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Alerting Service for GEO Satellite System

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***Abstract*—There are great differences between terrestrial cellular communication system and GEO (Geostationary Earth Orbit) mobile satellite system. In GEO mobile satellite system, subscribers could not be paged when the MES (Mobile Earth Station) is normally out of coverage area due to additional propagation path losses. To alert the subscribers in such situation, a more penetrative and computationally efficient coding modulation is needed. In this paper two kinds of orthogonal coded modulation, which are 6PSK based and BPSK based, are analyzed. Through compared with the common paging channel modulation method, and the performance analysis of them, we conclude that they can increase the SNR (Signal Noise Ratio) of actual transmitted information, which is greatly more than the SNR of data in the common paging channel. To be emphasized, we also confirm the predominance of 6PSK modulation.**

Keywords-GEO; alerting; orthogonal coded modulation; 6PSK; BPSK;

I. INTRODUCTION

It can be said that satellites are applied to mobile communications at the beginning of the satellite communications' appearance. Going through with several decades of continuous development, the ability of GEO (Geostationary Earth Orbit) mobile satellite system has made a rapid progress. But by the limitation of satellite platforms and technologies, in terms of coverage, communication capacity, communication capability, there is great distance between the early GEO mobile satellite system and the one which we are researching. Until 2000, with the launch of Thuraya, ACeS and the successful launch of Inmarsat IV in 2005, GEO mobile satellite system began to come into a new stage of development.

At present, the researches on GEO mobile satellite system use the successful experiences of terrestrial mobile communication system for reference, the system architectures of which adopt the class-GSM (Global System for Mobile Communications) network or CDMA (Code Division Multiple Access) or TDMA (Time Division Multiple Access) network. And at the same time, they consult and draw support from terrestrial mobile communication system's specifications. Especially in the core network layer, the existing terrestrial mobile network standards are fully used.

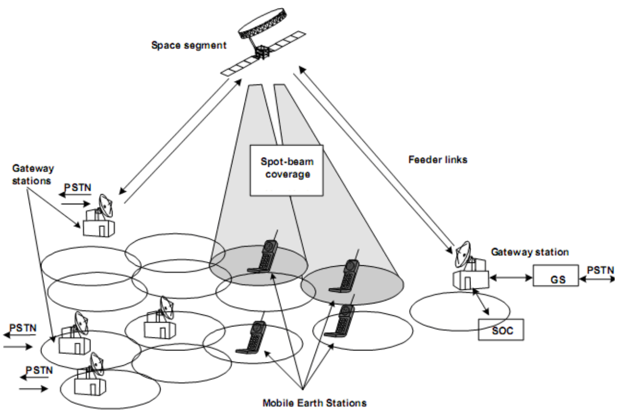

Figure 1. GEO mobile satellite system.

II. DIFFERENCE

Compared with terrestrial cellular system, there are great differences for GEO mobile satellite system in aspects such as the transmission characteristics, cell characteristics and the network structure [1]. Just due to the differences, it determines that we could not adopt the technologies and results of terrestrial mobile communication system directly. Instead, we need to research on the system architectures and key technologies which are compatible to the GEO mobile satellite system.

Fig. 1 shows one of the GEO mobile satellite system structure. Particularly speaking, differences between GMSS (GEO Mobile Satellite System) and terrestrial cellular communication system are mainly in the following areas:

A. Characteristics of Channel Fading

There are great differences between GSM system and GMSS in the transmission characteristics of channels. In GSM system, the mobile channels present the of Rayleigh fading characteristics mainly; on the other side, in GEO mobile satellite system, channels present Rician fading characteristics mainly. As the fundamental requirement, it is most important that the direct satellite-to-earth links. Or else, the weak satellite-to-earth signals will be interrupted by shielding caused by any factors. By virtue of this, generally, channels in GMSS make use of Rician fading model whose factor k is 7 to 9 [2], [3], [4].

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In addition to the fading characteristics, there is difference in signal strength. In terrestrial cellular communication system, the fading factor which depends on distance is 4 (In some models, this value even more great.). The signal strength makes quickly attenuation out of the cell boundary, and multiplex factor can be 7 or 4, with the minimum multiplex distance of a kilometer. On the other hand, in GEO mobile satellite system, all beams are from satellite. The transmission of signal depends on the free space fading whose fading factor is 2. Due to the distance between users and satellite in a beam is equal, the difference in user signal level, are all determined by the characteristics of satellite antenna. The two figures below shows the signal attenuation of the two kinds of systems. Fig. 2 shows that there is 19dB between the signals in boundary of adjacent cell in terrestrial cellular communication system. Fig. 3 is given the gain of three adjacent beam of multi-beam antenna. It shows that the main lobe of antenna is in adjacent beam entirely, even if the side lobe may also interfere with the distant beam, leaving the system frequency resource can be multiplexed only in hundreds or thousands of kilometers. As a matter of fact, compared with terrestrial cellular system, by virtue of the increase of frequency multiplex distance, the frequency resource is made more limited. Particularly speaking, the frequency utilization rate is important to the GMSS system.

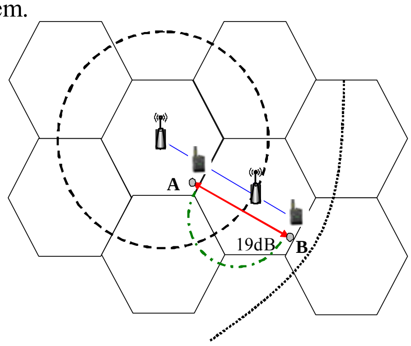

Figure 2. Signal attenuation of terrestrial cellular communication system.

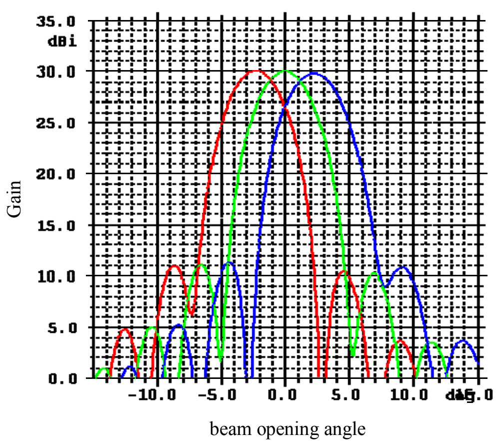

Figure 3. Signal attenuation of GMSS.

B. *Transmission Delay*

In GEO mobile satellite system, the distance between user terminal and gateway station (user terminal to gateway station and gateway station to user terminal) is farther than that between user terminal and base station in GSM system. For the GMSS system which adopts onboard-switching, the delay of terminal-to-terminal call is just about 270ms, on the other hand, for the GMSS system which adopts pipe transponder, the delay of terminal-to-terminal call is 540ms. No matter the former or the latter, they are all much longer than that in GSM system. As a result, the delay will make great influence on the quality of communication, the establishing time and so on.

C. *Power Constraint*

In terrestrial cellular communication system, although it is expected that while performance is advanced, the power of terminals and base stations is decreased, generally speaking, power is not the determinant factor affecting the capacity of system. Which is different with GMSS system, power is one of the most valuable resources of satellite. Making the same with frequency, it determines the capacity of the system to a big extent. The limited channel resources need to serve the "cell" whose scope is as big as hundreds to hundreds of kilometers. Therefore, the power constraint of GMSS determines the rarity of channel resources.

III. ALERTING SERVICE

In the GEO mobile satellite system based on TDMA, because of the poor locations of subscribers and the obscured satellite-to-earth links, subscribers can not look straight satellites. In order to establish calls successfully and to improve quality of services, the system needs a special alerting process for alerting user to move to an advantageous position [5]. Just as shown in Fig. 4. It allows subscribers to be paged even when the MES (Mobile Earth Station) is normally out of coverage area due to additional propagation path losses [6].

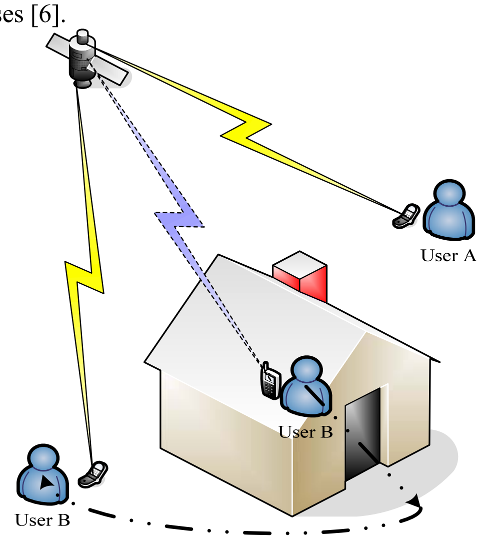

Figure 4. Alerting service.

On account of the serious case, the deeply fading will have a great impact on Alert service. Therefore, we choose the high-gain, strong correcting coding modulation techniques, to improve the quality of services. Besides, if the two signals which have been modulated are orthogonal, then the receive terminals can adopt correlation demodulation, which makes the demodulation more simple. So, adoption of high penetrative and computationally efficient orthogonal coding modulation techniques is decided in the system.

In this paper, 6PSK based coding modulation method [8] and BPSK based coding modulation method we proposed are compared and analyzed through simulations in the background of GEO mobile satellite system.

The satellite system under investigation is supposed to be GEO mobile satellite system based on TDMA. When the locations of users are disadvantageous, or serious shaded, and, the call could not be established, alerting happens [6].

Set a threshold of Page period T_{PA}, and a threshold of Alert period T_{HPA} (High-penetration Alerting). If no paging response from subscribers is received by the gateway station controller during the threshold T_{PA}, then they need to activate high-penetration alerting (HPA) process. This process can be viewed as a modified paging procedure on a higher penetration channel intended to reach MES in poor radio reception areas. The MES alerts the user to move to an area of better reception for call set-up [7].

The number of Pages (can be set to 0 ~ 2 times) prior to the Alerting Request messages, the number of Alert retries (can be set to 0 ~ 2 times) and timer periods are configurable. Fig. 5 presents a time line for a possible HPA alerting procedure scenario [7].

In this system, the timeslot is defined including 78 bits. The transmissions within these timeslots are known as bursts. After the channel encoding, an alerting burst occupies two slots [9], transferring 4 bits of information [10].

IV. ORTHOGONAL CODED MODULATION PROCESS

In the orthogonal coded modulation process, we adopt coding method to make 4 bits information mapped to 72 symbols [10] to be transmitted in the alerting channel, while adopt correlation process at the receive terminals. In this way, we can achieve the BER (Bit Error Rate) requirements of system by increasing the SNR (Signal Noise Ratio) of actual

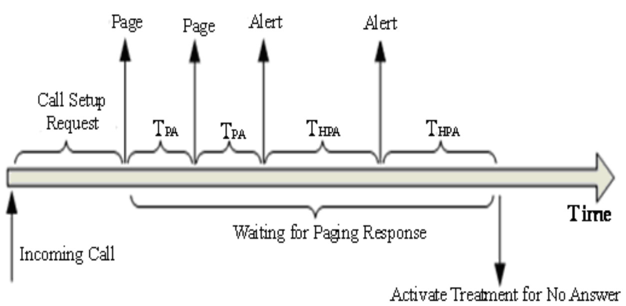

Figure 5. High-penetration alerting time line.

TABLE I. CODED BITS TO CODE WORDS MAPPING

Coded Bits	Code Words S_j	Coded Bits	Code Words S_j
0000	S_0	1000	S_8
0001	S_1	1001	S_9
0010	S_2	1010	S_{10}
0011	S_3	1011	S_{11}
0100	S_4	1100	S_{12}
0101	S_5	1101	S_{13}
0110	S_6	1110	S_{14}
0111	S_7	1111	S_{15}

transmitted information. The use of orthogonal coded modulation is due to that it can make the code words mutual orthogonal, which is convenient for demodulation.

The mapping from the 4 coded bits to one of the 16 sequences S_j is defined in Table I [8]. Where S_j is the code words, and j is the code words index, taking numbers from {0,…,15}.

In this paper, there are two kinds of orthogonal coded modulation methods, which are orthogonal coded modulation based on 6PSK (Hexa Phase Shift Keying) modulation, which we call it 6PSK modulation for short in this paper, and orthogonal coded modulation based on BPSK (Binary Phase Shift Keying) modulation, which we call it BPSK modulation for short in this paper also.

For the 6PSK modulation, a 72-symbol orthogonal code is generated as that [8]. We search for 18-dimensions code words. And each symbol is replicated over 4 successive symbol periods.

The most commonly used orthogonal code in communication systems is Hadamard-Walsh code. This code is based on Hadamard matrix, BPSK modulated, and the length of code words is 2^c, where c is integer. But it could not be used to generate an orthogonal code whose length is 72 symbols. So, through researches we consider that, if adopt the 24-dimensions Hadamard matrix, we can design a 72-symbol orthogonal code. The 16 row vectors are selected from 24-dimensions Hadamard matrix, and each symbol is replicated over 3 successive symbol periods.

The complex envelope of the transmitted signal is defined as follows [10]:

$$\mathrm{x}(t) = \mathrm{p}(t)\left[e^{j\varphi} \sum_{k=-\infty}^{\infty} \alpha_k \mathrm{h}(t-kT) \right]. \quad (1)$$

where
k is the symbols index in a timeslot, taking range from {0,…, 77}
φ is a random phase
p(t) is the ramp function
T is sampling interval
h(t) is the impulse response of a shaping filter defined as follows [8]:

$$\mathrm{h}(t)=\frac{\frac{5}{7}T^2}{\pi\left[\left(\frac{5}{7}T^2\right)\right]}\left(\cos\frac{1.35\pi t}{T}+\frac{5T}{7t}\sin\frac{0.65\pi t}{T}\right). \quad (2)$$

α_k are the modulating symbols defined as follows:

$$\begin{cases} k<0: & \alpha_k=0 \\ 0\le k\le 77: & \alpha_k \text{ see Table II and Table III} \\ k>77: & \alpha_k=0 \end{cases} \quad (3)$$

The modulating symbols are derived from a set of alerting channel sequence values $\boldsymbol{v}_k$ for 6PSK modulation according to Table II.

And sequence values $\boldsymbol{v}_k$ for BPSK modulation is shown in Table III.

The sequence value $\boldsymbol{v}_k$ is uniquely defined by one of the 16 sequences S_j in Table IV [8] or Table V as follows:

$$v_k=\begin{cases} \text{any of } (0,1) & k=0,1,2 \\ S_j(i) & j=\{0,1,...,15\}; k=3,4,...,74 \\ \text{any of } (0,1) & k=75,76,77 \end{cases} \quad (4)$$

where
i is the dimension index, for 6PSK modulation is computed as (5), taking numbers from {0,1,…,17} for the range of k values:

$$i=\left\lfloor\frac{k-3}{4}\right\rfloor. \quad (5)$$

and for BPSK modulation is as (6), taking numbers from {0, 1, …, 23} for the range of k values:

$$i=\left\lfloor\frac{k-3}{3}\right\rfloor. \quad (6)$$

with " └ ┘ " takes the integer part of the values.

TABLE II. 6PSK MODULATION

Sequence Values v_k	Modulating Symbols α_k
0	e^{j0}
1	$e^{j2\pi/3}$
2	$e^{-j2\pi/3}$
3	$e^{j\pi}$
4	$e^{j\pi/3}$
5	$e^{-j\pi/3}$

TABLE III. BPSK MODULATION

Sequence Values v_k	Modulating Symbols α_k
0	e^{j0}
1	$e^{j\pi}$

TABLE IV. CODE WORDS FOR 6PSK

Coded Words	(18 Dimensions)
S_0	0 3 0 3 0 3 0 3 0 3 0 3 0 3 0 3 0 3
S_1	0 0 1 1 2 2 0 0 1 1 2 2 0 0 1 1 2 2
S_2	0 3 1 5 2 4 0 3 1 5 2 4 0 3 1 5 2 4
S_3	0 0 2 2 1 1 0 0 2 2 1 1 0 0 2 2 1 1
S_4	0 3 2 4 1 5 0 3 2 4 1 5 0 3 2 4 1 5
S_5	0 0 0 0 0 0 1 1 1 1 1 1 2 2 2 2 2 2
S_6	0 3 0 3 0 3 1 5 1 5 1 5 2 4 2 4 2 4
S_7	0 0 1 1 2 2 1 1 2 2 0 0 2 2 0 0 1 1
S_8	0 3 1 5 2 4 1 5 2 4 0 3 2 4 0 3 1 5
S_9	0 0 2 2 1 1 1 1 0 0 2 2 2 2 1 1 0 0
S_{10}	0 3 2 4 1 5 1 5 0 3 2 4 2 4 1 5 0 3
S_{11}	0 0 0 0 0 0 2 2 2 2 2 2 1 1 1 1 1 1
S_{12}	0 3 0 3 0 3 2 4 2 4 2 4 1 5 1 5 1 5
S_{13}	0 0 1 1 2 2 2 2 0 0 1 1 1 1 2 2 0 0
S_{14}	0 3 1 5 2 4 2 4 0 3 1 5 1 5 2 4 0 3
S_{15}	0 0 2 2 1 1 2 2 1 1 0 0 1 1 0 0 2 2

TABLE V. CODE WORDS FOR BPSK

Coded Words	(24 Dimensions)
S_0	1 1 0 0 0 0 0 0 1 1 1 1 1 1 0 0 1 1 0 0 1 1 0 0
S_1	1 1 0 0 1 1 0 0 1 1 0 0 0 0 1 1 0 0 0 0 1 1 1 1
S_2	1 1 0 0 0 0 1 1 0 0 1 1 0 0 1 1 1 1 0 0 0 0 1 1
S_3	1 1 0 0 1 1 0 0 0 0 1 1 1 1 0 0 0 0 1 1 0 0 1 1
S_4	1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0
S_5	1 0 1 0 1 0 1 0 1 0 1 0 0 1 0 1 0 1 0 1 0 1 0 1
S_6	1 0 1 0 1 0 0 1 0 1 0 1 1 0 1 0 1 0 0 1 0 1 0 1
S_7	1 0 0 1 0 1 1 0 1 0 0 1 1 0 1 0 0 1 1 0 0 1 0 1
S_8	1 0 1 0 0 1 1 0 0 1 0 1 1 0 0 1 0 1 0 1 1 0 1 0
S_9	1 0 1 0 0 1 0 1 0 1 1 0 0 1 1 0 0 1 1 0 1 0 0 1
S_{10}	1 0 0 1 1 0 1 0 0 1 0 1 0 1 0 1 1 0 1 0 1 0 0 1
S_{11}	1 0 1 0 0 1 0 1 1 0 0 1 0 1 0 1 1 0 1 0 0 1 1 0
S_{12}	1 0 0 1 0 1 0 1 1 0 1 0 1 0 0 1 1 0 0 1 1 0 0 1
S_{13}	1 0 0 1 1 0 0 1 1 0 0 1 0 1 1 0 0 1 0 1 1 0 1 0
S_{14}	1 0 0 1 0 1 1 0 0 1 1 0 0 1 1 0 1 0 0 1 0 1 1 0
S_{15}	1 0 0 1 1 0 0 1 0 1 1 0 1 0 0 1 0 1 1 0 0 1 1 0

V. PERFORMANCE ANALYSIS

The performance analysis will be carried out in these following three aspects: bit error rate, cross-correlation and autocorrelation. Through the simulation and calculation, we compare the performance of 6PSK modulation and BPSK modulation.

The commonly used modulation method in GEO mobile satellite system is QPSK (Quadrature Phase Shift Keying). Here, we simulate the BER of QPSK modulation and orthogonal coded modulation, to illuminate the predominance of the new scheme.

Under the condition of deeply fading, there may be synchronization errors. Therefore, we hope the cross-correlation values remain small, while the autocorrelation values remain large, so that we could detect the transmission information exactly.

A. Bit Error Rate

The setting is fully synchronization in AWGN (Additive White Gaussion Noise) channel.

Fig. 6 shows the BER performance for the commonly used QPSK modulation and the orthogonal coded modulation based on 6PSK and BPSK.

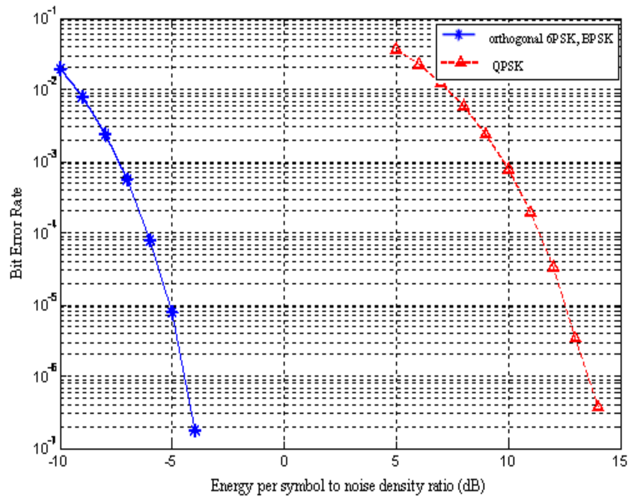

Figure 6. BER for QPSK, the orthogonal coded modulation based on 6PSK, BPSK.

As is shown in Fig. 6, the performance of BER has no difference between 6PSK modulation and BPSK modulation. And which is the most important, through the comparison, we could see, if the user is in a disadvantageous position, the orthogonal coded modulation based on orthogonal coded modulation can make the user have sufficient gain to achieve the Alert message, thereby, to improve the quality of services.

In Fig. 6, the energy of each symbol which is named E_s, and its relationship with E_b which is the energy of each bit is as follows:

$$E_s = \log_2{}^6 E_b \,. \qquad (7)$$

B. *Cross-correlation*

Cross-correlation is a standard method of estimating the degree to which two signals are correlated. It is also known as a sum of products which are obtained by multiplying two signals. To the performance of signal cross-correlation, the weaker is the better, that is, to the cross-correlation values the smaller are the better.

The cross-correlation value of the code words is defined as follows:

$$r_{j1,j2}(n) = \left| \sum_{m=0}^{71} x_{j1}(m) x_{j2}^{*}\left((m-n)\right)_{72} \right| . \qquad (8)$$

where

j1, j2 is the index of code words, taking numbers from{0,1,…,15}

x(n) is the equivalent low-pass denotation of symbols

"*" denotes conjugate

$((\ ))_{72}$ is the results of circulation.

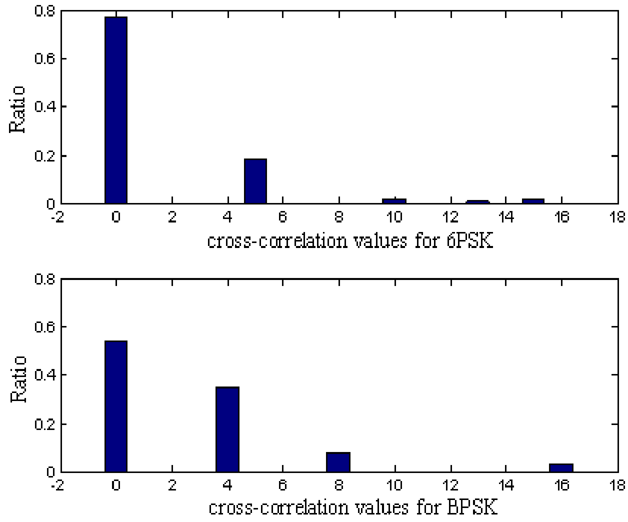

Figure 7. Distributing of cross-correlation values.

When the delay is a forward symbol or a backward symbol, the distributing of cross-correlation values are shown in Fig. 7. The vertical axis is the ratio of values, and the horizontal axis is the range of cross-correlation values. For example, 0 denotes the values in [0,1), where "[ )" denotes the range of values.

Through the researches for distributing of cross-correlation values, we could see that, 6PSK modulation is superior to BPSK modulation.

C. *Autocorrelation*

Autocorrelation is a kind of measurement, which is the cross-correlation of a signal with itself. It can be seen as a sum of products which are obtained by multiplying signals with its delay signals. There will always be a peak at a delay of zero. To the performance of signal autocorrelation, the stronger is the better, that is, to the autocorrelation values the bigger are the better.

The autocorrelation value of the code words is defined as follows:

$$r_{auto}(n) = \left| \sum_{m=0}^{71} x_i x_i^{*}\left((m-n)\right)_{72} \right| . \qquad (9)$$

where the denotations are the same as (8).

When the delay is a forward symbol or a backward symbol, autocorrelation values (cyclic autocorrelation) for 6PSK modulation and BPSK modulation are shown in Table VI.

As autocorrelation values (cyclic autocorrelation) are shown in Table VI, statistically speaking, when the delay is a forward symbol or a backward symbol, we can see that the percentage of autocorrelation values, which are bigger than 45, is approximately 81.3% (13/16) and is merely 25% (4/16)

TABLE VI. CODE WORDS AUTOCORRELATION VALUES

Delay	**A forward symbol**		**Synchroni-zation**	**A backward symbol**	
Code Words Index	***6PSK***	***BPSK***	***6PSK BPSK***	***6PSK***	***BPSK***
0	36.0000	56	72	36.0000	56
1	59.0169	56	72	59.0169	56
2	50.1099	56	72	50.1099	56
3	59.0169	56	72	59.0169	56
4	50.1099	24	72	50.1099	24
5	67.5500	28	72	67.5500	28
6	40.5832	32	72	40.5832	32
7	58.5577	40	72	58.5577	40
8	49.5681	36	72	49.5681	36
9	63.2139	40	72	63.2139	40
10	45.2990	36	72	45.2990	36
11	67.5500	36	72	67.5500	36
12	40.5832	40	72	40.5832	40
13	63.2139	40	72	63.2139	40
14	45.2990	40	72	45.2990	40
15	58.5577	40	72	58.5577	40

for BPSK modulation. Apparently, from this point of view, 6PSK modulation is superior to BPSK modulation.

VI. CONCLUSION AND DISSCUSSION

The orthogonal coded modulation, no matter based on 6PSK modulation or based on BPSK modulation, presents well performance to GEO mobile satellite system. It can increase the SNR of actual transmitted information. And also, the code words are mutual orthogonal, which is convenient for demodulation. Through the comparison between two kinds of orthogonal coded modulation methods, it is shown to us that, the orthogonal coded modulation based on 6PSK is superior to that based on BPSK in cross-correlation and autocorrelation aspects, although the performance of BER is the same.

But, there are still two main aspects for error. The first one is that, in actual situation, the errors of code words autocorrelation values resulting from the synchronization errors may not be the symbol-level. So, the analysis, here, is just the qualitative description of the overall performance. And, the second one is that, when delay occurs, we use the cyclic calculations. In actual situation, there may be errors, due to the random un-matched symbol values. However, because of this kind of values are less, the errors can be ignored.

In the future, we will consider more kinds of conditions which are more close to practical environment, and what is more, search for other orthogonal coded modulation schemes to optimize the performance in the GEO mobile satellite system.

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