Facsimile Signal Transmission Using WORM-ARQ in TDMA Cellular System

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ABSTRACT

This paper describes an error-free facsimile signal transmission scheme over the Japanese digital cellular (JDC) standard air interface (3-channel TDMA). To mitigate multipath fading effects and to achieve high transmission throughput, an efficient ARQ scheme, WORM-ARQ (ARQ with Window-control Operation based on Reception Memory) is proposed. Throughput efficiency with WORM-ARQ is evaluated through both laboratory and field experiments, and is described together with computer simulation results. The WORM-ARQ scheme has been applied to G3 facsimile signal transmission. Error-free document transmission can be realized at an average throughput of 4.8 kbps even with an average channel bit error rate of 10^{-2}.

1. INTRODUCTION

Digital cellular systems are now being developed in Europe, North America [1], and Japan [2, 3]. One great advantage of the digital system is its capability to transmit data information with higher throughput efficiency than current analog FM cellular systems. The needs for mobile data transmission services such as facsimile and computer communications are increasing rapidly [4, 5]. Required bit error rates (BER) for these services are quite different from those required by voice communications. Perfect error-free quality (or BER of less than 10^{-6}) is required for data communications, whereas for voice communications, the required BER is around 10^{-2}.

Land mobile radio channels are characterized by fast multipath fading [6] and shadow fading. These result in severe degradation of signal transmission performance. Furthermore, in cellular systems, the hand-off process can collapse the transmitted data stream. The errors occurring in the received bit stream due to these causes are quite bursty. Therefore, even if very powerful coding with large size interleaving is used, it is still difficult to achieve error-free transmission. Hence, an auxiliary feedback error control scheme such as automatic repeat request (ARQ) is necessary to achieve the very high quality data transmission needed.

There are three basic ARQ schemes : the SAW (stop-and-wait)-, the GBN (go-back-N)-, and the SR (selective -repeat)-ARQs [7]. Looking at practical protocols, ADCCP (advanced data communications control procedure) [8] employs GBN-ARQ, and HDLC (high level data link control procedure) [9] is based on either GBN-ARQ or SR-ARQ. These practical protocols are designed so as to meet the error occurrence statistics encountered in additive white Gaussian noise (AWGN) channels, where error occurrence in the received bit stream is almost random. However, this is not the case for mobile radio channels because long burst errors can be produced by fading, shadow fading and the hand-off process. In particular, the increase in errors produced in the backward channel significantly damages protocol operation [10]. Therefore, a new protocol is required to support high throughput data communication over mobile radio channels.

This paper proposes a high efficiency ARQ scheme, WORM-ARQ (ARQ with Window-control Operation based on Reception Memory), that has an SR mode and a GBN mode. The WORM-ARQ scheme makes it possible to provide a high quality data communication over the Japanese digital cellular (JDC) standard air interface (3-channel TDMA) [2].

Section 2 describes the proposed WORM-ARQ protocol in detail. Section 3 presents computer simulation results and the laboratory and field experiment results of the throughput efficiency evaluations with the WORM-ARQ and REJ-based HDLC protocols. Section 4 describes a G3 facsimile signal processing unit that uses the WORM-ARQ scheme. Laboratory experiment results for the the transmission time required to transmit an A4 size document are also described.

2. WORM-ARQ PROTOCOL

The proposed WORM-ARQ scheme has SR and GBN operation modes. The protocol switches from the SR mode to the GBN mode when a time-out happens in order to avoid confusion in the numbering of the frames transmitted. A negative acknowledgment (NAK) is transmitted via the backward channel in each time slot until this frame is received correctly. This makes it possible to apply a relatively long time-out period compared with those possible with conventional protocols so that the SR mode continues for a long time. This also produces a time diversity improvement on the backward channel.

2.1 Frame Format

The frame format of the WORM-ARQ scheme is

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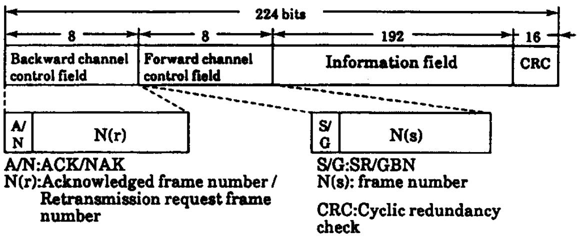

Fig.1 Frame format

shown in Fig.1. The frame is 224 bits long and is comprised of two control fields, an information field, and a 16-bit CRC check field for error detection. Piggybacking transmission is made possible with this frame format. The control fields are used to transmit forward and backward control information, each of which is 8 bits long. The information field is 192 bits long to support the maximum throughput of 9.6 kbps. The ARQ mode flag S/G and the transmission sequence number N(s) are included in the forward channel control field. The ACK / NAK flag A/N and the frame number N(r) are included in the backward channel control field, where retransmission for the frame with number N(r) is requested if A/N = N. Note that N(s) and N(r) are used cyclically with modulus M ($=2^m$), where m is the number of bits needed to describe N(s) and N(r).

2.2 Protocol

Fig.2 shows an example of the WORM-ARQ operation with M = 8 ($= 2^3$). RTF (= 4) is the number of frames transmitted during the round-trip delay. Frames that are received in error in the forward and backward channels are indicated by dashed arrows. The window is defined as the range of the sequence number of which the frames transmitted and received are accepted as indicating that illegal protocol progress has not happened. The upper and lower edges of the windows at the transmitter and receiver are also indicated in Fig.2.

(1) Transmitter Operation

WORM-ARQ has two operation modes : the SR mode and the GBN mode. WORM-ARQ usually operates in the SR mode. A time-out mechanism is used in order to avoid confusion in the numbering of the frames transmitted. The time-out is defined as the event in which the window bandwidth reaches its predetermined threshold value N. When time-out happens, the mode is switched to the GBN mode. Therefore, if the time-out threshold value N is set at M-1, the throughput efficiency is maximized because the time during which the protocol remains in the SR mode can be increased up to its maximum length for the given value of M. All the frames transmitted in the GBN mode are the frames that have been transmitted previously in either SR or GBN mode, however, unacknowledged. If in the GBN mode the bandwidth between the lower and upper edges of the transmitter window is found to be less than or equal to N-RTF+1, the WORM-ARQ returns to the SR mode.

If A/N = A, the received backward control field indicates that all the previous frames with N(s) ≦ N(r) mod M have been received correctly by the receiver, and the lower edge is set at [N(r)+1] mod M. If A/N = N, it indicates that the retransmission of previously transmitted frame with the sequence number N(s) = N(r) is requested, and that all the frames with N(s) < N(r) mod M have been received correctly. The lower edge is set at N(r). Once the frame with N(s) = N(r) is retransmitted, the transmitter ignores retransmission requests for the same frame during the period of RTF-1

Retransmission is not triggered when the backward frame including the backward channel control field is received in error.

In this example, the switch from the SR mode to GBN mode is triggered after the forward frame with S/G = S and N(s) = 0_1 is transmitted, because the window bandwidth reaches N (= 7). Once the forward frame with S/G = S and N(s) = 2 is retransmitted according to the retransmission request, the same frame is not retransmitted during RTF-1 (= 3 frames), even if retransmission requests for the frame are consecutively received.

(2) Receiver Operation

If the mode flag S/G = S, the upper edge of the receiver window is set at [the lower edge +N-1] mod M. If S/G = G, the upper edge of the receiver window is set at [the newest acknowledged sequence number in reception memory + 1] mod M.

If the reception memory in the receiver window indicates that there are no frames whose retransmission must be requested, the backward

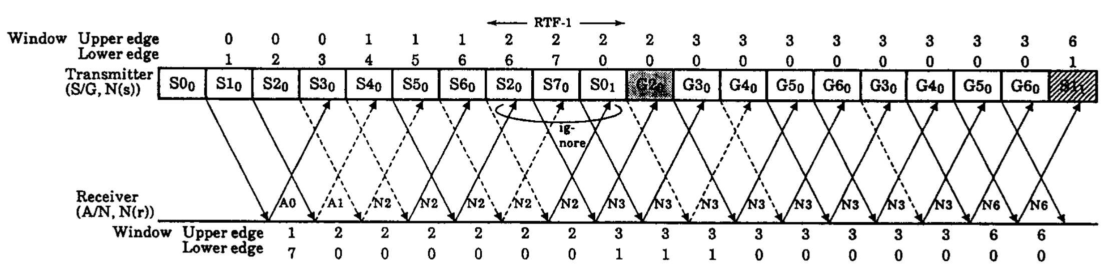

Fig.2 An example of WORM-ARQ operation

Modulus M=8
Time-out period N=7
Round trip delay frame RTF=4

channel control field with A/N = A and N(r) = N(s) is transmitted. If the reception memory indicates that there are one or more frames whose retransmission must be requested, the backward channel control field with A/N = N and N(r) = [the lower edge at the window of receiver] (= the oldest unacknowledged sequence frame number in reception memory) is transmitted. Thus, the receiver continues to issue retransmission requests until the requested frame is received correctly.

In this example, because the frame with N(s) = 2 is received in error, the receiver continues to transmit retransmission requests for this frame until this frame is received correctly. While retransmission for the frame with N(s) = 3 is being requested in the GBN mode, there is a possibility to receive different frames with N(s) ≠ 3 but satisfying "the lower edge" ≦N(s)≦"the upper edge"(in this example, the N(s)=5 frame is received).

3. Throughput Efficiency Evaluations

To evaluate the throughput efficiency of the WORM-ARQ scheme, computer simulations and laboratory and field experiments were conducted. Differentially coherent QPSK with postdetection selection diversity reception was used in the simulations and experiments.

3.1 Computer Simulations

The throughput efficiencies of the WORM-ARQ and REJ-based HDLC protocols in a Rayleigh fading channel were evaluated.

Fig.3 shows the simulated throughput efficiency for maximum Doppler frequency f_D = 40 Hz and M = 32 versus channel BER with RTF as a parameter. As the RTF increases, the WORM-ARQ protocol stays longer in the GBN mode. Since some of the frames which have already been received correctly are transmitted again in the GBN mode, the throughput efficiency decreases as the RTF increases. This feature is observed in Fig.3.

Fig.4 compares the throughput efficiency of the WORM-ARQ protocol against that of the REJ-based HDLC protocol. The throughput efficiency is shown as a function of the channel BER for f_D = 40 Hz and RTF = 6. The throughput efficiency with the WORM-ARQ is roughly 4 times as large as that with the REJ-based HDLC protocol at BER = 10^{-2}. This is because the REJ-based HDLC protocol is based on GBN-ARQ. Also, the WORM-ARQ requests retransmission in the backward channel several times and this produces a time diversity improvement.

3.2 Experiments

Laboratory experiments were conducted using a prototype of the WORM-ARQ processor. Throughput efficiency in a Rayleigh fading channel was evaluated. Fig.5 shows the measured throughput efficiency for RTF = 6 and M = 32 versus the channel BER with f_D as a parameter. Evaluated throughput efficiency with f_D = 40 Hz almost coincides with that of the computer simulation results in Fig.3. It is found from this figure that throughput η increases as f_D decreases. For f_D = 40Hz, η = 0.38 corresponding to 4.3 kbps transmission, can be achieved at BER = 10^{-2}. As f_D decreases, η increases. For f_D = 5 Hz, η = 0.55 at BER = 10^{-2}, which corresponds to 6.2 kbps transmission. The reason for these results is that bit errors for high f_D occur more randomly than for low f_D. This reflects the well-known characteristic that the channel capacity of burst channels is larger than that of random error channels.

Field experiments were conducted in a typical urban area of Yokohama. The average BER was evaluated by comparing the received and transmitted data. The transmitted data was equivalent to an A4 coded document, and the transmission time required to transmit this data was measured. Fig.6 shows the measured throughput efficiency for RTF = 14 versus average channel BER. The results show that the measured throughput efficiency almost agrees with that obtained in the computer simulations.

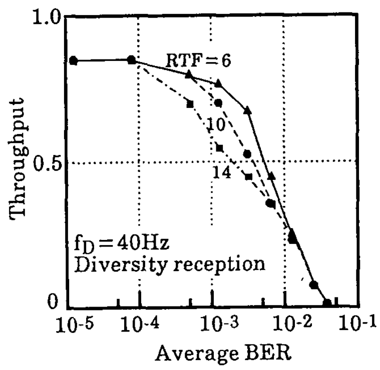

Fig.3 Throughput efficiency evaluated through computer simulations

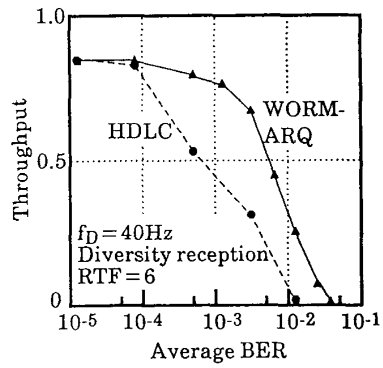

Fig.4 Throghput effficiencies with WORM-ARQ and HDLC evaluated through computer simulation

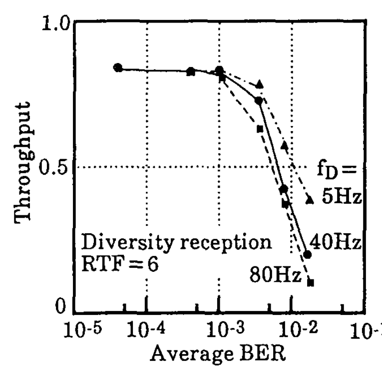

Fig.5 Throughput efficiency evaluated through laboratory experiments

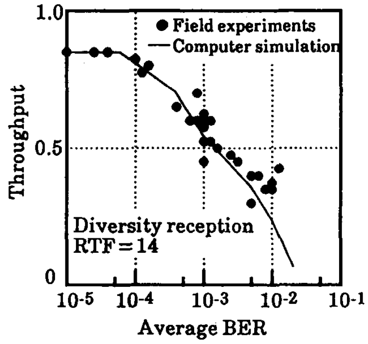

Fig.6 Throughput efficiency evaluated through field experiments

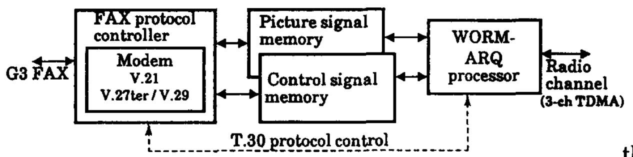

Fig.7 Configuration of G3 facsimile signal processing unit

4. G3 Facsimile Signal Transmission

The WORM-ARQ scheme was applied to G3 facsimile signal transmission. A prototype of facsimile signal processing unit developed is shown in Fig.7. The unit consists of FAX protocol controller, memories, and a WORM-ARQ processor. In the transmitter, the FAX protocol controller receives the control signal defined by T.30 from the facsimile terminal via a V.21 modem, and picture signal defined by T.4 via a V.27ter or V.29 modem. The received facsimile signals are formatted into the WORM-ARQ frame structure, and transmitted to the air interface by the WORM-ARQ processor. In the receiver, the WORM-ARQ processor receives the control and picture signals, and the FAX protocol controller then reformats them into the facsimile signal using the corresponding modems to transmit them to the destination facsimile terminal.

The transmission time required to receive an A4 size document was evaluated by laboratory experiments. Fig.8 shows the measured transmission time normalized by the coded document data size (bits) / 9600 (bps) for RTF = 6 and M = 32 versus the average BER with f_D as a parameter. The transmission time decreases with f_D at a high BER range because of the channel capacity increase explained in Section 3. The transmission bit rates of 5.5 ~ 2.7 kbps can be achieved at BER = 10^{-2} for all the f_D values examined. It should be noted here that we have already succeeded in realizing error-free facsimile signal transmission with an acceptable transmission time in a field experiment.

5. Conclusions

A high efficiency ARQ scheme, WORM-ARQ, capable of achieving high throughput transmission over the JDC standard air interface (3-channel TDMA) was proposed. The throughput efficiency of the WORM-ARQ protocol was evaluated through laboratory and field experiments and computer simulations. It has been shown that 4.8 kbps transmission can be achieved even with an average channel bit error rate of 10^{-2}. Error-free document transmission can be realized at 4.8 kbps throughput by using the proposed WORM-ARQ protocol.

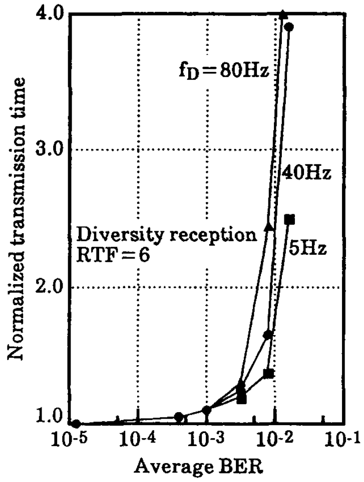

Fig.8 Transmission time evaluated through laboratory experiments

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