A Study on the Performance Analysis of Error Control Algorithms in Digital Cellular DS/CDMA Systems

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Abstract In this paper, the average error-rate characteristics is investigated as the number of users increases in the digital cellular DS/CDMA(Direct Sequence/Code Division Multiple Access) systems. Then, the performances of the various error control scheme applied to the data service of digital cellular DS/CDMA systems are compared and analyzed. That is, the performances of the conventional error control schemes such as Go-back-N ARQ(Automatic Repeat reQuest) and Selective-Repeat ARQ are analyzed in the circumstance of digital cellular DS/CDMA system. Also, the improved error control schemes which utilize variable window size and/or variable data packet size are proposed and evaluated in order to improve the performances of the conventional error control scheme such as Quick-Repeat ARQ and WORM ARQ schemes in the digital cellular DS/CDMA system environments. According to the simulation results, the performances of the improved scheme with variable window and variable frame size are superior to those of the conventional scheme in view of throughput and delay characteristics due to the robustness to the fading channel impairments.

1. Introduction

It may be the ultimate goal of communication to exchange information at any time, at any place and with any one. Also, it may be the role of the universal mobile communication service composed of switching technology, wire and wireless transmission technology to realize this goal. Today's mobile communication systems can be classified into TDMA(Time Division Multiple Access) and CDMA(Code Division Multiple Access) methodologies. Wideband TDMA is being developed in Europe and narrowband TDMA is being developed in Japan and North America. Also, extended TDMA is being developed in Hughes. As a CDMA technology, narrowband CDMA is being developed in Qualcomm and Wideband CDMA for PCN is serviced in Milicom, SCS mobilecom co. and other companies.

As multiple access methods for digital cellular mobile communication, there are FDMA (Frequency Division Multiple Access), TDMA and CDMA methods. In today's mobile communication, FDMA method is used, but the transition from FDMA to the TDMA method is made step by step. Also, CDMA is being developed to overcome the capacity limitation of TDMA. CDMA does not need the frequency dividing and assigned time slot. That is, using a same frequency, many users can transmit data simultaneously in CDMA systems so that they can maximize the traffic transmission capacity. However, up to date, only voice service using TDMA or CDMA has been investigated, but data service has not been studied in detail. Especially, the study for low-speed data transmission in TDMA system has been performed partially, but the data transmission in CDMA system has not been researched yet.

Therefore, the performance of the error control schemes for data service in CDMA systems that have excellent performance in user capacity and efficiency has been investigated in this paper. Interference phenomena appear when other user uses the system in CDMA. In voice service, interference effects are not serious due to small burstiness, but in the case of data service, it is necessary to study the protocol for reliability because the error-rate increases instantly due to high burstiness. Thus, the effective error control schemes are proposed and the performances of each error control scheme are analyzed through the computer simulation.

This paper is organized as follows. In Section 2, the average error-rate of the DS/CDMA system in fading channel environments in the case that the number of users increases is described. Also,
the effective error control schemes for CDMA systems are proposed in Section 3. Moreover, the performances of each error control scheme are analyzed and compared through the computer simulation in Section 4. Finally, conclusions are made in Section 5.

2. Error characteristics of digital cellular DS/CDMA systems

The performances of digital cellular DS/CDMA mobile communication systems are affected by multipath fading, multi-cell interference etc. So, the reliability of received information is reduced. In the consideration of these interferences, bit error rate due to the increase of user per cell has been studied in digital cellular DS/CDMA system. Thus, this BER (bit error rate) is used as channel characteristic variables for performance analysis in this paper.4

Average error-rate is expressed by Eq. (1) in fading channel environments. It is shown from Fig. 1 that the reliable data transmission of 3~4 users is possible when the SNR (Signal to Noise Ratio) is 20dB. The fading environment decreases the efficiency of system. This serious fading environments has been surmounted by RAKE receiver and diversity techniques in the present digital cellular DS/CDMA systems. Also, it could be seen that the average error-rate characteristics are affected severely as the number of users and multipath increases.

\[ P_e = \frac{1}{2} \left( 1 + \frac{L}{m!} \sum_{m=1}^{\infty} \left( \frac{L}{m!} \mu \right) \right) \quad (1) \]

where,

\[ \mu = \frac{2(L-1)}{3N} \left( \frac{3}{2} + \frac{\sum K(1+0.547K)}{\tau_b} \right) \]

Also, Fig. 1 shows the average error-rate characteristics as the number of users increases in the case of using FEC (Forward Error Correction) with block repetition code of which coding rate is 1/3.\(^{(6)}\) Then, the error correcting capability is defined by Eq. (2).

\[ e = \frac{1}{2} (n-1) \quad n : \text{inverse of code rate} \quad (2) \]

Therefore, it can be seen from Eq. (2) that one bit error is corrected by using block repetition code whose coding rate is 1/3.

As shown Fig. 1, we can see that the error probability could be improved in the case of using FEC code in the fading channel environments. This error-rate characteristics are used as channel model for performance analysis of each scheme in Section 4.

![Fig. 1. Average error-rate characteristics according to channel models in the digital cellular DS/CDMA systems.](image)

3. Error control schemes

3.1 Conventional error control schemes

Generally, channel codings such as FEC and ARQ schemes are used to increase the performance of mobile communication systems. In digital cellular DS/CDMA system, error detection and correction techniques like FEC schemes are used. It has been shown that the improvements of error-rate can be obtained by using the FEC scheme in Section 2. Also, for data service, the ARQ schemes are used in existing wire network. These ARQ schemes utilizes the retransmission of data frames whose error is detected and can be classified into as follows.\(^{(6)}\)

(1) Stop-and-Wait ARQ

The sender transmits continuously a next data frame when the ACK arrives from the receiver. That is, it does not transmit a next data frame until the ACK arrives.

(2) Go-back-N ARQ

This ARQ schemes is a variety of the continuous ARQ, that is, it transmits a chain of frames with window size. When the receiver detects an error, it sends the NAK frame, and it does not receive the next frames until the error frame is recovered. That is, sender retransmits the error and next transmitted frames when it
(3) Selective-Repeat ARQ

Generally, Selective-Repeat ARQ provides a more refined approach than Go-Back-N ARQ. The only frame that receives a NAK is retransmitted. On the other hand, the receiver must have enough buffer to store post-NAK frames until the error frame is recovered.

(4) WORM-ARQ (ARQ with Window-control Operation based on Reception Memory)

In digital cellular system, bursty error occurs by multipath fading, shadowing and handover. The bit error rate fluctuates from $10^{-1}$ to $10^{-9}$. So, the conventional ARQ does not operate well in digital cellular system. Thus, WORM-ARQ is suggested for control of dynamic error characteristics. It is a hybrid scheme that combines SR ARQ with GBN ARQ. That is, GBN ARQ is chosen in the severe error condition and SR ARQ is selected in the normal error condition.

(5) Quick-Repeat scheme

This algorithm is used for the retransmission of errored signalling information in digital cellular CDMA systems. Here, the same error frame is transmitted N times in the severe error condition such as handover.

3. 2 Improved error control schemes

3. 2. 1 The GBN and SR ARQ scheme with variable window size

To reduce the error-rate due to the the variation of channel environments, the window size of ARQ scheme is changed. That is, when the error-rate increases, the window size is decreased. Also, if the number of users for communication per cell is decreased, the window size is increased. This scheme can be expressed as shown in Table 1.

<table>
<thead>
<tr>
<th>bit error rate</th>
<th>window size</th>
</tr>
</thead>
<tbody>
<tr>
<td>BER $\leq 10^{-4}$</td>
<td>32</td>
</tr>
<tr>
<td>$10^{-4} &lt; BER \leq 10^{-3}$</td>
<td>8</td>
</tr>
<tr>
<td>$10^{-3} &lt; BER \leq 10^{-2}$</td>
<td>4</td>
</tr>
<tr>
<td>$10^{-2} &lt; BER$</td>
<td>2</td>
</tr>
</tbody>
</table>

After all, we can use the variable window size efficiently against a varying error-rate caused by channel impairments.

3. 2. 2 The GBN and SR ARQ scheme with variable window and frame size

Here, we consider another scheme which changes the window and the frame size simultaneously. In this case, if the error-rate increases, the window and frame size are decreased. Also, in the case of error-rate being low, the window and frame size are increased. These schemes are summarized in Table II.

<table>
<thead>
<tr>
<th>bit error rate</th>
<th>window size</th>
<th>frame size (bit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BER $\leq 10^{-4}$</td>
<td>32</td>
<td>172</td>
</tr>
<tr>
<td>$10^{-4} &lt; BER \leq 10^{-3}$</td>
<td>8</td>
<td>80</td>
</tr>
<tr>
<td>$10^{-3} &lt; BER \leq 10^{-2}$</td>
<td>4</td>
<td>40</td>
</tr>
<tr>
<td>$10^{-2} &lt; BER$</td>
<td>2</td>
<td>16</td>
</tr>
</tbody>
</table>

4. Simulation results and analysis

4. 1 Simulation modeling

In this section, the performances of error control scheme for cellular DS/CDMA systems are investigated through the computer simulation. Here, the DS/CDMA system of Qualcomm is considered as simulation model of CDMA system. Digital cellular system consists of subscribers, base station, trunk systems, and operation/management systems. Then, for the performance analysis of error control scheme in digital cellular DS/CDMA systems, only reverse link between subscribers and base station is considered.

The reverse link between subscribers and base station consists of logically separated 64 channels using 64 Walsh code. This 64 channels are composed of access and reverse traffic channel. The access channels can be extended from 0 to 32. Then, the rest channel except the channel which is allocated as access channel can be assigned as traffic channel. Here, it is assumed that the access channel is not assigned and the 64 channel is used as traffic channel.

The data transmission is performed through the forward traffic channel (base station to subscribers) or the reverse traffic channel (subscribers to base station) between the base station and subscribers. If data transmission rate is 9600bps, the frame format of reverse traffic channel is shown in Fig. 2.
The variable data transmission rates such as 9600, 4800, 2400, and 1200 bps are used in digital cellular DS/CDMA systems, but only 9600 bps is considered for data transmission rates in this paper. Then, the duration of data packet is 20msec. Here, it is assumed that the size of data frame is 172 bit (20msec) except the 12bit CRC (Cyclic Redundancy Check) and the 8bit tail. The traffic arrival time of data terminal is independent of each other and the interarrival time has exponential distribution. Thus, Poisson process is used for data traffic models. Here, the bursty error characteristics of mobile wireless channel environments are considered.

### 4. 2 Analysis and Discussion

Through the computer simulation, the performances of conventional Go-Back-N (GBN) ARQ, Selective-Repeat (SR) ARQ, improved ARQ with variable window size, and improved ARQ with variable window and frame size are analyzed in the digital cellular DS/CDMA system. Also, the performances of WORM ARQ and Quick-Repeat schemes are analyzed and compared. In this simulation, the error-rate characteristics of mobile wireless channel environments are considered. Also, throughput and delay characteristics are used as criteria for performance comparison.

The throughputs and delay characteristics of each schemes in the fading channel environments are shown in Fig. 3 and Fig. 4. In this circumstances, FEC scheme which uses the block repetition code having a one third code rate is considered.

As shown in Fig. 3, the throughput of the pure-SR scheme and SR scheme with variable window size(vw-SR) are similar due to the retransmission of only erroneous frame. Also, it is shown that GBN scheme and the GBN scheme with variable window size(vw-GBN) have a similar performance until the traffic density reaches at 0.2. However, the GBN with variable window size(vw-GBN) shows a better performance than GBN scheme in the case of traffic intensity being above 0.3 because the GBN scheme with variable window(vw-GBN) is robust against the severe error-rate due to the dynamic adjustment of window size.

On the other hand, it can be seen that the throughput of SR with variable frame size(vf-SR) is superior to that of other error control scheme including GBN with variable frame size(vf-GBN). That is, the adjustment of frame size is more important than that of window size in the fading channel environments. In the severe error condition, the short message is relatively very robust to the error compared with large message. Thus, the GBN with variable window and frame size(vwf-GBN) represents the highest throughput among the several GBN schemes. Also, the SR scheme with variable window and frame size(vwf-SR) represents the highest throughput among the entire ARQ schemes. Besides, it could be seen that the performances of WORM ARQ and Quick-Repeat scheme could not surpass those of GBN scheme with variable frame(vf-GBN) and SR scheme with variable frame(vf-SR). The average delay characteristics of various ARQ schemes in fading environments is shown in Fig. 4. Here, we can see that the GBN and SR scheme with variable window and frame size(vwf-GBN, vw-SR) are superior to the other schemes.

From the above results, it can be seen that SR scheme with variable window and frame size(vwf-SR) can adapt more dynamically to CDMA channel environments than other schemes.

### 5. Conclusions

The average error-rate of digital cellular CDMA systems due to the increase of users in fading channel environments is researched. Then, the improved effective error control schemes with variable window and data frame size to guarantee the reliability of data transmission are proposed. Also, the throughput and delay characteristics of those schemes are investigated in fading channel environments through computer simulation. According to the simulation results, it could be seen that the advantage of the variable window methodology can be applied effectively to the GBN scheme but can not be applied to the SR scheme efficiently due to the retransmission of only erroneous frame. Moreover, the performances of SR scheme with variable frame...
size is superior to those of SR scheme with variable window size because the SR scheme with variable frame size has a dynamic adaptation capability to the mobile communication channel environments. Furthermore, the SR schemes with variable window and frame size could be adapted more dynamically in bursty error-rate environments.

References