Integrated Mobility and Resource Management Mechanism for FMC Networks

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Abstract— **a network based method for an intelligent distribution of transport resources of heterogeneous points of attachment to the network among mobile nodes with multiple network interfaces is presented in this paper. Selection of the used network for a particular multimedia session is based on the QoS situation in access networks available for mobile node. A possible realisation using IP Multimedia Subsystem on the signalling plane is described. The proposed idea is based on the Fixed & Mobile Converged network architecture with Ethernet based data transmission developed in the ScaleNet[*] project. The performance of the presented mechanism has been evaluated by the computer simulation.**

Keywords: **Fixed & Mobile Convergence, resource management, mobility, QoS provisioning, IMS.**

I. Introduction

To increase revenues and win more customers, network operators have to introduce more and more interesting and attractive services and offer them not only in fixed access networks but also in the mobile network environment while subscribers are on the move. Multi-radio operation becomes a norm today since recent terminal devices have multiple network interfaces so that a connection to access networks based on different techniques is possible. Last mile access technology that a subscriber has to use in order to get a desired network service must therefore not be restricted to any particular technology neither in the wired nor in the wireless domain.

The convergence of fixed and mobile networks (Fixed & Mobile Convergence, FMC) has therefore become a hot topic again. Besides of the provisioning of network services independent from the used access the FMC means the usage of a single IP based network infrastructure to integrate diverse access networks into a single core. It reduces the installation and serving costs of the whole network significantly. FMC avails an easy and flexible extension and re-use of the existing infrastructure with new Points of Attachment to the Network (PoAN) if needed.

"Triple Play" is a headword in the service description nowadays, denoting increasing popularity of multimedia applications via a single IP connection besides of traditional data services in Internet. Pervasive and seamless connectivity of mobile subscribers to the network is one of the most important topics in this context since mobile users do not want to lose the connection to the network while on the move. Provisioning of the Quality of Service (QoS) is another important issue since mobile users want to experience available services with demanded QoS level in any network environment. Both of these problems are big challenges for network operators especially in FMC networks since the constraints of different access technologies vary very much. A QoS level available for multimedia services in fixed wireline networks (e.g. xDSL, FTTH) cannot be provided in the wireless access domain based on e.g. GPRS, UMTS or HSxPA. Available QoS resources differ in tens of times also among various wireless access techniques. New mechanisms must be developed to observe QoS resources available for multimedia applications and to adapt application parameters to the varying QoS level if needed. That is required to retain the Quality of Experience (QoE) for mobile users. Thereby a tradeoff between user requirements and network capabilities must be met since operators want to satisfy possibly more users using limited network resources.

In this paper a new network based integrated mobility and resource management mechanism for FMC networks is presented. Using this mechanism a dynamic allocation of available network resources to demanding mobile nodes with multiple network interfaces is possible. The distribution of network resources can be realised optimally since required resources needed to fulfil user demands are considered during resource allocation.

The rest of the paper is organised as follows: in Section II the idea of the new mechanism is introduced. Section III presents results of performance investigations performed to evaluate the potential benefits of the described system. Summary and insight into the current and future works finish the paper in Section IV.

II. Integrated Mobility and Resource Management Mechanism

The definition "mobility" is not restricted to denote a mobile node handing off between different PoANs. In this work the understanding of mobility is tightly coupled with problems of QoS provisioning in FMC networks. Resource management in FMC causes a problem of optimal selection of the most suited PoAN for every mobile node (MN), even for every maintained session. The demands of a mobile node must be satisfied while possibly lesser network resources shall be spent for that to be able to serve more users.

A. Related work

Some access technologies like IEEE 802.11f (WiFi), IEEE 802.16e (Mobile WiMAX) or 3GPP2 UMTS inherently

contain methods to avail continuous connectivity of mobiles to the network while handing off among PoANs of the same access technique. IETF groups developed the most known solutions for different OSI layers for the case when PoANs are connected to different IP domains. These are Mobile IP (MIP) with its further extensions, Fast MIP and Hierarchical MIP, NetLMM, solution for mobility using Host Identity Protocol (HIP), multihoming support using Stream Control Transmission Protocol (SCTP) and mobility with SIP. The listed approaches can support "transport" mobility of mobile nodes only. Transport mobility means that the IP connectivity of mobile nodes "only" remains uninterrupted so that mobile nodes can continue their sessions after a handover. QoS demands of the mobile node and available QoS resources are not considered in these solutions. It can happen that the IP connectivity of a mobile node is retained, but the new PoAN cannot fulfil QoS requirements of maintained applications so that MN's QoE decreases significantly especially in case of multimedia applications.

The Candidate Access Router Discovery (CARD, [5]) protocol is designed to consider some QoS related parameters of available PoANs to help the mobile node to select the most suited access router for the handover. However, mainly the particular load and the type of PoANs is considered, it is unclear how and in which format the exact QoS level for a particular mobile node can be estimated and how CARD entities may be informed about QoS requirements of maintained applications.

The IEEE 802.21 framework (Media Independent Handover, MIH [1]) "is being developed to facilitate smooth interaction and media independent handover between 802 technologies and other access technologies" ([1]). It defines new functions for both mobiles and access networks to accelerate handover decisions and to provide optimal network selection. MIH concentrates more on the extensions for mobile nodes on the link layer to detect faster newly appearing PoANs to be able to hand off to them assuming e.g. WiFi must provide better quality than e.g. UMTS. A handover to the new PoAN is, however, not necessarily required if QoS demands of a MN are fulfilled using its current PoAN. Furthermore, the newly detected PoAN can be overloaded so that theoretical QoS resources cannot be provided to the demanding MN after handover. Implementation efforts for MIH are huge as well as the interaction with applications is not clearly defined and the resource management of PoANs stays out of the scope of the 802.21 working group.

B. Network architecture

The presented work has been done in the scope of the research project ScaleNet [2], [3]. The main goal of the project is to develop a new architecture for FMC enabled Converged Access Aggregation Network (CAAN) as a building stone for NGN access networks. Generic mechanisms must be developed for mobility, QoS and AAA to be able to integrate any of present and future access technology into the common infrastructure. Universal Access Node Function (UANF) has been developed for that. UANF converts methods of particular access techniques to the generic interfaces used between the overarching CAAN management

and PoANs. As result a new architecture based on the Gigabit Passive Optical Network (GPON) technology has been developed with Ethernet based transport of data frames. Ethernet, WiFi, WiMAX, HSDPA and Mesh networks can be used to connect mobile terminals with multiple network interfaces to the CAAN. In [4] an example of mesh integration into the common CAAN architecture is detailed presented. Particularities of data transmission in Ethernet based networks have been used to avail simultaneous usage of available network interfaces for different sessions maintained by mobile nodes. A single IP address must be configured for the MN that is used for all of its network interfaces. The MN's IP address is therefore not changed during handovers across PoANs of the same or different technologies. The developed solutions are designed for inter-CAAN mobility whereby mobility protocols must not be applied to retain the IP connectivity uninterrupted. CAAN borders are defined by an Edge Router (ER) that connects the CAAN with IP backbone network.

IP Multimedia Subsystem (IMS, [6]) is used on the signalling plane to control all multimedia services available for customers. The usage of SIP enables that the IMS core elements have knowledge about QoS requirements of applications maintained by mobile nodes.

C. Idea of the integrated mobility and resource management mechanism

Fig. 1 presents an overview of the integrated mobility and resource management mechanism for FMC networks.
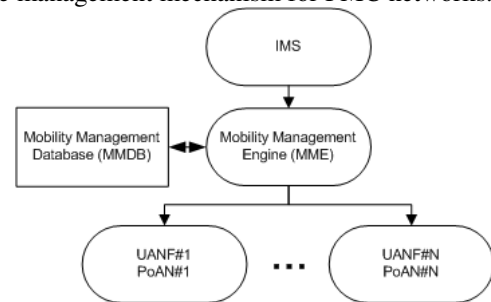

Fig. 1 Overview of the integrated mobility and resource management system

The Mobility Management Engine (MME) is the main logical function deciding which PoAN will be used for every session, i.e. performing mobility decisions. PoANs are first points of contact to the network for MNs. They firstly have information about connected MN's interfaces in the network so that they can inform the MME about the mapping to which PoAN a particular MN's interface is connected ($MAC_{1MN} \rightarrow PoAN_X$). This information is prepared and sent to the MME using UANF. MME stores that in the Mobility Management Database (MMDB). After initial connection of a MN a new IP address is configured for it and the complete information about the MN consisting of the list of available network interfaces (interface identifiers, e.g. hardware MAC addresses), the configured IP address and the IMS ID is stored in the MMDB. If further interfaces of the MN become active and connect to other PoANs, the related MMDB information ($MAC_{2MN} \rightarrow PoAN_Y$) is updated.

Upon initialisation of a new session the IMS core receives the initialising SIP signalling and can extract QoS

requirements of the new session from its SDP body. IMS requests the MME to select the most suited PoAN to serve the session. The IP address of the MN or its IMS ID is used as unique identifier of the MN. Using that identifier the MME extracts from the MMDB the information via which PoANs with which interfaces the MN can communicate. The MME generates then pre-negotiation requests to all PoANs that can be used for the communication. These requests contain the particular MAC address of the MN's interface and the required IP QoS information (e.g. bitrate, packet delay, packet jitter, error rates). Only PoAN has information about exact assignment of its transport resources so that it only can determine the QoS resources that can be provided for a specific MN. Using the MAC based identification of the MN a PoAN can extract QoS related information about the MN (like used modulation technique both in uplink and downlink, error rates, etc.) from its Management Information Based (MIB). Analysing the amount of transport resources available for assignment to the requiring MN the PoAN can detect the exact QoS resources for the MN. All PoANs send pre-negotiation replies to the requesting MME with detected QoS level for the MN. Transport resources needed to provide the estimated QoS resources are reserved until the PoAN receives a final commitment meaning the PoAN has been selected by the MME or resource release message meaning the PoAN will not be used for the session. In the pre-negotiation replies the QoS resources available for the demanding MN are contained as well as the information how many transport resources of the PoAN must be spent to fulfil the estimated QoS level. Applying a selection policy the MME selects the PoAN that will be used for the demanding session and sends final commitment to the selected PoAN. Resource release messages are sent to other PoANs so that the reserved resources can be released. Fig. 2 shows the assignment of transport resources of a PoAN in the vision of the MME.
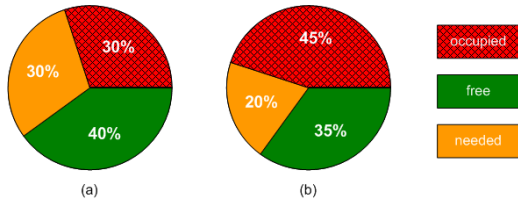

Fig. 2 MME vision: occupation of transport resources at different PoANs

The particularities of access technologies deployed in different PoAN are abstracted for the MME. Independent from the type of the access technology the percentage distribution of assigned, free and for the requiring session needed resources is sent to the MME. An example of the selection policy in the MME could be to select the PoAN that offers the most QoS resources while using minimal transport resources (Fig. 2 b) or while the most transport resources stay unoccupied so that they can be used for further sessions (Fig. 2 a). Functions performing the mapping of real transport resources to the percental part of the commonly available resources at a PoAN must be developed. It is a part of the integration task of the UANF for every particular access technology converged into the CAAN.

After final resource commitment at the selected PoAN the classifiers on the ER and on the MN are installed in order to distinguish data packets belonging to the new session and to transmit them from/to the MN using the selected PoAN. The complete information about the session like session ID, its QoS resources, the selected PoAN and MAC used on the MN, are stored in the MN related data of the MMDB.

Besides of the IMS core a selected PoAN can generate a request for the new selection. It happens if e.g. the quality of the wireless link between the MN and the PoAN decreases so that the PoAN needs more transport resources to provide the offered QoS level to the MN while these resources are not available on the PoAN. It also happens if the MN switches the used interface down. The MME knows the QoS requirements of the session since they are stored in the MMDB and the selection process is started again. If an alternative PoAN is found for the session, new classifiers will be installed on the ER and the MN. If not or the new QoS level is lower then the demanded one, the MN can be informed via the IMS plane about new QoS resources that will be available for it. This is very important for multimedia services since the MN can adapt the session parameters in order to continue the session instead of its freezing so that the MN's QoE is just a bit decreased.

D. Integration with IP Multimedia Subsystem

Since the IMS is used in the network as the overarching signalling system, it is beneficial to re-use network functionalities and elements defined by the IMS. ETSI TISPAN has defined Resource & Admission Control Subsystem (RACS, [7]) that is used in cooperation with IMS core elements to reserve needed transport resources Fig. 3 shows the realisation of the integrated mobility and resource management system using RACS functional elements.
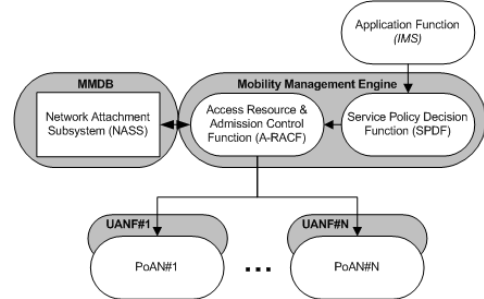

Fig. 3 Realisation of the IMRMS using ETSI TISPAN RACS

The Application Function (AF) is located in the IMS core (usually at one of the CSCFs) and can extract QoS related parameters from SIP signalling going through that CSCF. The logic of the MME can be realised within the Service Policy Decision Function (SPDF) or be distributed between the SPDF and Access Resource & Admission Control Function (A-RACF). The A-RACF can be considered as a help function that can communicate with Network Attachment Subsystem (NASS) to get information about PoANs via which the MN can communicate. The interface between the A-RACF and the UANF at PoANs is generic and does not depend on the used access technology of the PoAN.

III. PERFORMANCE EVALUATION

The described integrated mobility and resource management mechanism has been evaluated using network simulator ns2 [8].

A. Reference Simulation Scenario

1) *Network architecture:* Fig. 4 shows the network architecture that has been used in the performed simulations.
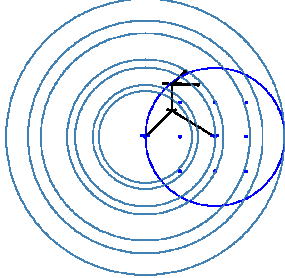

Fig. 4 Simulated network architecture

The CAAN consists of a WiMAX PoAN located in the centre of the figure and of a WiFi PoAN. The circles around the WiMAX PoAN show the coverage areas with different modulation techniques. Other related WiMAX parameters are listed in TABLE I, further details of the used WiMAX ns2 implementation can be found in [10].

TABLE I
WIMAX-RELATED PARAMETERS IN PERFORMED SIMULATIONS

Parameter	Value
Physical layer	OFDM
Channel bandwidth	7MHz
Frame length	10ms
OFDM symb./frame	294
DL:UL ratio	2:1
QoS support	Best effort traffic for all data packets
Scheduling policy	The same bitrate is provided to all demanding subscribers independent from their modulation technique

The coverage radius of the WiFi PoAN is the half of the radius of the WiMAX coverage with BPSK modulation. The raw bitrate of the WiFi PoAN is set to 54Mbit/s. Both PoANs are connected to an Ethernet switch that has a link to the Edge Router. These network components form one L2 network. Two application servers are connected to the ER.

Eight wireless nodes are located in the coverage areas of both WiMAX and WiFi PoANs in a square form around the WiFi PoAN as shown in Fig. 4. The wireless nodes are fixed and have two wireless interfaces: WiMAX and WiFi. The WiFi link quality (available bitrate) is the same for all nodes, the quality of WiMAX links is defined by the distance between the WiMAX PoAN and a wireless node.

All wired links between application servers, ER, Ethernet switch and PoANs have capacity of 1000Mbit/s and 1ms propagation delay. The time of all simulations is limited to 100 seconds.

2) *Emulated traffic:* Quality of ftp and VoIP traffic has been investigated. Ftp and VoIP data streams can be established between wireless nodes and application servers in both downlink and uplink directions in relation to the wireless nodes. The parameters of the ftp are selected according to [9], VoIP is modelled with G.711 codec using packets of 200 bytes (IP 20 + UDP 8 + RTP 12 + payload 160) with inter-packet arrival delay of 20ms. Mean duration of a VoIP session is 10ms with exponential distribution as well as the mean delay time of ftp and VoIP. Both delay times mean how long the user waits until the next session of this type will be established. For the ftp traffic it can be interpreted as a viewing time of the downloaded data, for the VoIP it is a pause till user starts a new VoIP session. All applications assigned to users start at 1sec simultaneously so that they are distributed automatically using mentioned delay times.

A Basic Traffic Set (BTS) consisting of an ftp and of a VoIP session (two data flows, one from a wireless node to the VoIP server and one in the reverse direction) may be assigned to every wireless node. Every second ftp session is established in the downlink direction, others in the uplink. The assignment of BTSs to wireless nodes is defined using parameter Sessions per User (SPU) that defines how many BTSs are assigned to every wireless node. E.g. if SPU is 0.5, a BTS is assigned to 4 random wireless nodes, if SPU is 2.5, two BTSs are assigned to all users and one BTS is assigned to 4 random nodes. There are then 4 users in the network maintaining 2 BTSs and 4 users with 3 BTSs.

3) *Implementation details:* Ns2 has been extended with Ethernet functionality. MAC based classifiers for MN and ER have been implemented so that packets from/to the same IP can be transmitted through the network using different paths (MN's network interfaces and PoANs). Immediately before the first data packet of a new session is transmitted classifiers on the wireless node and ER are installed. They define via which PoAN data packets of the new session must be sent.

4) *Interface Selection Policies:* The selection of the network interface and the appropriate PoAN for a particular session is a very complicated task. To optimally distribute the load in the network the QoS level that can be provided for a particular wireless node at each PoAN must be estimated and analysed as mentioned above. These implementations have not been performed yet. Instead, 5 different static policies have been defined to be able to investigate the benefits enabled by the possibility to simultaneously transmit data packets via multiple PoANs. Logically, the process of interface selection for a new session looks like the MME receives a request for a new session from IMS, applies selection policies and installs according classifier for the selected PoAN.

TABLE II
DETAILS OF COMPARED SELECTION POLICIES

Policy number	Policy		Number of users using	
	VoIP	ftp	WiFi	WiMAX
1	WiMAX	WiFi	8	8
2	WiMAX	WiMAX	8	0
3	WiFi	WiFi	0	8
4	random	random	8	8
5	WiFi	WiMAX	8	8

Parameters of evaluated policies are summarised in TABLE II. Random in policy#4 means that VoIP and ftp can be assigned both to WiMAX and to WiFi. If the session ID is odd, WiFi interface is used for the session, otherwise – WiMAX.

B. Simulation results

The best selection policy is the policy achieving the best trade off between user requirements and load of the whole network. Since VoIP and ftp traffic types have been investigated in the performed simulations, the best selection policy is the policy that avails highest bitrate for ftp and lowest delays for VoIP while used PoANs have the lowest load. Fig. 5shows the measured average ftp bitrate per session per user in downlink and uplink depending on the SPU.
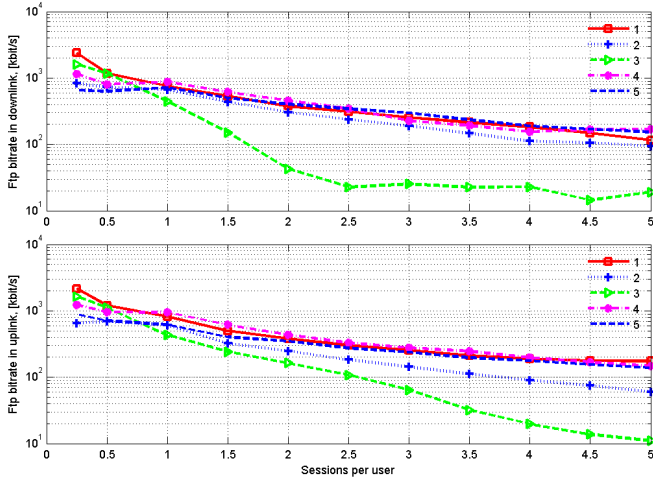

Fig. 5 Ftp bitrate

The behaviour of ftp curves is logical: the more data is transmitted, the lower the throughput of a particular ftp session. With low values of SPU the highest ftp bitrate can be achieved if the policy#1 is applied. The second highest ftp bitrate is provided if all data are transmitted using WiFi (policy#3). With this policy the ftp performance decreases, however, rapidly if the number of transmitted data in the network increases. Other policies excepting the policy#2 show the similar performance – average session ftp bitrate of approx. 180kbit/s in both downlink and uplink can be provided for every wireless user in the case every user maintains 5 BTSs.

Since ftp has lower QoS requirements than VoIP, the performance of the VoIP is a more deciding factor which policy is better. Fig. 6 presents the impact of SPU on the average VoIP delay in downlink and uplink. From the figure it can be seen that the best policy#1 for the case of ftp does not provide the best performance (the lowest VoIP delay) for VoIP with small SPU. Using policy#5 the lowest VoIP delay can be achieved in the downlink and using policies #5 and #3 lower VoIP delays can be achieved in the uplink. The average VoIP delay increases faster in downlink than in uplink with policy#3. It is because all VoIP packets in downlink are sent via the single WiFi PoAN that competes with a number of other wireless stations for transport resources of the WiFi channel (transmission opportunities). Since all WiFi stations and the WiFi PoAN have the same priorities, the probability

that a wireless station transmits all of its packets is higher than the probability that the WiFi PoAN transmits all its packets.
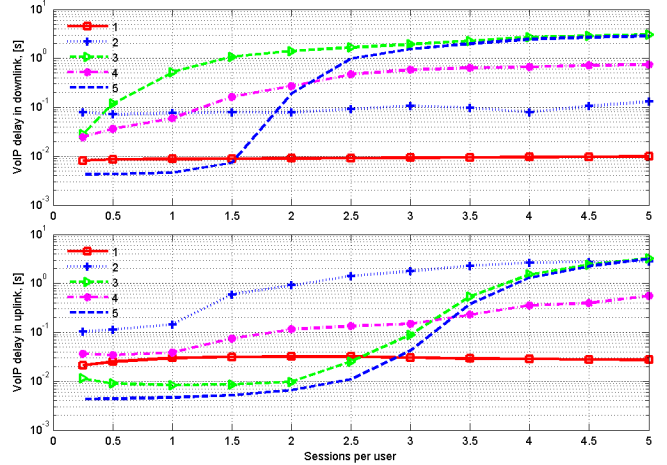

Fig. 6 VoIP delay

Consequently, the VoIP packet delay increases as well as the queue length of the WiFi PoAN (Fig. 8). The VoIP delay increases to the unacceptable (more than 150ms delay as in [11]) already when every user maintains an own BTS. In the uplink, instead, the performance of policies #3 and #4 is very good till SPU of 2.5. It means, if the network operator wants to provide the best possible VoIP quality, it has to deploy policy#5 both for downlink and uplink sessions when the load in the network is low. While the load is going to approx. 1.5 SPU, the policy for downlink should be changed to the policy#1 while policy#1 may still be applied in uplink till load of approx. 3 SPU. The dynamic switching of applied policies depending on the load in the network must be realised to provide best possible VoIP quality. Nevertheless, the policy#1 can provide a very acceptable VoIP delay for the whole range of the load in the network.

However, comparing performance of both, ftp and VoIP traffic, the ftp performance provided to users will be not the best in case the policy#5 is applied with low SPU values. To provide the best quality for ftp and VoIP, the policy#1 must be selected. Using this policy the VoIP delay is approx. 10ms in downlink and approx. 20-30ms in uplink while the ftp performance both in downlink and uplink is better than with any other policies. Other selection policies (#2 and #4) show intermediate performance that, however, decreases for VoIP very fast with increasing load.

VoIP delay is not a single VoIP parameter influencing VoIP QoE for users. Another very important parameter is the VoIP jitter. Results for VoIP jitter are not presented in this paper since it is lower than 20ms in both directions using any of the define policies. As a usual buffer of VoIP applications is 40ms, VoIP jitter will not impact the VoIP QoE for wireless users.

The usage of transport resources and buffer lengths at PoANs can be analysed to assess the load of a particular PoAN. Fig. 7 and Fig. 8 depict the load (usage of transport resources) and queue length of both PoANs. The WiMAX PoAN has the maximal load in case the policy#2 is applied since all data in the network are transmitted via it.
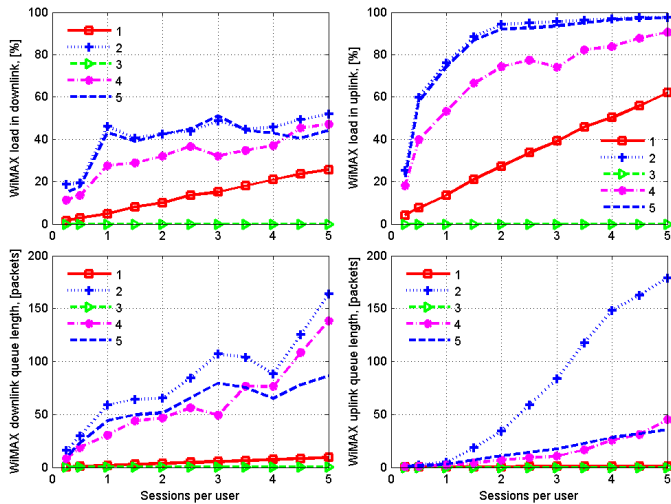
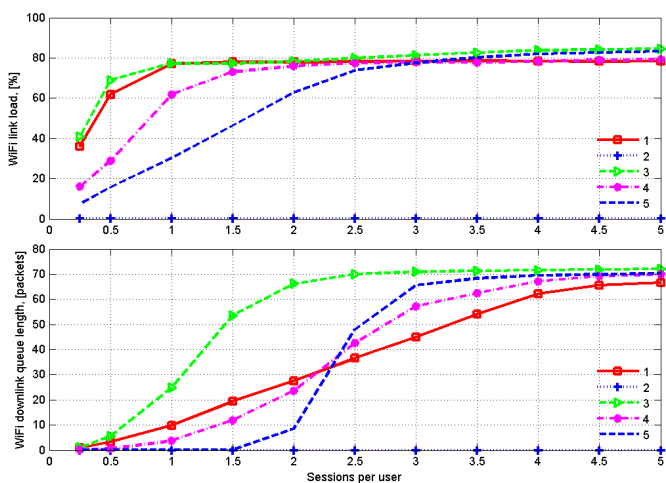Fig. 7 Load of the WiMAX PoAN

Fig. 8 Load of the WiFi PoAN

The same situation can be observed in WiFi when policy#3 is used. Analysing WiMAX load in downlink and uplink it can be seen that the uplink is more loaded than the downlink although the same number of data is exchanged in both directions. It is because fewer OFDM symbols are available for data transmission in uplink (DL:UL ratio is 2:1), also because some OFDM symbols in the uplink are reserved for the ranging and bandwidth request contention intervals. WiMAX load is almost the same for policies #2 and #5. From that it can be concluded that large tcp packets used for ftp data transmission result the main WiMAX load. Smaller VoIP packets may be transmitted without any problems even if the load in the network is high, so that low VoIP delays may be achieved as discussed above. That can be seen in Fig. 7 – the WiMAX load using policy#1 is minimal among all other policies using WiMAX. The load of WiFi link using policy#1 is almost the same as using policy#3 due to large tcp packets.

However, the larger the load of the WiFi link, the more collisions happen. As result, the VoIP performance decreases as Fig. 6 shows. As far as the downlink queue at the WiFi PoAN increases, the VoIP delay in downlink increases proportionally, that can be concluded from figures for WiFi load and VoIP delay in downlink from approx. 1.5 SPU.

Analysing WiFi queue size with policy#1 it can be assumed, that the delay for ftp packets increases proportionally with SPU load factor. However, a small additional delay of ftp packets does not have such a big negative effect on the ftp quality as in the case of VoIP that can be seen from Fig. 5.

From figures with load results it can finally be concluded that the policy#1 is the best one of the defined policies since it causes a higher load in WiFi only. The load of WiMAX base station is, instead, very low so that even more VoIP users (VoIP flows) may be supported using a single WiMAX PoAN.

IV. CONCLUSIONS AND FUTURE WORK

In this paper the idea of the integrated mobility and resource management mechanism for FMC access networks has been presented. Initial evaluations of the mechanism have been performed. From the presented results presented it can be concluded that the policy#1 is the best one for the assumed reference network scenario. However, the main summary of the performed investigations is that firstly, the simultaneous usage of multiple interfaces by wireless users may improve the performance of network services significantly. To improve the provided quality in the network more, the analysis of available QoS resources at particular PoANs is required as defined above. These investigations and implementations in ns2 are currently being performed.

Furthermore, as the next step, the mobility of users must be introduced and investigated to see the benefits of the system while a mobile node changes its location and available QoS for the maintained sessions vary.

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