Full Rate Full Diversity Wireless Multicasting for Vehicle-to-Vehicle and Vehicle-to-Infrastructure Communications

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***Abstract*—Multicasting is a spectrally efficient method for supporting group communication by allowing transmission of packets to multiple destinations using fewer resources. To incorporate cooperative diversity, Cooperative Extended Balanced Space-Time Block Codes (CEBSTBCs) have been proposed providing full diversity when one or more feedback bits are sent back via feedback channel. However, the CEBSTBCs are designed for cooperative unicast communication in the literature. This paper presents a novel wireless multicasting scheme which selects the optimum CEBSTBC for all vehicular users to support wireless multicast. The performance of the proposed scheme is investigated for not only vehicle-to-vehicle communication but also for vehicle-to-infrastructure cases. Extensive detailed simulations are performed to show the feasibility of full rate and full diversity multicast service provisioning in vehicular communications.**

Keywords-cooperative extended balanced space-time block coding; wireless multicasting; diversity; vehicular communications

I. INTRODUCTION

One of the space-time coding scheme is Orthogonal Space-Time Block Codes (OSTBCs), which provides full diversity advantage with low decoding complexity. The transmitted symbols are decoded separately using linear processing [1]. However, full diversity and full rate for more than two antennas cannot be achieved with OSTBCs. Several quasi-orthogonal STBCs that provide full rate at the expense of some loss in diversity [2],[3] and OSTBCs that provide full diversity with some loss in code rate [1], [4] have been proposed in the literature. In [5], full rate Balanced Space-Time Block Coding (BSTBC) have been proposed which achieve full diversity for arbitrary number of transmit antennas when one or more feedback bits are sent back via feedback channel. The main drawback of the BSTBC is limited coding gain. In [6-7], the Extended Balanced Space-Time Block Coding (EBSTBC) scheme has been proposed. In the EBSTBC, an arbitrary number of codes can be generated for improved coding gain.

Owing to insufficient antenna space, cost and hardware limitations, wireless users may not be able to support multiple transmit antennas. To overcome this difficulty, recently, researchers have been looking for methods to exploit spatial diversity using the antennas of different users in a network. This type of diversity is called the cooperative diversity [8] where virtual antenna arrays can be formed to overcome the drawback of channel correlation and space limitations of mobile unit. In addition, cooperative diversity reduces the required transmit power which leads to longer battery life and increases capacity in interference limited systems. The application of EBSTBCs into the cooperative communication is Cooperative Extended Balanced Space-Time Block Codes (CEBSTBCs), which was proposed in [7].

It is known that multicasting is an efficient method of supporting group communication as it allows for transmission of packets to multiple destinations using fewer network resources [9]. Along with the widespread deployment of wireless networks, the fast-improving capabilities of mobile devices, content and service providers are increasingly interested in supporting multicast communications over wireless networks.

Intelligent transportation systems (ITS) have recently attracted much attention from car manufacturers, road operators and standardization bodies. The primarily aim of ITS is to increase the road safety by means of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. Considerable effort has been dedicated to defining architectures, services and application scenarios for both V2V and V2I paradigms [10]. To the best our knowledge, there is no space-time block coding which achieves full rate and full diversity for more than one user for vehicular communication. In this paper, we propose a novel coding selection scheme for wireless multicasting. Extensive simulations are performed to show the feasibility of the full rate full diversity multicast service provisioning in V2V and V2I communication. In this regard, in the second section, the system models are described, in the third section, the CEBSTBCs are explained, in the fourth section, Multicast Cooperative Extended Balanced Space-Time Block Coding (MCEBSTBC) is presented, and in the last section, the results of the paper and the conclusion are given.

The following notation is used in the paper: The superscript * denotes the conjugate operation; Re{.} and Im{.} are the real and imaginary part of the argument, respectively. The operator $\lceil . \rceil$ rounds to the smallest integer greater or equal than its argument; the operator max(.) returns the largest of its operands and the min(.) returns the minimum of its operands.

II. SYSTEM MODELS

A. Vehicle-to-Vehicle System Model

The vehicle-to-vehicle system model consists of one source, N cooperative vehicles and L multicast vehicle users. All nodes are equipped with one single antenna. The Rayleigh channel model and the related second-order channel statistics originally proposed for a base station-to-mobile link fail to provide an accurate model for dynamic vehicle-to-vehicle link. Instead, the *cascaded (double)* Rayleigh fading channel model has been proposed [11-12], which provides a realistic description of an intervehicular channel where two Rayleigh fading processes are assumed to be generated by independent groups of scatterers around the two mobile terminals [13]. In the intervehicular system model, all channels are assumed to be frequency flat double Rayleigh fading channel. h_{sri} is the channel coefficient from the source vehicle to the ith cooperative vehicle (relay) and h_{ij} is the channel coefficient from the ith cooperative vehicle to the jth multicast vehicle user where i=1, 2,.., n and j=1, 2,.., L.

The channels are quasi-static, namely, the fading coefficients remain constant over the duration of one frame. Each multicast vehicle user is assumed to have perfect knowledge of its own channels. It is also assumed that the multicast users have no knowledge of the source vehicle-cooperative vehicle (relay) channels. Each cooperative vehicle is assumed to have perfect knowledge of its own source vehicle-cooperative vehicle channel. The cooperative vehicles employ amplify and forward protocol [8]. The noise is modeled as additive white Gaussian whose components are circular complex random variable with zero-mean and variance σ^2. P is the average transmitted power of the source vehicle and the cooperative vehicles. The source data bits are mapped by streams of y bits into M-ary phase shift keying (M-PSK) symbols, where $M=2^y$.

B. Vehicle-to-Infrastructure System Model

The vehicle-to-infrastructure system model is similar vehicle-to-vehicle system model except in the cooperative vehicle-multicast user channel part. In V2I system, cooperative vehicle to multicast user channels are assumed frequency flat Rayleigh fading channel where the channel gains are circularly complex Gaussian random variables and statistically independent from each other.

III. COOPERATIVE EXTENDED BALANCED SPACE-TIME BLOCK CODING

The Cooperative Extended Balanced Space-Time Block Coding (CEBSTBC) can be obtained when an extension matrix is multiplied with an Orthogonal Space-Time Block Coding [14-15]. Since Alamouti`s code is the only orthogonal code with rate one and minimum delay, the CEBSTBCs can be obtained as an extension of the Alamouti`s code [16].

$$\boldsymbol{C}=\boldsymbol{X}\boldsymbol{W}. \tag{1}$$

Here, $\boldsymbol{X}$ is the Alamouti’s code and $\boldsymbol{W}$ is the 2xN matrix where $N\geq 2$ and the rank of $\boldsymbol{W}$ must be 2. The following example shows how to generate the CEBSTBCs for three transmitters. Consider the CEBSTBC pair with transmission matrix

$$\boldsymbol{C}_1=\begin{bmatrix} s_1 & s_2 & as_2 \\ -s_2^* & s_1^* & as_1^* \end{bmatrix} \tag{2}$$

where $a=e^{j2\pi m/q}$, q is the extension level and m=0, 1,…q-1. The columns and rows of $\boldsymbol{C}_1$ denote symbols transmitted from three cooperative relays in two signaling intervals, respectively. The matrix $\boldsymbol{C}_1$ is obtained from the Alamouti code using Equation (1) where

$$\boldsymbol{X}=\begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix} \quad \boldsymbol{W}=\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & a \end{bmatrix}. \tag{3}$$

In this fashion, arbitrary number of the CEBSTBCs can be generated. It can be shown that the number of possible CEBSTBCs is $q^{N-2}(2^{N-1}-1)$ [7]. For that reason, the destination needs $N+d$ feedback bits ($N\geq 3$) to select any possible CEBSTBCs where $d=\left\lceil (N-2)\log_2 q \right\rceil -1$. N-2 feedback bits are needed to achieve full diversity as in CBSTBCs [14]. The rest of the d+2 feedback bits provide an additional coding gain.

IV. MULTICAST COOPERATIVE EXTENDED BALANCED SPACE-TIME BLOCK CODING

Multicast Cooperative Extended Balanced Space-Time Block Coding (MCEBSTBC) can be obtained when an optimum CEBSTBC is selected for all multicast users. The MCEBSTBC contains two phases: Multicast frame initialization phase and multicast transmission phase. In the first phase, the multicast users transmit their channel state information (CSI) to the selected multicast user and the selected multicast user selects the optimum CEBSTBC for all multicast users. This phase is shown in Figure 1. In Figure 2, multicast transmission phase is shown. In this phase, the source transmits data to the cooperative relays and the cooperative relays transmit to the multicast users according to selected the MCEBSTBC.

A. MCEBSTBC for Three Cooperative Vehicles

When three cooperative vehicles are present at the environment then, $\boldsymbol{C}_1$, $\boldsymbol{C}_2$ and $\boldsymbol{C}_3$ are available MCEBSTBC matrices. These matrices are

$$\boldsymbol{C}_1=\begin{bmatrix} s_1 & s_2 & as_2 \\ -s_2^* & s_1^* & as_1^* \end{bmatrix} \boldsymbol{C}_2=\begin{bmatrix} s_1 & s_2 & as_1 \\ -s_2^* & s_1^* & -as_2^* \end{bmatrix}$$

$$\boldsymbol{C}_3=\begin{bmatrix} s_1 & as_1 & s_2 \\ -s_2^* & -as_2^* & s_1^* \end{bmatrix}. \tag{4}$$

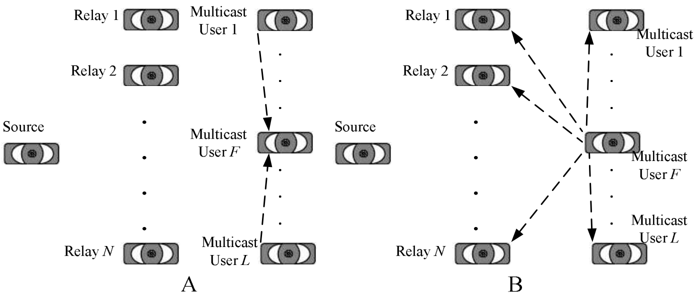

Figure 1. Multicast frame initialization phase of the MCEBSTBC: A) Channel coefficients are transmitted to the selected multicast vehicle user B) Selected code is transmitted both the cooperative vehicles and rest of the multicast vehicle users.

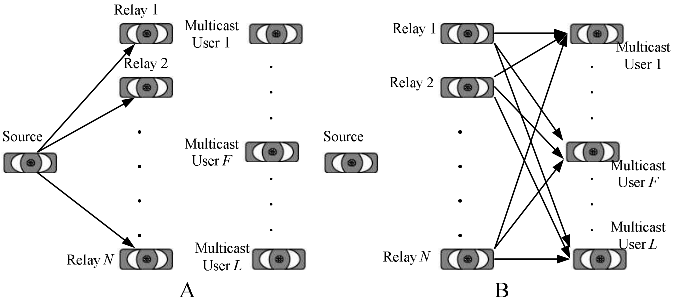

Figure 2. Multicast transmission phase of the MCEBSTBC: A) Broadcast phase B) Cooperation phase.

The selected multicast user picks the MCEBSTBC $\boldsymbol{C}_j$, j=1,2,3 that generates the optimum coding gain for all the multicast users. Two bits of feedback is needed to select the MCEBSTBC matrices and k bits of feedback is needed to select the feedback a where k =d+1. In [6-7], the optimum code is selected according to the single user channel coefficients. However, the optimum MCEBSTBC for all multicast users is selected according to the following maximin approach

$$A_1 = \max \left(\begin{array}{l} \min\left(\mathrm{Re}\left\{ a h_{21}^{*} h_{31} \right\}, \mathrm{Re}\left\{ a h_{22}^{*} h_{32} \right\}, \ldots., \mathrm{Re}\left\{ a h_{2L}^{*} h_{3L} \right\}\right), \\ \min\left(\mathrm{Re}\left\{ a h_{11}^{*} h_{31} \right\}, \mathrm{Re}\left\{ a h_{12}^{*} h_{32} \right\}, \ldots., \mathrm{Re}\left\{ a h_{1L}^{*} h_{3L} \right\}\right), \\ \min\left(\mathrm{Re}\left\{ a h_{11}^{*} h_{21} \right\}, \mathrm{Re}\left\{ a h_{12}^{*} h_{22} \right\}, \ldots., \mathrm{Re}\left\{ a h_{1L}^{*} h_{2L} \right\}\right) \end{array} \right). \tag{5}$$

where a is selected to maximize the terms in the brackets [14]. The optimum MCEBSTBC is employed after combining, the observations at the jth vehicle multicast user, to obtain

$$\hat{s}_{i,j} = \sqrt{\frac{P}{3}} \left[\left| h_{1j} \right|^2 + \left| h_{2j} \right|^2 + \left| h_{3j} \right|^2 + 2A_1 \right] s_i + \eta_{i,j}, \quad i = 1,2. \tag{6}$$

Here, $\hat{s}_{i,j}$ is the estimate of the ith symbol at the jth multicast vehicle user; η_{1j} and η_{2j} are the noise samples at the jth multicast vehicle user.

Fig. 3 shows the percentage of the channels that achieve full diversity for various multicast vehicle users when three cooperative vehicles are present in the environment. MCEBSTBC with one bit extension of feedback (MCEBSTBC (k=1)) achieves full diversity with only one user (unicast communication), since MCEBSTBC with one bit extension of feedback yields only 6 different codes. MCEBSTBC with two or more bit extension of feedback supports full diversity for two users. When five or more multicast users are present in the wireless environment, full diversity can be achieved in 70% or less of all possible channel conditions.

The following are the properties of the MEBSTBC for three cooperative relays:

i) One bit extension of feedback (k=1) cannot achieve full rate and full diversity for two multicast users.

ii) Two or more bit extension of feedback (k≥2) achieves full rate and full diversity for two multicast users.

iii) The full diversity can be achieved for an arbitrary number of multicast users, if the below inequality is satisfied for all possible channel conditions.

$$A_1 \geq 0. \tag{7}$$

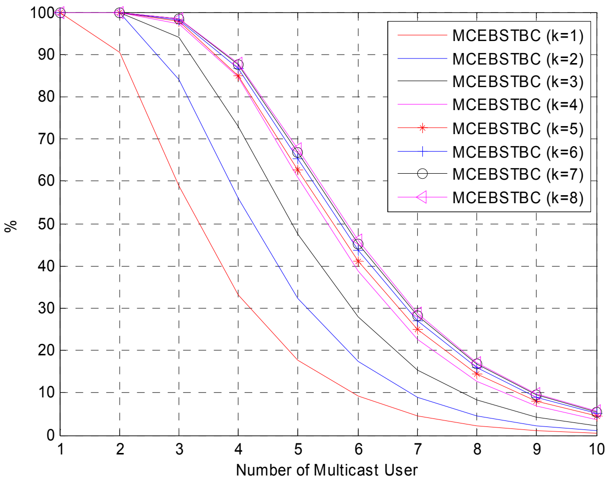

Figure 3. The percentage of the channels that achieve full diversity for various multicast vehicle users when three cooperative vehicles are present in the environment.

B. *MCEBSTBC for Four Cooperative Vehicles*

When four cooperative vehicles are present in the environment, available the MCEBSTBC matrices are

$$\boldsymbol{C}_1 = \begin{bmatrix} s_1 & as_1 & bs_1 & s_2 \\ -s_2^* & -as_2^* & -bs_2^* & s_1^* \end{bmatrix} \boldsymbol{C}_2 = \begin{bmatrix} s_1 & as_1 & s_2 & bs_1 \\ -s_2^* & -as_2^* & s_1^* & -bs_2^* \end{bmatrix}$$
$$\boldsymbol{C}_3 = \begin{bmatrix} s_1 & s_2 & as_1 & bs_1 \\ -s_2^* & s_1^* & -as_2^* & -bs_2^* \end{bmatrix} \boldsymbol{C}_4 = \begin{bmatrix} s_1 & s_2 & as_2 & bs_2 \\ -s_2^* & s_1^* & as_1^* & bs_1^* \end{bmatrix} \tag{8}$$
$$\boldsymbol{C}_5 = \begin{bmatrix} s_1 & as_1 & s_2 & bs_2 \\ -s_2^* & -as_2^* & s_1^* & bs_1^* \end{bmatrix} \boldsymbol{C}_6 = \begin{bmatrix} s_1 & s_2 & as_1 & bs_2 \\ -s_2^* & s_1^* & -as_2^* & bs_1^* \end{bmatrix}$$
$$\boldsymbol{C}_7 = \begin{bmatrix} s_1 & s_2 & as_2 & bs_1 \\ -s_2^* & s_1^* & as_1^* & -bs_2^* \end{bmatrix}.$$

$$A_2 = \max \begin{pmatrix} \min\left(\left[\mathrm{Re}\left\{ah_{11}^*h_{21}\right\}+\mathrm{Re}\left\{bh_{11}^*h_{31}\right\}+\mathrm{Re}\left\{a^*bh_{21}^*h_{31}\right\}\right],\ldots,\left[\mathrm{Re}\left\{ah_{1L}^*h_{2L}\right\}+\mathrm{Re}\left\{bh_{1L}^*h_{3L}\right\}+\mathrm{Re}\left\{a^*bh_{2L}^*h_{3L}\right\}\right]\right), \\ \min\left(\left[\mathrm{Re}\left\{ah_{11}^*h_{21}\right\}+\mathrm{Re}\left\{bh_{11}^*h_{41}\right\}+\mathrm{Re}\left\{a^*bh_{21}^*h_{41}\right\}\right],\ldots,\left[\mathrm{Re}\left\{ah_{1L}^*h_{2L}\right\}+\mathrm{Re}\left\{bh_{1L}^*h_{4L}\right\}+\mathrm{Re}\left\{a^*bh_{2L}^*h_{4L}\right\}\right]\right), \\ \min\left(\left[\mathrm{Re}\left\{ah_{11}^*h_{31}\right\}+\mathrm{Re}\left\{bh_{11}^*h_{41}\right\}+\mathrm{Re}\left\{a^*bh_{31}^*h_{41}\right\}\right],\ldots,\left[\mathrm{Re}\left\{ah_{1L}^*h_{3L}\right\}+\mathrm{Re}\left\{bh_{1L}^*h_{4L}\right\}+\mathrm{Re}\left\{a^*bh_{3L}^*h_{4L}\right\}\right]\right), \\ \min\left(\left[\mathrm{Re}\left\{ah_{21}^*h_{31}\right\}+\mathrm{Re}\left\{bh_{21}^*h_{41}\right\}+\mathrm{Re}\left\{a^*bh_{31}^*h_{41}\right\}\right],\ldots,\left[\mathrm{Re}\left\{ah_{2L}^*h_{3L}\right\}+\mathrm{Re}\left\{bh_{2L}^*h_{4L}\right\}+\mathrm{Re}\left\{a^*bh_{3L}^*h_{4L}\right\}\right]\right), \\ \min\left(\left[\mathrm{Re}\left\{ah_{11}^*h_{21}\right\}+\mathrm{Re}\left\{bh_{31}^*h_{41}\right\}\right],\ldots,\left[\mathrm{Re}\left\{ah_{1L}^*h_{2L}\right\}+\mathrm{Re}\left\{bh_{3L}^*h_{4L}\right\}\right]\right), \\ \min\left(\left[\mathrm{Re}\left\{ah_{11}^*h_{31}\right\}+\mathrm{Re}\left\{bh_{21}^*h_{41}\right\}\right],\ldots,\left[\mathrm{Re}\left\{ah_{1L}^*h_{3L}\right\}+\mathrm{Re}\left\{bh_{2L}^*h_{4L}\right\}\right]\right), \\ \min\left(\left[\mathrm{Re}\left\{ah_{21}^*h_{31}\right\}+\mathrm{Re}\left\{bh_{11}^*h_{41}\right\}\right],\ldots,\left[\mathrm{Re}\left\{ah_{2L}^*h_{3L}\right\}+\mathrm{Re}\left\{bh_{1L}^*h_{4L}\right\}\right]\right) \end{pmatrix}. \qquad (9)$$

The optimum MCEBSTBC for all multicast vehicle users is chosen according to Equation (9) where a and b are selected to maximize the terms in the brackets [14]. After combining the observations the estimates are obtained as shown in Equation (10). Here $\eta_{1,j}$ and $\eta_{2,j}$ are the noise samples at the jth mobile user.

$$\hat{s}_{i,j} = \frac{\sqrt{P}}{2}\left[\left|h_1\right|^2+\left|h_2\right|^2+\left|h_3\right|^2+\left|h_4\right|^2+2A_2\right]s_i+\eta_{i,j} \qquad (10)$$

where i=1,2.

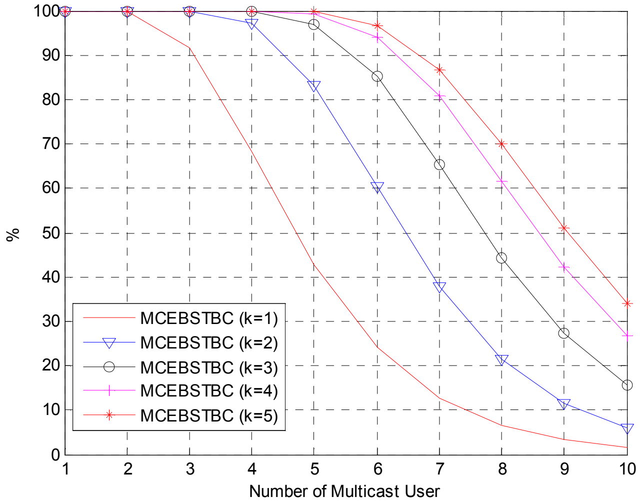

Figure 4. Percentage of all possible channel conditions that achieves full diversity for various multicast vehicle users when four cooperative vehicles are present in the environment.

Fig. 4 shows the percentage of channels that achieve full diversity for various multicast users when four cooperative vehicles are present in the wireless environment. MCEBSTBC with one bit extension of feedback (MCEBSTBC (k=1)) achieves full diversity and full rate for two multicast users. When eight or more multicast users are present in the wireless environment and up to five bit extension of feedback is available, full diversity can be achieved 70% or less of all possible channel conditions.

The following are the properties of the MEBSTBC for four or more cooperative relays:

i) One bit extension of feedback (k=1) can achieve full rate and full diversity for two multicast users.

ii) When four cooperative relays are present in the wireless environment, full diversity can be achieved for an arbitrary number of multicast users, if the inequality of Equation (11) is satisfied for all possible channel conditions.

$$A_2 \geq 0. \qquad (11)$$

V. PERFORMANCE EVALUATIONS

The bit error probabilities of the MCEBSTBC are evaluated for quaternary phase-shift keying (QPSK) modulation by computer simulations. The frame length is 128 symbol duration. The source vehicle-cooperative vehicle (relay) channels are better quality in signal-to-noise ratio (SNR) than cooperative vehicle-multicast vehicle user channels whose difference is quantified by differential signal-to-noise ratio (DSNR). In the Figures 5-8, DSNR is assumed to be 25 dB for three and four cooperative vehicles. For comparison, the bit error rate (BER) curve of the unicast CEBSTBC [7] is also included in Figure 5-8.

Figure 5 presents the bit error probabilities of the MCEBSTBC with four bits extension of feedback for three cooperative vehicles and various numbers of multicast vehicle users. It can be seen from the Figure 5 that the full diversity cannot be achieved for more than four multicast users since the slope of the curves is decreased. Compared to the MCEBSTBC with 2 multicast users (2 Mult. MCEBSTBC (k=4)), the CEBSTBC with four bits extension of feedback (Unicast CEBSTBC (k=4) [7]) has a SNR advantage of only 0.54 dB for a BER value of $1\mathrm{x}10^{-3}$. However, the MCEBSTBC with 2 multicast users (2 Mult. MCEBSTBC (k=4)) provides better performance than the CEBSTBC with one bit extension of feedback (Unicast CEBSTBC (k=1) [7]) and the system transmission rate is doubled. Relative to the MCEBSTBC with 3 multicast users (3 Mult. MCEBSTBC (k=4)), the MCEBSTBC with 4 multicast users (4 Mult. MCEBSTBC (k=4)), and the MCEBSTBC with 5 multicast users (5 Mult. MCEBSTBC (*k*=4)), the CEBSTBCs with four bit extension of feedback (Unicast CEBSTBC (*k*=4) [7]) has a SNR advantage of merely 1.1 dB, 1.7 dB, and 2.45 dB, respectively. The proposed MCEBSTBC sacrifices some coding gain to utilize system resources efficiently.

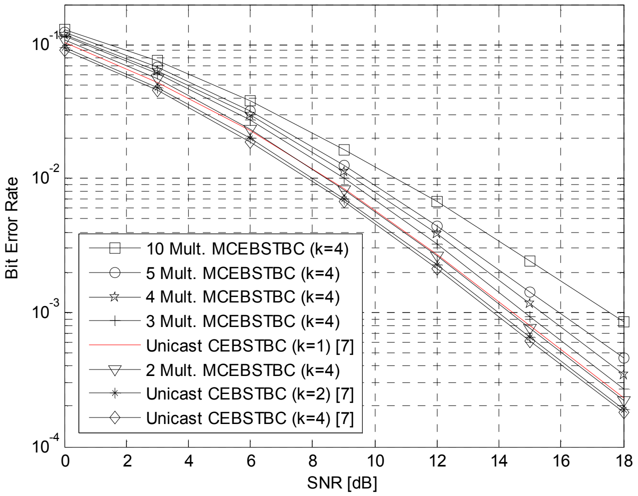

Fig. 5. BER of the CEBSTBC and the MCEBSTBC when three cooperative vehicles are present.

Figure 6 presents the bit error probabilities of the MCEBSTBC with four bits extension of feedback for four cooperative relays and various numbers of multicast users. It can be seen from the Figure 7 that the full diversity can be achieved for five multicast users since the slope of the curves does not change. Compared to the CEBSTBC with four bits extension of feedback (Unicast CEBSTBC (*k*=4) [7]), the MCEBSTBC with 2 multicast users (2 Mult. MCEBSTBC (*k*=4)) has a SNR advantage of just 0.77 dB for a BER value of 1x10^{-4}. However, the MCEBSTBC with 3 multicast users (3 Mult. MCEBSTBC (*k*=4)) provides just 0.25 dB worse performance than the CEBSTBC with one bit extension of feedback (Unicast CEBSTBC (*k*=1) [7]) and the system transmission rate is tripled. In comparison the MCEBSTBC with 3 multicast users (3 Mult. MCEBSTBC (*k*=4)), the MCEBSTBC with 4 multicast users (4 Mult. MCEBSTBC (*k*=4)), and the MCEBSTBC with 5 multicast users (5 Mult. MCEBSTBC (*k*=4)), the CEBSTBCs with four bit extension of feedback (Unicast CEBSTBC (*k*=4) [7]) has a SNR advantage of only 1.37 dB, 1.88 dB, and 2.21 dB, respectively. Once again, the proposed MCEBSTBC sacrifices a slight coding gain but the system transmission rate is increased *L* times.

In the sequel, we simulate the cooperative V2I communication. In this scenario, the multicast users are at the infrastructure and the cooperative vehicle-multicast users´ channels are Rayleigh fading. Figure 7 depicts the bit error probabilities of the MCEBSTBC with four bits extension of feedback for three cooperative vehicles and various numbers of multicast users. It can be seen from the Figure 7 that the full diversity cannot be achieved more than four multicast users since the slope of curves is decreased. Table 1 presents required SNR values for a BER value of 1x10^{-3}. It can be easily seen that the proposed MCEBSTBC sacrifices some coding gain to utilize system resources efficiently.

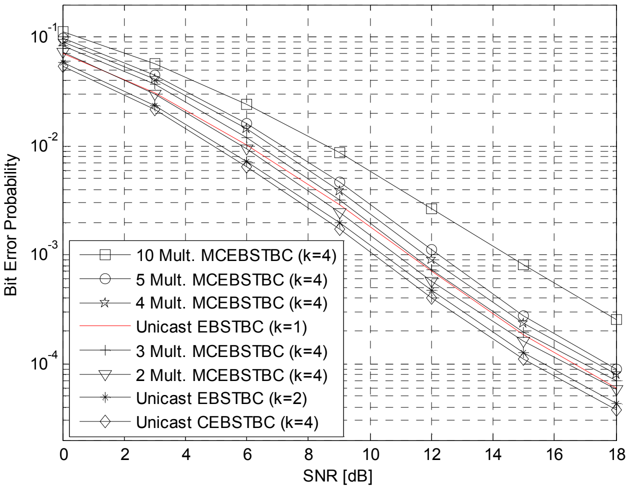

Fig. 6. BER of the CEBSTBC and the MCEBSTBC when four cooperative vehicles are present.

TABLE I. REQUIRED SNR VALUES FOR BER VALUE OF 1X10^{-3}

Unicast/Multicast Transmission Schemes	**Required SNR Values**
10 Mult. MCEBSTBC (*k*=4)	13.40 dB
5 Mult. MCEBSTBC (*k*=4)	11.76 dB
4 Mult. MCEBSTBC (*k*=4)	11.28 dB
3 Mult. MCEBSTBC (*k*=4)	10.79 dB
Unicast CEBSTBC (*k*=1) [7]	10.35 dB
2 Mult. MCEBSTBC (*k*=4)	10.33 dB
Unicast CEBSTBC (*k*=2) [7]	9.92 dB
Unicast CEBSTBC (*k*=4) [7]	9.78 dB

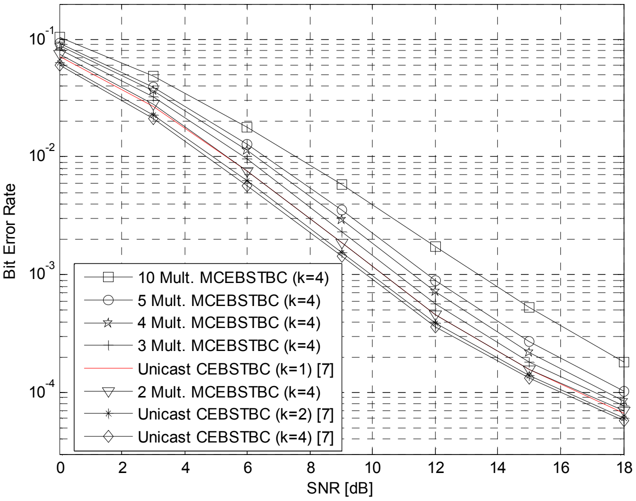

Fig. 7. BER of the CEBSTBC and the MCEBSTBC when three cooperative vehicles are present.

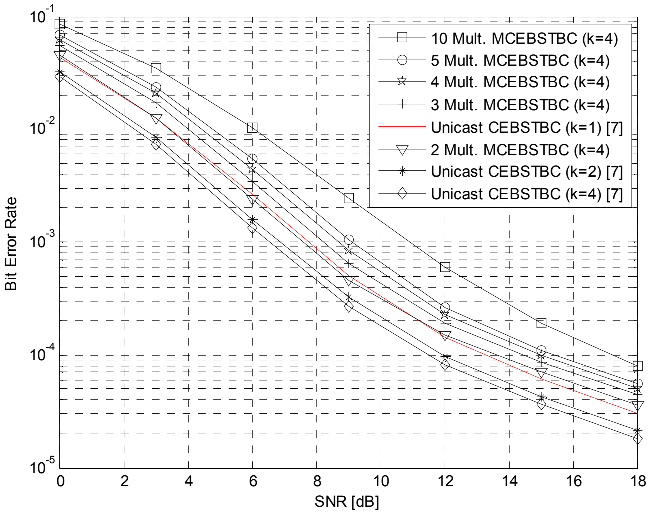

Fig. 8. BER of the CEBSTBC and the MCEBSTBC when four cooperative vehicles are present.

Figure 8 presents the bit error probabilities of the MCEBSTBC with four bits extension of feedback for four cooperative vehicles and various numbers of multicast users. It can be seen from the Figure 8 that the full diversity can be achieved for five multicast users since the slope of the curves does not change. Table 2 presents required SNR values for a BER value of $1x10^{-3}$. Once again, the proposed MCEBSTBC sacrifices a slight coding gain but the system transmission rate is increased *L* times.

TABLE II. REQUIRED SNR VALUES FOR BER VALUE OF $1X10^{-3}$

Unicast/Multicast Transmission Schemes	Required SNR Values
10 Mult. MCEBSTBC (*k*=4)	10.93 dB
5 Mult. MCEBSTBC (*k*=4)	9.10 dB
4 Mult. MCEBSTBC (*k*=4)	8.68 dB
3 Mult. MCEBSTBC (*k*=4)	8.22 dB
Unicast CEBSTBC (*k*=1) [7]	7.77 dB
2 Mult. MCEBSTBC (*k*=4)	7.58 dB
Unicast CEBSTBC (*k*=2) [7]	6.88 dB
Unicast CEBSTBC (*k*=4) [7]	6.55 dB

VI. CONCLUSION

In this paper, full rate and full diversity multicast service provisioning in V2V and V2I communications was analyzed and simulated. It has been observed that compared to the unicast CEBSTBC, the MCEBSTBC does not utilize all available codes and employs optimum CEBSTBC for all multicast vehicle users. This optimization sacrifices a slight coding gain to utilize system resources efficiently. Namely, by using the MCEBSTBC, the system transmission rate is increased in proportion to the number of multicast users. The larger cooperative vehicles present at the wireless environment, the fuller diversity full rate wireless multicasting can be achieved. The proposed multicast technique might be implemented easily in IEEE 802.11p [17] which defines enhancements to 802.11 required to support ITS applications [17].

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