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A Study on Up-link Transmission Power Control Scheme for Satellite Communication Systems

- Feedback Loop Control System -

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1. Introduction

Up-link transmission power control (TPC) is essential to reduce adjacent channel interference (ACI) and co-channel interference (CCI) due to rain attenuation in the satellite communication systems using 30/20 GHz frequency bands. Various kinds of TPC schemes have been proposed so far such as (1)open-loop scheme (up-link rain attenuation is estimated by that on beacon signals in down-link), (2)closed-loop scheme (up-link rain attenuation is estimated by that on self-transmitted signals in down-link) and (3)feedback-loop scheme (receiving stations measure desired channel quality and send back the control data to transmitting stations)(1)(2)(3). However, TPC schemes (1) and (2) can not achieve accurate rain attenuation estimation in the 30/20 GHz frequency bands. On the other hand, the feedback-loop TPC scheme has several advantages as follows. First, this scheme achieves more accurate rain attenuation estimation than TPC schemes (1) and (2), because the system scarcely suffers from rain attenuation of up and down links simultaneously. Second, this feedback-loop TPC scheme requires a little additional hardware when it is realized in central control systems. Third, this scheme is suitable for multi-beam TDMA systems which have essentially no closed-loop.

2. Feedback-loop TPC scheme

The assumed TDMA system using 30/20 GHz frequency bands is controlled by two reference stations which are backing up each other for site diversity. In this system, feedback-loop control scheme is adopted for TDMA synchronization and QPSK modulation/coherent demodulation scheme is used. As a forward error correction (FEC), convolutional encoding (rate:1/2, constraint length:4)/3-bit soft-decision Viterbi-decoding is used. The major Parameters of the assumed TDMA system are listed in Table 1. An example of TDMA frame format is shown in Fig.1. Since the reference stations always receive synchronization bursts from all traffic terminals for TDMA synchronization in feedback-loop control scheme, if the channel quality can be measured over such synchronization bursts, the reference stations can control the transmission power of all traffic terminals by sending back control data to respective traffic terminals. In order to measure the channel quality over short synchronization bursts, pseudo-error detection methods are required. This control is performed as well as that in the feedback loop TDMA synchronization. The target of the proposed up-link TPC scheme is to keep the satellite input level difference at less than 5 dB, while the channel bit error rate (Pe) is maintained at about

1×10^{-11}. In order to achieve this target, it is required to clarify the relationship between measurement time of Pe, and rain attenuation rate, the inaccuracy of Pe by pseudo-error detection methods and the TPC data errors induced by rain attenuation on control channels.

In the following section, accuracy of measured Pe by a pseudo-error detection method is investigated experimentally and theoretically. Moreover, the residual control error of the proposed control scheme with zero-order and first-order prediction is discussed.

3. Channel quality measurement

The pseudo-error detection method adopted in the proposed TPC scheme is shown in Fig.2. This method is a "soft-decision data based double threshold (SDT) pseudo-error detection method" which is a kind of double threshold pseudo-error detection(5) utilizing soft-decision data for FEC.

The experimental circuit diagram is shown in Fig.3. As shown in Fig.3, a QPSK modulator and coherent demodulator, convolutional encoder (rate:1/2, constraint length:4), 3-bit soft-decision viterbi-decoder, hard limiter as a TWTA simulator and roll-off low pass filters (roll-off factor:0.4) with transmission aperture equalizer are used. Clock rate is 6.144 MHz.

The experimental results on standard deviation (σ) of estimated Eb/No (translated from measured Pe) by SDT pseudo-error detection method v.s. number of symbols for averaging are shown in Fig.4. These results indicate that the standard deviation (σ) of estimated Eb/No is improved in proportion to $1/\sqrt{n}$ by taking an average over n symbols as compared with that of non-averaging estimated Eb/No. Moreover, those results show that a $\pm 3\sigma$ of estimated Eb/No is less than 1 dB by averaging over 10,000 symbols at Eb/No=12 dB point ($Pe=1\times10^{-11}$) which is the worst point required to estimate the channel quality in term of standard deviation.

4. TPC scheme with prediction

An example of TPC sequence is shown in Fig.5. In this sequence, the control interval of 2.56 second is assumed because this interval must be longer than the summation of (1)measurement time, (2)round trip delay, and (3)processing time at transmitting and receiving sides; First, in order to average pseudo-error over 10,000 symbols in the TDMA system using the frame format shown in Fig.1 (300 symbols per 20ms), measurement time more than 680ms is required. Second, 600ms of round trip delay is assumed according to the frame format shown in Fig.1. Finally, processing time at transmitting and receiving sides must be taken into account.

Thus, 2.56 s, twice of super frame period is chosen as a control interval as well as feedback-loop TDMA synchronization interval. With this control interval, zero-order predicted and first-order predicted TPC accuracies are investigated. In this investigation, the rain attenuation rate of $\pm$0.5 dB per 1.28 s is assumed according to(6) a typical example.

Zero-order prediction (without prediction)(6) is expressed by the relation $\hat{d}_n=\overset{*}{d}_{n-1}$, where $\hat{d}_n$ is a control value at $t=t_n$ and $\overset{*}{d}_{n-1}$ is a control value generated from measured data at $t=t_{n-1}$ (t_n:time at nth control interval). The residual control error with zero-order prediction is shown in Fig.6. It is seen form this figure that zero-order prediction generates $\pm$1.25 dB level offset and $\pm$0.5 dB fluctuation as residual control errors.

First-order prediction is expressed by the equation (1).

$$\hat{d}_n = ((d^*_{n-1} - d^*_{n-2})/T)1.5T + d^*_{n-1} \quad \text{(T:Control interval)} \qquad (1)$$

The residual control error with first-order prediction(6) is shown in Fig.7. As shown in Fig.7, transmission power control scheme with first-order prediction generates ±0.25 dB level offset and ±0.5 dB fluctuation as residual control errors.

Finally, the total residual control errors of the proposed TPC scheme are characterized to three errors; Eb/No estimation error (a_1), the residual offset error (a_2) and the fluctuation error (a_3). The total residual control errors with zero-order and first-order prediction are summarized in Table 2. This indicates that it is required to use first-order prediction in order to keep the satellite input power difference among TDMA bursts including adjacent channels at less than 5 dB.

5. Conclusion

In this paper, as an up-link TPC scheme, a feedback-loop control scheme managed by two central control stations, two reference stations backing up each other for site diversity in TDMA systems is proposed and discussed. Moreover, as pseudo-error detection method, the "soft-decision data based double threshold detection method" is proposed and investigated theoretically and experimentally. The results show that the proposed TPC scheme with first-order prediction is good enough to achieve the target of keeping satellite input level differences at less than 5 dB.

Reference

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(5)K. Feher et al,"Pseudo Error On-line Monitoring Concept, Design and Evaluation",Canada Elec. Eng. J., Vol.2, pp.33-36, Apr. 1977

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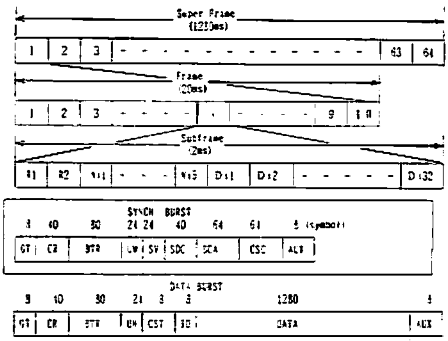
Table 1 Major parameters of TDMA system

Frequency bands	30/20 GHz
Number of access stations	Reference station : 2 Traffic terminal station : n (For example n=50)
Synchronization scheme for TDMA system	Reference station : Closed-loop Traffic terminal station : Feed-back loop
Modulation and demodulation scheme	QPSK modulation and coherent demodulation
Forward error correction scheme	Convolutional encoding (rate:1/2, constraint length:4)/3-bit soft-decision Viterbi decoding



R1(R2) :Reference(Sub-reference) burst
Nim :Trafic terminal synch. burst
Dil :Data burst
GT :Guard time
CR :Carrier recovery
BTR :Bit timing recovery
UW :Unique word
SV :Supervisory
SDC :Synch. & delay Control
SCA :Satellite channel assignment
CSC :Common signaling channel
AUX :Auxiliary
CST :Channel status transmission
ID :Identification(for user)

Fig. 1 An example of TDMA frame format

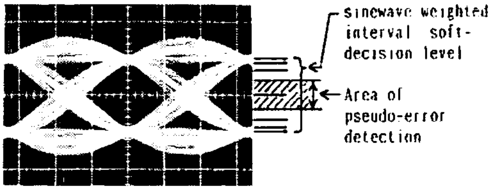


Fig. 2 A soft-decision data based double threshold pseudo-error detection method

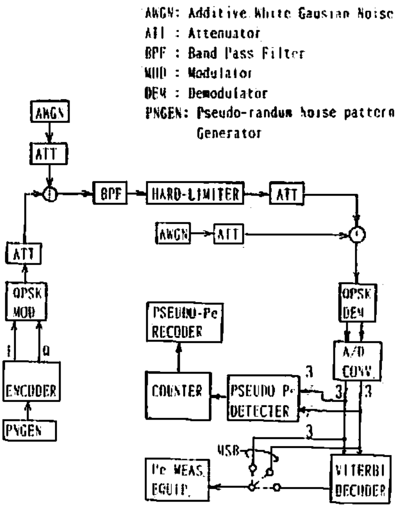


Fig. 3 Experimental circuit diagram to estimate channel quality

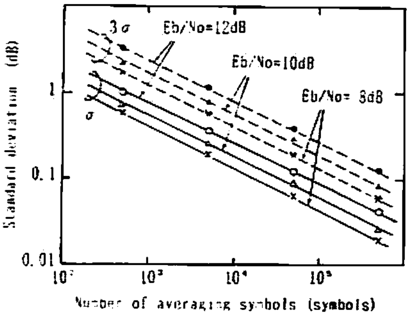


Fig. 4 Standard deviation of estimated Eb/No v.s. number of averaging symbols

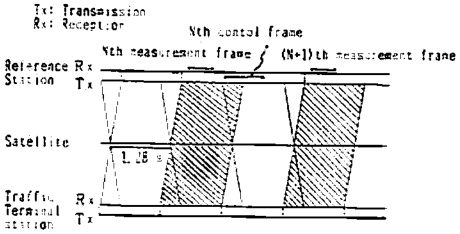


Fig. 5 An example of TPC sequence

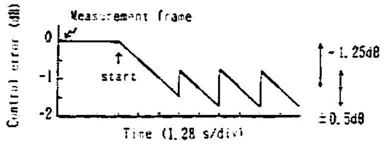


Fig. 6 Residual control error with zero-order prediction

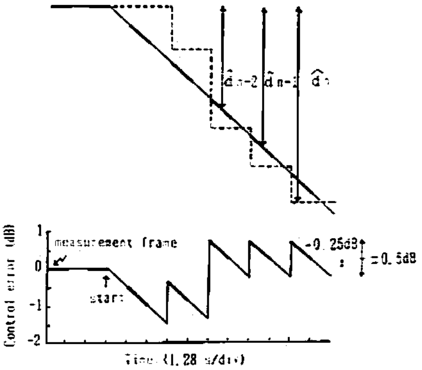


Fig. 7 Residual control error with first-order prediction

Table 2 Total residual control error

Prediction scheme	a_1 (dB)	a_2 (dB)	a_3 (dB)	total (dB)
Zero-order	±1	±1.25	±0.5	±2.75
First-order	±1	±0.25	±0.5	±1.75