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## Adaptive Data Rate Control TDMA Systems as a Rain Attenuation Compensation Technique

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### ABSTRACT

Rainfall attenuation has a severe effect on signal strength and impairs communication links for future mobile and personal satellite communications using Ka-band and millimeter wave frequencies. As rain attenuation compensation techniques, several methods such as uplink power control, site diversity, and adaptive control of data rate or forward error correction have been proposed. In this paper, we propose a TDMA system that can compensate rain attenuation by adaptive control of transmission rates. To evaluate the performance of this TDMA terminal, we carried out three types of experiments: experiments using a Japanese CS-3 satellite with Ka-band transponders, in-house IF loop-back experiments, and computer simulations. Experimental results show that this TDMA system has advantages over the conventional constant-rate TDMA systems, as resource sharing technique, in both bit error rate and total TDMA burst lengths required for transmitting given information.

### INTRODUCTION

The Communication Research Laboratory (CRL) has been carrying out L-band mobile satellite communications experiments using the Engineering Test Satellite Five (ETS-V), which was launched in 1987. This study will be extended to advanced mobile and personal communications at Ka-band and millimeter wave frequencies using the Communications and Broadcasting Engineering Test Satellite (COMETS), which will be launched in 1997 [1]. Advantages to use such higher frequencies are much wider available frequency bandwidth and substantial system size reduction. On the other

hand, we have to overcome such disadvantages as significant rain attenuation, larger Doppler shifts, higher RF component losses, larger phase jitters, etc.

At frequencies above 10 GHz, signal attenuation due to rainfall can have significant impairment on space-to-earth communication links. To compensate rain attenuation, several methods such as uplink power control[2][3], site diversity[4], and adaptive control of data rate and/or forward error correction techniques[5] have been proposed. Uplink power control and site diversity techniques are very useful for large or medium size earth stations at large networks covering different climatic regions. On the other hand, adaptive control of data rate and error correction techniques are more appropriate to small earth stations, since both small antenna size and limited RF transmit power impose a restriction over the range of the uplink power control. Moreover, these adaptive control techniques can compensate downlink attenuation as well as uplink attenuation.

In this paper, we propose a TDMA terminal with adaptive control capability of transmission rate to compensate rain attenuation. We carried out experiments using Japanese Communication Satellite-Three (CS-3) with Ka-band transponders to evaluate the performance of this terminal under rainfall conditions.

### ADAPTIVE TRANSMISSION-RATE TDMA

In this Adaptive Transmission-Rate TDMA terminal, later referred to as ATR-TDMA, a receive terminal that is suffering rain attenuation requests the transmit terminal to reduce transmission rate of the TDMA burst, according to degradation in bit error rate (BER) or carrier-to-

noise density ratio (C/No). Six different transmission rates are available in this terminal. For example, a transmission rate reduction by a factor of four can compensate the degradation of 6 dB due to rain attenuation. Therefore, this system enhances the power margin by 15 dB in all theoretically.

Figures 1 and 2 show a block diagram and a scheme of modulation and demodulation of the ATR-TDMA terminal, respectively. Data bit stream is stored in a buffer and divided into data bursts, the length of which corresponds to data bits within one TDMA frame. Data rate  $R_b$  is assigned as follows:

$$R_b = R_c / 2^{N-2} \quad \text{for } N=1, 2, 3, 4, 5, \text{ and } 6 \quad (1)$$

where  $R_c$  is the reference clock rate of 4.144 Mbps in the present system,  $N=1$  for QPSK, and  $N=2, 3, 4, 5, 6$  for BPSK. Therefore, six possible data rates are 8288, 4144, 2072, 1036, 518, and 259 kbps.

After the baseband signal is scrambled with a pseudonoise (PN) code generated at  $R_c$  bps, a carrier is PSK modulated in burst mode. Since PSK modulator always works at the same clock rate of  $R_c$ , every TDMA bursts always occupy the same frequency bandwidth.

Receive terminal recovers clock rate from the received signal and then recovers data clock from burst timing. The present transmission rate can be known from information bits stored in the preamble of a TDMA burst. After coherently demodulated PSK signal is descrambled by the same PN code,  $2^{N-2}$  bits are added with synchronous timing of clock rate and one information bit can be reproduced based on majority rule. This process of the synchronized sum is equivalent to reduce the transmission rate from  $R_c$  bps to  $R_c/2^{N-2}$  bps. For example, a transmission rate reduction by a factor of two extends the burst length twice and BER performance can be improved by 3dB in C/No.

The TDMA frame format and data burst format are shown in Figure 3. One TDMA frame consists of a reference burst, a synchronization burst, data bursts, and initial acquisition slot. The frame period is 15 milliseconds and one control frame of 1200 millisecond period consists of 80 frames. Each data burst is divided into a preamble for receiver synchronization and data bits. This preamble consists of two parts of P1 and P2. In P1, carrier and clock recovery

patterns, and an unique word for identifying each terminal and synchronizing a burst timing are included. In P2, identification codes for transmit and receive terminals, and information bits for control of transmission rate are included. Since information bits in P1 are essential for all terminals in this TDMA network, this part is sent at the lowest transmission rate. On the other hand, since bits in P2 is necessary only for transmit and receive terminals under communication, transmission rate of P2 is the same as data rate of each TDMA burst. Moreover, using majority-rule decision of preamble information that is received over several frames, the TDMA terminal can reduce possibility of incorrect operations in the TDMA network. Transmission rates can be changed only once within one control frame.

## RAIN ATTENUATION COMPENSATION EXPERIMENTS

### Satellite Experiments

We carried out experiments using the CS-3 satellite to evaluate the performance of the ATR-TDMA terminal at Ka-band satellite link. Communication channels were monitored by measuring both BER and C/No with measuring equipments and a personal computer.

Since allowable BER without FEC is designed to be  $10^{-3}$  in this system, we assigned BER of  $8.0 \times 10^{-4}$  or C/No that corresponds to BER of  $8.0 \times 10^{-4}$  as the threshold to change transmission rates. When BER or C/No is worse than the threshold for  $T_d$  seconds, transmission rate is reduced half. When BER or C/No is better than the threshold for  $T_u$  seconds, transmission rate is increased twice.

Figure 4 shows the experimental result that was controlled from degradation in C/No with  $T_d = 5$  seconds and  $T_u = 5$  seconds. Top of this figure shows rain attenuation of eighteen-hour measurement at satellite loop-back link ( including both 20 GHz and 30 GHz attenuation ) and 20GHz-beacon. Controlled transmission rates in kbps and measured BER are shown in middle and bottom of Figure 4, respectively. According to rain attenuation, the ATR-TDMA terminal controlled its transmission rate to keep BER better than the allowable BER with as high transmission rates as possible. This terminal can compensate rain attenuation actually up to about 15 dB ( although theoretically 16dB ). When

rain attenuation is larger than 15 dB or rain rate becomes faster than response time of this system, BER becomes larger than the allowable value. However, such unavailable time duration is improved and becomes considerably short.

With the lowest transmission rate at constant-rate TDMA terminals, we could keep BER better than the threshold like the ATR-TDMA terminal. However, total TDMA burst lengths required for transmitting the same information will become much larger than ATR-TDMA. Next, we study BER and total burst lengths of ATR-TDMA as a function of different Td and Tu values.

### In-house Experiments

Values of parameters Td and Tu are very important for effective control of transmission rate. In the TDMA network, time duration in one TDMA frame is a common resource for every terminals. When many user terminals suffer rain attenuation, several terminals will wait to access until a vacant time slot appear and some terminals will break down due to the degradation of communication links.

In in-house experiments, the receive terminal connects with the transmit terminal through IF port and monitors BER to detect degradation in communication link. C/No is degraded by additive white Gaussian noise according to rain attenuation data that were measured and stored using satellite links. Using several values of Tu and Td, BER and total burst lengths are measured and shown in Figure 5. As Tu becomes larger, BER becomes smaller, but TDMA burst lengths, with respect to the burst length of the fastest rate, become considerably large. Both improvement in BER and increase of burst lengths is more remarkable as Td becomes smaller.

Figure 6 shows comparison of this experimental result with the result obtained by the constant-rate TDMA terminal. The lower transmission rates of  $N=4$  and 5 can provide very good BER performance but the TDMA burst of this terminal will occupy a large part in one TDMA frame. The number of user terminals than can access this TDMA network is very restricted. The ATR-TDMA terminal has better performance in both BER and burst lengths than the conventional constant-rate TDMA.

### Computer Simulation

To study the effect in BER and burst lengths under different rain conditions and different Tu, and Td, we have carried out computer simulation of the ATR-TDMA system. C/No is controlled with measured data of rain attenuation and BER is calculated from the measured BER performance of the TDMA terminal. Table 1 shows typical values of Tu and Td, which correspond to different traffic conditions in a satellite transponder. In situation of mode #3, since only a few vacant time slots remain in one TDMA frame due to high traffic condition, transmission rate cannot be reduced quickly and has to be brought back to its rate as soon as possible after the weather improves. On the other hand, mode #4 prefers to maintain the communication quality rather than to shorten used burst lengths.

Figure 7 and 8 show the probability that BER is worse than the threshold as a function of used total burst lengths using rain attenuation measured for twenty rainy days. In Figure 8, data, which are picked up from severe rain events, are normalized with the result of mode #4.

Slow reduction of transmission rates in modes #2 and #3 increases the probability that BER is worse than the threshold up to about 20% in severe rain events as shown in Figure 7. Simulation results, however, shows that ATR-TDMA is effective to compensate rain attenuation under many different rain conditions.

Figure 8 shows that values of Tu is insensitive to the probability that BER is worse than the threshold and total burst lengths decrease as Td becomes smaller. Parameter Td is more important than Tu to improve BER performance under rain attenuation.

Since the response time should be less than rain attenuation rate for successful control of transmission rate, the optimum value of Td must be as small value as possible. However, one-way propagation delay for a geostationary satellite link is on the order of 0.25 seconds, and a similar amount of time is required for receive terminals to request reduction of transmission rates to their transmit terminals. Moreover, It will take a couple of seconds for receive terminals to measure BER or C/No for measuring rain attenuation, and there are also additional system processing delays including delay due to control algorithm. Therefore, control delay of transmission rates from instantaneous rain attenuation is inevitable. In spite of such delay factors, ex-

perimental results showed that Td of 3 to 5 seconds are effective to compensate rain attenuation.

## CONCLUSION

Adaptive transmission-rate TDMA system to compensate rain attenuation is presented. At the beginning, this system was developed for business networks consisting of different size earth stations at Ka-band frequency. Therefore, transmission rates available in this system may be too fast for applications of mobile and personal satellite communications. However, the same adaptive control scheme can be applied to these systems at lower transmission rates.

To evaluate the performance, we carried out three kinds of experiments: satellite experiments, in-house experiments, and computer simulations. The ATR-TDMA system showed advantages over the conventional constant-rate TDMA system to maintain both communication quality and capacity under rainy weather.

When we apply adaptive control of data rate to SCPC systems, the reduction of data rate will result also in a reduction of service quality. However, this TDMA scheme reduce transmission rate in RF, but does not reduce data rate at baseband. Thus service quality is not reduced except very severe rain and heavy traffic conditions. This adaptive control method is suitable to future mobile or personal satellite communication systems at higher frequencies such as Ka-band or millimeter wave for compensating rain attenuation.

## REFERENCE

- [1] S. Ohmori, et al. "Advanced Mobile Satellite Communication using COMETS Satellite in MM-wave and Ka-Band," *Proc. IMSC'93*, Pasadena, California, June 16-18, 1993.
- [2] I. Nishiyama, R. Miura, and H. Wakana, "Closed-loop Uplink Power Control Experiments in K-band using CS-2," *Proc. ISTS*, Tokyo, Japan, 1986.

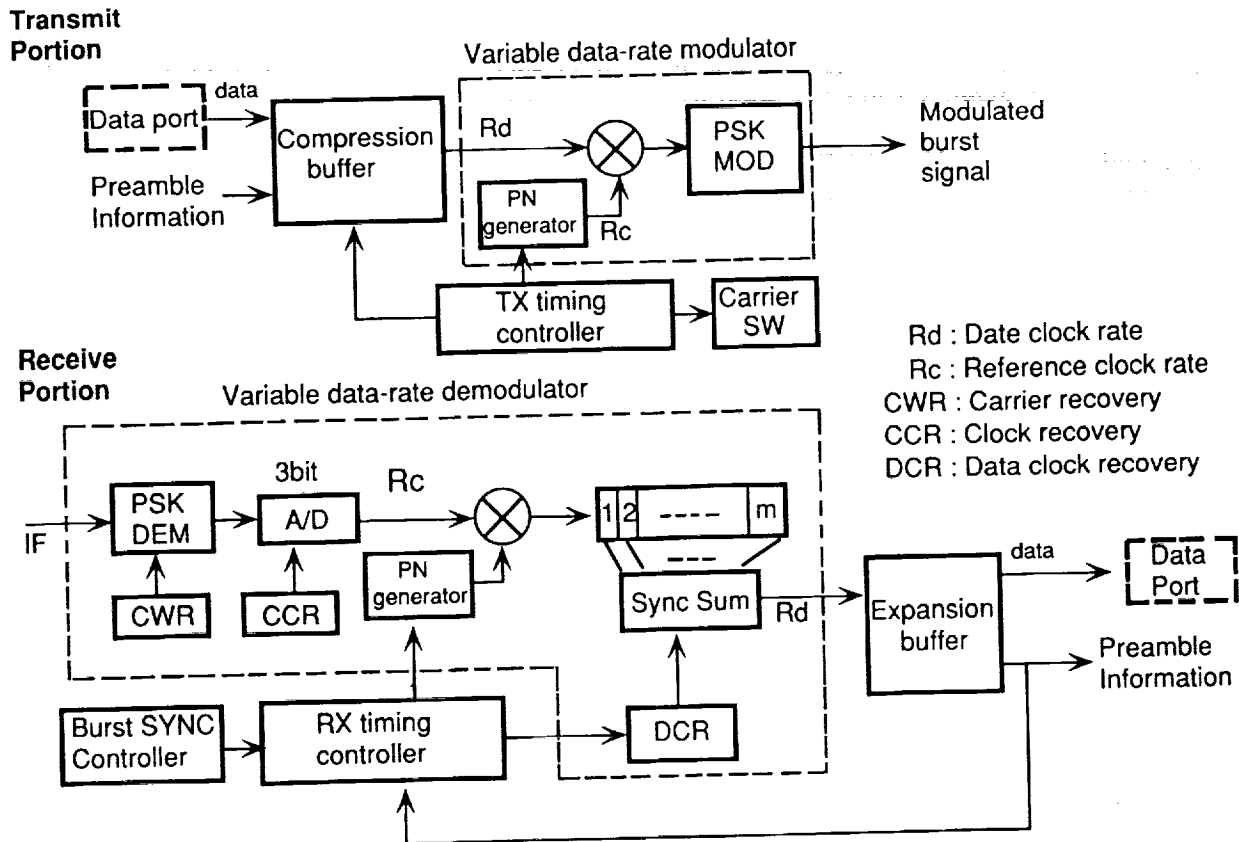


Figure 1. Block diagram of ATR-TDMA system

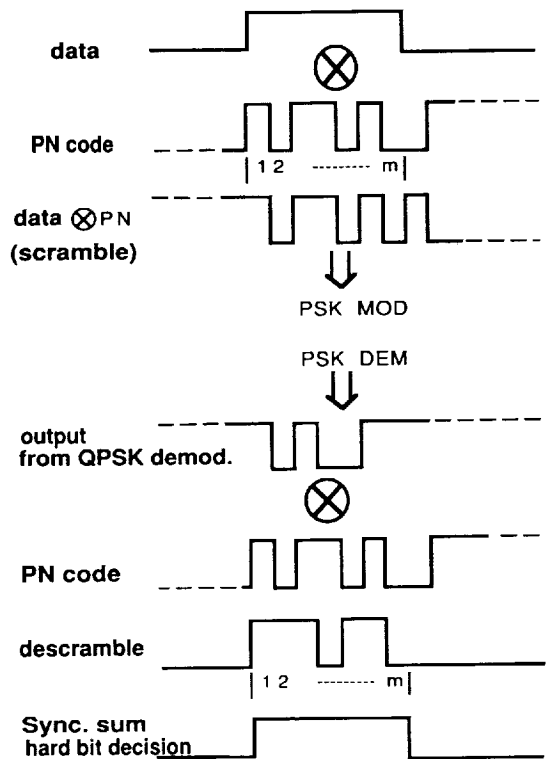


Figure 2. Scheme of ATR-TDMA

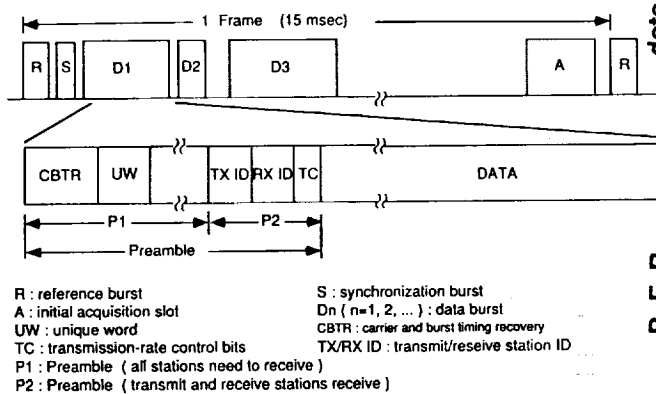


Figure 3 TDMA frame format

[3] V. O. Hentinen, "Error Performance for Adaptive Transmission on Fading Control," *IEEE Trans. Commun.*, vol. COM-22, pp. 1331-1337, 1974.

[4] CCIR Rep. 564-4, "Propagation Data and Prediction Methods required for Earth-Space Telecommunication Systems," *Recommendations and Reports of the CCIR*, vol. 5, ITU, Geneva, 1991.

[5] J. Hagenauer, "Rate Compatible Punctured Convolutional Code," *Proc. ICC'87*, pp.29.1.1-29.1.5, Seattle, USA, 1987.

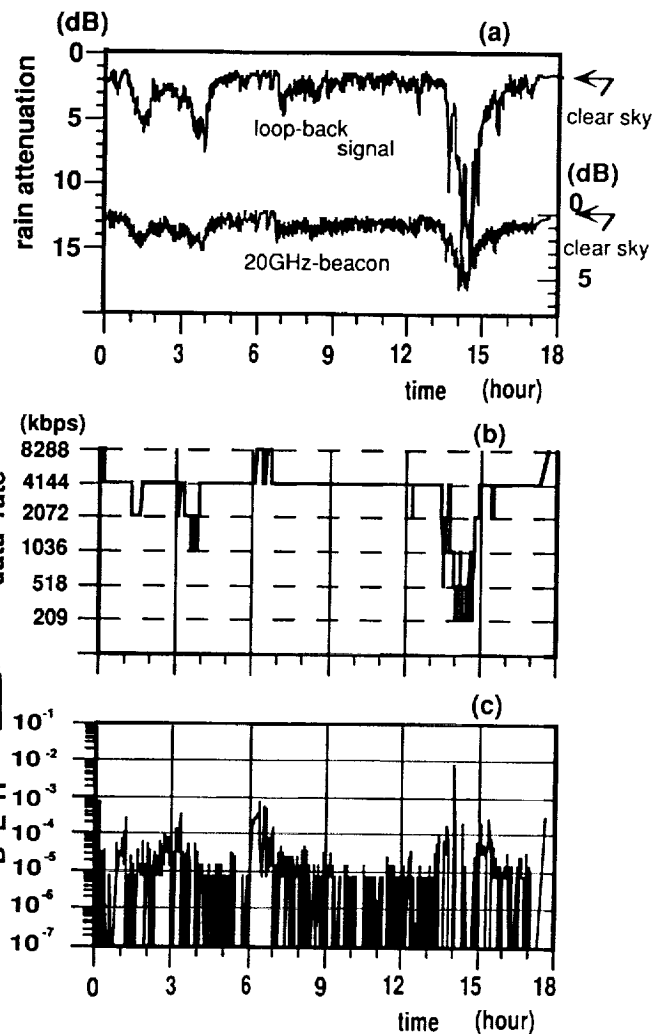


Figure 4. Experimental results using the CS-3 satellite (a) rain attenuation (b) transmission rate (c) BER

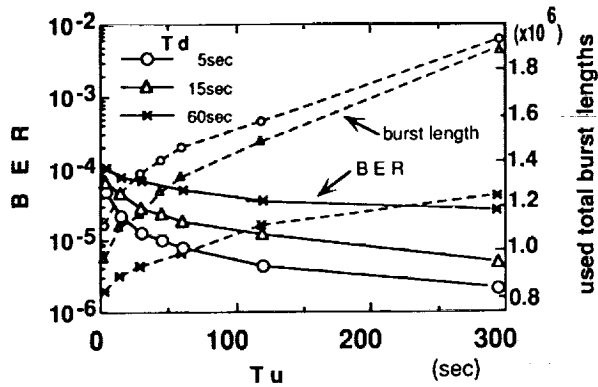


Figure 5 BER and used burst lengths as a function of  $T_u$  and  $T_d$

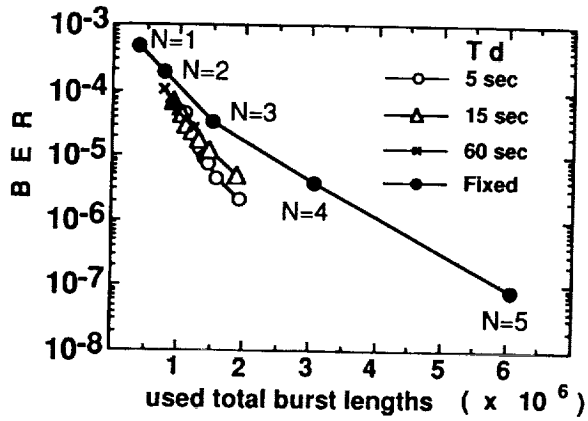


Figure 6. Comparison with constant-rate TDMA

Table 1. Four control modes using different  $T_d$  and  $T_u$

Control modes	$T_d$ in sec.	$T_u$ in sec.	Symbols
mode #1	3	3	●
mode #2	83	103	*
mode #3	83	3	△
mode #4	3	103	○

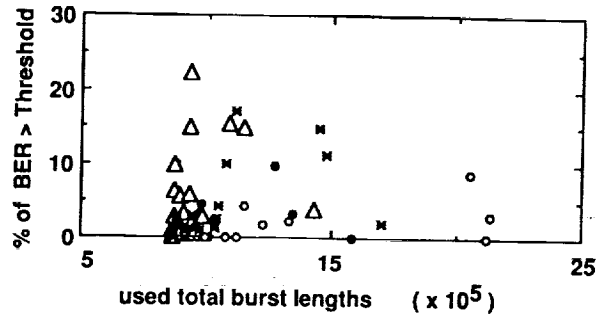


Figure 7. BER > threshold versus burst lengths

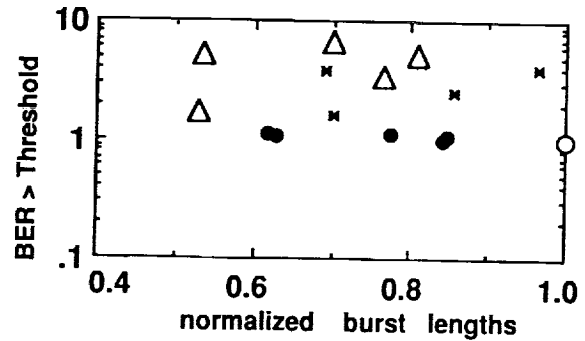


Figure 8. BER > threshold versus burst lengths normalized with the result of mode #4