# Coordinated Multi-point Transmission Combined with Cyclic Delay Diversity in Mobile Satellite Communications*

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**Abstract.** In OFDMA based MSS system, the beam planning with frequency reuse factor 1 may induce severe inter-beam interference due to the usage of the same subcarrier between user equipments of adjacent beams. In order to solve this problem, this paper shows a coordinated multi-point transmission scheme combined with cyclic delay diversity. The proposed scheme improves frequency usage efficiency in a beam boundary area and minimizes the interference between adjacent beams in an OFDMA based mobile satellite communication. In addition, Simulation results show that it makes the received signal to noise ratio increased due to diversity gain from cyclic delayed multi-point transmitted signals. This performance gain could be achieved without any modification of a conventional Single-Input and Single-Output tranceiver, differently from the space-frequency transmit diversity scheme.

**Keywords:** coordinated multi-point transmission, cyclic delay diversity, mobile satellite communications.

## 1 Introduction

Due to the increment of requirements to a high quality multimedia service, a mobile satellite service (MSS) system has been required to provide a broadband service. However, a very limited bandwidth has been allocated to the MSS. For example, a bandwidth of 30 MHz is allocated for the satellite component of IMT-2000 according to international mobile telecommunication union – radiocommunication sector (ITU-R). With this bandwidth, it is very difficult to realize a frequency reuse factor of three or seven because a wireless interface having a minimum bandwidth of 10 MHz is required to provide a broadband service. In practical, a frequency reuse factor of seven cannot be realized and the case of three requires that the entire frequency band has to be allocated to one operator. Therefore, it is essential to realize a MSS system having a frequency reuse factor of one to provide a broadband service.

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Most of the candidate radio interfaces for the terrestrial components adopted multi-carrier transmission technologies such as orthogonal frequency division multiplexing (OFDM). Not much attention had been paid to the study on OFDM based satellite systems due to serious peak to average power ratio (PAPR) problems, especially for a high power amplifier in the satellite system. Nevertheless, resent results reported application of OFDM in satellite systems [1]-[4], not only to utilize the advantage of OFDM system such as capability of high speed transmission but also to keep commonalities between the terrestrial systems. For example, DVB-SH adopted OFDM transmission [7], which is the same signal format defined in DVB-H for terrestrial systems. The main reason for adopting OFDM stems from the fact that satellite and terrestrial transmitters from a single frequency network (SFN). Recently European Telecommunications Standardization Institute (ETSI) have started feasibility study on OFDM based scheme might provide better performance than the conventional wideband code division multiple access (WCDMA) based scheme [8].

In case of a CDMA based MSS system, a frequency reuse factor of one may be realized by using a different spreading code for each beam to reduce interference between adjacent beams. However, in case of an OFDMA based MSS system which has been considered as IMT-Advanced radio interface technology, it is not easy to realize a frequency reuse factor of one. In the OFDMA based MSS system, the beam planning with frequency reuse factor one can induces severe inter-beam interference due to the usage of the same subcarrier between user equipments (UEs) of adjacent beams, especially where a UE is located in a beam edge. As a solution to this interference problem, OFDMA based MSS systems applying fractional frequency reuse (FFR) was proposed [5][6]. In the FFR, the users at the beam edge operate with a fractional of whole subcarriers available. In addition, the edge users are not negligible differently in terrestrial systems. Relative spectral efficiency of the proposed FFR scheme compared to the conventional scheme with frequency reuse factor of seven was shown in the reference.

As more intelligent frequency reuse techniques, in this paper, we propose coordinated multi-point transmission and its combination with cyclic delay diversity in mobile satellite communications.

## 2 Fractional Frequency Reuse Technique in an OFDMA Based MSS System

Figure 1 shows a frequency reuse pattern with three subcarrier groups in an OFDMA based multi-beam MSS system. Each beam is partitioned into two regions and each frame is divided into two time sections, T1 and T2, in each beam. The first time section, T1 and T2, in each beam. The first time section, T1 is allocated to UEs in the beam centre with radius of R1, and all of the three subcarrier groups can be used for transmission during this time period. On the other hand, the second time section, T2 is allocated to UEs in the beam edge. During this time period, only a single subcarrier group out of three can be used. In other words, all the subcarriers are reused in the beam centre region during T1, while only a single group is allocated into each beam during T2. In this case, the allocated subcarrier group must satisfy the orthogonality condition. We note that the user signals in two regions cannot be transmitted simultaneously because we cannot ignore the interference from the adjacent beams.

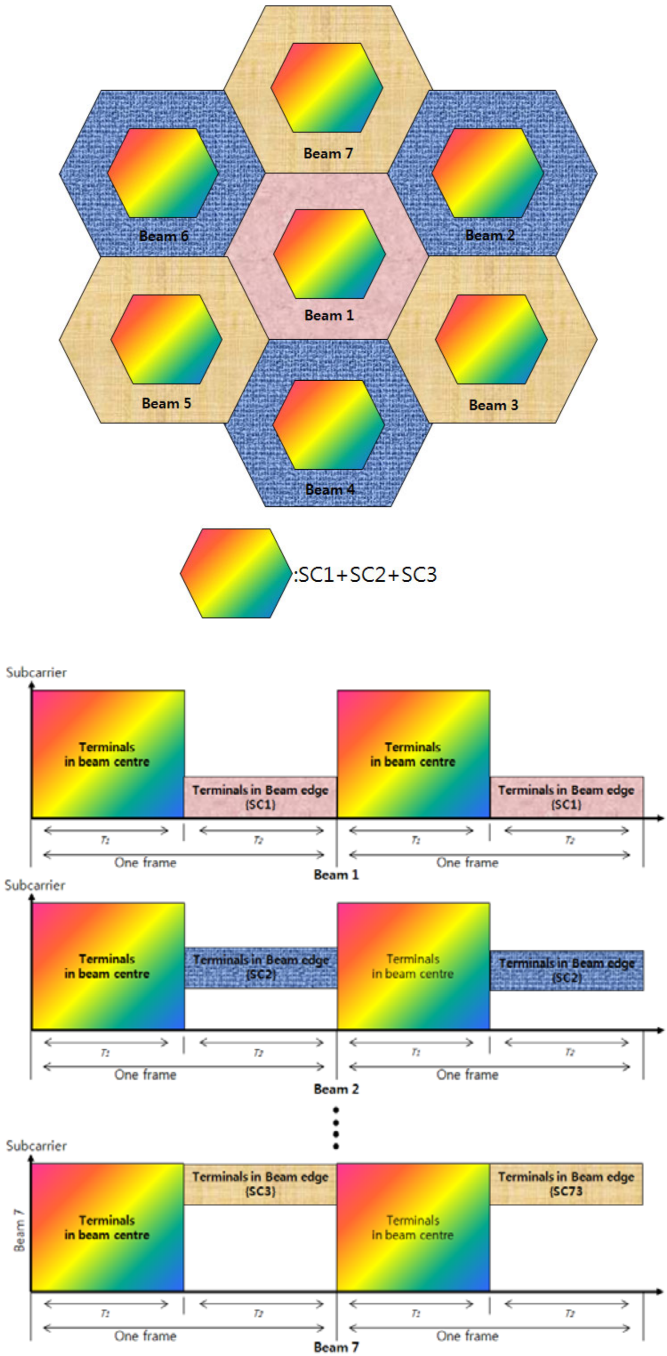


**Fig. 1.** Frequency reuse pattern for a multi-beam satellite system with three subcarrier groups

In case of using such a fractional frequency reuse scheme, maximum frequency usage efficiency of a beam boundary area is dropped to 1/3 compared to that of a beam centre area because a user in a beam boundary region uses only one of fractional subcarrier groups SC1 to SC3. Furthermore, a received Effective Isotropically Radiated Power (EIRP) from a satellite beam in a beam boundary region is lower than in a beam centre area. Accordingly, the UE capacity in a beam boundary is decreased and thus, digital divide between UEs in beam centre and edge regions is increased.

In order to solve these problems, we introduce a coordinated multi-point transmission for UEs located at a beam edge region. In the coordinated multi-point transmission scheme, beams cooperate with each other to provide a satellite communication service to a user rather than competing to each other. That is, the coordinated multi-point transmission scheme means a multi-beam transmission scheme that enables a signal from an adjacent beam to improve a communication service quality. The coordinated multi-point transmission will be described in detail though Sections 3 and 4.

## 3 Coordinated Multi-point Transmission in an OFDMA Based MSS System

The figure 2 shows a system using a coordinated multi-point transmission scheme. We assume that a satellite transmits signals for UE1 to UE3 through beam 1. UE1, UE2 and UE3 means terminals located at the beam centre region, a two beams-overlapped region, a three beams-overlapped region, respectively. In reference [5], users in a beam boundary area use different resources at adjacent beams in order to receive a signal from only one of overlapped beams without severe interference. On the other hands, in the coordinated multi-point transmission, a user in a beam boundary region receives its own signals through whole overlapped beams that enable to make coordinated multi-point transmission. For example, in reference [1], UE2 receives its own signal from only beam 1 and a signal from beam 3 overlapped with beam 1 may cause severe interference to UE2. Similarly, UE3 receives its own signal from only beam 1 and signals from beams 2 and 3 overlapped with beam 1 may cause higher interference to UE3 than UE2. On the other hands, in the coordinated multi-point transmission, the beam 3 signal does not cause interference to the UE1 signal but enhance it. Similarly, beams 1, 2 and 3 cooperate with each other in order to transmit the UE3 signal through the same resource. Accordingly, a reception performance of the UE2 and UE3 can be improved.

In conclusion, the coordinated multi-point transmission can improve a received signal to noise ratio (SNR) because a user receives a signal from adjacent multiple beams although the user is located at the beam edge region. Furthermore, interference can be avoided because an adjacent beam also transmits its own signal. If many users are located at a predetermined boundary region, the coordinated multi-point transmission scheme in an OFDMA based MSS system can flexibly allocate a large subcarrier region to the users at the predetermined boundary region. Thus, frequency efficiency can be improved.

Figure 3 illustrates a multi-beam MSS system consisting of one beam and six adjacent beams. In the multi-beam MSS system, a signal is transmitted during the same frequency band f1 from all beams to realize a frequency reuse factor 1. All beams are divided into a beam centre region and a beam boundary area similarly in reference [5]. In the case of beam 1, its boundary region is divided into six two-beam overlapped areas and six three-beam overlapped areas. In Fig. 3, whole subcarriers can be used in beam centre region while fractional subcarriers should be used in six two-beam overlapped areas and three-beam overlapped areas.

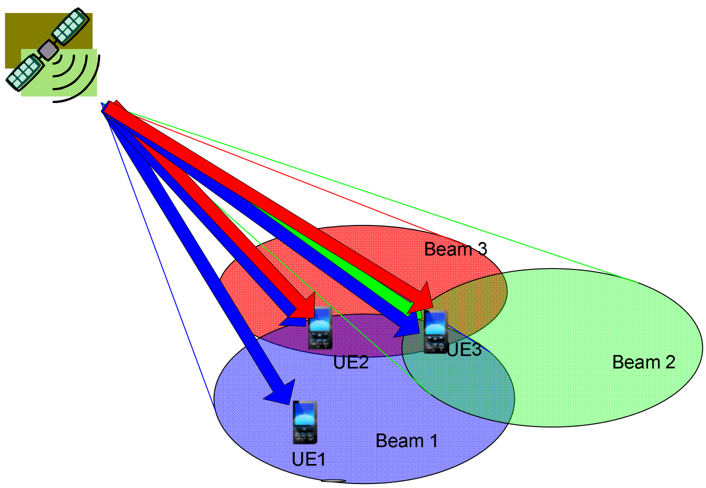


**Fig. 2.** Coordinated multi-point transmission concept in mobile satellite communication

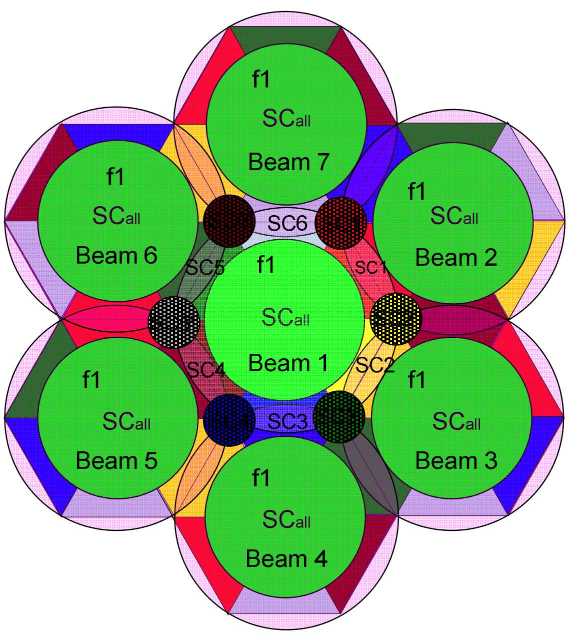


**Fig. 3.** Fractional frequency reuse pattern example for coordinated multi-point transmission

Figure 4 shows one example of frame structures to realize the fractional frequency reuse of Fig.3 for coordinated multi-point transmission in an OFDMA based MSS system. In this figure, one frame is divided into three transmission interval in time domain and six subcarrier groups in frequency domain. The first, second, and third transmission intervals, T1, T2, and T3 are allocated to a beam centre UE, a two-beam overlapped UE, and a three-beam overlapped UE, respectively. The beam centre UE can receive its own signal over whole subcarrier during T1 while the two-beam and three-beam overlapped UEs can have frequency resource over only predetermined fractional part of whole subcarriers such as subcarrier groups SC1 to SC6 and SC1' to SC6'. SC1 to SC6 and SC1' to SC6' are considered for six two-overlapped regions and six three-overlapped regions, respectively. The size of each subcarrier group can be flexibly decided depending on the traffic demand over each corresponding region. For example, in Fig. 4, we can know that the traffic demand in the two-beam overlapped regions would be high at the beam 1 edge region overlapped with beam. In the same principle, in case of the three-beam overlapped regions, the beam 1 edge region overlapped with both beam 3 and 4 or both beam 5 and 6 would require high traffic demand during T3. We can also control the duration of the time interval T1, T2 and T3, considering the required capacity from UEs in the beam centre, two-beam overlapped , and three-beam overlapped regions.

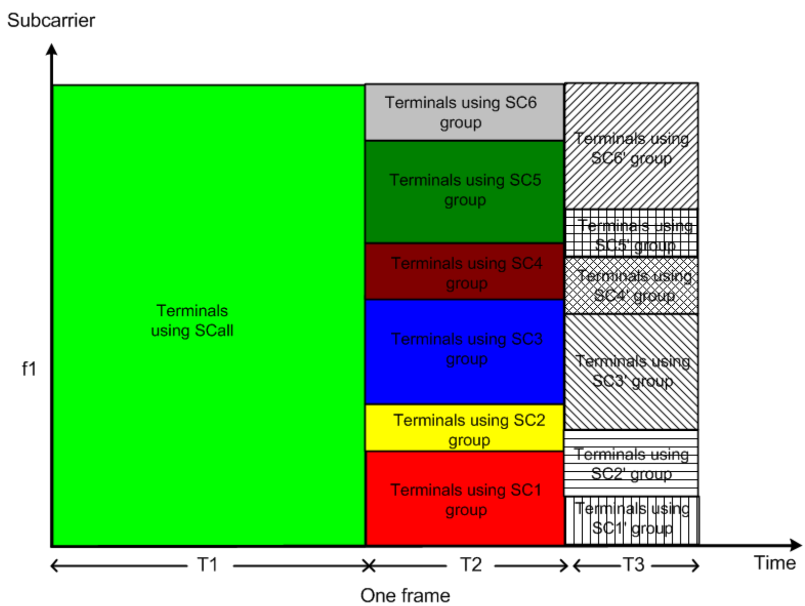


**Fig. 4.** Frame structure example for coordinated multi-point transmission

## 4 Coordinated Multi-point Transmission Combined with Cyclic Delay Diversity

As mentioned in Section3, the coordinated multi-point transmission in an OFDMA based MSS system makes the received SNR of beam edge UEs increased and the interference from adjacent beams reduced according to multiple reception of own signal over the same resource from the targeted and adjacent beams. However, because in this scheme an UE simply receives the multiple same signals, we cannot obtain any diversity gain. Therefore, in this Section, we consider the coordinated multi-point transmission applying cyclic delay diversity (CDD).

CDD is a diversity scheme used in OFDM based telecommunication systems, transforming spatial diversity into frequency diversity avoiding intersymbol interference. CDD involves transmitting the same set of OFDM symbols on the same set of OFDM subcarriers from multiple transmit antennas, with different delay on each antenna [9]. The delay is applied before cyclic prefix is added, thereby guaranteeing that the delay is cyclic over the Fast Fourier Transform (FFT) size.

Adding a time delay is identical to applying a phase shift in the frequency domain. As the same time delay is applied to all subcarriers, the phase shift will increase linearly across the subcarriers with increasing subcarrier frequency. Each subcarrier will therefore experience a different beamforming pattern as the non-delayed subcarrier from one beam interferes constructively or destructively with the delayed version from other coordinated beams. The diversity effect of CDD therefore arises from the fact that different subcarriers will pick our different spatial paths in the propagation channel, thus increasing the frequency-selectivity of the channel.

As a CDD for a case with two transmit antenna ports, we can express mathematically the received symbol $r_k$ on the $k^{th}$ subcarrier as

$$r_k = h_{1k}x_k + h_{2k}e^{j\phi k}x_k \quad (1)$$

where hpk is the ricia fading channel from the pth beam, and $e^{j\phi k}$ is the phase shift on the $k^{th}$ subcarrier due to the delay operation. We can see clearly that on some subcarriers the symbols from the second transmit beam will added constructively, while on other subcarriers they will add destructively. Here, $\phi = 2\pi d_{cdd}/N$, where N is FFT size and $d_{cdd}$ is the delay in samples.

The number of resulting peaks and troughs in the received signal spectrum pattern across the subcarriers therefore depends on the delay parameter dcdd: as dcdd is increased, the number of peak and troughs in the spectrum also increases. This help to illustrate how CDD enhances the channel coding gain by introducing frequency selectivity into a possibly flat fading channel.

Applying the CDD scheme to coordinated transmission, each coordinated multi-point transmitted signals from a satellite is applied to difference cyclic delay values in the same signal for a targeted user. This induces transmit diversity between coordinated multi-point transmitted signals since different cyclic delay values makes different frequency selectivity in the coordinated transmission signals.

## 5 Simulation Results

In order to assess the performance enhancement of the proposed diversity scheme, we apply a simple simulation model. We assume the signals for beam 1 and beam 2 are modulated using the QPSK scheme and, in a case of coded transmission, coded in the convolutional coding scheme with generation polynomial of $[172\ 133]_8$, code rate of

1/2, constraint length of 7, and the length of a codeword with 288. The decoding of a received signal is done by Viterbi algorithm. We also assume that the amplitude of fading from the satellite beams to the receiver is uncorrelated or fully correlated Rician distributed with factor K of 3 dB. As in a normal satellite channel, we assume that fading is constant across whole subcarriers in one OFDM symbol and the receiver has perfect knowledge of the channel. Finally, we consider that the signal power from each beam of the satellite put on equal power. This case corresponds to a UE in a boundary region between two beams.

Figure 5 and 6 show bit error rate (BER) performance of the coordinated multi-pointed transmission schemes over an uncorrelated Rician distributed channel in cases of uncoded and coded transmission, respectively. We assume that the number of total subcarriers in one OFDM symbol is 288 corresponding to the length of one convolutional coding codeword.

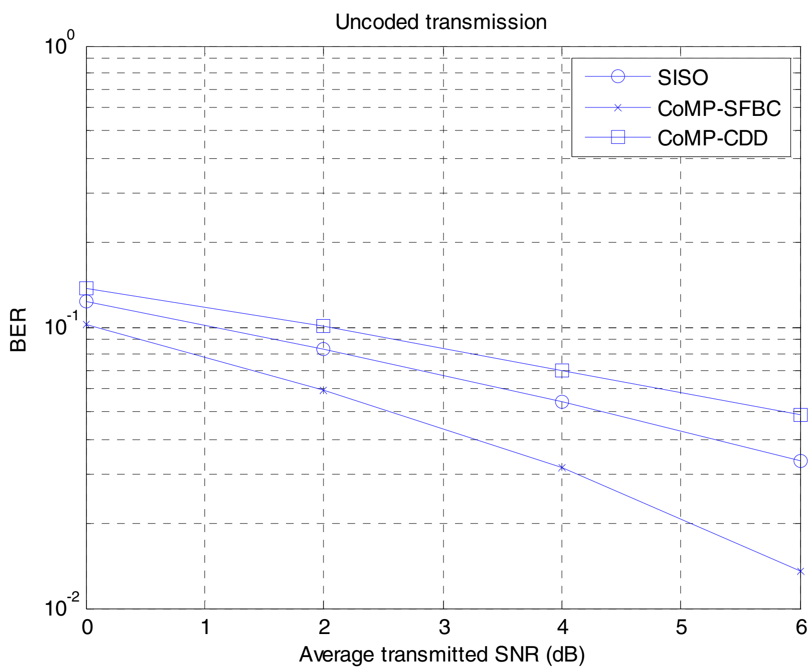


**Fig. 5.** Uncoded transmission in multi-beam mobile satellite communication

In Fig. 5, it is noted in uncoded transmission that the coordinated transmission with CDD has no advantages and performance degradation due to loss of the received SNR while the coordinated transmission with space frequency block code (SFBC) applying to Alamouti code can make performance improved due to space diversity gain.

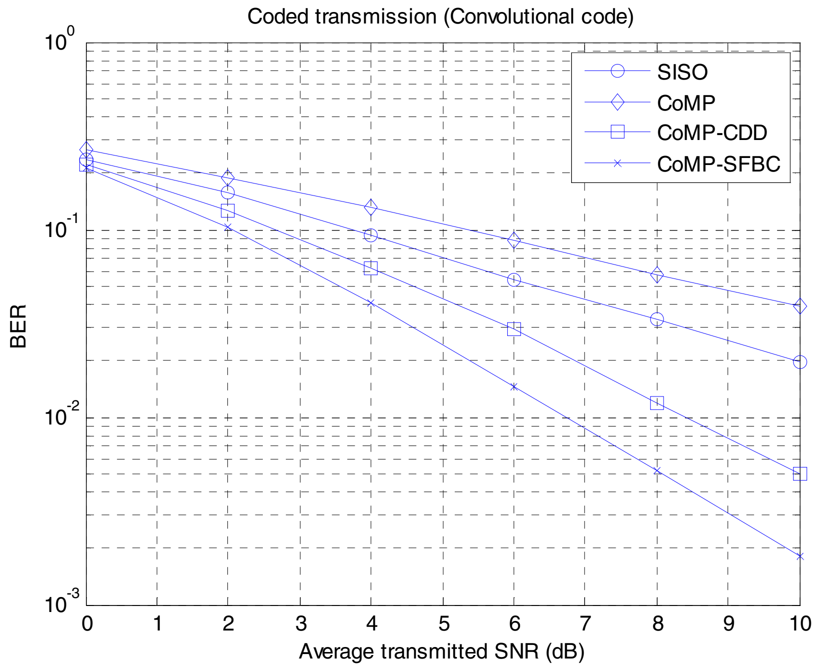


**Fig. 6.** Coded transmission in multi-beam mobile satellite communication

In Fig.6, it is noted in coded transmission that the coordinated transmission should be combined with one of possible diversity schemes for performance enhancement. In the conventional single transmission, whole coded bits in one codeword suffer from the same channel fading due to the frequency flat fading characteristic of satellite communication channel, and thus coding performance is not good. By the way, in the coordinated multipoint transmission with CDD, a cyclic delayed beam signal increase frequency selectivity on the coordinated transmission channel, and thus we can get more coding gain over one codeword corresponding to the length of whole subcarriers. Clearly, the coordinated multipoint transmission with SFBC has best performance due to perfect diversity gain.

Figure 7 shows BER performance of the coded coordinated multi-pointed transmission over an uncorrelated Rician distributed channel according to various cyclic delay shift values. As seen in the figure, a degree of spatial diversity gain in the CoMP-CDD scheme depends on the value of cyclic delay shift. From the figure, we know that this scheme get best diversity gain when the value of cyclic delay shift is 1/16 of the length of whole subcarriers. It comes from the fact that the power variance of the CoMP-CDD signal is largest in that value. In addition, it is noted in the figure that performance of the CoMP CDD scheme is degraded in the cyclic delay shifts less than 1/16 of the length of whole subcarriers as well as corresponding to the half of the length of total subcarriers.

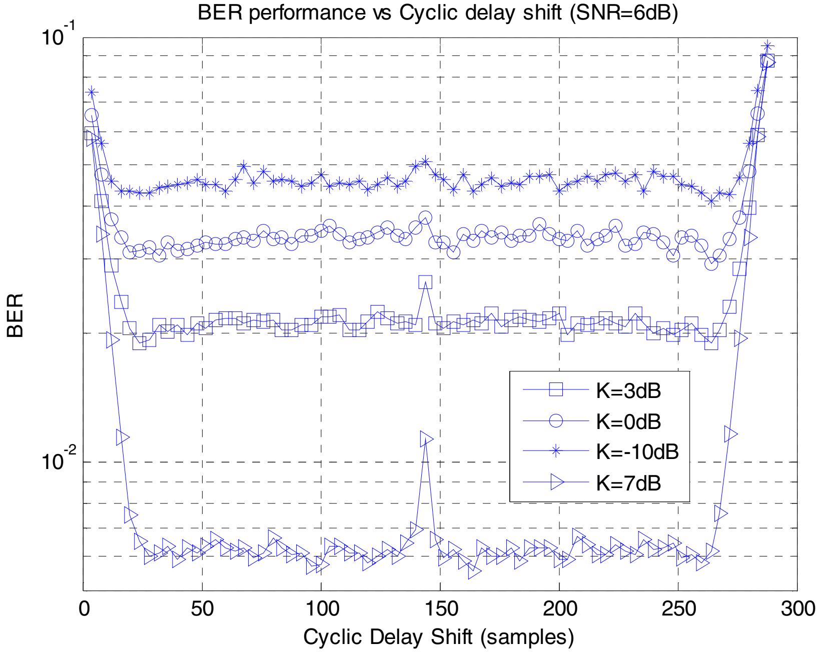


**Fig. 7.** BER performance gain according to various cyclic delay shifts

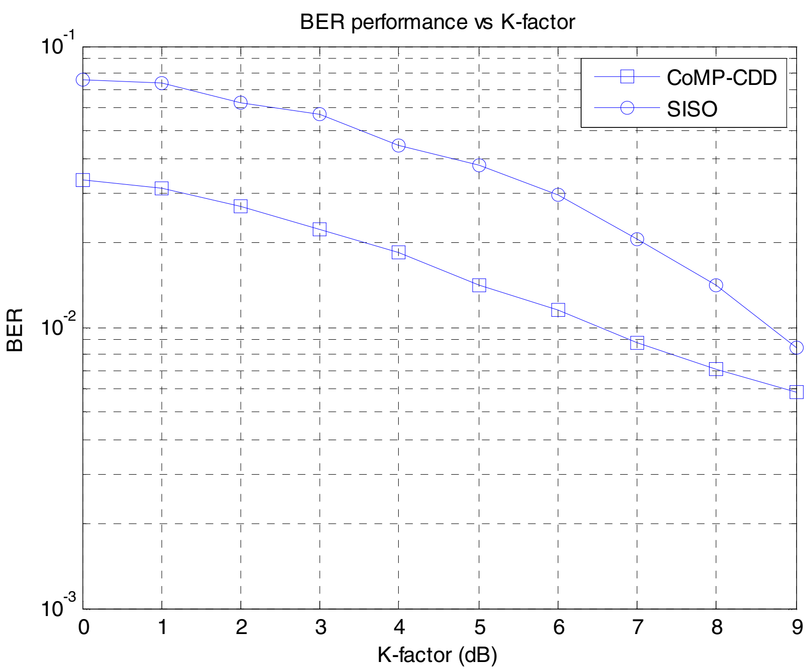


**Fig. 8.** BER performance gain according to various K-factors

Finally, Fig. 8 represents BER performance of the coded transmission according to various K-factors. As seen in the figure, performance enhancement due to diversity gain is kept below K-factor of 6 dB while BER performance is degraded as K-factor is increased over 8 dB. It comes from the reason that the dominant factor for performance improvement would be Rician fading from a strong line-of-sight component rather than diversity gain from the CDD scheme. It is noted in coded transmission.

## 6 Conclusion and Further Works

In this paper, we proposed a coordinated multi-pointed transmission and its combination with cyclic delay diversity in a mobile satellite system. We introduced the basic concept and frame structure of the proposed cooperative transmission and its combination example with the cyclic delay diversity scheme for performance enhancements. Multiple beam signals generate signals in the way that the multiple received signals from several beams can be combined to produce spatial diversity gain. We demonstrated from the simulation results that the proposed method can provide stable improved performance in an OFDM based multi-beam mobile satellite system for a beam edge region and coded transmission. We note that this performance gain could be achieved without any modification of a conventional SISO receiver, differently from the space-time transmit diversity scheme. By the way, in the scheme, the frequency reuse efficiency may be reduced because adjacent beams have to cooperate with each other to communicate with only one user. However, I believe that such a possibility can be overcome through performance enhancement in a edge region with the proposed scheme. Detail analysis on overall system capacity considering these both reduced frequency reuse efficiency and improved performance will be addressed in the future.

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