A novel MAC layer adaptation for General Packet Radio Service-Satellite mode (GPRS-S) data communication

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Abstract: This paper emphasises on the implementation of the flow control and resource allocation mechanisms of the Medium Access Control (MAC) layer of GPRS. Also, its design for adaptability to the satellite network has been considered. In addition, the two systems have been compared in terms of transmission-time, for different data sizes. The results obtained show a lot of promise for satellite based Personal Communication Services (PCS) applications, especially the dual mode phone technology (which supports both the Cellular & Satellite service modes), leading to Geo-Mobile Satellite Systems (GMSS). GMSS has the potential of providing an affordable, compact, low power, high quality, and attractive solution for the rapidly growing mobile satellite services community.

Keywords: General Packet Radio Service, Geo-Mobile Satellite Systems, Resource Allocation, Flow Control

1 Introduction

The requirement for high-speed data transmission, especially packet data transmission, brings with it a whole new set of challenges for the next generation systems. The major thrust of emerging wireless systems is the ability to support high-speed data services, especially packet data services ranging from 144 Kbps to 2 Mbps, and to enable multimedia services, global roaming and operation in multiple fixed and mobile environments.

GPRS provides effective utilization of the scarce radio resources and is ideally suited for bursty data transmissions. It enables instant, anywhere and anytime-wireless access to IP based networks such as the public Internet and Local Area Networks [4].

The GPRS system is an additional data bearer service of GSM, in order to satisfy the increasing demand for mobile data communications and the recent developments of mobile data applications. It provides a packet switched data transmission within GSM and a packet access to data networks. The MAC layer defines the procedures that enable multiple MSs to share a common transmission medium, which may consist of one or several physical channels (PDCHs). This paper, concentrates mainly on MAC layer procedures and adaptation of the terrestrial system to the satellite mode and their comparison.

The material in this paper is organized as follows. The next section contains a brief description of the GPRS radio interface, emphasizing on the MAC layer. The following section describes the design phase, emphasizing on the adaptation of the relevant terrestrial system entities to the satellite mode. Implementation and comparison of procedures concerned to both the modes are given subsequently. Then results are presented and finally conclusions are drawn.

2 GPRS Radio Interface

The GSM system, referred to as 2G (2nd Generation), is suitable for voice transmission, though it also supports data-centric applications. With GSM, a circuit switched system, data transfer rates around 10kbps can be achieved. This limitation along with many other problems persistent with GSM data, such as higher costs, inefficient usage of bandwidth, longer session establishment times, complexity of getting Internet access etc., led to the necessity of Packet Switched services in GSM. The circuit switched data is good for cases when continuous data flow is needed. In GSM the billing is based on time, not on amount of data. Also, the circuit switched data is not optimal for packet-based protocols such as IP. It is also not suited for bursty traffic [3]. The development of GPRS was aimed at taking care of all these aspects.

GPRS uses packet switched resource allocation, in which resources are allocated only when data is to be sent or received. It incorporates flexible
channel allocation mechanism in which 1 to 8 time slots can be allotted to a user. Active users share the available resources. Uplink and downlink channels are reserved separately. Also, GPRS and circuit switched GSM services can use the same time slots alternatively.

Typical applications of GPRS include standard data-network-protocol based applications such as WWW, FTP, Telnet, conventional TCP/IP & X.25 based applications, P2P applications such as toll road system, train control system and P2M applications such as weather & road traffic info, news & fleet management. It also supports web browsing, E-mail, WAP, E-commerce and many more [2].

2.1 MAC Layer Details

<table>
<thead>
<tr>
<th>MS</th>
<th>BSS</th>
<th>SGSN</th>
</tr>
</thead>
<tbody>
<tr>
<td>IP</td>
<td></td>
<td></td>
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<tr>
<td>SNDCP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LLC</td>
<td>LLC Relay</td>
<td></td>
</tr>
<tr>
<td>RLC/ MAC</td>
<td>RLC/ MAC</td>
<td>L2</td>
</tr>
<tr>
<td>Phy</td>
<td>Phy</td>
<td>L1</td>
</tr>
</tbody>
</table>

Fig.1: GPRS User Plane Protocol Stack

The MAC layer is situated between RLC and physical layers. The MAC procedures include the functions related to the management of shared transmission resources, i.e., PDCHs and reception of control blocks. The basic radio packet is a RLC/MAC data block, called simply as data block. It uses a sequence of four timeslots on a PDCH, called block period. A Temporary Block Flow (TBF) is a physical connection used to support the transfer of a number of data blocks. Each TBF is assigned a Temporary Flow Identity (TFI) by the network. Three medium access modes, for uplink transmission, are supported: dynamic, extended dynamic and fixed. The MS, in dynamic allocation mode, monitors the Uplink State Flag (USF) field, contained in the downlink blocks, in order to recognise its assigned uplink block periods. The extended dynamic allocation is a simple extension of the dynamic one adapted to deliver large volume data packets. In fixed allocation mode, the assigned block periods are fixed at the establishment of TBF. New types of packet data logical channels are defined and mapped dynamically onto a 52-multiframe [1].

MAC modes are defined: the packet idle mode where no TBF exists and the packet transfer mode where the MS is allocated radio resource providing a TBF. The MAC procedures, at MS side in packet idle and packet transfer modes, include: performing the cell reselection, monitoring and acquisition of the system information on the broadcast channels. In packet idle mode, the MS monitors the paging channels. At the network side, the MAC procedures contain the system information broadcasting, the measurement reports, the cell change order procedures and the paging procedures.

2.1.1 MAC Functionality

Medium access is based on the slotted ALOHA reservation protocol. In general, there are 3 phases on the uplink:

1. Contention - a slotted ALOHA random access technique is used to transmit reservation requests.
2. Notification - the BTS transmits a notification to the MS indicating the channel allocation for a pending uplink transmission.
3. Transmission - the data transfer occurs without contention.

On the downlink, there are 2 phases:

1. Notification - the BSS transmits a notification to the MS indicating the channel allocation for a pending downlink transmission.
2. Transfer - the MS monitors the indicated channels, and the transfer proceeds without contention.

2.2 GPRS Logical Channels

Major channel categories in GPRS are:

1. Packet Common Control Channel PCCCH
2. Packet Broadcast Control Channel PBCCH – transmits system information to all GPRS terminals in a cell.
3. Packet Traffic Channels PTCH - for data and control traffic.

<table>
<thead>
<tr>
<th>Chl.Name</th>
<th>Direction</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTCH -PDTCH</td>
<td>Downlink &amp; uplink</td>
<td>Data transfer</td>
</tr>
<tr>
<td>-PACCH</td>
<td>Downlink &amp; uplink</td>
<td>Assoc.control</td>
</tr>
<tr>
<td>PBCCH -PBCCH</td>
<td>Downlink</td>
<td>Broadcast control</td>
</tr>
<tr>
<td>PCCCH -PRACH</td>
<td>Uplink</td>
<td>Random access</td>
</tr>
<tr>
<td>-PAGCH</td>
<td>Downlink</td>
<td>Access grant</td>
</tr>
<tr>
<td>-PPCH</td>
<td>Downlink</td>
<td>Paging</td>
</tr>
<tr>
<td>-PNCH</td>
<td>Downlink</td>
<td>Multicast</td>
</tr>
</tbody>
</table>

Table 1. GPRS logical channels and their functions
2.3 GPRS Full-rate Frame Structure

The super-frame structure consists of 4 x 26 frames as shown in Fig.2. Each row comprises of 26 TDMA frames. In every row frames 1-12 and 14-25 contain eight traffic slots each. TDMA frame number 13 is not used for transmission (Idle frame) and is available to be used by the mobile receiver to capture and decode a broadcast control channel signal burst from a neighbouring station.

26 frames=120 ms

Fig.2 GPRS Superframe Structure

TDMA Frame

557us

Burst Burst Burst Burst Burst Burst Burst Burst

Fig.3 GPRS Frame Structure

3t 57 data 1f 26 synch 1f 57 data 3t

8.25 guard

Fig.4 GPRS Traffic Channel Slot Structure

Every 26th frame in the super-frame structure (the last column in Fig.2) contains Slow Associated Control Channel (SACCH) information. Each SACCH message is interleaved over 4 SACCH bursts in each super-frame. Each SACCH frame comprises of 8 time slots (1 per traffic slot), allowing one unique SACCH channel per mobile link. Each mobile is allocated 1 out of the 8 time slots in each frame. Digitally coded voice data frames for a mobile are interleaved over 8 successive frames, maintaining the same time slot in every frame [7].

3 Satellite Mode Design Issues

In terrestrial mobile systems the user moves successively through a series of cells. In satellite communication systems the satellite footprint (acting like a cell) moves through the users. These two systems differ mainly in the Physical Layer (OSI layer1) parameters. Hence an interface, called Gateway Earth Station, is needed.

(Geo-stationary Earth Orbit) GEO Vs LEO (Low Earth Orbit): A GEO satellite system is placed at an altitude of about 36,000km (so that it makes one complete revolution in 24h). Its orbit lies in the plane of the equator and appears stationary to an observer on the earth. Communications are available 24h/day in the coverage area. Worldwide coverage is possible with only 3 satellites. A LEO Satellite System consists of a constellation of many satellites in circular orbits at altitudes ranging between 500-1500km. Orbits are inclined or polar or a combination of the two. Coverage area & duration depend on the number of satellites, their altitudes & their orbit inclinations.

Satellite systems complement terrestrial systems to provide rapid diffusion of services to the mass-market [3]. Advantage of the satellite component in PCS is that it is able to support complete coverage for the deployment of terrestrial mobile systems, coverage extension to maritime & aeronautical users, and truly global roaming capabilities. Satellites are also able to provide an overlay of cells to the existing micro and macro cells. LEO satellites are able to form larger cells of several hundred km in radius. To further overlay the larger cells, GEO satellites with multiple beams can form super-cells. Communication satellites can serve as international gateways, provide direct personal connectivity & can offer extended coverage to land mobile systems, so that when a user falls out of the terrestrial coverage area, the dual mode (with terrestrial & satellite transceivers) capabilities of the handset will communicate with the satellite component. Some of the services provided include, high quality voice, global roaming with a single number access, integral pager for standby call alerting, in-built position determination, fax & data handling capabilities.

3.1 Adaptation to Satellite Mode

To achieve the greatest synergy with the GPRS cellular mode, the GPRS TDMA format has been adopted, virtually intact, for the satellite down link. The same bit-rate, bandwidth, and slot length are taken, but the frame period is increased from GPRS's 8-slot (or 16 slot in half-rate mode) frame length to a 16-slot/32-slot format. Indeed all three formats (8/16/32-slot) can be radiated from the satellite depending on the loading. It is an attractive option to offer the same speech quality as GSM using an identical wave form during periods when the satellite is sufficiently under-loaded to permit using 8 time slots. The 4-slot mode is used on the up link when the 16-slot down link mode is used or 8-slot on the up link when the 32-slot down link mode is used. The 4:1 ratio in time slots translates to an up link slot of four times the length of a down link slot.
carrying information at \( \frac{1}{4} \) the bit rate in \( \frac{1}{4} \) the bandwidth.

### 3.1.1 Satellite Waveform Details

The basic super-frame format for satellite communications is similar to the GPRS half-rate format in which a particular mobile uses only every alternate TDMA frame (8 slots), making effectively 16 slot frames of twice the length (9.23ms). This is referred to as the full-rate satellite mode. A half-rate satellite mode is also defined where by a mobile uses only every 4th TDMA frame (8 slots) making effectively a 32-slot frame of length (18.46 ms). The use of the 32-slot mode or the 16-slot mode depends on the traffic distribution and channel conditions.

### 3.1.2 Modified Slot Structure for GPRS-S

The super-frame structure for the full-rate satellite mode is shown in Fig.5. In this figure the first 12 frames contain 16 traffic slots each and the 13th frame contains 16 SACCH slots. Each SACCH slot is associated with a corresponding traffic slot. To preserve one SACCH per each traffic slot (now 16), the SACCH frame is combined with the IDLE frame (GSM) to make a 16-slot SACCH frame.

![Fig.5 Full Rate Satellite Super-frame Structure](image)

### 3.2 MAC Layer for GPRS-S

The main MAC layer issues for GPRS-S are:

- access mechanism and
- reservation procedure

For access mechanism, performance of slotted-ALOHA is more efficient than pure-ALOHA. However, the use of slotted-ALOHA for satellite communication is limited due to long path delay-difference between the inner and outermost points in a satellite spot-beam, which imposes a long guard period (GP). Necessary GP for inner spot-beam is much lower. Hence, to design the random access protocol for the worst case (i.e. low PRACH performance) the land earth station (LES) can divide the PRACH slots in to different sizes for inner and outer spot-beams. Due to long ACK delay, GPRS user terminal cannot wait for ACK of every contention attempt. Thus it’s assumed that GPRS user terminal continues to contend on the PRACH until it receives a paging from LES on the PAGCH. This paging message contains reservation information if the required resource is available or queuing information if resources are occupied. In the latter case, GPRS user terminal will stop contending.

Total average transmission delay is,\[ D = D_c + D_a + D_s \] where,

- \( D_c \) : average contention delay (attempting to get through PRACH)
- \( D_a \) : average access delay experienced by MS (to go from access queue to serving queue)
- \( D_s \) : average serving delay (due to transmission of packets and retransmission of erroneous packets)

### 4 Implementation Issues

The implementation phase focuses on the flow control and resource allocation mechanisms of the MAC layer of GPRS. Using the principles relevant to terrestrial system, the implementation has been carried out for the satellite network, incorporating the modifications discussed above.

For both the terrestrial & satellite networks, two data transfer modes have been taken up for implementation: namely, uplink & downlink modes. As indicated in the flow diagrams below, the uplink data transfer mode is quite complex as it involves completion of channel request, uplink assignment, resource request & resource allocation stages, before the actual data transfer can begin from the MS. However the downlink data transfer procedure is quite simple, in the sense that allocation of resources for the downlink data transfer is directly done by the BSS, as it has complete control over the resources. Hence BSS can directly begin the data transfer, once the MS has been paged about this.

In GPRS data transfer mode, a ratio of 1:4 is maintained during the allocation of resources for the uplink and downlink modes, respectively. This is due to the fact that, considering the major applications of GPRS, the amount of data transferred on the downlink is quite large compared to on the uplink, as is evident in the case of web browsing. In this perspective, it is imperative that the uplink mode has been considered mainly to demonstrate the flow control and resource allocation mechanisms and the downlink data transfer
mode for the purpose of comparing the two network types. The implementation has been carried out for both the networks separately and the comparisons have been drawn, taking into consideration different sizes of data ranging from a few hundred bytes to hundreds of kilobytes. An error-free data transfer environment has been assumed. Comparisons are drawn taking into consideration a single user at a time. All the implementations carried out and the results obtained are from the MAC layer perspective of GPRS.

The flowcharts given above explain the various aspects involved in the uplink and downlink transfer modes. As can be seen, the uplink procedure involves the completion of random access procedure before the transmission of data can begin. The random access procedure is quite complex, since control of all the resources lies with the network. On the other hand, data transfer in the downlink mode is straightforward as the BSS has the complete control over the resources and the data transfer can begin, once the MS is informed about it.
5 Results

The graphs shown above give the comparison between the two modes of operation considered. Data sizes ranging from hundreds of bytes to a few hundred kilobytes are considered. For small sizes of data, terrestrial network yields faster performance. However, the satellite network is preferable as the data size increases.

6 Conclusions

The results obtained here during the implementation of flow control and resource allocation procedures of GPRS MAC layer, carried out for the terrestrial network in both uplink and downlink modes & its adaptability to the satellite mode and comparison between the two, show a lot of promise for satellite based PCS applications. The GPRS-S can thus be explored for data transfer functionality in a wireless communication environment. The comparisons convey the fact that, the effect of round trip delay in satellite systems becomes less significant as multiple users are supported & as the size of data increases. However, the terrestrial system is preferable for transmission of small amounts of data and for short message services.

The MAC layer issues are open for further enhancements, making it possible to explore new dimensions for achieving enhanced performance and efficiency. Employing efficient multiplexing techniques can further increase the data rates. A more complex environment with errors in transmission has to be considered to give an insight into a more realistic situation. Multiple users can be supported to enhance service accessibility. Dual mode phone technology, which leads to GMSS, has a great potential in the rapidly growing mobile satellite services market.

References:
[7] Bell Labs Technical Journals
[8] ETSI documents on GPRS Phase 2+