차세대 위성 DMB 서비스에 대한 STC 방식의 성능

박운희*, 정회원 김 수 영*, 김희욱**, 안도섭**

Evaluation of STC schemes for future S-DMB services

Un-hee Park*, Sooyoung Kim* , Heewook Kim**, Do-seob Ahn** *Regular Members*

요 약

시공간 부호(Space-time codes; STC)는 부가적인 대역폭 요구 사항 없이도 다중경로 환경에서 부호화 이득을 얻을 수 있는 효율적인 방식이다. 위성시스템에서도 시공간부호를 이용하여 지상 중계 장치와의 협동 다이버시티 이득 구현이 가능함이 제안되어 왔다. 특히 위성 DMB 시스템에서는 방송 서비스의 단방향 특성으로 인하여 전송 다이버시티를 이용하여 성능을 향상시키는 것이 매우 효율적이라고 할 수 있다. 본 논문에서는 차세대 위성 DMB 서비스의 성능을 향상시키는데 기여할 수 있는 여러 가지 STC 방식의 성능을 비교한 결과를 제시한다. 본 논문에서 제시하는 방식들은 위성과 지상의 중계기가 서로 협동적으로 동작하여 STC 부호화 이득을 얻을 수 있도록 하는 방식이다. 또한, 향후 이런 방식들을 개발함에 있어서 고려해야 할 점들을 기술한다.

Key Words : satellite DMB, space-time block coding, transmit diversity

ABSTRACT

Space-time codes (STC) can achieve the diversity gain in a multi-path environment without additional bandwidth requirement. Recent study results reported that satellite systems can also achieve this diversity gain by using space-time codes in a cooperative network with terrestrial repeaters. Due to uni-directional nature of satellite DMB services, transmit diversity can be considered as one of the most effective ways to improve the performance. In this paper, we demonstrate various simulations results of STC schemes which can contribute to improve performance of future satellite DMB services. The STC schemes introduced in this paper provides diversity gains by combing independent coded signal from the satellite as well as from the terrestrial repeaters. In addition, we discuss a few points which should be considered to develop and implement these STC schemes.

Ⅰ. Introduction

Multimedia broadcast and multicast services (MBMS) will play an important role in the future mobile system. Due to inherent characteristics of a satellite system, such as wide service coverage, flexibility in network topology, multicast capability, and etc., it is one of the most efficient ways to provide the MBMS. A cooperative satellite-terrestrial network can provide the MBMS of high quality by efficiently mixing the most powerful aspects of each network. Cooperative satellite-terrestrial networks have been deployed for several satellite systems including Korean satellite digital multimedia broadcasting (S-DMB) system and the XM-radio system in USA [1][2].

In order to improve the performance of those systems, an efficient diversity technique using space-time coding (STC) was proposed [3][4]. These techniques do not require any channel quality information (CQI) to adapt channel. In this scenario, the terrestrial repeaters and the satellite transmit the STC encoded signal through cooperation. In this case the terrestrial repeater should be equipped with the encoding capability, instead of being a simple amplifier. The signals

* 전북대학교 전자정보공학과 디지털통신시스템 연구실(fairyuni@chonbuk.ac.kr, sookim@chonbuk.ac.kr), ** 한국전자통신연구원 광역무선전송연구팀

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from the satellite and terrestrial equipment are operated for achieving STC gain.

Generally, we can increase the diversity gain from a STC scheme by increasing the number of transmit antenna. In the previous research in [3][4], the 2×1 Alamouti scheme was applied, and different STC codes are allocated to neighboring terrestrial repeaters. This implies that if we apply n×1 (n > 2) schemes, we may further increase the diversity gain. In this paper, we evaluate the performance of various STC schemes applied to cooperative satellite-terrestrial systems.

The rest of the paper is organized as follows. In section 2, we describe a system configuration of the cooperative satellite-terrestrial network where STC schemes can be applied. Section 3 presents various STC schemes for cooperative satellite-terrestrial system. In section 4 we present the simulation results of various STC schemes, and also investigate performance characteristics by considering near-far problem of the terrestrial repeaters. Finally, the conclusion is drawn in section 5.

Ⅱ. System Architecture

Figure 1 presents cooperative satellite-terrestrial network incorporating STC schemes. In the network, a multi-spot beam satellite in geostationary orbit and an ensemble of terrestrial cell sites with repeaters are deployed. We assume that the satellite transmits data to user terminals and all repeaters on the ground. Then, each of the repeaters transfers the received signal into a given encoded format, and retransmits them to the user terminal.

With the system architecture in Fig. 1, the repeaters and satellite may cooperate to transmit space-time coded signals, and the repeaters have the ability to encode signals rather than being simple amplifiers. A user terminal has the ability to receive the STC-encoded signals. Referring to Fig. 1, in the gateway transmitter, a STC encoded signal sequence, e.g. [STC code 1] is transmitted to the satellite. The satellite, then, passes through the sequence to the user terminal and all repeaters. When a repeater receives [STC code 1], then it generates another STC signal format, [STC code *i*]. The repeater, now send the encoded sequence [STC code *i*] to the user terminal. If the user terminal receives multiple signals from many repeaters and also from the satellite, then it can achieve STC gains using multiple signals.

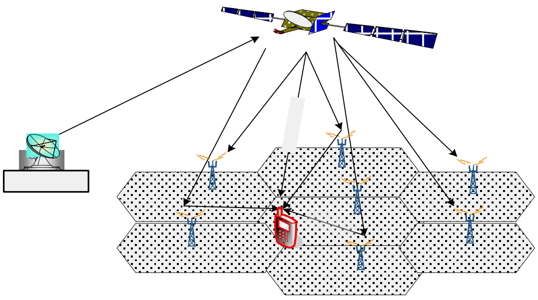

그림 1. 시공간 부호를 적용한 협력적인 위성-지상간 통신 시스템 네트워크 구조
Figure 1. Network architecture for satellite-terrestrial network incorporating STC schemes

Ⅲ. STC scheme for cooperative satellite-terrestrial system

1. Application of the Alamouti scheme

Alamouti proposed a simple and efficient transmit diversity scheme called space-time block coding (STBC) [5]. Figure 2 shows the principles of the transmit diversity using STBC scheme described in [5], where two complex symbols, s_1 and s_2, are transmitted from antennas 1 and 2 to a receiving antenna. The encoded signals are transmitted pair by pair and thus the two symbols, s_1 and s_2, are sent simultaneously by antennas 1 and 2 during the first symbol period T, followed by $-s_2^*$ and s_1^* during the subsequent symbol period T, where* represents the complex conjugate operation.

Each transmitting antenna sends half of the total power P_t through channels h_1 and h_2. The signals received during the two consecutive symbol periods $2T$ with noises of n_1 and n_2 are r_1 and r_2. By using orthogonal characteristics encoding matrix, we can derive the corresponding channel matrix which is also orthogonal. In this way, optimum decoding to obtain $\hat{s}_1$ and $\hat{s}_2$ can be performed at the receiver using a simple linear processor.

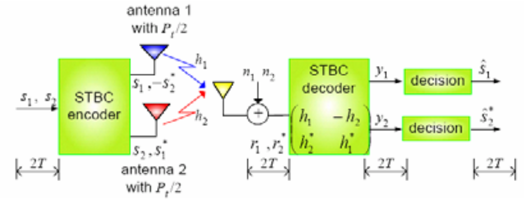

그림 2. Alamouti 방식의 기본 개념
Figure 2. Basic concept of Alamouti scheme

In the 3rd generation partnership project (3GPP), a slightly different encoding rule was applied to the STBC scheme. In the first symbol period T, s_1 and $-s_2^*$ are transmitted simultaneously by antennas 1 and 2, respectively. While s_2 and s_1^* are transmitted during the subsequent symbol period T [6]. The signals received during the period $2T$ also result in two orthogonal terms, and hence can be decoded with a linear processor.

This encoding method can be applied to the cooperative satellite-terrestrial network shown in Fig. 1 [4]. We map the satellite to antenna 1 in Fig. 2, and thus a signal set consisting of [s_1, s_2] is transmitted serially during the period $2T$ through the satellite antenna. Therefore, it is not necessary for the satellite to have encoding capability, since it just passes on the signals received from the source. Now, we map the terrestrial repeaters to either antenna 1 or antenna 2 in Fig. 2. The repeaters randomly select a signal set consisting of either [s_1, s_2] or [-s_2^*, s_1^*], and send it serially during the period $2T$.

In this way, a user terminal can receive various possible combinations of code sets. If the user terminal receives two different signal sets, i.e. [s_1, s_2] from the satellite or one of the repeaters and [-s_2^*, s_1^*] from one of the repeaters, then it can utilize the transmit diversity. Otherwise, if the user terminal receives the same signal sets they would be treated as repetition codes, and in this case the performance would be the same as that when STC is not employed.

2. Application of STC schemes using more than 3 transmit antennas

Generally as the number of transmit antennas are increased, we can expect an increase in the diversity gain. Similarly, if we use the STC scheme for more than two transmit antennas in the cooperative network, we may able to achieve more diversity gain. Unfortunately, for more than two transmit antennas, we have to sacrifice the spectral efficiency and/or diversity gain. For this reason, Tarokh proposed a STC scheme for more than two transmit antennas with the rate less than 1 [7]. In order to increase the spectral efficiency, a quasi-orthogonal space-time block coding (QO-STBC) scheme was proposed [8][9].

The QO-STBC scheme can provide full rate, but there exists interference factors from neighboring signals at the signal detection process. This causes increase in decoding complexity as well as performance degradation.

In order to solve this problem, our previous research introduced an efficient STBC scheme for three or four transmit antennas which can increase the performance compared to the existing methods for the cooperative satellite-terrestrial systems [9]. In the new approach, we first used the QO-STBC scheme for maximizing the spectral efficiency, derive a new encoding matrix which can overcome the most critical disadvantages of the conventional QO-STBC schemes. This new scheme not only can improve the performance but also can use maximum likelihood (ML) decoding by simple linear detection process.

By using the conventional encoding matrix X_4 for four transmit antenna system in [8],

$$X_4 = \begin{bmatrix} X_{12} & X_{34} \\ X_{34} & X_{12} \end{bmatrix} = \begin{bmatrix} x_1 & x_2 & x_3 & x_4 \\ -x_2^* & x_1^* & -x_4^* & x_3^* \\ x_3 & x_4 & x_1 & x_2 \\ -x_4^* & x_3^* & -x_2^* & x_1^* \end{bmatrix}. \quad (1)$$

An encoding matrix for three transmit antenna scheme X_3 was derived by eliminating a column in (1). In this example, we eliminate the last column as in (2).

$$X_3 = \begin{bmatrix} x_1 & x_2 & x_3 \\ -x_2^* & x_1^* & -x_4^* \\ x_3 & x_4 & x_1 \\ -x_4^* & x_3^* & -x_2^* \end{bmatrix}. \quad (2)$$

Due to the quasi-orthogonality of the encoding matrices, the corresponding channel matrices are also quasi-orthogonal. In the case of an orthogonal scheme, the received signals are decoded using a detection matrix *D* defined as $H^H \cdot H$, where H^H is a Hermitian of *H*. For an O-STBC scheme, the detection matrix is always a diagonal matrix, and this enables the use of simple linear decoding.

However, for QO-STBC schemes, this cannot be applied, because the detection matrices are not diagonal. Therefore, the detection matrix includes interference factors by neighboring signal. These causes not only increase in decoding complexity but also high performance degradation. In order to solve this problem, our previous study derived an interference-free detection matrix for three transmit antenna system, and then found the corresponding encoding matrix. Because of the interference-free detection matrix, the decoding can be accomplished by a simple linear process. We refer to this as linearly decodable (LD) –QO-STBC scheme.

For example, the channel matrix corresponding to X_3 can be represented by

$$H_3 = \begin{bmatrix} h_1 & h_2 & h_3 & 0 \\ h_2^* & -h_1^* & 0 & -h_3^* \\ h_3 & 0 & h_1 & h_2 \\ 0 & -h_3^* & h_2^* & -h_1^* \end{bmatrix}, \qquad (3)$$

where h_j is the channel coefficient between the *j*th transmit antenna and the receiver. We applied the Givens rotations to eliminate the interference factors in the detection matrix for three transmit antenna system, and found a new channel matrix [10].

$$H_{m3} = \begin{bmatrix} h_1 - h_3 & h_2 & h_1 + h_3 & h_2 \\ h_2^* & h_3^* - h_1^* & h_2^* & -(h_1^* + h_3^*) \\ h_3 - h_1 & -h_2 & h_1 + h_3 & h_2 \\ h_2^* & h_3^* - h_1^* & -h_2^* & h_1^* + h_3^* \end{bmatrix}. \quad (4)$$

The encoding matrices corresponding to H_{m3} is derived from the relationship between an encoding matrix and its channel matrix, which is expressed as:

$$X_{m3} = \begin{bmatrix} x_1 + x_3 & x_2 + x_4 & x_3 - x_1 \\ -x_2^* - x_4^* & x_1^* + x_3^* & x_2^* - x_4^* \\ x_3 - x_1 & x_4 - x_2 & x_1 + x_3 \\ x_2^* - x_4^* & x_1^* - x_3^* & -x_2^* - x_4^* \end{bmatrix}. \quad (5)$$

This new encoding matrices is quasi-orthogonal. However, since its channel matrix H_{m3} is an orthogonal matrix, we can use simple linear decoding process, for example for three transmit antenna scheme, as given by:

$$\hat{X} = H_{m3}{}^H \hat{\Gamma} = H_{m3}{}^H H_{m3} X_{m3} + H_{m3}{}^H N. \qquad (6)$$

In order to apply this scheme to the cooperative satellite-terrestrial network in Fig. 1, we consider the first antenna as the satellite and the other two antennas are two different terrestrial repeaters. In other words, the satellite sends signal sets in the first column of X_{m3}, i.e. [s_1+s_3, -s_2^*-s_4^*, -s_3-s_1, s_2^*-s_4^*] during four consecutive symbol times. Based upon receiving these, two different repeaters re encode the signals in the form of the second and third columns of X_{m3}, and transmit them to the user terminal, respectively.

Ⅳ. Simulation Results

In this section, we estimate the performance of various STC schemes applied to the cooperative satellite-terrestrial systems. We model a path from the first antenna to the receiver as the path from the satellite to the user terminal, and this is modeled as a Rician channel. We applied two different Rician *K* factor values of 5 dB and 20 dB. We model two paths from the other two antennas to the receiver as the paths from two different terrestrial repeaters to the user terminal, and these are modeled as Rayleigh channels.

The signal is modulated by using QPSK, and the total transmit signal power was equally divided by the number of transmit antennas. As in other conventional STBC schemes, we assumed that fading is constant over two or four consecutive symbol periods, and the receiver has perfect knowledge about the channel.

Figure 3 and 4 show the BER performance of various STC schemes for cooperative satellite-terrestrial network. We used Rician *K* factor of 5 and 20 dB for the simulations shown in Fig. 3 and 4, respectively. When the Alamouti scheme is applied to the cooperative network, the path from the satellite channel does not help for adding diversity gain, instead it contributes to add signal power. Therefore, as shown in Fig. 3, if the *K* value is comparatively small, indicating the channel is similar to a Rayleigh channel, the performance of the cooperative scheme with the Alamouti code is worse than a normal 2X1 Alamouti scheme. dBin consideration of satellite channel.

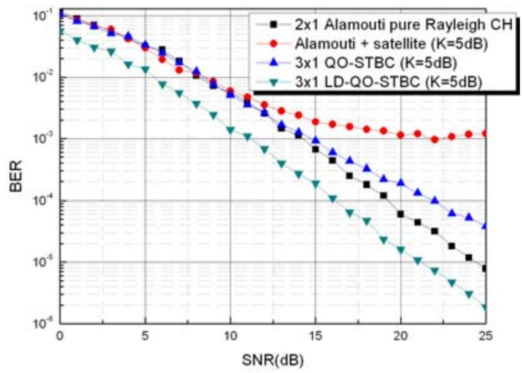

그림 3. 위성-지상 통합 망에서 위성 채널의 라이시안 인자가 5 dB일 때 여러 가지 STC 방식의 성능

Figure 3. BER performance of STC schemes in cooperative satellite-terrestrial network when K=5 dB for satellite channel.

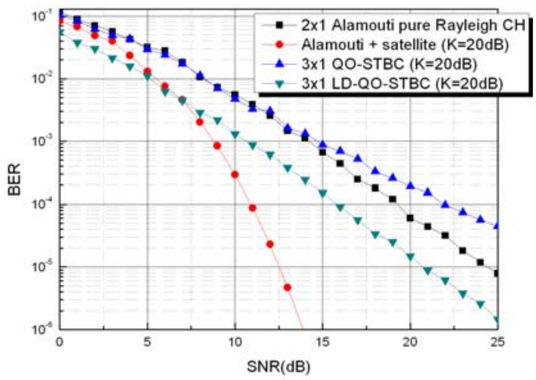

그림 3. 위성-지상 통합 망에서 위성 채널의 라이시안 인자가 20 dB일 때 여러 가지 STC 방식의 성능

Figure 3. BER performance of STC schemes in cooperative satellite-terrestrial network when *K*=20 dB for satellite channel.

On the other hand, if we can have a strong satellite signal, i.e. with comparatively large K value, then the performance of the cooperative system with the Alamouti code is the best choice. When we use 3X1 STC scheme, it is clear from Fig. 3 and 4 that the LD-QO-STBC scheme achieved better performance than the conventional QO-STBC scheme.

Ⅴ. Conclusion

In this paper, we presented an efficient transmit diversity scheme which can be efficiently applied to the cooperative satellite-terrestrial system. Performances of various STC schemes, including 2X1 STC scheme combined with the uncoded satellite signal and 3X1 STC scheme, are introduced. The STC scheme introduced in this paper are jointly employed in the terrestrial repeaters and the satellite in order to get diversity gain at the user terminal. The simulation results presented in this paper suggest the optimum scheme depending the channel conditions.

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저 자

박 운 희(Un-Hee Park)

2008년 2월: 전북대학교 전자정보공학부 학사
2008년 3월~현재: 전북대학교 전자공학 석사 과정

<관심분야> 이동/위성통신

김 수 영(Soo-Young Kim)

1990년 2월: 한국과학기술원 전기 및 전자공학과 학사
1990년 2월~1991년 9월: ETRI 연구원
1992년 10월: Univ. of Surrey, U.K 공학석사
1995년 2월: Univ. of Surrey, U.K 공학박사
1994년 11월~1996년 6월: Research Fellow, Univ. of Surrey, U.K
1996년 8월~2004년 2월: ETRI 광대역무선정송 연구 팀장
2004년 3월~현재: 전북대학교 전자정보공학부 부교수

<관심분야> 오류정정부호화방식, 이동/위성통신

김 희 욱(Hee Wook Kim)

2001년 8월: 고려대학교 전기전자전파공학부 학사
2004년 2월: 한국과학기술원 전자공학과 석사
2004년 3월～현재: ETRI 광역무선연구그룹 광대역무선전송연구팀

<관심분야> 위성통신, OFDM, 동기, MIMO

안 도 섭(Doseob Ahn)

1988년 2월: 경북대학교 공학사
1990년 2월: 경북대학교 공학석사
1990년 2월~현재: 한국전자통신연구원 팀장 (책임연구원)

<관심분야> 위성통신, 성층권통신(HAPS)