MBMS Service Provisioning in UMTS/WLAN Heterogeneous Architectures

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Abstract

The support of broadcasting and multicasting as an efficient L3-based service poses rigorous requirements to the next generation mobile communication architectures. When IP multicasting has been seriously considered in mobile systems, soon has emerged the proposal of Multimedia Broadcast Multicast Service (MBMS) for 3G networks and beyond. However, with the spreading of versatile heterogeneous wireless systems, like the cooperation of European 3G (UMTS) and Wireless Local Area Network (WLAN), the problem of wireless IP datacasting arises in more complicated ways. In order to extend MBMS for UMTS/WLAN heterogeneous architectures we approach a novel framework along with a suitable and efficient WLAN MAC extension. In this paper we also evaluate the performance of our proposal using a discrete event simulation environment called OMNeT++.

1. Introduction

As a result of recent years' rapid development in both wired (xDSL, DOCSIS) and wireless (UMTS, WiMAX, WLAN) access networks, heterogeneous network architecture has been created. However, the heterogeneous nature of networks offers a wide range of possible applications. It is important to note that various available access networks enable the users to connect always to that access network which they prefer the most, according to the Always Best Connected (ABC) concept [7]. The access technology selection criteria can be determined by either the terminal (available bandwidth or application requirements) or the end-users' preferences (cost) or even by the network (network management issues). Based on the constructed criteria functions an efficient vertical handover solution should be implemented to achieve the best performance possible. However, not only appropriate vertical handover method is needed to achieve optimal performance, but the applications should also be adapted to the wireless environment. Thus point-to-multipoint applications – such as mobile TV broadcasting – that put serious demands on the scarce radio resources might be modified. Two different point-to-multipoint schemes are distinguished according to the grouping concept of the destination nodes. On one hand in case of broadcasting all the simultaneously connected nodes will receive the packets. On the other hand in case of multicasting certain user groups can be addressed as destination by means of complex registration processes performed by the end-users.

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As a part of the 3GPP task force activity the Multimedia Broadcast Multicast Service (MBMS) concept was created to establish a work frame for the point-to-multipoint downlink bearer service for IP data in UMTS environment [16], [11], [15]. As the UMTS penetration has reached a critical level, research on MBMS service standards was launched to overcome the shortcomings of the already existing Cell Broadcast Service (CBS) and to introduce more sophisticated multicasting and broadcasting. The core concept of MBMS is to save radio resources by sharing them between users belonging to the same multicast group. MBMS relies on the Packet Switched (PS) domain that was set in the GPRS principles [9] but it uses IP protocol in a more sophisticated way, extends the functionalities of RNC, SGSN and the GGSN to offer MBMS services, and introduces a new functional entity called the BM-SC (Broadcast/Multicast Service Center). BM-SC serves as an ingress point for multicast content providers, and manages and sets up the MBMS transport services of the PLMN. If multicast support is enabled in the core network the MBMS services can be even more efficient. In case of multicasting a single bearer can be used by multiple clients that are registered in the same multicast group and MBMS contexts [16] are used to store data about clients and applications to distinguish mobility and MBMS session management. In order to achieve the separation, MBMS uses two different context environments: user equipment context and bearer context.

However, currently there is no standard that could serve as an MBMS extension to other access networks (e.g. WLAN or WiMAX). UMTS offers widespread coverage area and high accessibility and mobility with low delay, but bandwidth remained still fairly low. As a result of low bandwidth the number or the quality of simultaneous MBMS sessions might be limited. WLAN access technology is capable of providing higher bandwidth but only in a smaller coverage area with limited mobility and QoS support. The integration of UMTS and WLAN networks offers a good chance for combining the advantages of the two access technologies.

In order to TSG SA1 workgroup of 3GPP has defined six levels for the UMTS/WLAN interworking. Each level describes the next, more advanced step on the integration path while setting up a flexible and scalable framework to realize full cooperation [1], [8]. The UMTS/WLAN interworking model defined by 3GPP [2] extends the UMTS services to the WLAN network (by inserting the *WLAN Access Gateway* (WAG) and the *Packet Data Gateway* (PDG) nodes into the UMTS reference architecture) and secures AAA functions for the cooperating networks. Despite the fact that 3GPP developed three interworking model (two with roaming and one without roaming support), the handover standards between the different access networks has not been finalized yet thus active connections may be broken when performing vertical handover [4].

The cooperation of wireless technologies should also focus to the specific requirements set by the MBMS framework to use the radio resources most efficiently. Thus more sophisticated value added services based on MBMS structure can be offered. This was our main motivation behind the work of creating a framework suitable for broadcasting and multicasting applications in integrated UMTS/WLAN architectures.

The rest of this paper is organized as follows. In Section 2 the detailed overview of our framework for MBMS service provisioning in heterogeneous UMTS/WLAN systems is described and our MBMS-compatible WLAN MAC protocol is introduced in Section 3. We present our simulation results regarding the performance of our WLAN MAC extension in Section 4, and finally the paper is concluded in Section 5.

2. MBMS Services in UMTS/WLAN Heterogeneous Systems

2.1. The Proposed Architecture

In this section we introduce our proposed framework for providing MBMS services in WLAN segments of 3GPP-defined UMTS/WLAN interworking architectures.

Our proposal modifies the 3GPP architecture itself and extends several functions of different network elements in the basic structure. In our framework PDG is connected to BM-SC through Wi and Gmb interfaces, while MBMS service provisioning processes between PDG and BM-SC are handled in conformity with the corresponding 3GPP MBMS standards. Therefore, PDG must implement all the MBMS-specific functions of GGSN and must hide the characteristics of the WLAN segment. Besides ensuring IP connection between UMTS and WLAN network parts, the extended PDG also controls MBMS service provisioning in the WLAN segment by defining specific mechanisms for accessing MBMS services from WLAN sections of the interworking structure. In order to provide MBMS in UMTS/WLAN heterogeneous systems and to offer Quality of Service for MBMS applications in such architectures, our framework also possesses a novel, MBMS-compatible WLAN MAC multicasting method which is adaptable for the IEEE 802.11e QoS standard as well [18]. Due to substantial differences between broadcast and multicast MBMS modes we discuss the details of our recommended architecture for the two cases separately in two subsections followed by the WLAN MAC protocol and the QoS mapping scheme.

2.1.1. MBMS Broadcast Services

In case of broadcast service provisioning the proposed architecture can be easily derived from the 3GPP UMTS/WLAN interworking architecture because there is no need for bearer-specific user interactions and no MBMS UE context has to be maintained in the network entities. The BM-SC indicates the start of a MBMS broadcast transmission by sending a *Session Start Request* message to the PDG, which creates the MBMS Bearer Context for the service and gets the list of the edge routers located in the WLAN segment from the BM-SC. Based on this list the PDG will build GTP (GPRS Tunneling Protocol) tunnels in order to transmit the MBMS broadcast packets towards the appropriate WLAN networks, then informs the BM-SC about the successful service activation by sending a *Session Start Response* message. If the UMTS operator cooperates with more WLANs, the PDG should take care of multiplying the MBMS packets for every different WLAN networks and – in conjunction with the WAG – transmitting them through GTP tunnels towards the edge routers of each WLAN segment (Figure 1). The edge routers decapsulate the tunneled packets and deliver them to the clients based on IP broadcasting. After detecting the end of the broadcast transmission, the PDG removes the bearer context and initiates the tunnel removal procedures.

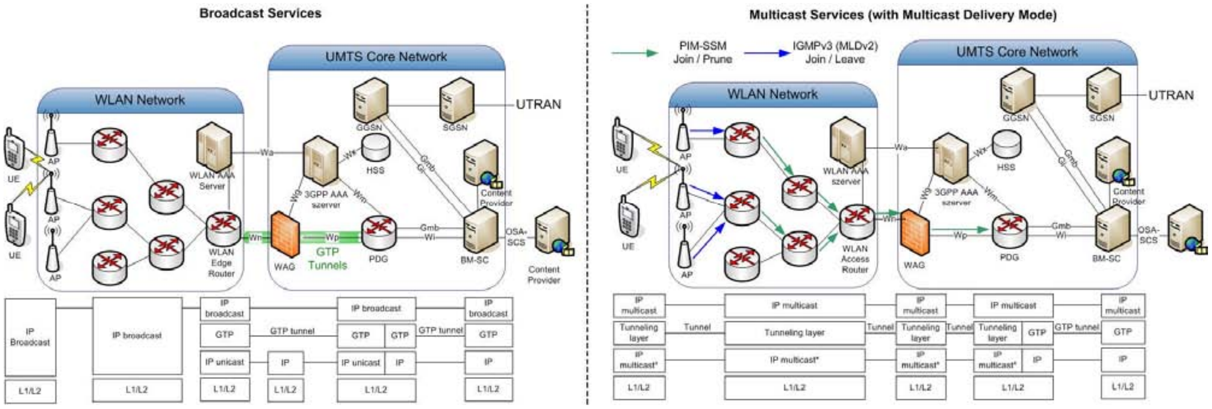


Figure 1. MBMS Service Provisioning in the WLAN Segment of 3GPP UMTS/WLAN Interworking Architectures

2.1.2. MBMS Multicast Services

Serving MBMS multicast requires user interaction (i.e. UE contexts should be taken care of) since clients must explicitly join one or more multicast services. In our framework MBMS multicast service provisioning in WLANs is achieved by extending the functions of PDG: service provisioning phases between BM-SC and PDG are the same as defined between BM-SC and GGSN in 3GPP MBMS standards. A client (i.e. an authenticated and authorized WLAN user) initiates the connection to the service providing UMTS network by acquiring the IP address of the PDG (i.e. the connection point towards the UMTS network part) from the service announcement information (W-APN identifier, multicast address) delivered either by HTTP / FTP mechanisms, MBMS broadcasting or by other push services. Based on the client's subscriber profile and AAA policies of the operator the PDG checks whether the user is authorized to use WLAN 3GPP IP Access services. If yes, a *Remote IP Address* will be assigned to the WLAN client and an IPSec tunnel will be built between the client and the PDG in order to assure a secure channel for MBMS signaling in the UMTS/WLAN architecture. The subscriber creates the MBMS UE context, and then sends an *Activation Request* message expressing its will for joining a given multicast group. After receiving this request, the PDG sends an *Authorization Request* message to the BM-SC which either grants or denies the join request (*Authorization Response*). In case of successful activation the BM-SC and the PDG also creates the MBMS UE context containing the user information of a particular bearer service. If the PDG doesn’t already have the MBMS bearer context with the bearer service data, a *Registration Request* message will be sent towards the BM-SC. Right after the registration took place, the BM-SC adds the PDG to the list of the downstream nodes of the particular MBMS bearer service, and sends the required MBMS bearer context information to the PDG using a *Registration Response* message. After finishing the context activation procedures, the PDG informs the client about the fact of successfully joining the service’s multicast group (*Activation Accept*). The connection build-up procedure and the transmission of MBMS data packets between PDG and WLAN UE may be continued in two different ways (i.e. different delivery modes) depending on the subscriber profile and the available network resources.

2.1.2.1. Unicast delivery mode

If the WLAN network or the WAG / PDG nodes do not support IP multicasting, or the decision logic decides not to use multicast delivery [12], then all the MBMS data traffic will be delivered to the WLAN UE using unicast forwarding within the IPSec tunnel formerly set up between the PDG and the UE. In that case the list of the downstream nodes in the PDG's MBMS bearer context contains the unique identifier of the WLAN UE and the PDG sends the packets towards the UE using an appropriate point-to-point IPSec tunnel. Therefore PDGs are responsible for encapsulating the multicast packets and tunneling them into IPSec tunnels uniquely distinguished by the UEs transport IP addresses. PDGs are taking care of marking the transport packets' DiffServ fields according to the QoS class defined by the BM-SC. The signaling and the data traffic use the same IPSec tunnel between the WLAN UE and the UMTS network. *Deactivation Request* messages are sent by UEs in order to unsubscribe a listened multicast service (i.e. to instruct the PDG to delete the subscriber's MBMS UE context and update the list of downstream nodes) while *Deregistration Request* messages are used by BM-SCs to inform the PDGs about the end of a MBMS transmission and to initiate the removal of all IPSec tunnels and MBMS contexts regarding the ended service. Because of the unicast-based transmission of this delivery scheme, standard unicast can be used in the WLAN MAC layer as well.

2.1.2.2. Multicast delivery mode

MBMS service data can be transmitted towards WLAN UEs using multicast distribution trees if WAG, PDG and routers support IP multicasting. This is what we call multicast delivery mode in our framework: data transmission between PDG and subscribed WLAN nodes is handled using distribution trees identified by specific multicast addresses, thus saving network resources in many scenarios compared to the point-to-point based unicast case (see Figure 1). (Note that the scheme is similar to when multicast-capable core routers are used in a standard UMTS-MBMS architecture for delivering multicast data traffic in order to decrease the load of GGSN and SGSN nodes [16]. However, signaling traffic between UEs and PDG will still pass a unicast IPSec tunnel.) This method assumes that the multicast routers of the WLAN segment support dynamic management of user profile-based exclude and include filtering [6], PIM-SSM protocol [21] and IGMPv3 or MLDv2 group management mechanisms [3], [20].

In multicast delivery mode the subscriber UE will get the service data throughout a distribution tree, thus PDG should insert a special multicast address (belonging to the successfully accepted MBMS service) into the *Activation Accept* message which will be sent towards the WLAN UE. Handling the special multicast addresses and managing the exclude and include filters in cooperation with the AAA server is also a task of the PDG: multicast routers of the WLAN segment must be informed about whether a particular user has the rights of joining a bearer service or not (i.e. whether the IGMP / MLD *join* messages should be accepted by the routers). If the subscriber gets the green light, the PIM-SSM distribution tree can be established from the Last Hop Routers to the PDG. Note that all the required information (IP address of PDG and the special multicast address) is given for this procedure by the *Activation Accept* message.

After the distribution path has been set up, the PDG addresses the multicast packets arriving from the BM-SC with the special multicast address belonging to the particular MBMS service. Therefore, during MBMS multicast services, packets between PDG and WLAN UEs are delivered using the special multicast address of the distribution tree in the *Transport IP Layer*, while multicast group addresses used by the BM-SC will be applied as *Remote IP Addresses*. It is important, that the list of the downstream nodes in the PDG's MBMS bearer context contains the addresses of multicast routers forming the distribution tree and not the addresses of WLAN UEs as in unicast delivery mode. If a client wants to unsubscribe a MBMS bearer service, it uses an IGMP / MLD *leave* message for leaving the special transport layer multicast group, then sends a *Deactivation Request* message to the PDG in order to remove its MBMS UE context and update the BM-SC. Provided that the removed MBMS UE context was the last one on a particular MBMS service, the PDG removes the MBMS bearer context as well and sends a *Deregistration Request* message to the BM-SC resulting in the deletion of the distribution tree and the IPSec tunnels right after receiving the *Deregistration Response* answer.

The WAG entity is an organic part of the distribution tree: supports IP multicasting mechanisms by forwarding / filtering the signaling and data packets according to the network policies. Furthermore, if the multicast-capable routers of the WLAN and UMTS segments constitutes only non-continuous islands, the WAG and the edge router of the WLAN segment are responsible for transmitting the multicast data through the sets of non-multicasting routers using traditional unicast communication. The peformance of the multicast delivery could be improved if L2 switches in the WLAN segment support IGMP snooping [5], thus instead of L2 flooding a rational interface-selection scheme can be used.

In order to preserve the advantages of the IP layered multicast delivery on the air interface as well, our framework contains an efficient, MBMS-compatible WLAN MAC protocol.

3. WLAN MAC extensions for MBMS services

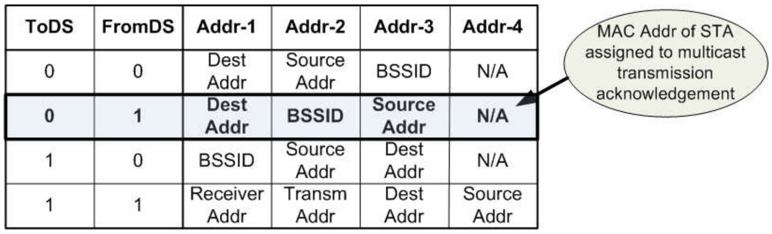
3.1. MBMS-compatible WLAN MAC protocol

The 802.11 standards define the physical and the MAC layer of the WLAN networks [10], but they suffer from several undesired properties concerning multicasting or broadcasting applications. The dynamic medium access, the fading in signal level and the mobility cause frequent and high variation of the transmission channel. Due to the rapid and random fluctuation the exact capacity is not known in advance. Apart from challenges of the radio channel the difference of subscribers is also a difficulty in proper unified multicast service provisioning.

Due to the previously mentioned reasons the packet loss in WLAN segment can be high so the quality of MBMS streaming applications is significantly degraded making them unenjoyable.

We propose a WLAN MAC multicast transmission method that applies acknowledgement-based retransmission technique for diminishing the packet error ratio on the WLAN air interface and mainly considers the requirements of delay-sensible MBMS streaming applications. The solution is based on the following mechanism. In the header of the multicast packet the WLAN access point assigns a receiver that has to send acknowledgement as the leader of the multicast group. The leader is selected by round-robin or other methods and this role is valid for only the transmission of actual multicast frame. In case weights are assigned for each member of the group and the leader is selected according to these weights then the transmission can be optimized for a given subset of subscribers, depending on the decision algorithm.

Most of the multicast algorithms in the literature (e.g. [19], [13], [14], [22]) add new control frames or significantly modifies the control and data messages, therefore their usage would be rather circumstantial. To avoid this problem we elaborated a multicast mechanism that is based on the usage of WLAN MAC address fields saying only three of the four address fields are set (see Figure 2) by the AP if the data source is outside the WLAN distribution network, i.e. the actual AP-AP transmission can be excluded (ToDS=1 and FromDS=1). Thus the AP can use the fourth address field to mark the leader station for acknowledging during the transmission of unidirectional multicast MBMS services.



ToDS	FromDS	Addr-1	Addr-2	Addr-3	Addr-4
0	0	Dest Addr	Source Addr	BSSID	N/A
0	**1**	**Dest Addr**	**BSSID**	**Source Addr**	**N/A**
1	0	BSSID	Source Addr	Dest Addr	N/A
1	1	Receiver Addr	Transm Addr	Dest Addr	Source Addr

Figure 2: Overview of WLAN Addresses in our Scheme

According to the timeout restriction of transmission of streaming MBMS services in case of multicast transmission the AP sets a retransmission threshold, which enables only a few retransmissions at most, thus by making a tradeoff between the delay and packet loss. The large transmission delay can be avoided and the reliability of the multicast transmission mode becomes higher. If the leader (responsible for acknowledging) leaves the multicast group without notifying the AP during MBMS transmission, the traffic will not be clogged because the AP reaches the retransmission threshold within a short time.

In case the AP receives a multicast frame with empty *Address 4* field then one member of the multicast group is selected. This station has to send acknowledgement during the transmission of the multicast frame.

If the multicast packet is larger than the RTS threshold then the AP first sends an RTS message to the selected leader that has to reply with CTS control message if it is ready to receive the data and the channel is clear (see Figure 3). If the AP does not receive the answer within SIFS time then the multicast retransmission counter is increased and the back-off period is started. In case the number of retransmissions exceeds the multicast retransmission threshold the AP deletes the multicast packet from its buffer and tries transmitting the next queued frame and selects a new leader. The back-off interval is enlarged in parallel with the increasing number of retransmission attempts, i.e. the multicast traffic is also involved in the binary exponential back-off algorithm. Meanwhile, the multicast threshold is lower than the limit for unicast mode, therefore the multicast transmission has an upper edge on the unicast traffic to ensure the time requirements.

If the multicast packet is smaller than the RTS threshold, i.e. the data frame is short, then the RTS/CTS mechanism is skipped but the multicast frames transmitted in the same way as in case of packet transmissions with RTS/CTS control messages.

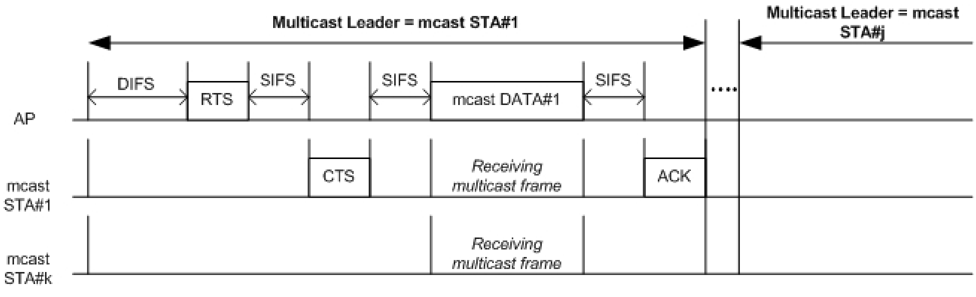


Figure 3: Successful transmission with RTS/CTS mechanism

3.2. MBMS QoS Mapping in the WLAN Segment

Mapping the QoS classes defined in the 3GPP UMTS standards to the WLAN segment of an UMTS/WLAN heterogeneous architecture is not easy because the traffic parameters of an UMTS and a WLAN network are very different preventing the possibility of exact projection [23]. The QoS requirements of MBMS services are defined by the BM-SC, and the same QoS level should be provided for every subscribed client. In our framework, the MBMS bearer service built up in the UMTS segment is responsible for the QoS provisioning between PDG and BM-SC, while the QoS mapping between heterogeneous networks follows the recommendations of the 3GPP UMTS/WLAN interworking standards (i.e. the UMTS traffic class used in a MBMS service will be denoted to the WLAN segment by marking the DiffServ field of IP packets [2], however, MBMS services use only the unidirectional *background* and *streaming* classes of UMTS standards). The QoS level derived from the DS field of IP packets can be sustained based on 802.1D's 802.1p tags in the L2 distribution network of the WLAN segment [2]. IEEE 802.11e compatible WLAN interfaces define four categories for QoS provisioning of WLAN data frames, while 802.1D supports mapping of traffic classes into access queues. Therefore, the 802.1p tags indicating the QoS classes of MBMS services can be mapped into 802.11e access queues.

Our WLAN multicasting method is compatible with this 802.11e-based mapping scheme. The priority of the multicast traffic can be ensured by appropriate traffic class selection during the virtual contention within each terminal. Apart from this, the priority also should be ensured in the medium during the “real contention” period. We can solve the problem with adequate CIFS time setting. In 802.11e the highest priority class uses SIFS+ 1 timeslot length for transmission. To ensure priority the CIFS should be selected smaller that this time period (but larger than SIFS).

4. Simulation Results

This section presents the performed experiments to evaluate the performance of our proposed WLAN MAC multicasting mechanism designed to accommodate MBMS services in UMTS/WLAN heterogeneous architectures. Based on the INET subsystem of the public-source OMNeT++ discrete event simulation framework [17], we modeled and implemented our novel MAC protocol and compared its performance to the standard 802.11 multicast solution. The INET's WLAN Medium Access Control, the WLAN AP management layer, and the WLAN air interface were modified and extended in order to fit the simulator code for handling multicast frames in accordance with both the 802.11 standard and our MAC solution. Our simulation model is based on one 802.11b WLAN cell operating in infrastructure mode with one Access Point, 15 randomly positioned multicast clients were continuously moving inside the cell, and 2 traditional unicast WLAN clients were responsible for generating unicast load. The model contains one multicast service provider (i.e. multicast source) creating downstream MBMS flows of 500 byte sized packets in constant bitrate. The flows arrived at the Ethernet interface of the WLAN AP were aired into the cell using the following parameters:

- *thermal noise level* / *receiver minimum input level sensitivity*: -100dBm / -80 dBm,
- *maximal output power*: 2mW,
- *radio data rate*: 11 Mbps,
- *mobile terminal velocity*: 2 m/sec,
- *multicast retransmission threshold*: 1 with Random Leader Selection.

During our simulations we analyzed the multicast packet loss introduced at the link layer, the average end-to-end delay of multicast frames and the delay variation under varying unicast background traffic conditions and three different MBMS streaming rate (48, 192, and 386 kbps).

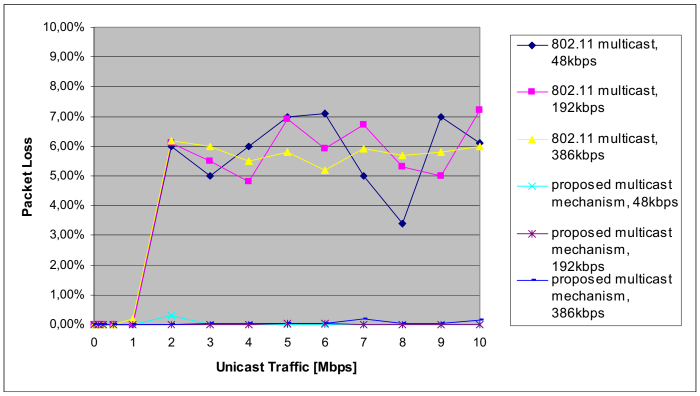


Figure 4: Packet loss of Multicast Transmission

Figure 4 shows the packet loss as a function of different unicast load in a WLAN cell. One can recognize that the packet loss is still infinitesimal in case of 802.11 WLAN defined unacknowledged multicast transmission when the background unicast traffic is low. However, independently from the multicast data rate if the unicast load becomes heavier the packet loss suddenly rises, which is caused by the frequent collisions with acknowledged unicast traffic. In spite of this fact, our proposed algorithm in the lack of acknowledgement resends the lost multicast frame when the back-off time expires and the channel is clear. Thus the rate of unsuccessful transmissions heavily degraded, however, we still had some lost packets. The reason was the occasionally exceeded retransmission threshold and the dropped frames, or the valid leader acknowledgement while some other stations had lost packets due to bad radio conditions.

The average end-to-end delay is represented in Figure 5. One can observe that the heavier the unicast traffic, the longer the transmission time towards the multicast receivers due to the larger number of waiting packets queued in the AP's buffer caused by the more burdened medium. The lower rate multicast traffic suffers from lower average end-to-end delay since it generates lower load for the channel and the AP. Compared to the 802.11 standard defined multicast transmission in case of our method the delays are slightly higher. The reason of this phenomenon is the incremented back-off interval after a loss of acknowledgement from the leader station. The significant growth of transmission delay is obstructed by the low retransmission threshold for multicast data.

Figure 5 also illustrates the maximum of delay fluctuation (jitter). In case of low load the fluctuation is also low, but when the unicast background traffic exceeds 2 Mbps the jitter suddenly becomes high because the multicast frames are buffered for longer time while the preliminary queued data is transmitted, furthermore the channel is also more often detected to be occupied.

In case only a few packets are buffered beforehand the multicast frame, the transmission can be performed fast and the time difference between the multicast receptions can be quite low. Based on these facts the jitter can take its values from a relatively large range. In most of the cases the 802.11 standard defined multicast mode ensures lower jitter upper bound related to our method. This can be explained with the incremented back-off interval of our multicast transmission solution when error is detected.

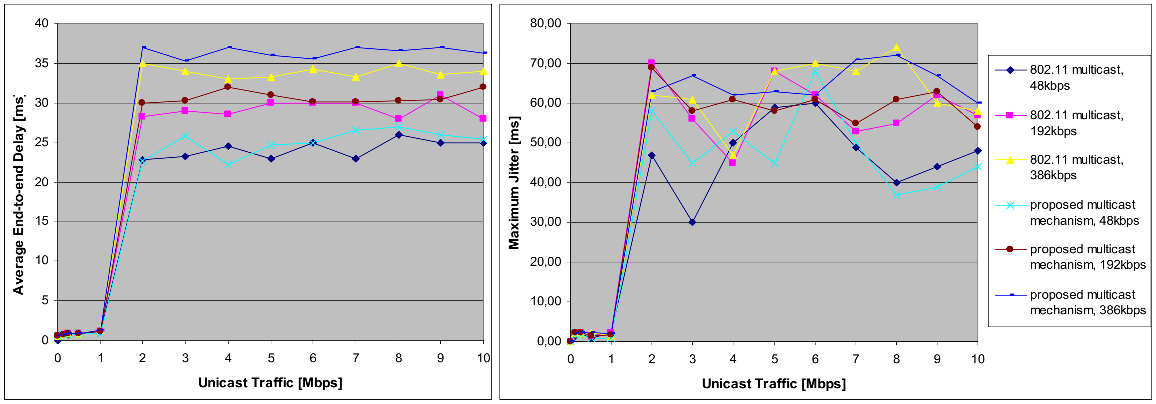


Figure 5: Average multicast end-to-end delay and Maximal Jitter values of multicast frames

5. Conclusions

In this paper we have proposed a novel framework which is suitable for MBMS service provisioning in WLAN segment of interworking heterogeneous UMTS/WLAN networks based on the 3GPP defined model. The integration of UMTS/WLAN architectures with MBMS offers a good chance for combining the advantages of multicasting and the two access technologies. A significant advantage of our framework is that no BM-SC modification is needed.

As a part of our framework we have proposed an appropriate WLAN medium access mechanism to ensure reliable an efficient multicast transmission in the WLAN segment. The protocol was modeled in INET subsystem of the OMNeT++ simulation environment. In order to examine the performance of our WLAN multicast method we have performed several simulations and compared the multicast solution defined by the 802.11 standard. Results show that the elaborated multicast protocol ensures efficient protection against the high packet loss of multicast frames in the WLAN air interface and also show that the delay of multicast transmission is only slightly increased compared to the 802.11 defined method. Thus our protocol can be applied even in case of delay-sensitive traffic.

The most important possible development is the evaluation of the proposed WLAN MAC protocol by further simulations, especially the examination of time dependent characteristic and packet loss for different higher layer traffic (e.g. RTP). It is also worth examining the performance within different channel condition, for instance in modulation changing situation when adaptive modulation is applied. The mapping between UMTS and WLAN QoS can also be the subject of further analysis.

Acknowledgement

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