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An Efficient Mechanism for UMTS Multicast Routing

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Abstract In this paper, we present a novel scheme for the multicast transmission of data over Universal Mobile Telecommunications System (UMTS) networks. Apart from the normal multicast transmission over UMTS, we consider the handling of exceptional cases caused by user mobility scenarios. The proposed scheme is in accordance with the current specifications of the Multimedia Multicast/Broadcast Service (MBMS) defined by the 3rd Generation Partnership Project (3GPP) and introduces minor modifications in the UMTS architecture and the mobility management mechanisms. The proposed scheme is implemented as an ns-2 network simulator module. The performance of the proposed scheme is validated and analyzed through ns-2 simulation experiments. This new module can be employed to investigate various aspects of UMTS multicast. Furthermore, in order to further highlight the contribution of our mechanism, we have implemented two multicast congestion control mechanisms for UMTS and we have measured their performance for MBMS transmissions.

Keywords modeling · simulation · multicast · UMTS · MBMS

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Acronyms

BM-SC	Broadcast Multicast-Service Center
CN	Core Network
GGSN	Gateway GSN
GPRS	General Packet Radio Service
GSN	GPRS Support Node
HLR	Home Location Register
MBMS	Multimedia Broadcast/Multicast Service
PDN	Packet Data Networks
RNC	Radio Network Controller
RNS	Radio Network Subsystem
SGSN	Serving GSN
UE	User Equipment
UTRAN	UMTS Terrestrial Radio-Access Network

1 Introduction

UMTS constitutes the third generation (3G) of cellular wireless networks which aims to provide high-speed data access along with real time voice and video calls. In parallel, wireless data is one of the main motivations of the next generation standards [4]. Along with the widespread deployment of the third generation cellular networks, the fast-improving capabilities of the mobile devices, content and service providers are increasingly interested in supporting multicast communications over wireless networks and in particular over UMTS.

Multicast is an efficient method for data transmission to multiple destinations. Its advantage is that the sender's data are transmitted only once over the links which are shared along the paths to a targeted set of destinations. Data duplication is restricted only in nodes where the paths diverge to different subnetworks [2]. 3GPP identified the need for multicast routing in UMTS networks and started the standardization of MBMS framework [1]. Several researchers [2, 5, 6, 17] have investigated the requirements and proposed mechanisms for the multicast transmission over UMTS networks. However, the performance of the proposals was assessed through analytical models and processes. No simulation experiment has been conducted to validate the service provision with the impact of user mobility over the service continuity.

In this paper, we present a novel scheme for the multicast transmission of data over UMTS networks. This scheme is the major contribution of this work and has been designed with respect to the current specifications of the MBMS service defined by the 3GPP. The design of our scheme has been done in a way that minimizes the transmitted packets and makes efficient use of the network resources. Apart from the normal multicast transmission of data over UMTS, we considered the handling of special cases caused by user mobility scenarios. User mobility is the distinctive feature of cellular networks and it is our belief, and the motivation behind our study, that user mobility situations are of major importance for mobile networks and must be thoroughly examined through simulation. Our proposed scheme can cope with the user mobility without any disruption of the service provision or any packet loss. It was our major goal to develop an easily deployed scheme that introduces just minor modifications in the UMTS architecture and the mobility management mechanisms that exist for unicast data transmission [1].

The other aspect of this work is that this scheme has been implemented as a new module in the widely used ns-2 network simulator [7]. This new module was used to evaluate our proposed routing scheme. It is important to highlight that our contribution is a platform that could be employed by researchers to validate and analyze multicast mechanisms over UMTS networks. Some areas of active research that may be boosted by the deployment of our module are MBMS service congestion control, UMTS multicast group management, multicast radio resource management, MBMS Quality of Service (QoS), and analysis and testing of mobility scenarios. To demonstrate the contribution of the proposed mechanism, we have implemented two single layer multicast congestion control mechanisms for UMTS, namely TCP-Friendly Multicast Congestion Control (TFMCC) and Pragmatic General Multicast Congestion Control (PGMCC) and we have measured their performance for MBMS transmissions.

This paper is structured as follows: Section 2 presents the motivation behind our study and the related work in the specific field, while Section 3 presents an overview of the standardized MBMS service provision. In Section 4, we analyze the design of the proposed scheme. Section 5 describes the implementation of this new scheme in ns-2. Section 6 is presents the simulation results. Finally, the planned next steps and the concluding remarks are briefly described in Section 7 and Section 8 respectively.

2 Motivation and related work

Although UMTS networks offer high capacity, the expected demand will certainly exceed the available resources. Thus, the multicast transmission over the UMTS networks constitutes a challenge and an area of research. Actually, the adoption of multicast routing over mobile networks poses a different set of challenges in comparison with multicasting over the Internet. First, multicast receivers are non-stationary, and consequently, they may change their access point at any time. Second, mobile networks are generally based on a well-defined tree topology with the non-stationary multicast receivers being located at the leaves of the network tree. The construction of a source-rooted shortest-path tree over such a topology is trivial and may be achieved by transmitting only a single packet over the paths that are shared by several multicast recipients. However, as a result of user mobility, there are several cases where this simplified view of the mobile network is violated. It is therefore not appropriate to apply conventional IP multicast routing mechanisms in UMTS, since they are not designed to take into account the need for mobility management that mobile networks require.

Due to the above reasons, the research work presented in [5], that analyses the use of commonly deployed IP multicast protocols in UMTS networks, could not be efficiently implemented in UMTS networks. In particular, the presented multicast mechanism is based on the standard hierarchical tunneling of UMTS for distributing multicast packets to the multicast users. This means that each tunnel may only be established for a single subscriber. Considering a group of N multicast users, a single multicast packet must be duplicated and transmitted N times throughout the network in order to reach all destinations. Depending on the distribution of the multicast users within the coverage area, this may lead to an inefficient usage of network resources.

A solution to the above described problem is presented in [6] and [15]. The authors, in order to overcome the one-to-one relationship between a single subscriber and a GPRS Tunneling Protocol (GTP) tunnel that is inherent to the hierarchical routing in UMTS, implement a Multicast-Packet Data Protocol (M-PDP) context for each multicast group in the GGSN and SGSN. Furthermore, the authors propose the introduction of a number of new tables in GGSN, SGSN and RNC, while for multicast packet forwarding some trivial changes in the GTP are required.

The author in [17], analyzes two basic approaches for the implementation of MBMS in a UMTS network. The main idea of both approaches is to overcome the gap between the current service support in a UMTS network on one side and the current support for multicasting in IP networks on the other. The first approach modifies already implemented procedures in UMTS network and defines new ones to support IP multicasting within the UMTS. The second approach uses existing functionality provided by the UMTS network to bring current IP multicasting support from IP networks, as close as possible to the end-users.

However, the performance of the above presented proposals was assessed through analytical models and processes. No simulation experiment has been conducted to validate the service provision along with the impact of user mobility over the service continuity for MBMS transmission. Our study focuses on this direction and in this paper we present a mechanism for the multicast transmission of data over UMTS networks. Our proposed scheme is implemented as an ns-2 network simulator module. The design of our scheme has been done in a way that minimizes the transmitted packets and makes efficient use of the network resources. Furthermore, the mechanism, except for the basic multicast packet forwarding functionality, incorporates multicast group management and mobility management functionalities. Additionally, the scheme is in accordance with the current specifications of the MBMS service defined by the 3GPP and introduces minor modifications in the UMTS architecture and the mobility management mechanisms.

To sum up, the goal achieved by this work is threefold. At a first level, since no simulation experiment has been conducted to validate the service provision along with the impact of user mobility over the service continuity for MBMS transmissions, our mechanism provides a realistic approach for multicast packet forwarding in UMTS that could be used for validation and testing of MBMS service provision. At a second level, we would like to highlight that our contribution is an ns-2 module for multicast routing in UMTS that could be employed by other research groups to validate and analyze multicast mechanisms over UMTS networks. Some areas of active research that may be boosted by the deployment of our module are MBMS service congestion control, UMTS multicast group management, multicast radio resource management, MBMS QoS, and analysis and testing of mobility scenarios. At a third level, our mechanism is in accordance with the 3GPP specifications regarding the MBMS framework but furthermore, it incorporates several basic and compulsory enhancements. The innovation of our work stems from the novel routing algorithm and the introduction of a module that bridges the UMTS network simulation and the multicast data transmission in the widely used ns-2 network simulator.

3 Overview of UMTS and MBMS

3.1 Basic UMTS architecture

The basic UMTS network architecture is split in two parts: the User Equipment (UE) and the Public Land Mobile Network (PLMN). The PLMN is further divided into two land-based infrastructures: the UMTS Terrestrial Radio-Access Network (UTRAN) and the Core Network (CN) (Fig. 1). The UTRAN handles all the radio-related functionalities. The CN is responsible for maintaining subscriber data and for switching voice and data connections.

The UTRAN consists of two kinds of nodes: the Radio Network Controller (RNC) and the Node B. The Node B constitutes the base station and provides radio coverage to one or more cells (Fig. 1). A single RNC and the Node Bs which it controls constitute a Radio Network Subsystem (RNS).

The CN is logically divided into the Circuit-Switched (CS) domain and the Packet-Switched (PS) domain. All of the voice related traffic is handled by the CS-domain, while the PS-domain handles the transfer of data packets. The PS-domain is more relevant to the multicast data transmission which is the scope of this paper and, therefore, in the remainder we focus on the PS-functionality. The PS-domain of the CN consists of two kinds of General Packet Radio Service (GPRS) Support Nodes (GSNs), namely the Gateway GSN (GGSN) and the Serving GSN (SGSN). The SGSN is the centerpiece of the PS-domain. It provides routing functionality, it manages a group of RNSs and interacts with the Home Location Register (HLR) which is a database permanently storing subscribers' data. The GGSN provides the interconnection between the UMTS network and the other Packet Data Networks (PDNs) such as the Internet [4, 8].

3.2 MBMS framework

The basic MBMS architecture is almost the same as the existing UMTS architecture in the PS-domain. The most

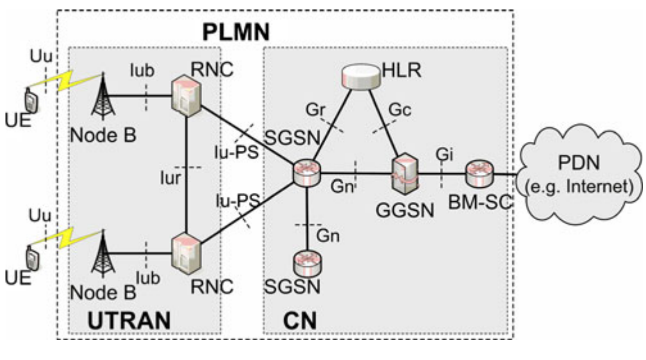


Fig. 1 UMTS architecture for MBMS service

significant modification is the addition of a new node called Broadcast Multicast–Service Center (BM-SC) (Fig. 1). In this node, the MBMS data are scheduled and interfaces are provided for the interaction with the content provider. In order to reduce the implementation costs, the intention of the 3GPP is to limit the changes introduced in the existing radio and core network architectures. For simplicity reasons, in our analysis we consider the functionality of the BM-SC incorporated in the GGSN [9].

There are two types of MBMS service mode: the broadcast and the multicast. In broadcast mode, data are delivered to a specified area without knowledge of the receivers and whether there is any receiver at all in this area. However, in the multicast mode the receivers have to signal their interest for the data reception to the network and then the network decides whether the user may receive the data or not. Since the multicast mode is more general than the broadcast one, we present the operation of the MBMS multicast mode and the way that the mobile user receives multicast data. The reception of an MBMS multicast service is enabled by certain procedures. These are: Subscription, Service Announcement, Joining, Session Start, MBMS Notification, Data Transfer, Session Stop and Leaving (see Fig. 2). The phases Subscription, Joining and Leaving are performed individually per user, while the other phases are performed per service. The sequence of the phases may be repeated, depending on the need of transferring data. Moreover, Subscription, Joining, Leaving, Service Announcement and MBMS Notification may run in parallel to other phases.

More specifically, during the Subscription phase a relationship is established between the user and the service provider. This relationship allows the user to receive the MBMS multicast service. The phase that follows is the Service Announcement. During the Service Announcement the users are informed about the range of the available MBMS user services. Joining is the phase during which the subscriber becomes member of a multicast group. Session Start phase triggers the bearer resource establishment for Data Transfer. During the MBMS Notification phase, the users are informed about forthcoming MBMS Data Transfer. The transmission of the multicast data takes place during the Data Transfer phase. After the data transmission, there is the Session Stop phase when the GGSN determines that there is no more data to send and initiates the release of the bearer. Finally, if a subscriber wants to quit the multicast group membership, he proceeds to the Leaving phase [1].

Fig. 2 Phases of MBMS multicast service provision

4 The proposed scheme

In this section, we present the scheme for the multicast transmission of data over UMTS. Furthermore, we analyze the handling of special cases caused by user mobility scenarios. Our analysis is based on the MBMS system architecture [1, 9]. For the sake of simplicity, and without the loss of generality, we consider that the GGSN incorporates the functionality of the BM-SC.

4.1 Packet forwarding mechanism

If we consider the GGSN node as root then we may conclude that the network topology of the UMTS has a tree-like form (see Fig. 7). Our multicast mechanism takes advantage of the tree-like topology of the UMTS networks and introduces Routing Lists (RLs) in every node of the network apart from the UEs. In the RL of a node, information is kept about which nodes of the lower level connect the current node with the UEs belonging to a specific multicast group. Consequently, there is one RL for each multicast group in each node (except for the UEs). The packet forwarding during the Data Transfer phase is based on the RL processing in each node. If an incoming multicast packet, reaches a node, the corresponding RL is scanned. If RL is non-empty, the packet is duplicated and is transmitted once to each lower-level node existing in the RL. This procedure is repeated recursively in the lower-level nodes until each copy of the packet reaches its destination.

At this point, we must mention the existence of two other kinds of lists. Additionally to the RLs, the Drift Routing Lists (DRLs) are used in the RNCs and the Multicast Group Lists (MGLs) in the GGSN (Fig. 3). The DRLs are lists which are used when inter-RNS soft handover has occurred. Each DRL corresponds to a multi-

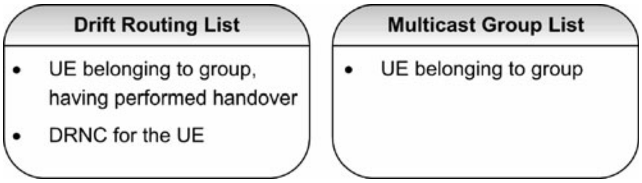


Fig. 3 Additional types of lists

cast group and contains pairs of RNC-UE. The multicast transmission over the Iur interface (see Fig. 1) is achieved through the DRLs and will be thoroughly explained in Section 4.3. Each MGL corresponds to a specific multicast group and maintains the UEs belonging to the group. These lists enable GGSN to retrieve the UEs belonging to a specific multicast group. Obviously, MGLs and RLs are not static elements but they are updated each time a UE joins or leaves a multicast group or when user mobility events transform the mobile network topology.

4.2 Multicast group management

Consider a UMTS network providing an MBMS service. Suppose that a UE has completed the Subscription phase and wants to join a multicast group provided. In this case, the Service Announcement phase is executed. UE sends a message to the GGSN, requesting the list of available multicast groups. When the message reaches the GGSN, the GGSN sends a reply message to the UE with the available multicast groups and the Service Announcement phase ends. The UE decides which multicast group(s) wants to join in. Figure 4 describe the steps of our scheme's Joining phase.

1. The UE sends a join-request message to the GGSN, specifying the multicast group mg in which the UE wants to join in.
2. The GGSN checks the subscription profile. If we suppose that the GGSN accepts the request, the UE is added in the corresponding MGL. Then, it checks if the SGSN which serves the UE, exists in the relevant RL. If it does not exist, it adds it in the RL. Finally, the GGSN sends an acknowledgement message to the serving SGSN.
3. When the SGSN gets the acknowledgment, it examines if the serving RNC of the UE exists in the RL that it maintains for the multicast group. If the RNC does not exist, the SGSN adds it in the RL. Then it forwards the acknowledgment to the RNC.
4. When the RNC gets the acknowledgment, it adds the UE in the proper RL and forwards the acknowledgment to the UE.

When the UE receives the acknowledgment, the establishment of the context has been confirmed.

On the other hand, when a UE decides to leave a multicast group, the Leaving phase takes place. The message sequence during this phase is similar to the one described above.

1. The UE sends a leave-request message to the GGSN, specifying the multicast group in which the UE wants to quit.
2. The GGSN removes the UE from the corresponding MGL. Then, it examines if there is another UE in the MGL which is served by the same SGSN. If there is none, the SGSN is removed from the relevant RL. Finally, the GGSN sends an acknowledgement message to the SGSN.
3. When the SGSN receives the acknowledgment, it examines if there is another UE which is served by the RNC and participates in the mg. If there is none, the RNC is removed from the RL. Then, the SGSN forwards the acknowledgement to the RNC.
4. When the RNC gets the acknowledgment, it removes the UE from the relevant RL and forwards the acknowledgment to the UE.

The UE receives the acknowledgment and the procedure is completed. When the procedure is completed, the UE is not member of this multicast group and future packets for this multicast group will not be transmitted to this UE.

4.3 User mobility handling

Consider a UE that is a member of a multicast group and a MBMS multicast service provision that is in the Data Transfer phase. While the multicast packets are being transmitted to the members of this multicast group, the specific UE moves into another cell. Supposing that this cell is controlled by a different RNC, an inter-RNS soft

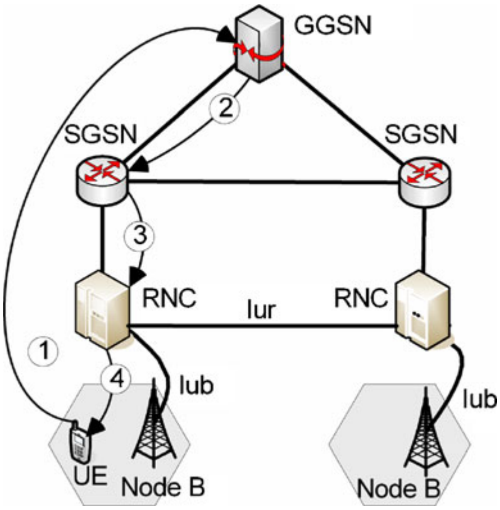


Fig. 4 Joining/leaving phase

handover will be performed. In this case, the UE receives data simultaneously from the two involved Node Bs. The basic concept of inter-RNS soft handover is that the handover is transparent to the SGSN(s). Thus, when inter-RNS handover takes place the data are transmitted through the Iur interface (Fig. 1). The proposed mechanism introduces the DRLs for the multicast transmission over the Iur interface. Multicast over the Iur interface takes place when multiple handovers from the same source RNS to the same target RNS have occurred.

The source RNC is called Serving RNC (SRNC) and the target RNC is called Drift RNC (DRNC). Figure 5a describes the steps of the inter-RNS soft handover procedure. The proposed mechanism is based on the existing handover procedure of UMTS but it incorporates several extensions in order to assure MBMS service continuity. These extensions are pointed out during our analysis.

1. The SRNC decides to make a handover based on the measurements from the UEs. An Iur connection is established between SRNC and DRNC and the SRNS requests radio link.
2. If radio resources are available, the DRNC forwards the request to the Node B in which the new cell belongs.
3. When the allocation of the radio resources is completed, the Node B sends an acknowledgement message to the DRNC and starts receiving uplink data from the UE. When the DRNC gets the acknowledgement, it adds the UE in the RLs related to the multicast groups that the UE belongs. Then, the DRNC forwards the acknowledgment to the SRNC.
4. When the SRNC gets the acknowledgment, it inserts the UE/DRNC pair in the DRLs related with the multicast groups that the UE belongs in.
5. Finally, the UE is informed of the handover and receives the connection information. Now the UE receives the same data from the two involved Node Bs.

Regarding the packet forwarding mechanism, an additional check must be made in the RNCs. This new functionality is related to the existence of the Iur connections and it is based on the DRLs processing. In more detail, if a multicast packet reaches an RNC, not only the corresponding RL but also the corresponding DRL is scanned. If DRL is non-empty, the packet is duplicated and is transmitted once to each DRNC existing in the DRL. These transmissions are made over the corresponding Iur interfaces and follow the multicast forwarding concept. If a UE has performed subsequent handovers, multiple DRNCs correspond to its connection. In that case, this procedure is repeated recursively in the DRNCs until of the packet reaches the last DRNC. Finally, this DRNC will transmit the packet to the UE.

Consider the previous scenario and suppose that, after a time interval, the UE is outside the coverage area of its first cell. In this case, a SRNS relocation procedure is triggered. This procedure is used to move the UTRAN-to-CN connection point from the SRNC to the DRNC. If the DRNC is connected to the same SGSN as the SRNC, an intra-SGSN SRNS relocation procedure is performed. Otherwise an inter-SGSN SRNS relocation procedure takes place. Figure 5b illustrates the latter case which is the most general of the two. Note that the proposed mechanism uses existing mobility management mechanisms but with several extensions for multicasting.

1. The current SRNC detects that SRNS relocation of the UE to a DRNC is needed. The SRNC sends a “relocation required” message to the old SGSN which

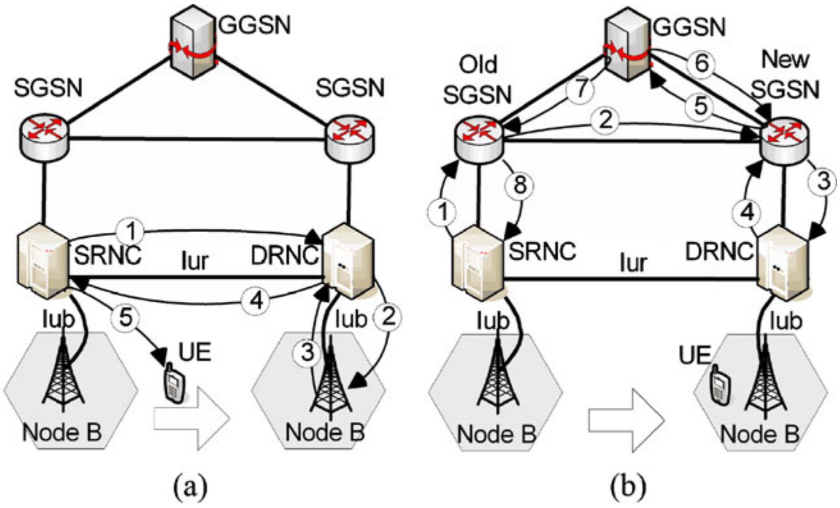


Fig. 5 User mobility handling: **a** inter-RNS handover and **b** inter-SRNS relocation

indicates that the SRNC is the source RNC and the DRNC is the target RNC.

2. The old SGSN sends message “relocation request” to the new SGSN. Additionally, the new SGSN gets aware of the multicast groups in which the UE participates. The MBMS related context is also transferred.
3. The new SGSN sends message “relocation request” to the target RNC. The target RNC is informed by the new SGSN in which multicast groups the UE belongs. Finally, the target RNC performs an update of the relevant RLs, although this is not mandatory because the UE has already been inserted in the RLs during the soft handover procedure
4. A “relocation-ack” message is sent from the target RNC to the new SGSN. The new SGSN examines each RL related with the multicast groups that the UE participates. If the target RNC is not contained, it is added in the RL.
5. The new SGSN creates MBMS bearer context and registers on the GGSN. The GGSN examines each RL related with the multicast groups that the UE participates. If the new SGSN is not contained, it is added in the RL.
6. GGSN notifies the new SGSN of the UE registration. The connection is now switched from old SGSN to new SGSN.
7. The GGSN notifies the old SGSN that the service is deregistered for the specific UE. The old SGSN examines each RL related with the multicast group that UE participates. If there is no other UE which is served by the source RNC and participates in the corresponding multicast group, source RNC is erased from the RL.
8. The source RNC is notified by the old SGSN that relocation is completed. All the records containing the UE are removed from all the DRLs and RLs of the source RNC. From now on the target RNC is considered to be the SRNC of the UE.

The case of intra-SGSN SRNS relocation is similar. All the above steps are valid given that both SRNC and DRNC are connected to the same SGSN.

5 The ns-2 module description

As we mentioned above, the proposed scheme was implemented as an ns-2 network simulator module in order to be evaluated. In this section we describe some implementation aspects along with a short description of the way our module can be deployed and used.

5.1 The ns-2 network simulator

Ns-2 is an open-source tool which is very commonly used by the international scientific community. It constitutes a very powerful simulation environment and is able to simulate a very wide range of networks, including wireless networks. The simulator is written in the C++ programming language. Additionally, OTcl scripting language is used as a command and configuration interface. Ns-2 supports all the basic network protocols (like TCP, UDP and RTP), several types of traffic (like FTP, Telnet, HTTP, CBR and VBR), queue management schemes (like RED, DropTail and CBQ) and routing algorithms (like Dijkstra and Bellman Ford). In addition, error models can be defined to simulate deterministic and probabilistic packet losses or link failures during network operation [7]. Ns-2 is therefore considered to be a powerful tool for the design of new protocols and for the evaluation of the correctness and the performance of new transmission mechanisms.

Ns-2 does not natively support the UMTS network functionality. Therefore, it was patched with its Enhanced UMTS Radio Access Network Extensions for ns-2 (EURANE) extension [3]. The EURANE is a set of extensions which implement the three UTRAN nodes which ns-2 does not support. In more detail, the EURANE enables the definition of RNC, Node B and UE nodes and realistically simulates their functions. Moreover, this extension enables the declaration of the following UTRAN transport channels: Forward Access Channel (FACH), Random Access Channel (RACH), Dedicated Channel (DCH) and High Speed Downlink Shared Channel (HS-DSCH) [4].

5.2 New implementation

Multicast routing is natively supported in ns-2 for many protocols and node types. Additionally, the EURANE extension for ns-2 offers an almost complete support of unicast transmission over UMTS. Although the MBMS service standardization has already started, no extension for ns-2 has been implemented for the support of multicast routing in UMTS. Consequently a major motivation of our work was the implementation of a module that bridges multicast data transmission and UMTS networks simulation. This module could boost the research at the specific domain and the full specification of the MBMS service.

Our introduced module implements, using the C++ programming language, the multicast packet forwarding scheme described in the previous section. In order to implement this module, first of all, we had to introduce the RLs in each node of the UMTS network except for the UEs. Thus, we created a new class named *Routing_List*. Moreover, we used inheritance in order to define two new sub-classes derived from super-class *Routing_List*. These subclasses are named *Multicast_Group_List* and *Drift_Routing_List* and represent the MGLs in the GGSNs and DRLs in the RNCs respectively.

Every list is a double linked list which contains the appropriate methods in order to be read and modified. In an SGSN, for example, we are able to retrieve the nodes of the next level (RNCs) that are served by the same SGSN and are members of the multicast group *m_group_id* by calling the *Routing_List* class method *Get_Next_Level_Nodes (m_group_id)*. In the GGSN, a method of the sub-class *Multicast_Group_List* called *Get_UEs(m_group_id)* is provided returning the UEs that are members of the multicast group indicated by the argument *m_group_id*. Similarly, the sub-class *Drift_Routing_List* has a method called *Get_Drift_RNCs(m_group_id)*.

Likewise, there are methods that update appropriately the lists. For instance, in every node there is a method called *Set_Next_Level_Node(m_group_id, next_level_node, UE_id)*, that adds the next level node to the *Routing_List* that is related with the argument *m_group_id*. Obviously, in case that the related *Routing_List* has not been created yet, the above method creates a new *Routing_List* related with the *m_group_id* and then inserts the item in it. For the case of the removal of a next level node, the method *Remove_Next_Level_Node(m_group_id, next_level_node, UE_id)* is used. Similarly, there are relevant methods which update the MGLs and DRLs.

Due to the association of each item of the *Routing_List* with a specific UE through the attribute UE_id, the execution of the method *Get_Next_Level_Nodes(m_group_id)* would be rather ineffective. For the fast access and modification of the *Routing_List*, the items with different next_level_node attribute are linked with a second level of links (this level of links is appeared below the list items in Fig. 6). This implementation increases efficiency when the current node receives traffic. There is no need to scan the whole file; only the second level links are examined. The same approach has been followed in order to increase efficiency during the scanning of *Drift_Routing_List*.

The next step of the implementation was to create the mechanism which fills these lists and to organize the procedures described in Section 4. The method *Set_Next_Level_Node(m_group_id, next_level_node, UE_id)* is executed when a Joining phase takes place. Instead, when a Leaving phase takes place the *Remove_Next_Level_Node (m_group_id, next_level_node, UE_id)* is employed to remove the relevant item. For the communication of the nodes, as well as the transmission of the multimedia data we used RTP/RTCP messages [10]. Since the RTP/RTCP protocols are fully functional in the EURANE module, only minor modifications were introduced to the RTP/RTCP protocol implementation. The purpose of these modifications was to include some additional information in the RTP/RTCP packet headers. In more detail, this information includes the type of the request/response, the *m_group_id*, the *UE_id* as well as the Quality of Service (QoS) profile of the associated UEs.

5.3 Using the module

The intention of this paragraph is to provide a short description of the installation and configuration requirements for our module. Our module comes in the form of an additional UMTS C++ library which needs to be compiled with the rest of the ns-2 source code. These C++ files are available in [16]. First of all, we assume that a reasonably standard Linux distribution is used. Another requirement is a recent *gcc* installation with the STL library included. The installation of our module is easily performed by patching the existing ns-2 source tree with our library files. The *Makefile.in* file should be updated in order to include our library as an input for *configure*. Finally, the patched ns-2 executable can be built using the *make* command.

As we have already mentioned, the OTcl scripting language is employed by the ns-2 user as a command and configuration interface. The implemented module has enriched this interface in order to support the various events related with multicast. The user can trigger Joining and Leaving phases with the OTcl commands *join-mgroup* and *leave-mgroup* respectively. This command needs as attributes the *UE_id* as well as the *m_group_id*. Moreover, an inter-RNS soft handover can be executed by the command *inter-rns_handover*. The target Node B *target_Node_B* must be specified, apart from the *UE_id*, when this command is given. Finally, the *srns-relocation* command with the *UE_id* as a parameter is employed when an SRNS relocation procedure has to be performed for a specific UE. At this point, it has to be mentioned that the simulator can itself identify the kind of the SRNS relocation (intra-SGSN or inter-SGSN) through the examination of the network topology.

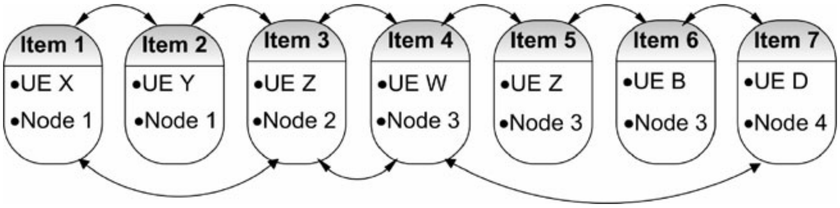


Fig. 6 Two-way linkage of the items in DRLs

6 Simulation experiments

6.1 Simulation topology and parameters

For our simulation model, we considered the topology presented in Fig. 7. We assumed that the external node connected to the GGSN, was a media server which imported the multicast video traffic in our examined UMTS network. This traffic is addressed to a specific multicast group of UEs. The number of UEs comprising the multicast group during the experiments, varied from 20 to 200. Nevertheless, the performance of our proposed scheme was independent of the multicast group size. Since we did not want to create a symmetrical topology, we differentiated the number of the UEs located in each Node B service area. For the sake of simplicity, we considered that there was only one multicast group which the UEs of the network could join. The video data was transmitted in the form of RTP traffic. This means that, using the RTCP reports, the GGSN had the opportunity to gain useful statistical information. The bit rate of the video was 256 Kbps and the packet size was 512 bytes. Regarding the transmission of the multicast packets over the UTRAN interfaces, DCHs are used as transport channels.

The statistical parameters that we focused on in order to evaluate the performance of the proposed mechanism, was the bandwidth consumption and the message complexity. Moreover, the service continuity was rigorously monitored through the analysis of the simulation log. The simulations log showed that no packet loss takes place during the procedure and, therefore, the service continuity is secured.

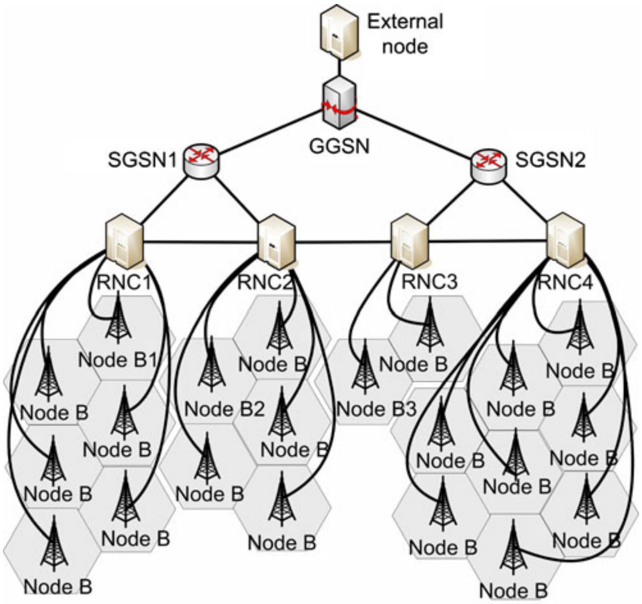


Fig. 7 Simulation topology

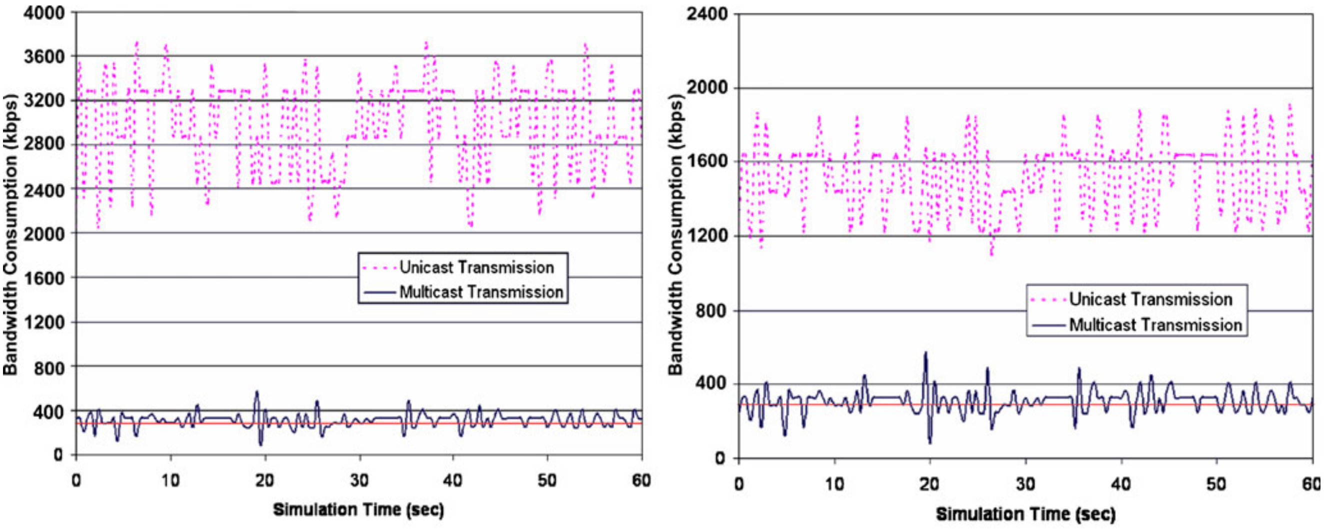
6.2 Simulation results

At first, we calculated the bandwidth consumption in the links of the UMTS network when the multicast scheme is used for the video transmission. Then, we compared it with the bandwidth consumption in the same links when multiple unicast transmission is used. In Fig. 8, we present the result over the links GGSN-SGSN1 and SGSN1-RNC1. In the first case we supposed that the recipients are 10 UEs which have joined the multicast group and are served from SGSN1. In the second case, the recipients are 5 UEs which have joined the multicast group and are located in the RNS controlled by RNC1.

We can observe from the Fig. 8 that, during the multicast transmission, the bandwidth consumption in these links was approximately equal to the theoretical video bit rate (256 Kbps) represented by the straight line. This occurs because in the multicast scheme, the packets are transmitted only once over each link of the network until they reach the mobile users. Instead, in the unicast scheme the same packets are transmitted multiple times over every link. This means that the bandwidth consumption increases. In more detail, we conclude that the fraction of the difference of the two lines, depicted in the figures, depends on the number of the members of the multicast group. This bandwidth consumption gain is the main property and the most important benefit of the multicast data transmission.

The other aspect that we examined was whether the service continuity is secured by our scheme. By the term service continuity, we mean that all packets are delivered correctly to all receivers without any disruptions of the service. Apart from the normal case when multicast data transmission is taking place, we analyzed the most critical phase for service disruption which is the phase when mobility procedures are performed.

In order to examine the service continuity during user mobility procedures, we simulated the following scenario. We considered the previously described video traffic of 256 Kbps and a UE located in the cell covered by Node B1 (Fig. 7). After 20 s of receiving multicast data, the examined UE performed a handover to the cell covered by Node B2. Obviously, an inter-RNS/intra-SGSN soft handover took place. The packets were transmitted to RNC2 through the Iur interface which connects RNC1 and RNC2. At 40 s, SRNS relocation was requested from RNC1 and, when the procedure had been completed, the RNC2 was the new SRNC of the UE and the Iur was released for that session. At 60 s a new handover took place. That time it was an inter-RNS/inter-SGSN soft handover to the cell served by Node B7. Finally, a second SRNS relocation was requested. This request came from RNC2 and the target RNC was RNC3. During the relocation procedure the Iur interface between RNC2 and



(a) (b)

Fig. 8 Bandwidth consumption in: **a** GGSN-SGSN1 and **b** SGSN1-RNC1 links

RNC3 was released and RNC3 was the SRNC of the UE. The simulation stopped at 100 s. During this time, we calculated the bit rate of the data received by UE1. The results are presented in Fig. 9.

We can observe that the bit rate of the data received from the UE is stable during the above described scenario. Moreover, analysis of the simulation log shows that no packet loss took place during the whole procedure. Instead, all the packets addressing to the multicast group were properly delivered to the moving UE. Thus, we can conclude that the service continuity is secured and the UE keeps receiving packets while moving across different RNSs and being served by Iur interfaces.

Additionally, we examined the multicast transmission of video over the Iur interface. We supposed that multiple handovers had taken place from the same source RNC to the same target RNC. We considered the same network topology of Fig. 7 and we supposed that 4 UEs were located in the RNS controlled by RNC1. These UEs are members of a multicast group and MBMS service provision for that group is in the Data Transfer phase. During this simulation 4 subsequent inter-RNS handovers took place at 20 s, 40 s, 60 s and 80 s respectively. We supposed that the new cells are located in the RNS controlled by RNC2 and that the handovers were not followed by relocations. The simulation was terminated at 100 s. In this case, we calculated the bandwidth consumption in the Iur interface connecting the RNC1 with RNC2. Then, we compared the results with the bandwidth consumption in the same link when multiple unicast is used. Figure 10 visualizes the result of the comparison.

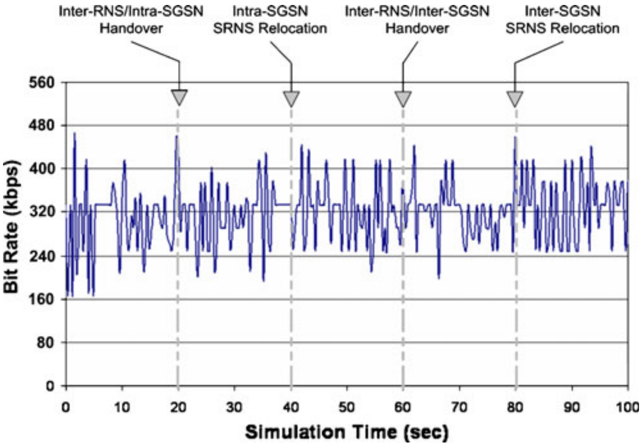


Fig. 9 Bit rate received during user mobility scenario

Figure 10 depicts clearly the efficiency in the use of the Iur interface of our proposed multicast scheme. It is obvious that the bandwidth consumption remains stable without depending on the number of handovers. On the contrary, the existing multiple unicast mechanism causes increment of the transmitted load, making this interface a potential bottleneck.

Finally, a fundamental issue that should not be overlooked is how the message complexity scales with the numbers of UEs. For this purpose, we considered a single multicast group and we counted the message complexity for different numbers of multicast group members. The number of multicast group members varied from 1 up to 100. In this experiment the typical probabilities for the execution of handovers and SRNS relocations were based on these proposed in [18]. Moreover for simplicity reasons the impact of the complexity of each message was considered to be the same and not to depend on the sending or receiving nodes. The experiment was executed twice. In the

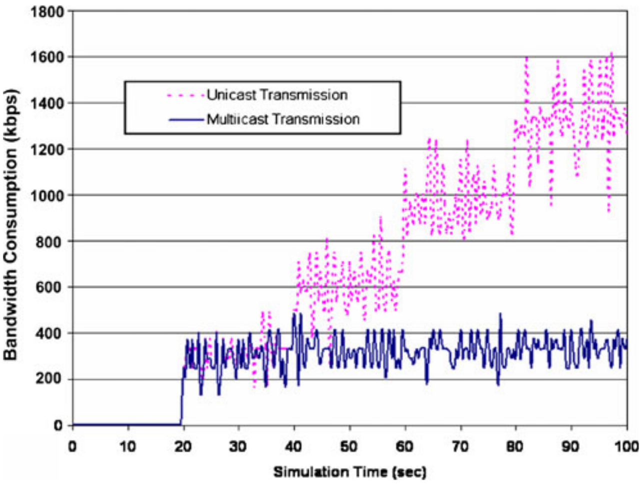


Fig. 10 Multicast transmission over Iur interface

first execution the UEs participated in the multicast group while in the second the network parameters were exactly the same but without any multicast group participation. During each instance of the experiment we measured the complexity of the messages related to the examined UEs.

Figure 11 depicts the message complexity ratio of the experiment with multicast group participation. The message complexity has been normalized with the message complexity when none of the UEs participates in a multicast group. The horizontal axis shows the number of UEs belonging in the examined multicast group. The vertical axis shows the accumulative message complexity which is normalized by the corresponding one when multicast is not used.

The results illustrated in Fig. 11 confirm the small overhead that is added to the regular message complexity. What is more important and proves the scalability of the proposed scheme is that when the number of the multicast group member increases, the overhead on the complexity does not seem to depend on the number of UEs and tends to be close to 12–13%.

At this point it should be noted that similar experiments were conducted using more multicast groups. Nevertheless, no differentiation from the above described result was noticed. This was expected since the message complexity does not depend on the number of multicast group defined in the PLMN.

6.3 Evaluation of two congestion control mechanisms for UMTS

In this section, we study the applicability of multicast congestion control over UMTS networks. We analyze two well known multicast congestion control schemes, namely TFMCC and PGMCC and we evaluate their applicability in UMTS. The above schemes are implemented in the ns-2 UMTS multicast module proposed in this paper. Our intention is to highlight the contribution and the usefulness of the proposed ns-2 UMTS multicast module.

TFMCC is an equation-based multicast congestion control mechanism which is reasonably fair towards competing TCP flows. In order to compete fairly with TCP, TFMCC receivers individually measure the current network conditions and calculate a rate that is TCP-friendly on the path from the sender to themselves. The rate is determined using an equation for TCP throughput, which roughly describes TCP's sending rate as a function of the loss event rate, round-trip time (RTT), and packet size. The sending rate of the multicast transmission is adapted to the receiver experiencing the worst network conditions. For more information of TFMCC and its adaptation for UMTS networks we refer the reader to [11] and [12].

On the other hand, PGMCC is a single rate multicast congestion control scheme, which is TCP-friendly and achieves scalability, stability and fast response to variations in network conditions. In general, the receiver reports are a fundamental component of PGMCC. They are sent back to the sender as NAK or ACK fields and based on them the sender regulates the transmission rate. Additionally, the receiver with the worst throughput is elected as acker being in charge of sending positive ACKs to the sender. The identity of the acker is carried as a field in each data packet.

In PGMCC, the loss rate is estimated in each receiver. The estimated loss rate is sent back to the multicast sender with NAKs and ACKs. In order to measure its loss rate, each receiver interprets the packet arrival rate as a discrete signal (1 for lost packets, 0 otherwise). The signal is then passed through a discrete-time linear filter, whose response and computational costs are chosen accordingly. The sender regulates the transmission rate based on the worst throughput received. For more information of PGMCC and its adaptation for UMTS networks we refer the reader to [13] and [14].

After implementing the above schemes in the ns-2 UMTS multicast module, the first aspect that we examine

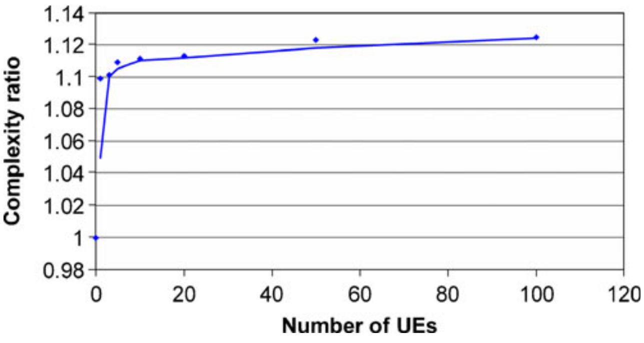


Fig. 11 Overhead in message complexity

is the protocol fairness of the above schemes for UMTS. In other words, we consider the fairness of the schemes towards other competing flows when they share common links.

More specifically, we consider a UMTS network with a single-bottleneck topology. The bottleneck is applied over a link connecting an SGSN with an RNC node (Iu interface) (Fig. 7). The PLMN serving area consists of several tens of cells and the examined multicast groups consists of several hundreds of UEs (from 100 up to 1,000 in each multicast group). In the topology, 50 servers are sending TCP traffic to as many UEs, whereas 10 multicast servers are sending multicast traffic to as many multicast groups (5 servers use TFMCC and 5 servers use PGMCC). UEx belongs to two multicast groups and is receiving multicast traffic. The first multicast group uses the TFMCC as a congestion control mechanism whereas the other group uses the PGMCC. At the same time, UEx is receiving TCP traffic from an external node. Figure 12 shows the throughput of the TFMCC flow against the PGMCC and TCP flows. The average throughput of all flows closely matches each other. Moreover, TFMCC achieves a smoother rate than TCP and PGMCC since TFMCC actual values have smaller deviation from the average throughput than TCP and PGMCC values.

An important concern in the design of congestion control schemes is their responsiveness to changes in the network conditions. This behavior is investigated using the single-bottleneck topology. During the simulation, we change the applied loss rate of the bottleneck link. The simulation lasts for 150 s. During this time interval three different loss rates are applied over the Iu interface. A TFMCC flow is monitored along with a PGMCC and a TCP flow sharing the bottleneck link. The results of the simulation for the three competing flows are presented in Fig. 13.

As shown in Fig. 13, the schemes' throughputs closely match the TCP throughput at all three loss levels. Moreover, the adaptation of the sending rate is fast enough for both of the schemes. The results show that the PGMCC scheme has immediate reaction to the changes in the loss rate. Actually, the simulator logs show that the UEs need 1,200–2,000 ms after the change of the loss rate in order to adapt to the new loss rate. These figures of response time are close enough to the corresponding time of TCP (about 1,000–1,500 ms). On the other hand, TFMCC has slower reaction since its adaptation time is about 1,500–2,500 ms. However, as in the experiment described previously, the TFMCC preserves the smoothest rate of all schemes.

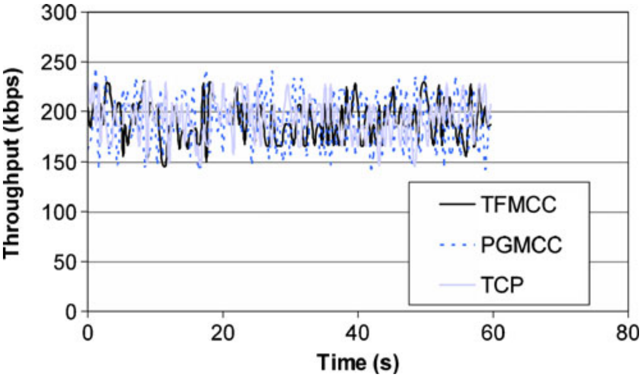


Fig. 12 Throughput in a single-bottleneck UMTS network. TFMCC vs. PGMCC vs. TCP flow

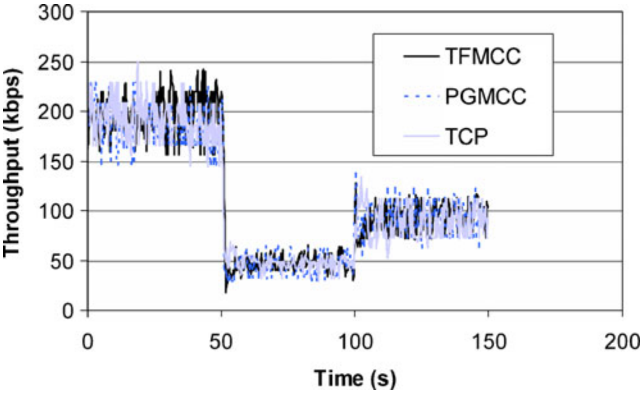


Fig. 13 Responsiveness to changes in the loss rate

The last concern of our experiments is the evaluation of the two schemes when packet losses occur due to radio channel degradation. We examine the behavior of the TFMCC and PGMCC when a radio channel is permanently degraded, which in turn means buffer overflow and packet rejections in the corresponding Node B. In the examined UMTS network, the radio link connecting the UEx with the Node By we suppose that is permanently degraded.

In more detail, we simulate the wireless channel degradation by applying a loss rate of 20% over the packets transmitted via the corrupted wireless link. In the beginning of the simulation, no radio channel degradation occurred. After 50 s of simulation, we apply the error rate over the wireless channel connecting the UEx with Node By. We monitor the changes in the throughput of the corrupted wireless link for 100 s. The experiment is executed three times, once for each scheme and once for the TCP traffic, with exactly the same parameters. The results of this experiment are presented in Fig. 14.

In the beginning of the simulation, no congestion existed and the throughput matches the available bandwidth of the wireless link. After 50 s of simulation, the 20% packet loss rate is applied. Obviously, the two schemes, unlike TCP, do not immediately react to this degradation because they consider it as temporary degradation. Soon after, the buffer of the Node B overflowed and the two congestion

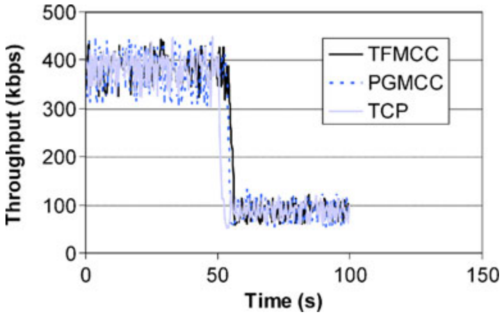


Fig. 14 Throughput of the schemes vs. TCP during radio channel degradation

control schemes are able to distinguish the nature of the degradation. It takes about 5 s for PGMCC and 6 for TFMCC to fully adapt to the new network conditions. Nevertheless, this time interval may differ according to the bit-rate of the transmission and the size of the buffer in Node B. The corresponding time interval for TCP is less than 2 s.

For more results regarding the evaluation of TFMCC and PGMCC in UMTS we refer the reader to [12] and [14].

7 Future work

The result of our work is a platform that supports multicast routing over UMTS along with user mobility and group management functionality. This platform could constitute the basis for research and a large scale of experiments related to this scientific domain.

The step that follows this work could be the study of an MBMS handover mechanism in RNC in order to optimize the transmission of the multicast data in the Iub interface. Additionally, an innovative algorithm could be developed which would choose the most efficient transport channel for the transmission of the multicast packets depending on the distribution of the users and the network topology at any given time. In this way, interesting issues must be taken into account such as the user mobility, the maximum number of users that a channel can service as well as power control issues. Additionally, we plan to enhance the implementation of the proposed mechanism so as to keep track of various parameters.

Furthermore, another step may be the formulation of a multicast group control mechanism dedicated to UMTS networks. In some cases, a permanently degraded wireless channel connecting a specific UE with its corresponding base station may cause a large reduction of the transmission rate and eventually generic multicast service degradation. To this direction, it may be specified under which circumstances radio channel degradation would cause expulsion of a UE from a multicast group.

Finally, a future step could be the evaluation of multicast congestion control schemes belonging in other classes (like multi-rate or layered schemes). It may be examined whether these schemes can be applied over UMTS multicast and possible modifications may be proposed. These schemes may also be evaluated through comparison with the schemes presented in this paper.

8 Conclusions

In this paper, we proposed a novel scheme for the multicast delivery of data over UMTS networks. Our scheme is based on the existing UMTS architecture and, therefore, minor modifications are introduced in the UMTS architecture and the mobility management mechanisms. The proposed scheme bridges multicast routing with UMTS network simulation. We implemented the proposed scheme as an ns-2 module in order to evaluate its performance. We described the implementation of our module and its usage. The module can be easily installed and configured as an ns-2 extension.

Additionally, we validated and analyzed our module through simulation experiments under various network topologies and user distributions. The simulation results showed that our module implements a correct and efficient multicast delivery of data in UMTS. It leads to the decrement of the transmitted packets and an efficient use of the UMTS network resources. Apart from the normal multicast transmission of data, special attention was paid to the handling of exceptional cases caused by user mobility scenarios. The simulation results showed that our proposed scheme can cope with the user mobility without any disruption of the service provision or any packet loss. Moreover it was experimentally confirmed that the existing scheme adds a small overhead to the regular message complexity but without affecting scalability since the overhead on the complexity does not depend on the number of mobile terminals.

Furthermore, we analyzed and evaluated the ability of the proposed mechanism to handle multicast group management procedures such as join or leave requests. These two procedures are of major importance for our mechanism, mainly due to the fact that they have a direct impact to the initialization phase of the RLs and to the efficient operation of the whole mechanism.

Finally, in order to further evaluate the proposed multicast packet forwarding mechanism, we implemented, as an application of the proposed mechanism, two multicast congestion control mechanisms for UMTS, namely TFPCC and PGMCC, and we measured their performance for MBMS transmissions.

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