# Study on Power Saving for Cellular Digital Packet Data over a Random Error/Loss Channel

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*Abstract*— **This paper investigates the impact on the power saving mechanism (PSM) of the cellular digital packet data (CDPD) caused by random frame errors and losses. To combat such random frame errors and losses, a selective repeat (SR) protocol of automatic repeat request (ARQ) protocols in charge of recovery of garbled/lost frames is combined with the original PSM of CDPD. We then study the enhanced PSM and investigate the effect of channel conditions including bit error rate and frame loss probability as well as frame buffer size and window size of SR-ARQ to the PSM through numerical examples. The results provided in this paper are able to serve as guidelines on system design and parameter setting for CDPD when an imperfect channel is taken into consideration to reflect the realistic situation.**

## I. Introduction

Due to the fact that limited power is supplied by batteries, how to efficiently make use of battery power consumed by a mobile phone handset is a challenging and urgent issue in the wireless communication networks, e.g., CDPD [2], [3], [7], wireless LAN [8] etc. We note that although CDPD is the data network overlaid over the first generation cellular system, i.e., advanced mobile phone system (AMPS) [3], it still draws much attention of researchers; for instance, [4], [5], [6] are some of recent papers addressed CDPD-related issues.

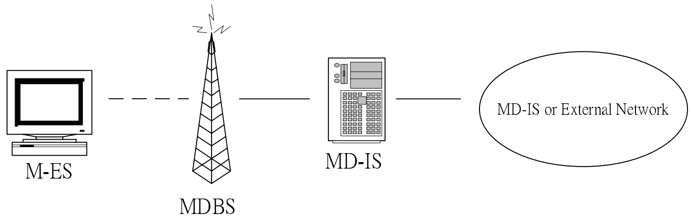


Fig. 1. The architecture of CDPD.

For readers' convenience and for self-consistency, we briefly review the system architecture of CDPD here. As shown in Fig. 1, the user end terminal is called mobile end system (M-ES) and several M-ESs are connected to the so-called mobile data base station (MDBS) through the AMPS air interface which may cause transmitted signals to be distorted by the background noise. This is the reason why we consider the random error/loss channel here to investigate its impact on the PSM of CDPD. There are two types of links defined for the air interface (frequently called as CDPD channel stream), i.e., reverse link and forward link which are links that data frames are sent from the M-ES to the MDBS and the MDBS to the M-ES, respectively. The MDBS is not only connected to several M-ESs, but also connected to a mobile data intermediate system (MD-IS) which is responsible for mobility management and routing to other MD-ISs or fixed end systems (F-ESs).

We now further describe the power management of CDPD. An M-ES is allowed to enter *sleep mode* to reduce the power consumption once the temporary equipment identifier (TEI) for the M-ES is assigned and the sleep mode operation is requested during the TEI assignment procedure. The sleep mode operation works as follows. An M-ES triggers a T203 timer, i.e., an *element inactivity timer* when it completes a frame transmission, e.g., acknowledgement (ACK) frame in the reverse link; then the timer counts down to zero (When the value of a timer reaches zero, we call it as the timer timeouts/expires.). But the timer should be reset when there are data frames requiring the M-ES to receive or send before it expires. Once the timer expires, the M-ES then enters the *sleep mode* and does not send/receive data frames until it *wakes up*. Therefore, an individual buffer for the M-ES at the MD-IS is necessary to queue data frames temporarily while the M-ES is in *sleep mode*. If the buffer is full, then extra data frames get dropped. To wake up the sleeping M-ES, another T204 timer, i.e., the *TEI notification timer* is maintained and periodically triggered by the MD-IS for each channel stream. As T204 timer expires, the MD-IS broadcasts a frame containing TEIs with pending frames to be delivered but queued in their buffers at the MD-IS and all M-ESs wake up to listen to the broadcast message during the broadcast period. If the TEI for a specific M-ES is found in the frame, then the M-ES leaves the sleep mode and sends a receiver ready (RR) frame to the MD-IS to notify the MD-IS that it is ready to receive the pending frames. If an RR frame is not received by the MD-IS, the MD-IS triggers the T204 timer again. If its own TEI of the M-ES is not found in the frame, then it remains in the sleep mode. For more detailed description for the PSM of CDPD over a perfect channel, readers can refer to [6] and [7]. In [7], the simulation approach was utilized while [6] provided the system performance using an analytic method. However, both of above mentioned papers assumed the perfect channel which

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can not reflect realistic situation in the real communication environment; therefore, we try to incorporate this factor into consideration and observe the effects of frame random errors and losses on the PSM. In addition, we combine the original PSM of CDPD with an SR-ARQ [1] and study the system performance under various channel parameters, e.g., bit error rate (BER) and frame loss probability (FLP) and different sizes of frame buffer or control window.

The rest of the paper is organized as follows. In Section II, we describe the combination of SR-ARQ and PSM. Section III gives numerical examples and discussions on the enhanced PSM. Finally, Section IV concludes the paper.

## II. Combination of SR-ARQ and PSM

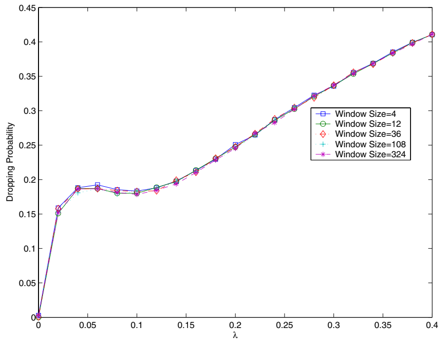
In the literature, SR has been proven the promising ARQ among the three basic retransmission protocols: stop-and-wait (SW), go-back-N (GBN), and SR [1]. Hence, we adopt the SR-ARQ here for the following discussion. SR-ARQ is a window-based retransmission scheme. Initially, the sender sends $W_{SR}$ frames to the receiver and maintains a sending window with $W_{SR}$ maximum in-flight frames, where $W_{SR}$ denotes the window size; then the receiver acknowledges for correctly received frames by sending back (positive) ACKs in which the sequence number of the next expected frame is indicated and acknowledges for garbled frames by sending negative ACKs (NAKs) in which the sequence number of the next expected frame is also indicated. Once the sender receives an ACK, it deletes frames with sequence numbers lower than the sequence number indicated by the ACK and then sends the frames to be transmitted, while it just retransmits the frame indicated by the NAK. All above descriptions merely consider the error-permitted channel but not the lossy channel. To incorporate the frame loss situation, extra timers can be used to accomplish the loss recovery. Here we call such timers as frame retransmission timers. Typically, the initial value set for the frame retransmission timer is much smaller than that of T203 or T204.

Taking the SR-ARQ into consideration, the events and actions for both MD-IS and M-ES of the modified/enhanced PSM are described as follows.
Events and actions for the MD-IS: *1) Arrival of data frames from other MD-IS or network*: Put these frames into the buffer if there is available space or just discard overflowed frames. If the T203 timer for the M-ES does not expire, then deliver frames queued in the buffer with sequence numbers to the M-ES (via MDBS) and set a frame retransmission timer for each frame until the maintained sending window is greater than the window size. *2) Arrival of a data frame from an M-ES*: Trigger the corresponding T203 timer. Check whether the frame is necessary to retransmit or not? If yes, send a NAK; otherwise send an ACK and check whether the sequence number is within the receiving window? If not, just discard the frame (a duplicated frame is received!). *3) Timeout of T204 timer*: Broadcast a TEI notification frame including all "sleeping" TEIs to all M-ESs and trigger T204 timer again. *4) Timeout of T203 timer*: Record the status of the corresponding TEI as "sleeping". *5) Timeout of a frame retransmission timer*: If T203 timer does not expire, then resend the frame and set the frame retransmission timer. *6) Receipt of RR*: Trigger the corresponding T203 timer and deliver frames queued in the buffer with sequence numbers to the M-ES (via MDBS) and set a frame retransmission timer for each frame until the maintained sending window is greater than the window size. *7) Receipt of an ACK or a NAK*: Trigger the corresponding T203 timer. If an ACK is received, then remove all frames in the queue whose sequence numbers are smaller than the sequence number indicated by the ACK and update the sending window. If a NAK is received, then resend the expected frame. Finally deliver affordable frames in the buffer to the M-ES and set frame retransmission timers until the maintained sending window is greater than the window size.
Events and actions for the M-ES: *1) Arrival of a data frame from the MD-IS*: Check whether the frame is necessary to retransmit or not? If yes, send a NAK; otherwise send an ACK and check whether the sequence number is within the receiving window? If not, just discard the frame (a duplicated frame is received!). Finally trigger the T203 timer. *2) Time to wake up*: Listen to the broadcast frame from the MD-IS. If its TEI is found in the frame, then send an RR frame to the MD-IS and trigger the T203 timer. *3) Timeout of T203 timer*: The M-ES then enters the sleep mode. *4) Timeout of a frame retransmission timer*: Resend the frame and set the frame retransmission timer and T203 timer. *5) Receipt of an ACK or a NAK*: If an ACK is received, then remove all frames in the queue whose sequence numbers are smaller than the sequence number indicated by the ACK and update the sending window. If a NAK is received, then resend the expected frame. Finally deliver affordable frames in the buffer to the MD-IS and set frame retransmission timers and the T203 timer until the maintained sending window is greater than the window size.

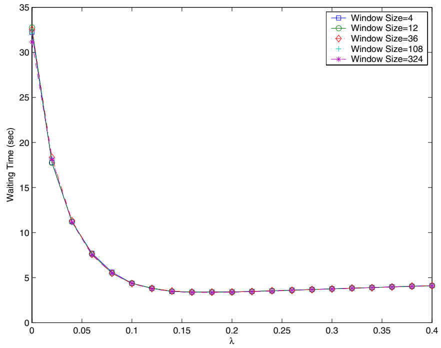
## III. Numerical Examples and Discussions

### A. Simulation Modelling and Assumptions

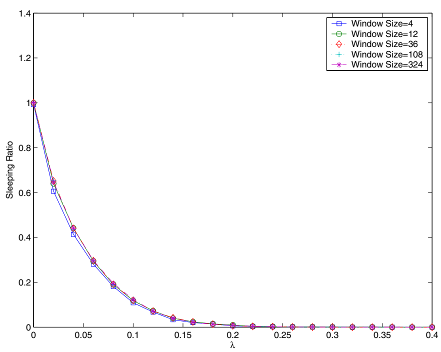
In this paper, we assume the data frames from other MD-ISs or external fixed networks to MD-IS for an M-ES are generated by a Poisson process with rate $\lambda$ accompanying with a uniform distribution $U(L_l, L_u)$ to model the variable numbers of frames of fixed length ($f_{len}^d$ in bits for data frames, and $f_{len}^c$ in bits for control frames, such as ACK, NAK, and RR). In the following numerical experiments, we fix $L_l = 1$, $L_u = 10$, $f_{len}^d = 256$, and $f_{len}^c = 8$. For the buffer size, we set 10 or 30 times of data frame space. Since the data rate of CDPD is 19.2 kbps, the frame transmission time is $f_l/19200$ seconds, where $f_l$ represents the frame length in bits. When a frame is transmitted, there are three possible cases: 1) the frame is correctly received; 2) the frame is received with erroneous bits; 3) the frame is lost. To model bit error and frame loss, we simply use two independent Bernoulli random variables to indicate whether the frame is correctly received, garbled or lost. We note that the relation between the frame error probability (FEP) and BER is FEP =




(a) Dropping probability.

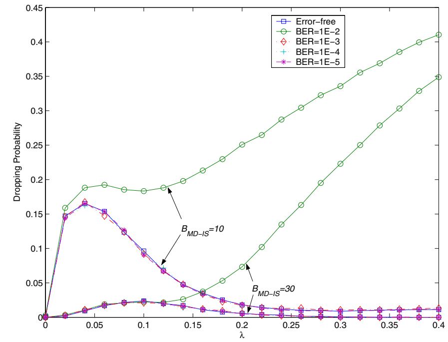



(b) Waiting time.

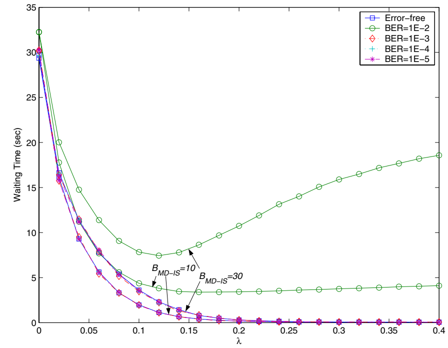



(c) Sleeping ratio.

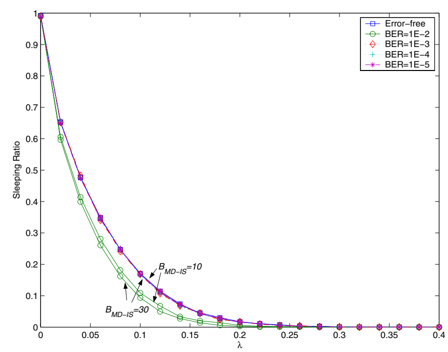
Fig. 2. System performance for various SR-ARQ window sizes with BER $= 10^{-2}$, FLP $= 0$, and $B_{MD-IS} = 10$.




(a) Dropping probability.




(b) Waiting time.




(c) Sleeping ratio.

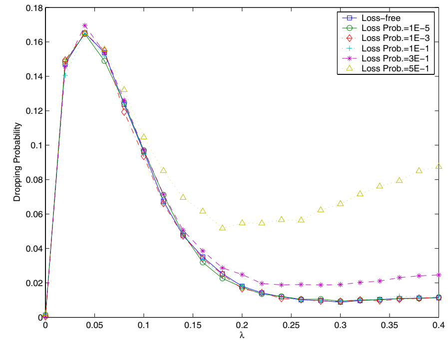
Fig. 3. System performance for various BERs with FLP $= 0$ and $W_{SR} = 4$.

$1 - (1 - \text{BER})^{f_l}$. For $f_l = 256$, the possible pairs of (BER, FEP) are $(10^{-2}, 0.924)$, $(2.5 \times 10^{-3}, 0.473)$, $(10^{-3}, 0.226)$, $(10^{-4}, 0.025)$, $(10^{-5}, 2.5 \times 10^{-3})$. The relation holds since no error correcting code is employed in this paper for the sake of simplicity though the Reed-Solomon $(63, 47)$ code is used in real operations of CDPD. Hence, one or more erroneous bit(s) cause(s) an erroneous frame. As for frame loss probability, the same probability is assumed for data frames, ACKs/NAKs, and RR frames to reflect the frame losses caused by congestion or other reasons. As we mentioned previously, the frame retransmission timer to handle the frame loss is required. Here we set a fixed initial value $T_{ft} = 0.1$ seconds to the frame retransmission timer. And the initial values of timer T203 and T204 are set to $T_{203} = 30$ seconds and $T_{204} = 60$ seconds which are the default values used by CDPD [7]. In the following simulation experiments, we concentrate on the performance of the enhanced PSM for a specific M-ES fed by data frames coming from the MD-IS.

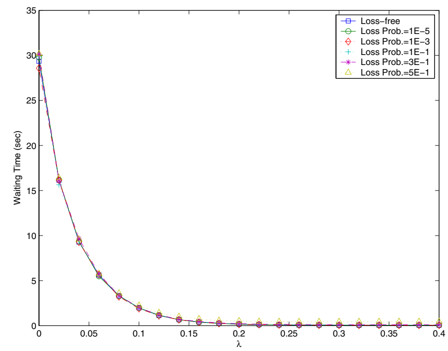
### B. Experimental Results and Discussions

We study here the performance of the PSM by observing the (frame) dropping probability, (frame) waiting time, and sleeping ratio. Now let us first observe the effect of the SR-ARQ window size. Fixing BER $= 10^{-2}$ and buffer size at MD-IS $B_{MD-IS} = 10$, we see that the SR-ARQ window size affects little to the PSM as shown in Fig. 2 with window size ranging from 4, 12, ... to 324 since the system is observed under the light traffic load. Of course, a larger window size results in smaller frame dropping probability and frame waiting time but higher sleeping ratio because of the pipelining effect. In the following, we choose the SR-ARQ window size

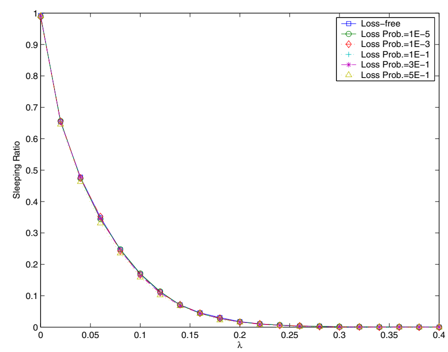
$W_{SR} = 4$. Now we pay our attention to the channel-related factors, i.e., BER and FLP. In Fig. 3, we assume that the channel is loss-free but may cause bit errors with BER varying from 0 (error-free), $10^{-2}$, $10^{-3}$, ... to $10^{-5}$. From Figs. 3(a) and 3(b), we notice the followings. (i) Both of frame dropping probability and frame waiting time for BER $= 10^{-2}$ deviate dramatically from those when BER $< 10^{-2}$. In fact, they deviate profoundly when BER $\geq 2.5 \times 10^{-3}$ according to our more detailed examination of numerical data which are not shown in Fig. 3. (ii) For BER $= 10^{-2}$, these two performance measures change their trends compared to the error-free results with knee points at $\lambda \doteq 0.1$ (for $B_{MD-IS} = 10$) and $\lambda \doteq 0.12$ (for $B_{MD-IS} = 30$), at which these two performance measures start to increase profoundly rather than to decrease or slightly to increase over the range $\lambda = 0 \sim 0.4$ as those observed in the error-free case. This shows that the channel condition is indeed worse enough when BER $= 10^{-2}$; hence, retransmission of error frames turns into the main system burden. (iii) As for the dropping probabilities and waiting times when BERs are lower than $10^{-3}$, they approach the result of the error-free (and loss-free) channel. (iv) Under the worse channel condition, increase of the buffer size can compensate the effect of frame errors but incurs longer frame waiting time (thus, lower sleeping ratio). In Fig. 3(c), we examine the sleeping ratio of the PSM under various BERs. Again, we notice that (i) increase of both BER and buffer size causes the sleeping ratio to drop down since more frames are sent to the M-ES; (ii) the sleeping ratios for BERs lower than $10^{-3}$ are comparable and posses about 50% more sleeping ratio than that when BER is $10^{-2}$. In Fig. 4, we assume that the channel is error-free but may cause frame losses with FLPs varying among 0 (loss-free), $10^{-5}$, $10^{-3}$, $10^{-1}$, 0.3, and 0.5 under $B_{MD-IS} = 10$ and $W_{SR} = 4$. In contrast to FEP, we first note that the above FLPs may cause effects similar to those with BERs smaller than $2.5 \times 10^{-3}$ (using the relation FEP $= 1 - (1 - \text{BER})^{f_l}$). Hence, we see from Fig. 4(a) that the dropping probabilities fall within the range $(0, 0.17)$ caused by these FLPs as those caused by BERs lower than $2.5 \times 10^{-3}$. In addition, we find out that when $\lambda \in (0, 0.1)$, dropping probabilities almost coincide regardless of different FLPs. Beyond that range, noticeable differences are observed and all first drop and then raise at $\lambda = 0.18$ for FLP $= 0.5$, at $\lambda = 0.23$ for FLP $= 0.3$, and at $\lambda = 0.3$ for FLP $\leq 0.1$, respectively. As for frame waiting time and sleeping ratio, negligible differences for these FLPs due to the truncation of the finite buffer (see Figs. 4(b) and 4(c)). As for results under the hybrid channel, i.e., the channel with both bit errors and frame losses, they are shown in Figs. 5(a)–(c), which exhibit the composite phenomena caused by bit error rate and frame loss probability discussed above.




(a) Dropping probability.




(b) Waiting time.




(c) Sleeping ratio.

Fig. 4. System performance for various FLPs with BER $= 0$, $W_{SR} = 4$, and $B_{MD-IS} = 10$.

## IV. Conclusions

Taking the imperfect channel into consideration, the power saving mechanism of CDPD has to incorporate an ARQ protocol to combat frame errors and losses. In this paper, we select the SR-ARQ to work with the PSM of CDPD and study the resultant system performance under different channel conditions and system parameters. Based on the simulation results, we reach the following main observations. 1) System performance is insensitive to the SR-ARQ window size under the light traffic load; hence, we suggest that 4 is enough. 2) Even with the SR-ARQ, the channel with bit error rate higher than $10^{-2}$ or the channel with frame loss probability larger than 0.1 deteriorates the system performance much. 3) For BER $\leq 10^{-2}$ and FLP $\leq 0.1$, the sleeping ratio of an M-ES is affected little by the SR-ARQ. Hence, the above observations support that a SR-ARQ with proper parameters can appropriately recover frame errors and losses but remain lower power consumption for the M-ES under the typical channel condition, i.e., BER $\leq 10^{-2}$ and FLP $\leq 10^{-3}$.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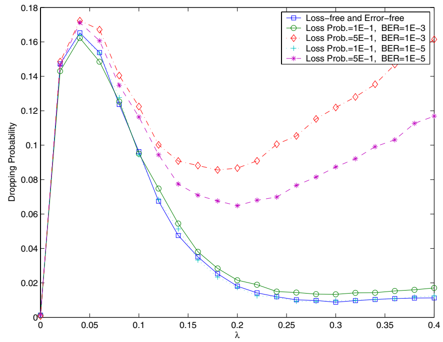
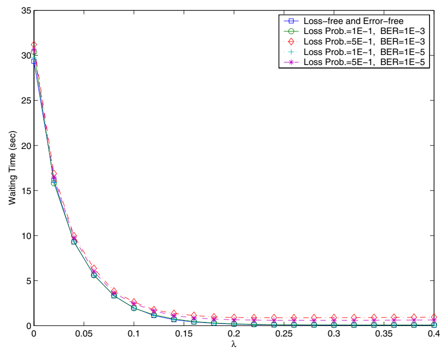
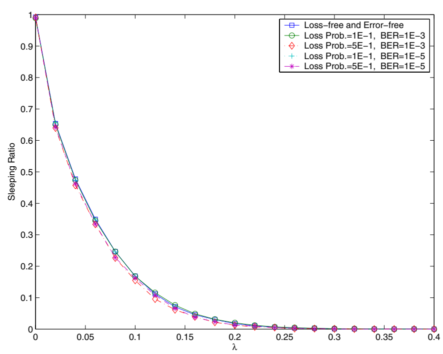



(a) Dropping probability.




(b) Waiting time.




(c) Sleeping ratio.

Fig. 5. System performance for various combinations of BERs and FLPs with $W_{SR} = 4$ and $B_{MD-IS} = 10$.

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