Acknowledgment Procedures at Radio Link Control Level in GPRS

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Abstract

In this paper we investigate the acknowledgment procedures used at radio link control level of General Packet Radio Service (GPRS), where GPRS is a new GSM service designed for packet switched data transmission over GSM network. An introduction to the Radio Link Control and Medium Access Control (RLC/MAC) layer and its procedures is exposed in this paper, giving special attention to the acknowledgment parameters and operations. After presenting the channel models used, we analyze the performance of the acknowledgment procedure over a stationary channel model and a noisy wireless channel model affected by burst of errors. In order to ameliorate the performance of RLC layer, we describe and analyze a new additional hybrid FEC/ARQ mechanism. The purpose of the new mechanism, which can operate with the current one, is to decrease the number of control blocks used for RLC acknowledgment mechanism and thus reduces the packet transmission delay.

I. Introduction

The European Telecommunications Standards Institute (ETSI) standardizes, for GSM Phase 2+, the system GPRS as a new additional data bearer service in order to satisfy the increasing demand for mobile data communications and the recent developments of mobile data applications. The GPRS service provides a packet switched data transmission within GSM and a packet access to data networks. The physical channels (i.e., timeslots), available in a GSM cell, are dynamically shared between GPRS and other GSM services and the ones associated with GPRS are called Packet Data Channels (PDCHs). The data packets to/from different mobile stations can be multiplexed on the same PDCH and one mobile station can use many PDCHs simultaneously to transmit or receive data packets.

The specifications for Phase 1 GPRS, which are more or less completed, provide a basic functional GPRS service and define the Point-To-Point (PTP) services for either connectionless and connection-oriented network protocols. The radio interface of GPRS system is defined in [4] and an overview is given in [2]. The radio interface link layer in GPRS contains two sublayers: Logical Link Layer (LLC) and RLC/MAC layer. The LLC provides a highly reliable ciphered logical link and defines two LLC modes of operation: unacknowledged and acknowledged. This Layer is independent of the underlying radio interface protocols, notably the mode of operation. The RLC/MAC, described in [5], is the main subject of this paper. At RLC level, an acknowledgment mechanism based on selective repeat ARQ protocol can assure the reliable delivery of data packets. Both unacknowledged and acknowledged mode of operation at RLC level are defined. At physical link layer, the Forward Error Correction (FEC) coding, performed by four coding channel schemes and introduced in [4], allows the detection and correction of transmitted code words and the indication of uncorrectable code words. In this paper, we centralise our studies on the acknowledgment procedure defined at RLC level and we describe the new additional hybrid FEC/ARQ mechanism that we proposed in [1].

The material in this paper is organized as follows. The next section contains a rapid description of the RLC/MAC layer procedures. We present simplified scenarios of uplink and downlink transmission; after which, we focus on the procedures which define the acknowledgment mechanism. The channel model, presented in the section III, is the two-state Markov chain model, called Gilbert channel model ([7] and [9]). The analysis of acknowledgment mechanism with this channel model is exposed in the forth section. Basing on analysis done in [1], for a stationary channel model, the number of acknowledgment messages and the delay introduced by the acknowledgment mechanism are analyzed and evaluated. The additional acknowledgment mechanism, proposed in [1], is described in more details in section V. The new mechanism is derived from Non

Selective Repeat (NSR) protocol [3], therefore the resulting mechanism can be presented like a new hybrid FEC/ARQ one. The main objective of this mechanism is to reduce the number of control packets used in acknowledgment procedure and consequently to ameliorate the acknowledgment procedure performance. The simulation results are given and discussed in section VI, showing the interest of the modification proposed. Finally, conclusions are drown.

II. Procedures of RLC/MAC layer

The RLC/MAC layer is situated between LLC and physical layers and imitates an important sublayer of the GPRS radio interface. The MAC procedures enable multiple MSs to share a common transmission medium which may consist of several physical channels, PDCHs. This sublayer, also, provides collision avoidance, detection and recovery procedures and priority handling. The RLC sublayer performs the segmentation and re-assembly of LLC-PDUs into RLC data blocks. It includes Backward Error Correction (BEC) procedures which enable the selective retransmission of uncorrectable data blocks. The PTP services use acknowledged transfer mode on the radio interface for reliable delivery. Therefore, only the acknowledged mode of operation at RLC level is considered in the rest of this paper.

Definitions

◊ The basic radio packet is the RLC/MAC data block, using a radio resource corresponding to four bursts (i.e., 456 encoded bits after channel coding), but the access packet uses smaller amount of resource (i.e., one burst). A RLC/MAC data block, called simply **data block**, uses a sequence of four timeslots on a PDCH, called **block period**, to be transmitted. The field **Block Sequence Number** (BSN) is used to number data blocks.

◊ A **Temporary Block Flow** (TBF) is a physical connection used by the network and the MS to support the unidirectional transfer of a number of data blocks carrying one or more LLC-PDUs on one or more PDCHs.

◊ The **Uplink State Flag** (USF) is contained in downlink blocks and used to reserve the corresponding uplink block period in the case of dynamic allocation.

◊ New types of **packet data logical channels** are defined and mapped dynamically onto a 52-multiframe [4]. They include Packet Broadcast Control Channels (PBCCH), Common Control Channels (PCCCH) such as: Random Access (PRACH), Access Grant (PAGCH) and Paging (PPCH), and traffic channels such as: Data Traffic (PDTCH) and Associated Control (PACCH).

◊ The physical layer provides four different **coding channel schemes**, noted CS-1 to CS-4, for data blocks and the CS-1 is always used for control blocks except for the access bursts.

The RLC/MAC mechanism, defined in [5], is designed according the GSM/GPRS features, but the overall concept can be implemented on any TDMA system. It realizes packet access and can be seen as a possible and detailed implementation of the general Packet Reservation Multiple Access (PRMA) protocol [8]. The RLC/MAC mechanism consists in the establishment and transmission of a Temporary Block Flow (TBF). This mechanism can be presented, in the case of uplink traffic, by the following simplified scenario. The MS transmits an access request burst on PRACH. Therewith, the network responds, on PAGCH, with an uplink packet resource assignment which contains the medium access mechanism used and its parameters. At the reception of the uplink packet resource assignment, the MS transmits a sequence of data blocks and the network responds periodically by an acknowledgment message, noted Ack/NAck, which indicates (if any) the erroneous data blocks. Eventually, the MS retransmits the erroneous blocks. The delivery is concluded when the network transmits a positive acknowledgment (Ack) message announced as the last one. The three medium access mechanisms supported are: dynamic, extended dynamic and fixed. The resource assignment message, in the case of dynamic allocation, includes a list of PDCHs and the corresponding USF value per PDCH. When the MS detects its corresponding USF, it transmits a data block at the next block period. The extended dynamic allocation is a simple extension of the dynamic one adapted to deliver large volume data packets. In the case of fixed allocations, the resource assignment message communicates a detailed fixed uplink resources allocation to the MS i.e., the PDCHs assigned and a bitmap representing the assigned block periods per PDCH.

For downlink TBF transfer, the simplified scenario of the RLC/MAC mechanism can be presented as follows. If the MS is in "standby" MM state, the GPRS mobility management entity performs the paging procedure by sending a paging request on a PPCH. The MS responds with an access burst with cause value of "page response" and its MM state becomes "ready". Once the MS is in "ready" MM state, the network transmits a downlink packet resource assignment on PAGCH indicating the PDCHs that will be used for downlink transfer. One block period later, the network starts to transmit a sequence of data blocks and thereafter asks for an Ack/NAck. The MS sends an Ack/NAck indicating (if any) the erroneous data blocks. When the MS receives correctly all the data blocks, it sends an Ack and the delivery is terminated.

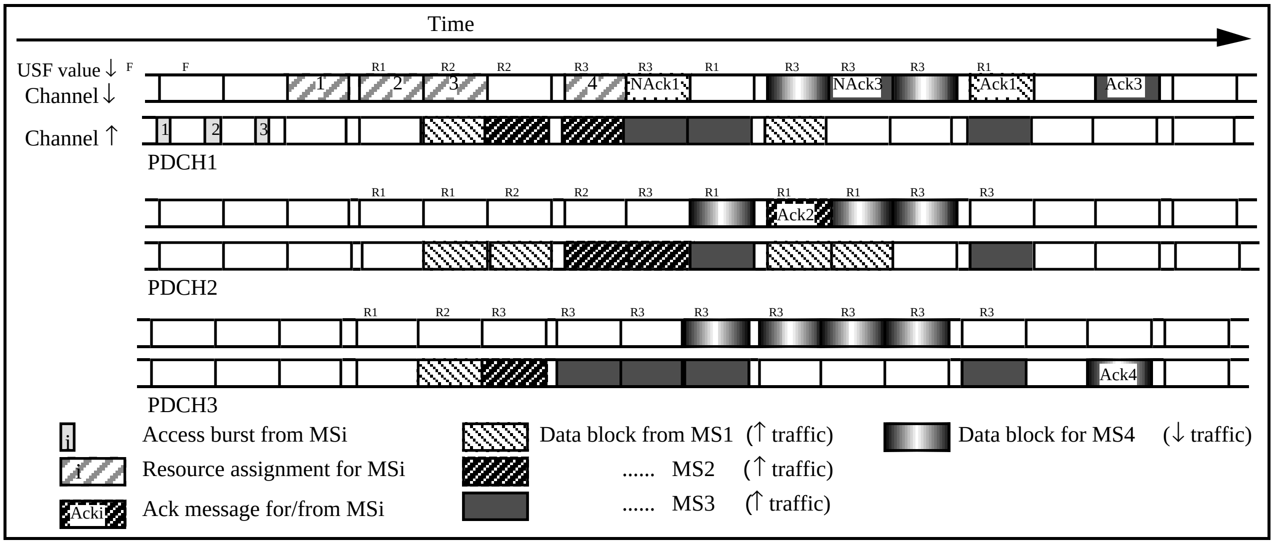

Figure 1. Transmissions scenario with 4 TBF, (3↑ et 1↓)

The data blocks transfer in RLC acknowledged mode is controlled by a Selective Repeat Automatic Repeat reQuest (SR-ARQ) mechanism which uses windows with maximum size W set to (W = 64). Each RLC transmitter entity, simply called Tx, transmits blocks within a window of W blocks. The RLC receiver entity, called Rx, periodically sends a temporary Ack/NAck. A Tx has a transmit window delimited by V(S), the BSN of the next block to be transmitted, and V(A), the BSN of the oldest data block that has been positively acknowledged. When Tx detects a transmit window stall condition i.e., [V(S) = V(A) + W] modulo 128, it indicates this condition to Rx and retransmits the oldest data block which are not yet acknowledged, then the next oldest one, etc. The receive window at Rx is limited by V(R), the number of the next block expected to be received, and V(Q), the number of the oldest data block received. An Ack/NAck corresponds to a control block and contains the contemporary value of V(R) and a bitmap indicating the acknowledgment status of, at most, W previous received blocks. On reception of an Ack/NAck, the Tx eventually retransmits the erroneous data blocks and readjusts its sending window. A missing Ack/NAck is not critical and a new one can be issued whenever. The network manages the scheduling of Ack/NAck for both ↑ and ↓ traffic and can send, or ask the MS to send, an Ack/NAck "when needed" [5].

Figure 1. presents a transmission scenario considering three PDCHs. It comprises: three ↑ TBF transmissions from MS1, MS2 and MS3 and one ↓ TBF to MS4. Every ↑ transfer procedure contains: access burst from the MS, uplink resource assignment message, transmission of the TBF of 4 (MS1), 5 (MS2) or 6 (MS3) data blocks, reception of a NAck or an Ack (i.e., NAck1, Ack2 and NAck3), re-transmission (from MS1 & MS3) of erroneous blocks and at the end, reception of an Ack. We notice in this figure that: USF="Free" is reserved for access bursts, USF="R1" is reserved for MS1, USF="R2" for MS2 and USF="R3" for MS3 and any MS can use the three PDCHs to transmit its data blocks. The figure contains only one ↓ transfer from the network to MS4 which is already in "ready" MM state. The procedure of this transfer contains a downlink resource assignment message, transmission of 9 data blocks and finally an Ack sent from MS4. The PDCH1 is called Master PDCH since it supports PCCCH and PBCCH. Otherwise, PDCH2 and PDCH3 can carry only traffic channels and they are called Slaves PDCH.

III. The Channel model

The aspects, that have to be taken into account to modeling the wireless channel, include: statistical distribution of the co-channel interference, speed of the mobile user, characteristics of the surrounding environment e.g., propagation and multipath models and notion of modulation technique used. Detailed studies, for the planning of such system, have been done in [12]. To simplify the wireless channel modeling, it is assumed that the transmission medium is modeled as a discrete two-state Markov chain (Figure 2). This channel model was introduced by Gilbert [9] and analyzed in e.g., [7].

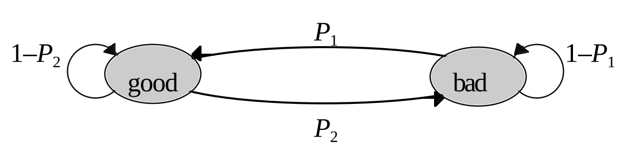

Figure 2. The transmission channel model

The state "good" in Figure 2, is the quiet state where the Bit Error Rate (BER) is ρ_{GOOD} and the state "bad" is the noisy state where the BER is ρ_{BAD}. The probability P_1 is the transition probability from "bad" to "good" and P_2 is the one from "good" to "bad". It is assumed, in order to simplify the model's treatment, that one time frame in the model corresponds to one block period, i.e., the noisy bursts last for a multiple of block periods. For the above channel model, we have that:

1) the average burst length is $N_{BAD} = 1/P_1$,
2) the average BER is $\rho_m = (P_2\rho_{BAD}+P_1\rho_{GOOD}) / (P_1+P_2)$ and
3) the probability of being in the bad state, or the duty cycle of the noisy burst, is $P_{BAD} = P_2 / (P_1+P_2)$, and the one of being in the good state is $P_{GOOD} = P_1 / (P_1+P_2)$.

The BLock Error Rate (BLER) in the bad state, BLER_{BAD}, depends on ρ_{BAD} and on the channel coding scheme used i.e., CS-1 to CS-4 and $\text{BLER}_{\text{GOOD}}$ depends on ρ_{GOOD} and on the CS used. In GPRS transmission system, the four following parameters P_1, P_2, BLER_{BAD} and $\text{BLER}_{\text{GOOD}}$ can define completely the channel model. The average BLER (BLER_m) can be given, similar to the average bit error rate, by: $\text{BLER}_m = P_{BAD}\, \text{BLER}_{\text{BAD}} + P_{GOOD}\, \text{BLER}_{\text{GOOD}}$. (1)

IV. Acknowledgment procedure analysis

Notations and assumptions

- Using the same assumptions and notations as in [1], it is assumed that the intrinsic delay introduced by one Ack, D_{Ack}, (or NAck, D_{NAck},) message transmission and handling is: $D_{Ack} = 30$ ms and $D_{NAck} = 40$ ms. (2)
- Let B denotes the TBF length in data blocks. We consider, similar to [1], that the transmission of a TBF takes place as presented in the flow chart of Figure 3.
- The feedback channel is assumed noiseless [7], and this can be justified by considering proper transmission on feedback channel (e.g., high transmission power).
- We assume the using of an error detecting code able to detect all the error patterns.

Let $N^{-}(B)$ and $N^{+}(B)$ denotes successively the number of NAck and Ack messages sent for one TBF, initially consisting of B data blocks. The evaluation of $N^{-}(B)$ and $N^{+}(B)$ in the case of a stationary channel model i.e., BLER is fixed within the TBF transmission, is done in [1]. These evaluations can be used in the case of non stationary channel model in replacing the fixed BLER which define the stationary channel model by the average BLER, BLER_m, given in (1). Using (2), the average delay, D_{TBFAck}, introduced by Ack/NAck messages for one TBF is given by: D_{TBFAck} (ms) = 40 E[$N^{-}(B)$] + 30 E[$N^{+}(B)$]. (3)

V. A proposal modification on acknowledgment mechanism

Basically, the fundamental techniques used to maintain reliable data communication in wireless packet networks over noisy channels include FEC mechanisms and ARQ mechanisms, as well as their hybrids. Since in FEC mechanisms, the transmitted information rate (K/N related to coding rate) is constant regardless of the channel conditions, but the reliability falls as the channel degrades. On the other hand, transmitted information rate of ARQ mechanisms depends mainly on channel quality, but the reliability is almost independent of the channel error rate. The three classical ARQ schemes are: Stop and Wait (SW), Go-Back-N (GBN) and Selective Repeat (SR); the current RLC-level GPRS acknowledgment mechanism uses the last one. In this section, the new hybrid FEC/ARQ mechanism, proposed and outlined in [1] for RLC level GPRS, is presented in more details and many propositions for its implementation are done.

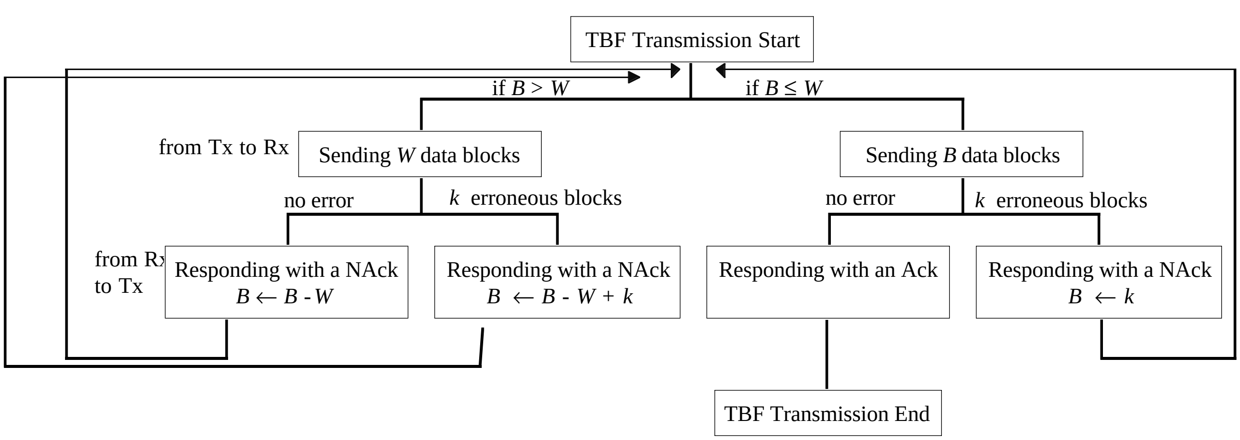

Figure 3. A transmission of one TBF containing *B* data blocks

The coding in the proposed mechanism has basic parameters $[n_{MAX}, k_{MAX}, d_{MAX}]$ with: $d_{MAX} = n_{MAX}–k_{MAX}+1$. Reed Solomon (RS) code can be used. The code is defined over an alphabet of symbols where a symbol represent the payload of a data block. A code word involves information blocks (I-block) and redundancy blocks (R-block). Assuming a perfect error detecting, the code can correct up to $d_{MAX}–1$ erased blocks. Shortening the code by some parameter K' and puncturing it by "deleting" Λ' R-blocks give specific versions of the RS code with the following flexible parameters $[N = n_{MAX} – K' – \Lambda', K = k_{MAX} – K', D = d_{MAX} – \Lambda']$ and relation $D = N–K+1$ is still valid [10].

The reference parameters of the coding scheme associated are fixed by a $[n_{MAX}, k_{MAX}, d_{MAX}]$ code which may correspond to some shortened version of the RS code. The W blocks of an ARQ window are divided in groups of, at most, K blocks where $K \leq k_{MAX}$. The proposed scheme uses feedback signaling (i.e., OK, NOK and SNAck) indicating the reception status of a group of blocks. The OK signal indicates that Rx has received correctly the previous group but NOK signal means that sending R-blocks could recover missing blocks. A NOK signal could indicate the requested number of redundancy blocks. The SNAck signal indicates that missing blocks can not be recovered by FEC procedure and Ack/NAck procedure will be responsible of the recovery. The new mechanism considers a time window size corresponding to the channel memory for a mobile class.

In order to explain the functionality of the additional mechanism, let's consider a simple TBF transmission scenario. The RLC transmitter entity, Tx, sends K (e.g., K=16) I-blocks. If Tx receives an OK signal, it discards the last group of blocks, transmitted before a time window size, from its buffer considering that they are correctly received. If Tx receives a NOK signal, it sends, at most, Λ R-blocks. The Tx stops to send R-blocks if it receives an Ack/NAck or an OK signal for the concerned group. If Tx receives a SNAck signal, it keeps the previous group in its buffer and switches to SR mechanism. The RLC receiver entity, Rx, responds with a feedback signaling every time it detects a group end. When Rx has to send the fourth (for K=16) SNAck, it sends a NAck message to acknowledge the four "noisy" corresponding groups. Both K and Λ could be not fixed at the beginning of the transmission and their values could be adapted to the channel condition. A data block will be

- IC, (I-block Continue) an information data block which is not the last one of the TBF,
- IE, (I-block End), last information data block of a TBF,
- R, R-block numbered and called: R1, R2, ... etc.

In the following paragraph, some modifications, on the RLC/MAC header format, are proposed in order to contain the feedback signals and to indicate the block category (information or redundancy). The payload type field can be used to indicate the block category. The BSN field (7 bits), used to number information blocks, could be used to number R-blocks and to give information about the corresponding group i.e., its "number" and its length in blocks. The Final Bit Indicator (FBI) field in downlink blocks and Countdown Value (CV) field in uplink blocks can be associated to the BSN field when the block is a redundancy one. For uplink traffic, the USF field can be extended by, at least, three bits to contain the feedback signals. Two bits can be used to indicate the feedback signals status: OK, NOK or SNAck and one bit to indicate the corresponding group. To extend the USF field, the fields called RRBP and S/P can be used. On the other side, in the case of downlink traffic, the MS sends in assigned idle slots a special access burst, which is used by the network to derive the timing advance. The number of mobile stations using the same PDCH can attain, limited by the Timing Advance Index (TAI), 16 MS. We propose that the base station assign more than one idle slot every eight multiframes to permit the MS to send more often its burst. This burst can contain the feedback signals.

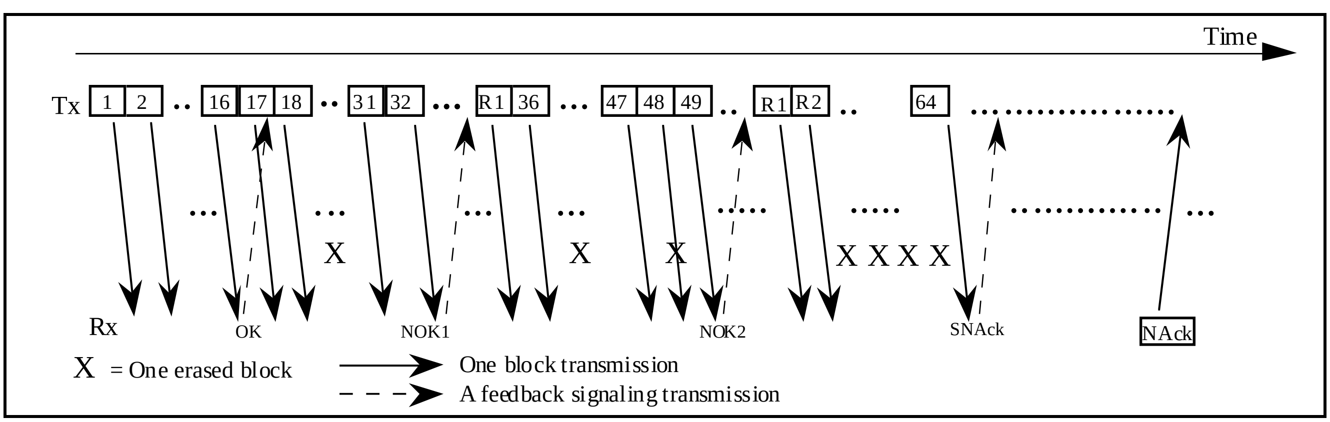

Figure 4. Example of a TBF transmission using the proposal mechanism

Figure 4. gives an example of a large volume TBF transmission, with the proposal mechanism, considering that $K = 16$ and $\Lambda = 2$. The NOK signal have two values: NOK1 and NOK2 meaning that Rx asks for one or two R-blocks. The first group, BSN∈{1,16}, is correctly received by Rx i.e., Tx receives an OK. The second has one error, so Tx receives a NOK1 and transmits one R-block. The third group has two errors, therefore the Rx sends a NOK2 and Tx responds with two R-blocks. The forth group errors could not be recovered by two R-blocks, so this group has to wait a NAck to be corrected. After SNAck signals, Rx sends a NAck message which contains a bitmap indicating erroneous blocks number. The additional mechanism yields, as shown in Figure 4, to limit the number of control blocks. The reduction of Ack/NAck number, principally, economizes feedback resources and ameliorates the transmission delay.

VI. Simulation results

The utility of the additional proposed mechanism seems more significant for applications containing infrequent transmission of large volumes of data than frequent transmission of smaller volumes of data. It is, apparently, more important when the channel quality is time varying. Since the principal aim of the additional mechanism is to limit the number of acknowledgment messages, the performance criteria analyzed is the average value of Ack/NAck number sent by Rx to receive correctly a TBF. The new additional mechanism parameters used in these simulations are: $K = 16$, $\Lambda = 2$ and NOK signal can indicate the number of required R-blocks. The BLER is calculated, with frequency hopping in a typical urban environment, in function of Carrier-to-Interface ratio (C/I) in [11]. Two channel models are proposed: "constant" channel quality and "time varying" channel quality. The first channel model, where the C/I ratio is constant within a TBF transmission, is analyzed in [1] and the control blocks number reduction was exposed using the FUNET model as a traffic load model. Simulations done in this paper use a new traffic load model (i.e., WWW model) explained later. The second channel model considers a "time varying" channel quality such as the Gilbert channel model presented in Section III. In these simulations, the bad and good states, successively, correspond to the following values of 10log(C/I): 2, 18.

The traffic load model used in the following simulations is the WWW service model exposed in [6]. It is a non real time service which consists of a **session** arrival process model. A packet service session contains one or several **packet calls** where a packet call corresponds the downloading of a WWW document. After the document is downloading, the user is consuming amount of time called **reading time**. A packet call constitutes of a bursty sequence of **packets**. The number of packets in a packet call can be geometrically distributed random variable with a mean set to 25. The packet size distribution used is a Pareto distribution with cut-off. So, the packet size is defined as min(MaxPS, P) where MaxPS is the maximum allowed packet size, MaxPS = 66666 bytes and P is normal Pareto distributed random variable and its PDF is: $F_x(x) = 1 - (81{,}5 / x)^{1{,}1}$. Assuming that the average interarrival time between packets is small enough to transmit all the packets of one packet call within one TBF, the TBF length is considered as the summation of all packets length within one packet call.

The graphs in Figure 5. represent the average number of Ack/NAck necessary to receive correctly a TBF with a stationary channel model versus the C/I (or channel quality). Each graph corresponds to one of the four channel coding schemes. We notice that the average value of Ack/NAck number decreases considerably when the channel coding rate decreases. The proposed additional modification, exposed in V, compatible with the present acknowledgement mechanism, presented in II, decreases, notably, the average value of Ack/NAck number and this decrease depends on channel coding scheme used and on channel quality i.e., C/I.

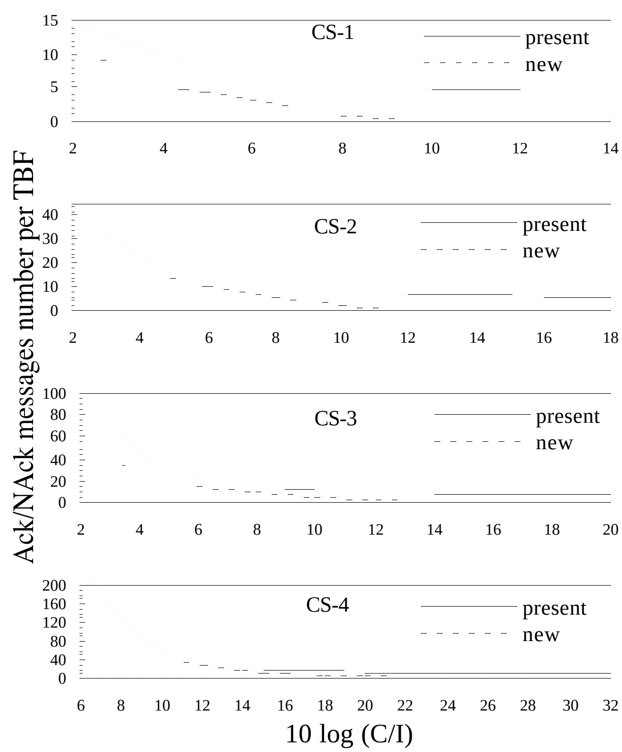

Figure 5. Ack/NAck messages number per TBF vs C/I (stationary channel model)

In figures 6, 7, 8, 9 and 10, the channel model consiederd is the Gilbert channel presented in section III. The graphs in Figure 6. contain the average number of Ack/NAck, necessary to receive correctly a TBF, versus the average number of data blocks transmitted in bad state ($1/P_1$) with $1/P_2$ set to ($1/P_2 = 20$). In the case of high value of $1/P_1$, when the channel coding rate increases, the Ack/NAck number increases. The proposed additional modification decreases the average number of Ack/NAck messages. The average number of Ack/NAck necessary to receive correctly a TBF versus the average number of data blocks transmitted in good state ($1/P_2$) is illustrated in figures 7, 8, 9 and 10 where the value of $1/P_1$, successively, set to 10, 5, 2, 1. The Ack/NAck number decreases when the value of $1/P_2$ decreases with the same $1/P_1$. The increase of Ack/NAck number, due to the increse of the channel coding rate, is more pronounced when $1/P_1$ is more important. The proposed additional modification reduces the average number of Ack/NAck. The benefit drawn from this modification depends on the CS used and on the channel parameters i.e. P_1 and P_2 e.g., for the same CS, the reductin of Ack/NAck number is more important when the value of $1/P_1$ is lower. The utility of the new mechanism is often more important when CS-1 is used. The profits obtained on Ack/NAck number, in principle, economize feedback radio resources, hence increase the throughput of opposite direction traffic, and reduce the delay of data delivery.

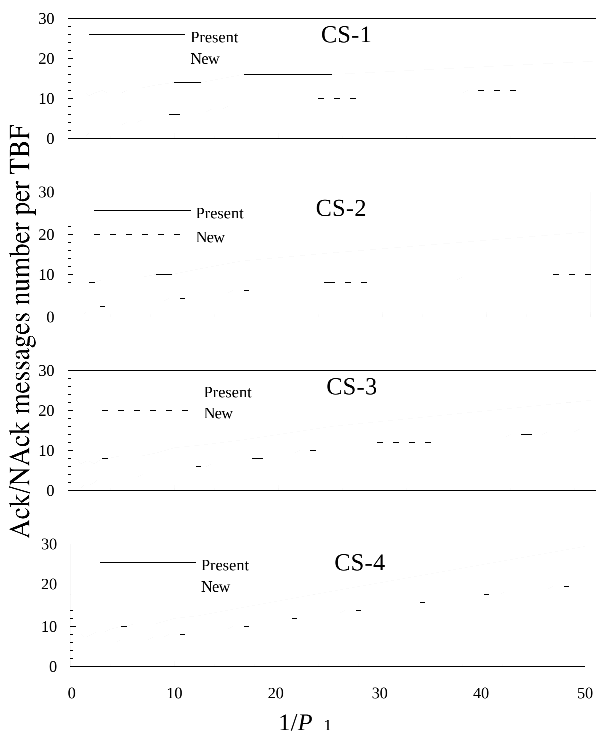

Figure 6. Ack/NAck messages number per TBF vs $1/P_1$ ($P_2 = 0.05$)

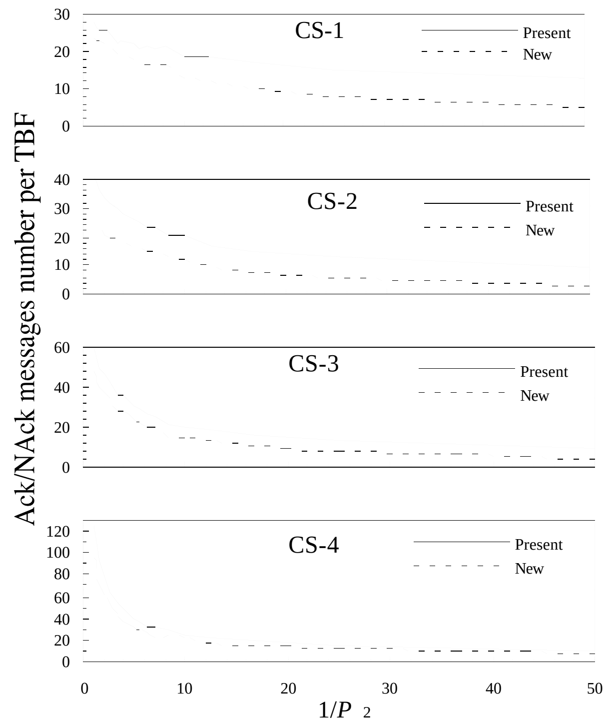

Figure 7. Ack/NAck messages number per TBF vs $1/P_2$ ($1/P_1 = 10$)

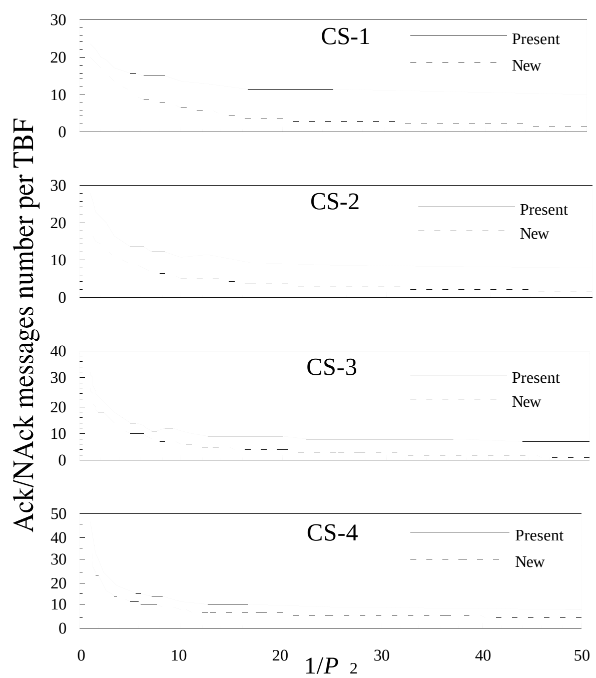

Figure 8. Ack/NAck messages number per TBF vs $1/P_2$ ($1/P_1 = 5$)

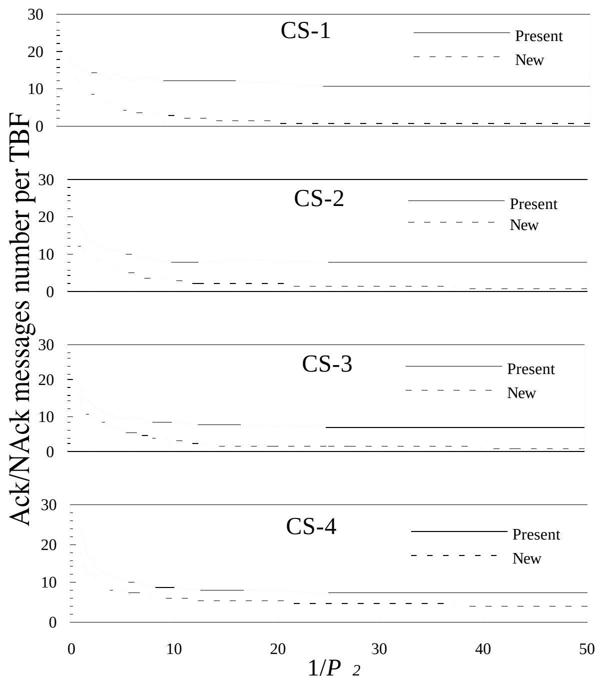

Figure 9. Ack/NAck messages number per TBF vs $1/P_2$ ($1/P_1 = 2$)

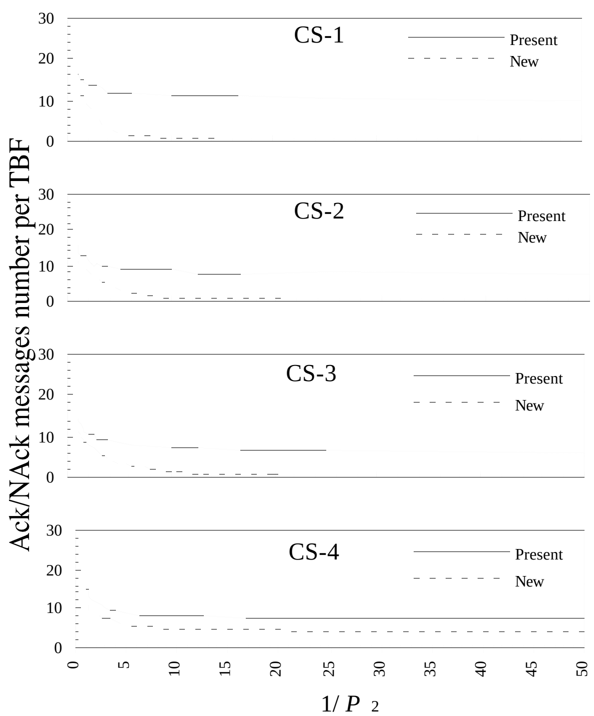

Figure 10. Ack/NAck messages number per TBF vs $1/P_2$ ($1/P_1 = 1$)

VII. Conclusion

This paper presents the RLC/MAC sublayer in GPRS and studies the current acknowledgment mechanism used in GPRS RLC-level. This acknowledgment procedure is analysed with Gilbert wireless channel model. In this paper, the complementary scheme, that we proposed in [1] in order to improve the performance of RLC sublayer, is described in more details. The new mechanism can be seen as a possible implementation of the Non Selective Repeat (NSR) mechanism for point-to-point communications, although the NSR mechanism was initially conceived for point-to-multipoint communications [3]. The capacity of the proposal acknowledgment scheme to reduce the number of control messages (Ack/NAck) is affirmed by simulation methods with different channel models and parameters. The profit obtained on Ack/NAck number reduces the delay of data delivery.

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