sc. and M.Sc. degrees in Electrical Engineering from the Ss. Cyril and Methodius University in Skopje, R. Macedonia, in 2002 and 2006, respectively. Currently, he is working on his Ph.D. in the area of future wireless and mobile networking. From 2005 he is also employed as networks development specialist at T-Mobile, Macedonia. He has published 20 papers in journals and conferences. His research interest is in the area of mobile and wireless packet-based networks, and Quality of Service.

Toni Janevski is born in Skopje, Republic of Macedonia, on October 15, 1972. He received the B.Sc., M.Sc. and the Ph.D. degrees in Electrical Engineering from the Ss. Cyril and Methodius University in Skopje, R. Macedonia, in 1996, 1999, and 2001 respectively. From 1996 to 1999 he was with Mobimak (now T-Mobile, Macedonia) GSM mobile operator in R. Macedonia. From October 1999 he is with Faculty of Electrical Engineering in Skopje. From July 2001 to November 2001, he was at IBM T.J. Watson Research Center, New York, USA. He has written the book "Traffic Analysis and Design of Wireless IP Networks", published by Artech House Inc. in 2003. Also, he is an author/co-author of more than 100 published research papers. He is a Professor at the Faculty of Electrical Engineering and Information Technologies, Ss. Cyril and Methodius University in Skopje, Macedonia. His research interests include wireless and mobile networks, Internet technologies, Quality of Service, network design, traffic theory and internetworking. He is a Senior Member of IEEE.