Resource Efficient Multicast for 3G UMTS Wireless Networks

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Abstract—The European Telecommunication Standard Institute proposed IP multicast for third generation Universal Mobile Telecommunication System (UMTS) Broadband wireless networks. In their proposed approach, multicast messages are sent as multiple unicast messages to all active multicast group members in the UMTS network. As a result their proposed scheme is inefficient in terms of internal infrastructure and radio resource usage; and multicast packets incur significant delays. We propose a resource efficient IP multicast scheme, which significantly reduce radio resource usage and message delay. The proposed scheme uses IP tunnels and efficient unicast routing within the UMTS infrastructure to eliminate unnecessary message duplication and transmission. We also proposed the use common multicast channels in the efficient utilization of radio resources. Common multicast channels are designed to accommodate the varying and channel characteristics of active multicast users. We also propose a secure mechanism to distribute common radio group key to active multicast users.

***Index Terms*—Multicast, UMTS**

I. Introduction

The Internet has become a major force in the development of new and innovative technologies for telecommunication networks. Packet data traffic is experiencing an exponential growth that is fueling the need for broadband communication networks. Network operators are migrating to IP based broadband network infrastructure to meet existing and emerging needs. Wireless network operators face a similar challenge and they are adapting to the current trend by deploying wireless broadband networks. The most widely deployed second-generation (2G) mobile radio networks are based on the Global System for Mobile Communications (GSM). Second generation GSM wireless networks are being extended with the General Packet Radio Service (GPRS)/Universal Mobile Telecommunications Systems (UMTS) [1, 2, 3] to create third generation (3G) broadband networks.

An important feature that is fueling the need for wireless broadband Internet access is realtime multicast streaming involving Internet audio and video; interactive home shopping, virtual reality games, simulation and training. Multicast is a communication scenario where a multicast server sends data to member clients in a bandwidth efficient manner. A single copy of the data is sent to all clients sharing the same network and radio resources.

Several authors [8, 13] have proposed multicast schemes to address deficiencies or add multicast capabilities to second-generation wireless networks. One multicast scheme proposed for second-generation wireless network is based on the use of short message service (SMS) cell broadcast capability. This approach has the advantage of making use of protocol functions and capabilities that are already provided in the standards and available in the deployed networks. The SMS cell broadcast approach, however, is not suitable for high bandwidth realtime multicast due to limited available transmission bandwidth.

The European Telecommunication Standard Institute (ETSI) [1, 2] has proposed an IP multicast scheme, intended for GPRS/UMTS wireless network multicast. In this scheme, multicast messages are sent as multiple unicast messages to all active multicast members. As a result, the proposed scheme is very inefficient in terms of resource usage, and incurs significant packet delays. This approach in its current form is unsuitable for high bandwidth realtime multicast.

In this paper we propose a resource efficient and secure IP multicast scheme. The proposed scheme makes use IP tunnels and efficient unicast routing and message transmission to minimize unnecessary duplication and transmission of IP multicast messages within the UMTS network infrastructure. Efficient radio resource usage is achieved by the use of common multicast channels. A number of multicast users are assigned to a physical channel over which multicast messages are transmitted during active sessions. We also propose solutions to the problem of common multicast channel ciphering and key distribution to active users on a multicast channel.

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II. UMTS ARCHITECTURE

UMTS networks consist of three interacting domains; Core Network (CN), UMTS Terrestrial Radio Access Network (UTRAN) and User Equipment (UE) as shown in Fig. 1. The main function of the core network is to provide switching, routing and transit for user traffic. Core Network also contains the databases and network management functions.

The basic Core Network architecture for UMTS is based on GSM network with GPRS. All equipment has to be modified for UMTS operation and services. The UTRAN provides the air interface access method for User Equipment. Base Station is referred as Node-B and control equipment for Node-B's is called Radio Network Controller (RNC).

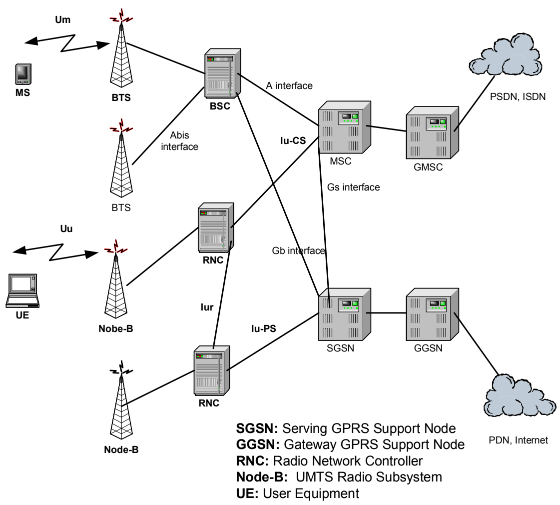

Fig. 1: UMTS Network Architecture

The Core Network is divided into circuit switched (CS) and packet switched (PS) domains. Circuit switched elements are Mobile services Switching Center (MSC), Visitor Location Register (VLR), and Gateway MSC and packet switched elements are Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN). Both domains share some network elements, like Equipment Identity Register (EIR) Home Location Register and Authentication center (AUC).

Wide band CDMA technology has been selected for UTRAN air interface. UMTS WCDMA is a Direct Sequence CDMA system where user data is multiplied with quasi-random bits derived from WCDMA Spreading codes. In UMTS, in addition to channelization, codes are used for synchronization and scrambling. WCDMA has two basic modes of operation Frequency Division Duplex (FDD) and Time Division Duplex (TDD).

The functions of Node-B are air interface transmission/reception, modulation/demodulation, physical channel coding, micro diversity, error handing, and closed loop power control.

The functions of RNC are radio resource control, admission control, channel allocation, power control settings, handover control, macro Diversity, ciphering, segmentation/reassemble, broadcast signaling and open Loop Power Control.

The UMTS User Equipment (UE) works as an air interface counterpart for Node-B and can operate in one of three modes of operation. Packet Switched (PS)/Circuit Switched (CS) mode of operation: in this mode the Mobile Subscriber (MS) is attached to both the packet PS domain and CS domain, and the MS is capable of simultaneously supporting PS and CS services. In PS mode of operation the MS is attached to the PS domain only and may only operate services of the PS domain. However, this does not prevent CS-like services to be offered over the PS domain (like Voice over IP). In CS mode of operation, the MS is attached to the CS domain only and may only operate services of the CS domain.

III. PROPOSED THIRD GENERATION IP MULTICAST

In this section, we describe our proposed resource efficient multicast scheme, including common group key distribution and handoff, as well as compare multicast transmission cost incurred by the GPRS/UMTS IP multicast schemes.

A. Resource Efficient Multicast Scheme

The proposed IP multicast scheme enables GPRS/UMTS mobile terminal to participate in a multicast session while engaged in a voice and/or data call. The concept of a radio group and radio group member is introduced in this scheme. A number of multicast group members are assigned to logical channels on the same physical channel, thus forming a radio group. Since the same physical channel is used for local user and multicast communication, a single receiver (i.e. demodulator) is required.

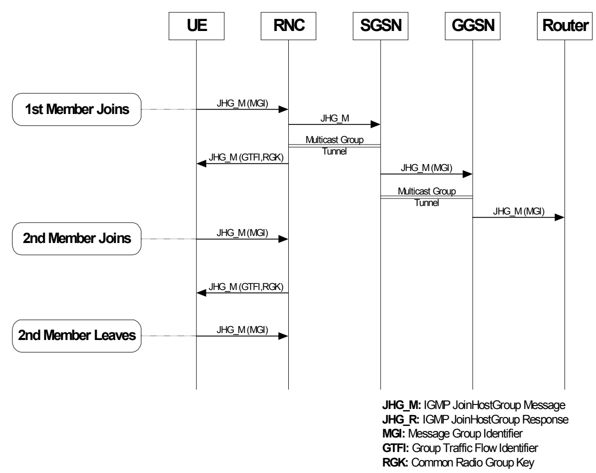

Fig. 2: Multicast Group Member Activation and Transmission Path Establishment

Multicast group member activation and transmission path establishment is presented in Fig. 2. For each multicast Radio Group, the RNC associates a Group Traffic Flow Identifier (GTFI) and a Radio Group Identifier. Whenever the first multicast group member joins a multicast group, it sends an *Internet Group Management Protocol (IGMP) JoinHostGroup Request* containing the multicast group identifier. The RNC assigns the multicast group member to a radio group, updates the active group member list, forwards the *IGMP JoinHostGroup Request* from the multicast group member to the SGSN and sends an *IGMP JoinHostGroup Response* to the multicast group member. The *IGMP JoinHostGroup Response* contains the GTFI and common radio group key. Upon receiving the *IGMP JoinHostGroup Request*, the SGSN updates its active RNC list for the multicast group, forwards it to the GGSN and establishes a tunnel to the RNC for the multicast group, if the RNC was previously inactive. Upon receiving the *IGMP JoinHostGroup Request,* the GGSN adds the SGSN to its active list for the multicast group and establishes a tunnel to the SGSN, if it was previously inactive, and sends the *IGMP JoinHostGroup Request* to the multicast router to which it is connected.

When the second multicast group members in the same cell joins the multicast group, it also sends an the *IGMP JoinHostGroup Request* the RNC assigns it to the active radio group and sends an *IGMP JoinHostGroup Response* to the requesting group member.

After receiving the *IGMP JoinHostGroup Response* message, the UE tunes and listen to network transmissions with the GTFI and uses the common group cipher key to decipher received messages. A third party who is also aware of the multicast group identifier and the multicast address cannot join the session since it does not possess the group key.

Whenever a user wants to leave a multicast group, it sends an *IGMP LeaveHostGroup Request* to the RNC, which removes the entry from its active list. If there are no active members remaining in the cell, the RNC removes the radio group channel, sends an *IGMP LeaveHostGroup Request* to the SGSN and releases the tunnel to the SGSN for the multicast group if they are no remaining active radio groups. After the tunnel has been released, the SGSN checks whether there are active RNCs remaining. If there are no remaining active RNCs, the SGSN sends an *IGMP LeaveHostGroup Request* to the GGSN and releases the tunnel to the GGSN for the multicast group. The GGSN then removes the SGSN from its active list for the multicast group. If there are no remaining active SGSNs, the GGSN sends the *IGMP LeaveHostGroup Request* to the multicast router to which it is connected.

The design approach for the GPRS/UMTS network results in a multicast source distribution tree as described in Fig. 3. In this model, all elements of the infrastructure perform multicast routing functions.

B. Multicast Group Key Distribution

Active multicast users of the same group share a common radio group key for deciphering packets received during a multicast session. The RNC, in order to prevent unauthorized access to multicast sessions, changes this multicast common radio group key periodically. As long there is at least one active member in a multicast radio group, the RNC maintains the associated active multicast radio group list. Members leaving the multicast radio group still possess the common radio group key stored in its memory and if unchanged, they will still be able to participate in multicast sessions using the radio group key. The RNC periodically regenerates the common radio group key, encrypts it using the current group key and periodically multicast it to active members in the radio group. The multicast radio group key message contains a flag indicating whether subsequent messages are encrypted with the new key (i.e. the group key is active). The multicast radio group key message is transmitted with the active group flag off for a specified period. This allows each radio group member to update the radio group key prior to receiving messages encrypted with the new radio group key (i.e. radio group key updates are synchronized). The RNC also sets the radio group key update pending flag for all active radio group members and starts an associated timer. Upon expiration of this timer, all radio group members with the radio group key update pending flag set are removed from the active list.

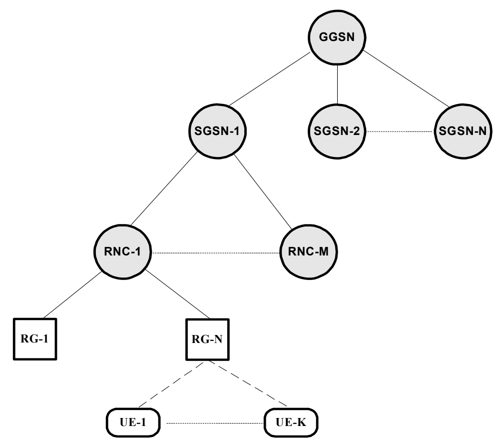

Fig. 3: Unicast Source Distribution Tree

On receiving an encrypted group key message, an active radio group member decrypts the encrypted radio group key and compares it with the current radio key stored in its internal memory. In the event that a mismatch occurs, the active radio group member sends an *IGMP JoinHostGroup Request* to the RNC on its local channel. The RNC receives the *IGMP JoinHostGroup Request* and checks the radio group member list of the indicated multicast group. The RNC sends an *IGMP JoinHostGroup Response* containing the new radio group key to the radio group member, and resets the radio group key update pending flag, if the radio group member is already active. Otherwise the multicast group member is assigned to a radio group and the radio group active list updated. The *IGMP JoinHostGroup Response* is encrypted using the radio group member's private key.

The common group key message that is periodically multicast to the active members in the radio group also contains a change flag to indicate whether the encrypted common group key is active. This flag is set to active after a fixed period. This fixed period is designed such that active group members can complete the group key update process within the allotted time.

C. *Multicast Message Transmission Cost*

The GGSN continuously monitors the incoming packets, from the packet data network (PDN) to which it is connected, with active multicast IP addresses and upon receiving a packet with an active multicast address of the group identifier, it duplicates the packet and routes it to active SGSNs. The SGSNs, in turn, duplicates the packet and sends them to active RNCs. In this way the number of multicast packet transmitted within the core network and the radio access network is kept to a minimum.

Let the average cost per multicast packet incurred over the air interface of the current 3G GPRS/UMTS standard be the number of message frames transmitted per multicast packet. The number of frames is computed as described below:

Let the multicast packet length be *L* and the number of bytes per frame be *M*. The number of frames per multicast packet is:

$$k = \lceil L/M \rceil \quad (1)$$

Let the average number of active users be $\overline{N}$ and the average number of retransmitted frames be γ. The average cost θ is the average number of multicast message transmitted over the air interface per multicast message, is:

$$\theta = k\overline{N}(1+\gamma) \quad (2)$$

The average cost incurred over the air interface for the resource efficient multicast scheme is computed as follows:

Let the average number of radio groups per cell be $\overline{N}_g$, the average number of active cells per RNC be $\overline{N}_c$, and the average number of active RNCs be $\overline{N}_r$. The average cost is computed as follows:

$$\theta_c = \overline{N}_g \overline{N}_c \overline{N}_r k(1+\gamma) \quad (3)$$

The product $\overline{N}_g \overline{N}_c \overline{N}_r$ is the average number of radio groups in the system. The average normalized cost is the ratio of the averaged number of radio groups in the system to the average number of active group members. Fig. 4 presents graphs of multicast cost per multicast message versus the population of active multicast group member. The cost performance improves as the number of multicast group member per multicast channel increases. In our simulations, we modeled the ETSI proposed scheme as having one multicast member per channel.

IV. Simulation Results

Simulations were performed to measure and compare the packet delay, variance and multicast message throughput per user by the schemes proposed in [1, 2, 8] and our proposed delay and resource efficient multicast scheme, with and without background traffic. The OpNet simulation tools was used to implement the GPRS/UMTS network as a multicast source distribution tree, and eight users engaged in File Transfer Protocol (FTP) sessions, transferring 50-KiloByte files every 50 seconds, provided the background traffic for the simulations. The start times of the sessions are exponentially distributed with a parameter of 10 seconds.

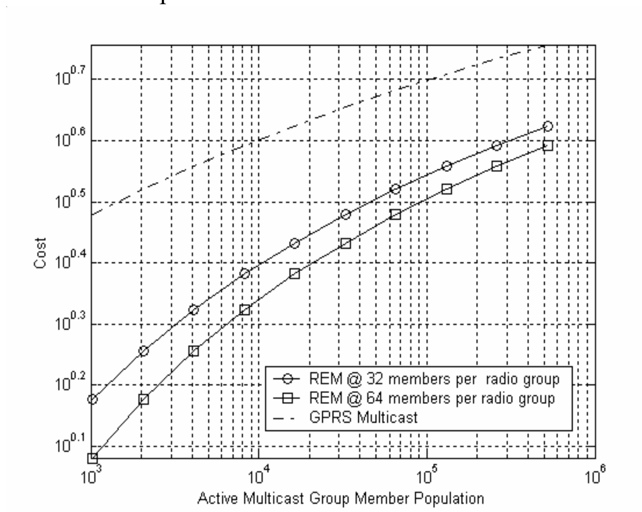

Fig. 4: Transmission Cost per Multicast Packet

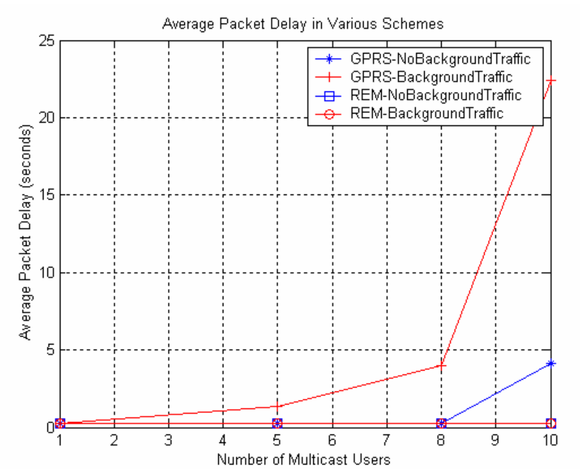

Fig. 5: Packet Delay vs. Active Users

The simulation results comparing multicast packet delay are presented in Fig. 5, which show that the average delay experienced by users in our proposed scheme is very small, compared to the GPRS/UMTS scheme, and remains constant as the active user population per radio group is increased. The delay performance of our scheme is the same with and without background traffic. In the current GPRS/UMTS scheme, the delay increases moderately up to eight users with background traffic and then sharply beyond eight users per channel. For example, between eight and 10 users, the average delay increases from 4 seconds to approximately 22.5 seconds. Without background traffic, the delay is negligible up to eight users, after which it increases linearly to approximately 4 seconds at 10 users per channel.

The delay variance versus multicast users is presented in Fig. 6. The delay variance for the scheme GPRS/UMTS scheme increases moderately up five users and then very sharply with further increase in multicast users. The resource efficient scheme experiences fixed and negligible packet delay thus illustrating its superior performance over the ETSI scheme.

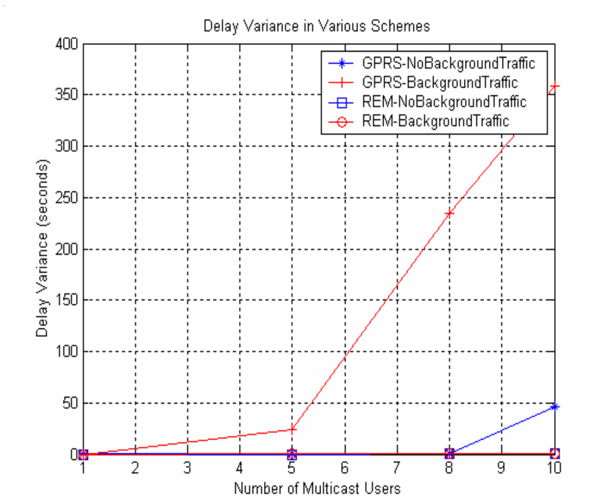

Fig. 6: Packet Delay Variance vs. Number of Multicast Users

In Fig. 7, we present simulation results comparing multicast user packet throughput. The results show that our proposed scheme experienced very little degradation, as the number of active users per radio group is increases, with and without background traffic. The high-bandwidth realtime multicast scheme proposed in [1,2] experienced significant fall off in per user packet throughput as the number of active users is increased. Without background traffic, negligible fall off in packet throughput occurs until a point is reached (i.e. at 8 active users) where the fall off becomes significant. The graphs on per user packet throughput also show that our proposed scheme is significantly better than existing schemes.

V. Conclusion

Wireless Internet access will continue to accelerate technological innovations, in support of many communication applications that are currently offered or will be offered on fixed networks. The end result will be that network operators are faced with a large array of choices on how to build reliable and efficient next-generation wireless networks.

The analysis of the resource efficient multicast scheme shows that it is efficient in terms of packet delay, throughput, and multicast transmission cost. Both the throughput and packet delay performance, as demonstrated by simulation, out performs existing schemes. The proposed scheme is clearly an efficient scheme that will facilitate realtime multicast in emerging wireless broadband networks.

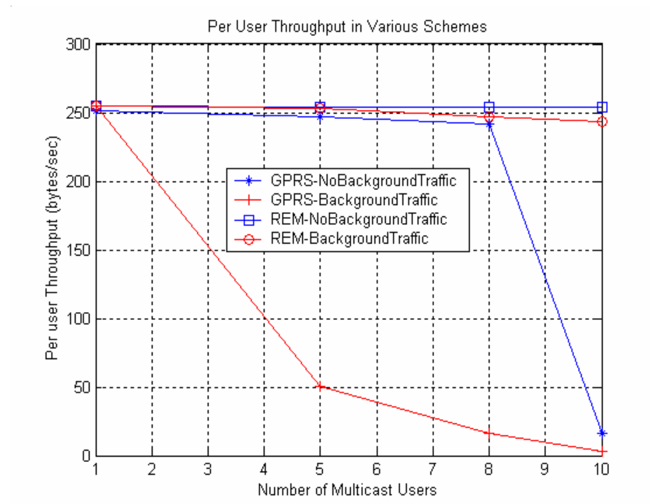

Fig. 7: Per user Throughput

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