Impact of the cell update mechanism in GPRS

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Abstract- **Cellular Packet Systems such as GPRS rely on Cell Update (CU)/Routing Area Update (RAU) mechanisms to provide continuous connectivity within the service area. This paper is aimed to evaluate the impact that these mechanisms have on system performance. As we will state in the paper, the CU/RAU procedure could originate the loss of user data packets that, in case of reliable data services, it could increase the amount of retransmission signaling to cope with such packet losses. In any case, it should be useful to characterize the amount of user data traffic affected in order to take into account this effect when QoS criteria are pursued.**

I. INTRODUCTION

Mobile technology will soon be widely used as an access mechanism to the Internet. One of the first steps to achieve such a goal is the General Packet Radio System (GPRS). GPRS is intended to offer packet switched mobile data and becomes an efficient approach to upgrade the existing GSM network to a packet switched system on the way to 3G. GPRS implies to add a complete packet-switched core network to the GSM-Network Switched Subsystem (NSS) and leave almost unchanged the GSM Base Station Subsystem (BSS). Fig. 1 depicts a basic GPRS architecture. The main extension needed in the BSS segment is the Packet Control Unit (PCU) to interface data packets to the GSM-BSS and to control and manage most of the radio related functions of GPRS. On the core network side, GPRS consists of two types of GPRS Support Nodes (GSNs): the Gateway GSN (GGSN) and the Serving GSN (SGSN). The GGSN provides the interface towards external packet data networks such as ones based on Internet Protocol (IP). The transmission of the Network Layer Packet Data Units (N-PDU) between GGSN and SGSN relies on tunneling mechanisms over an intra-PLMN IP backbone network. The SGSN exchanges N-PDUs with the mobile station through the GSM BSS by establishing a LLC (Logical Link Control) link. N-PDUs are encapsulated into LLC frames and transmitted through the PCU. In the air interface LLC frames are further segmented into Radio Blocks (RB) managed by the Radio Link Control/Medium Access Control (RLC/MAC) mechanism.

For each GPRS-attached mobile there is a SGSN in charge of keeping updated the relevant mobility data, known as *mobility management (MM) context*, to allow data transmission from/to the mobile station. This information includes the identity of the cell where the mobile is camping on in case of the mobile being in *ready* state [1]. A GPRS-attached mobile shall continuously monitor the control channels of the serving cell and the ones of the neighbor cells in order to perform the cell re-selection mechanism. The cell-reselection makes the mobile station to camp on the best cell according to certain criteria as path loss, signal level threshold, hysteresis values and priority classes [2]. Cell re-selection is normally controlled by the mobile station although the network may control the procedure in some specific cases. When the mobile decides to camp on a new cell, the re-selection mechanism triggers the Cell Update (CU) or Routing Area Update (RAU) procedures to allow the network to update its current configuration.

This paper is aimed to evaluate the impact that the CU/RAU mechanisms have on system performance. As we will explain in next section, these procedures could yield to the loss of user data packets buffered at the old PCU. Although this user data information could be later on recovered by LLC signaling in case of reliable data services, it is still important to take into account the increase in retransmission signaling needed to cope with such packet losses. For all these reasons, our interest is to characterize the amount of traffic buffered at the PCU when the CU/RAU is performed in order to take into account this phenomenon when QoS criteria are pursued.

The paper is organized as follows. Section II addresses mobility procedures defined in GPRS and states the situations in which packets could be lost or transferred between PCUs. The description of the scenario and model assumptions taken into account to perform the analysis is described in Section III. Section IV includes some simulation results and finally Section V concludes the paper.

II. MOBILITY PROCEDURES

GPRS defines three states to characterize the mobility activities related to a subscriber: *idle*, *standby* and *ready*. When the mobile is switched on, its state is set to *idle*. Within this state, the mobile only performs GSM cell selection and re-selection processes but does not perform any GPRS specific mobility procedure. In order to be able to use GPRS services the mobile must initiate a GPRS-attach procedure. On success, mobility state of the mobile becomes *standby* and a valid MM context is established and hold in the SGSN with information about location and routing.

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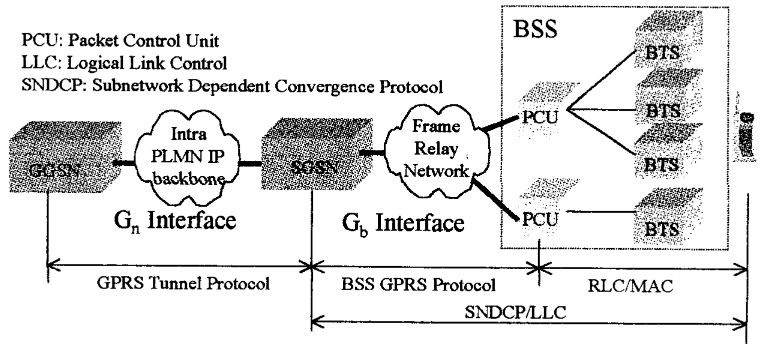

Figure 1. GPRS architecture and user plane transport protocols

Among other, the MM context contains the identity of the routing area (RA) in which the mobile is camping on. Cells are grouped in routing areas (RA) in order to reduce the needed signaling to keep updated the mobility contexts when the mobile is in *standby* state. So, while being in *standby* state, the mobile station should perform the RAU procedure in order to keep updated MM context information. When transmission takes place the mobile enters into *ready* state. Within this state the location information maintained in the MM context contains the identity of the cell where the mobile is camping on. Thus, MS is forced to trigger a CU procedure whenever a cell reselection is performed within the same RA. On the same way, even in *ready* state, if the MS detects that the new cell also belongs to a new RA, a RAU procedure is executed instead of a CU. A RAU procedure could also force the GPRS core network to update the tunneling mechanism between GGSN and SGSN when the new cell belongs to a new SGSN. This case is known as a inter-SGSN RAU opposed to intra-SGSN where the new RA also belongs to the same SGSN.

Both location management procedures use the LLC and RLC/MAC protocols for message transmission across the G_b and radio interfaces. CU and RAU mechanisms originate the transmission through the new cell of an uplink LLC frame containing the MS's identity to the SGSN. In the direction towards the SGSN, the BSS shall add the cell identity to all BSSGP (BSS GPRS Protocol) frames [3]. When the BSSGP PDU (Packet Data Unit) containing the LLC frame and the new identifier of the cell is correctly detected at the SGSN, the SGSN records this MS's change of cell and further traffic towards the MS is conveyed over the new cell. While the RAU procedure consists of a 'request/reply' message exchanging with the SGSN [1], a CU only requires the reception at the SGSN of a valid LLC PDU carried inside a BSSGP PDU containing a new identifier of the cell.

In GPRS, the reselection mechanism is mainly based on power level issues, load status of the candidate cells or simply depend on the operator configuration that could prioritise some cells to carry out the GPRS traffic. When the mobile terminal decides to carry out the cell reselection procedure, the mobile is not aware of the amount of information devoted to it that could be buffered in the BSS. Thus, when a cell reselection is performed, there could be certain amount of data buffered in the PCU unit that needs to be managed. This management may basically be to flush the old buffer and rely on LLC retransmission capabilities to recover from data losses (in case that the transmission mode is acknowledged) or, whenever it is possible, to transfer the buffered data to the new PCU [3]. Whatever the solution shall be, our interests is to quantify the impact of the CU/RAU mechanism in terms of the number of packets stored at the old PCU buffer. For the sake of simplicity, hereafter, we will refer to them as lost packets. It is noticed that this effect only appears in the downlink since in the uplink LLC frames waiting to be transmitted through the air interface will be simply re-directed through the new cell.

III. ENVISAGED SCENARIO AND MODEL ASSUMPTIONS

A simulation model using OPNET tool has been developed to analyze the impact of the cell reselection mechanism in terms of packet losses. Basically the assumed scenario is illustrated in Fig. 2. Such a scenario is used to model the execution of a CU/RAU mechanism between two GPRS cells belonging to the same SGSN (intra-SGSN).

As it is shown in the Fig. 2, user data reaching the SGSN is supposed to be buffered at the SGSN node and also at the PCU unit, since the first uses a shared packet media to transfer data (BSSGP protocol over a Frame Relay network) and the latter performs scheduling policies at the RLC/MAC layer to assign radio resources. The implementation of a flow control mechanism in the Gb interface is also addressed since this mechanism may also influence directly in the load of the different buffers. Particularly, the relevant aspects taken into account in our analysis are the following:

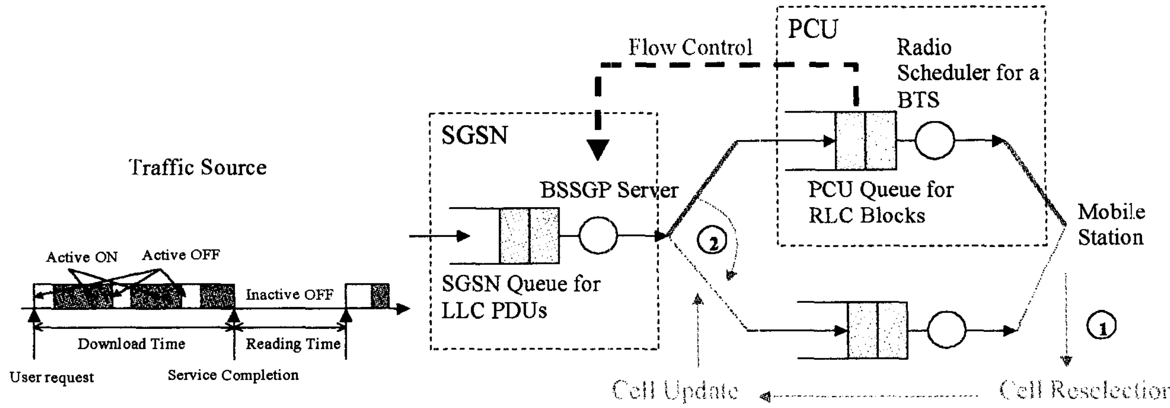

Figure 2. Model for the downlink channel from SGSN to the MS.

A. Traffic Characterisation

In the analysis we assume that the user under test has set up a data session that lasts for all the simulation time. As results obtained are highly dependent on the traffic characteristics, it is assumed that during the session the user is only engaged in a WWW browsing service because of its probably widest usage on mobile data access services.

The WWW traffic follows an ON-OFF pattern [4]. The ON period represents the file transmission time in the downlink and its value depends on the file size but also on the available bandwidth. A complete download consists of a successive number of individual file transfers (accounted for possible embedded references in a Web page) and a relatively short time interval to consider when the MS is processing the received Web page component (Active OFF in Fig. 2). After a Web page has been completely download, there is an OFF period without data transmission (Inactive OFF in Fig. 2) to take into account the reading time of the received information. The file size follows a Pareto distribution with the following probability function:

$$F_w(x_w) = 1 - \left(\frac{k_w}{x_w}\right)^{\alpha_w}$$

where the minimum file size is k_w=1000 bytes and the heavy-tailedness is α_w=1.5. The distribution of packet size is truncated at 64 kbytes to take into account that very large files are unlikely to be requested by mobile users. The number of embedded references in a WEB page is also modeled by a Pareto distribution with a minimum k_f=1 file and shape parameter α_f=2.43. The inactive OFF time follows a Weibull distribution with parameters a=0.328 and b=1.46. Finally, inactive OFF also follows the Pareto distribution with a minimum time k=1s and shape factor α=1.5.

B. Flow Control in the Gb interface

The Gb interface connects the BSS and the SGSN, allowing the exchange of signaling information and user data. As resources in the G_b interface are given to a user upon activity, a flow control algorithm is required in the downlink to assure that the SGSN shall never transmit more data than can be accommodated within the BSS buffers. In the uplink, there is no need of performing a flow control mechanism since bandwidth restrictions are in the air interface. In this case, once a LLC-PDU is successfully received at the PCU from the MS, it is immediately transmitted towards the correspondent SGSN. On the other side, in the downlink, LLC-PDUs at the SGSN need to pass through the flow control procedure before being forwarded to the PCU.

BSSGP flow control mechanism allows SGSN to locally control its transmission output towards the BSS based on certain flow control parameters sent by the BSS (see Fig. 2). The flow control shall be performed on each BSSGP virtual connection (BVC) and on each MS. A BVC refers to a single addressable entity in the Gb interface such as the radio management entity associated to a single cell within a PCU. Although the flow control algorithm in the downlink channel is up to the manufacturer, reference [3] provides a conformance definition to decide which LLC-PDUs are conforming to the flow to an individual MS or to a BVC over the Gb interface. Fig. 3 depicts this conformance definition algorithm.

The algorithm is based on a set of internal variables managed entirely at the SGSN (B=Bucket counter; B*=Predicted value of the bucket counter; L(p)=Length of the incoming LLC-PDU p; T_p=Time of the last transferred LLC-PDU and Tc=Arrival time of LLC-PDU) and two flow control parameters sent by the BSS for each BVC and MS individual flow:

- B_{max}=Maximum Bucket Size in bytes for a BVC or MS.
- R=Bucket leak rate for a BVC or MS

Basically, the algorithm avoids the transmission of more than B_{max} octets to the buffer and assumes that the corresponding buffer in the BSS is served by the radio scheduler unit at a transmission rate given by R bytes/s. A detailed description of how this algorithm works is given in [3].

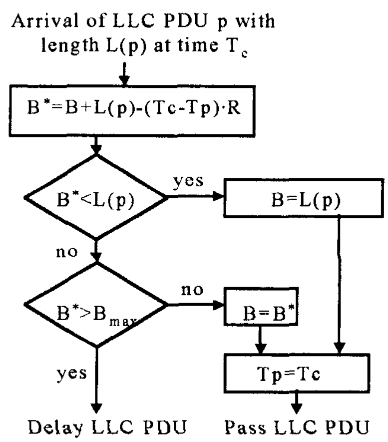

Figure 3. Conformance Definition Algorithm for BSSGP Flow Control.

C. Radio Scheduling at the PCU

A parallel simulation tool has been developed to characterize the scheduling delay in the radio interface. In the downlink, LLC-PDU frames remain buffered at the PCU until the radio scheduler proceeds to their transmission. LLC-PDU frames are segmented into RLC blocks and each one is transmitted over four bursts of an assigned slot in consecutive TDMA frames. A single slot in a GPRS carrier could accommodate a Packet Data Channel (PDCH) that allows the transmission of a complete RLC block each 20 ms. The amount of useful data contained in a RLC block depends on the coding scheme, named from CS-1 to CS-4, used in the air interface.

D. Location Management Functions Updating Time.

A parameter named Tc is defined to take into account the time interval spent by the execution of a CU or RAU procedure. This time interval lasts from the time when MS decides to perform a cell reselection until the time that routing tables are correctly updated in the SGSN and the information is transferred across the corresponding BTS. During this interval downlink traffic could be still directed to the old BTS.

IV. RESULTS

Results have been obtained to characterize the magnitude of the number of packet losses in the downlink direction when a CU/RAU procedure is performed. Although results have been found to be highly dependent on source traffic behavior and on transmission delay between the PCU and the MS, they could be used to estimate the relevance of such effect. The reference parameters considered are explained hereafter.

The WWW traffic source generates a mean rate of 8.5kbits/s. The downloaded files are segmented into network packets of 570 bytes corresponding to the IP default size. The source peak rate has been limited to 22.8kbits/s by fixing a minimum time period equal to 200 ms between consecutive generated IP packets. Once the network layer packets arrive at the SGSN, they pass firstly through the SNDCP layer and afterwards they are encapsulated into LLC frames. The size of the two added headers has been considered to be 13 bytes. Before LLC frames in the SGSN could be transmitted towards the corresponding PCU, the flow control conformance algorithm is applied with R=15 kbits/s and a maximum buffer size of 8000 bytes. In the PCU, LLC frames are stored again in a buffer while waiting for transmission to the MS. We assume that MS is capable of receiving simultaneously from 2 PDCH, and consequently, using a CS-2, MS could get information at a maximum rate of 26.8 kbits/s. The random behaviour of the scheduling time corresponds to the application of a FIFO policy. The load in the radio interface is such that the mean transmission time per byte is increased a 50%, giving a mean effective rate around 17.86 kbits/s when a transmission takes place. This reduction also includes the effect of considering a BLER (Block Error Rate) fixed to 10%.

Under previous stated assumptions, Fig. 4 provides the cumulative density function (CDF) of the number of lost LLC frames. This number is directly the number of packets buffered in the PCU when the CU/RAU mechanism is performed. The period between consecutive cell reselections is long enough to avoid transient effects in collected statistics. Results are plotted in terms of the time needed to update the routing information in the SGSN after a cell-reselection execution (T_c). As it is shown, a Tc=200ms could lead to a loss of at least one LLC frame around 40% of the times. In the same case, more than 5 LLC frames are lost in a 20% of the times. Even when the procedure was instantaneous the probability that no packet is lost is below 50%. On the other hand, an excessive delay in updating routing tables, e.g. when T_c=1s, could originate that more than 12 frames are lost a 10% of the times.

Apart from the bursty nature of the traffic source, the amount of lost packets depends strongly on the flow control parameters. This fact is depicted in Fig. 5 where the packet loss CDF is plot versus four configurations of B_{max} and R. In this case, Tc has been fixed to 200ms. As it is shown in the figure, a reduced rate R leads to a lower number of packet losses since packets are retained at the SGSN buffer.

However, the percentage of situations with no packet losses is less than 20%. A largest rate leads to a higher number of packet losses but also there are more situations where no packet is lost. The effect of the buffer size B_{max} is practically unnoticeable under this analyzed situation.

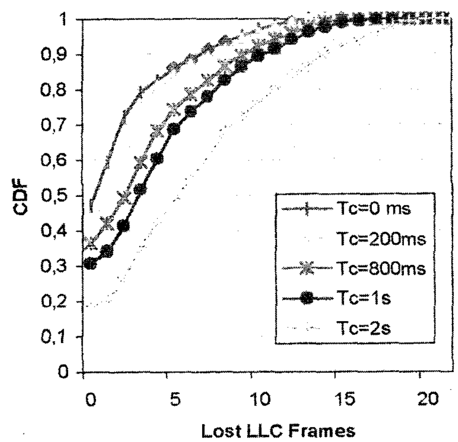

Figure 4. CDF of Lost LLC frames for different Tc.

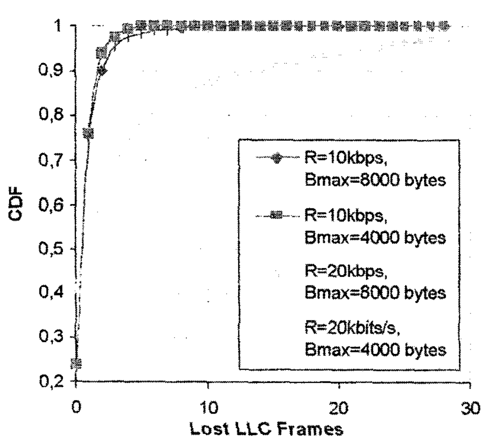

Figure 5. CDF of Lost LLC frames for different flow control parameters

Furthermore, when trying to optimize the flow control parameters in terms of packet losses also it is noticed the need to take into account the effects in transmission delay. This fact is reflected in Fig. 6 where mean transmission delay between SGSN and MS and mean number of lost LLC frames are plotted versus flow control rate R. It is shown that mean traffic loss increases with R but SGSN-MS delay exhibits the opposite behavior. Therefore, a trade-off between both effects needs to be addressed when designing optimal flow control mechanisms.

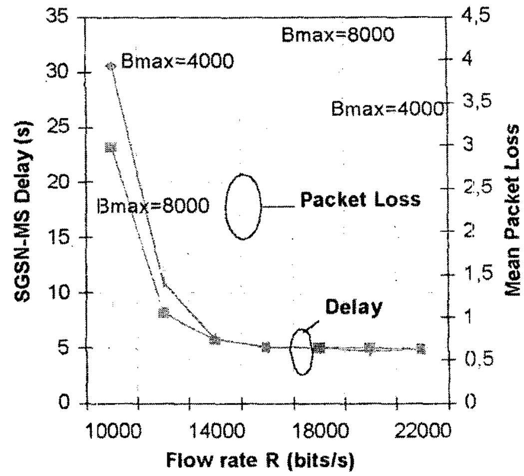

Figure 6. Trade-off between lost packets and transmission delay

V. Conclusions

Location management mechanisms defined in GPRS could originate the loss of packets in the PCU. In this paper a model to analyze and quantify such a effect has been proposed. Results have been found to be highly dependent on traffic characterization but the magnitude of this effect has been shown to be enough relevant to take into account such behavior when QoS is pursued. A solution to mitigate this fact could be the addition of buffer status information in the cell-reselection criteria.

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