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Improvement of the Link Reliability for Ship Ad-Hoc Network by Employing Multiple Antennas

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ABSTRACT

For the purpose of providing high data rate real-time services, radio transmission technologies (RTT) for ship ad-hoc network (SANET) based on the Recommendation ITU-R 1842-1 are designed. Physical layer parameters of SANET are contrived to meet the requirements of the specification. In order to improve the link reliability for SANET, in this paper, we investigate the performance of the SANET with the multiple antennas, where receive combining (RC), transmit diversity (TD), and beamforming (BF) are employed, respectively. Based on the analysis of the packet error rate (PER) under the highly correlated maritime wireless channel model, we select the efficient multiple antenna schemes for SANET to improve the link reliability. In addition, the optimal MCS levels for the single-carrier (SC) SANET with the bandwidth of 25 kHz, and the multi-carrier (MC) SANET with the bandwidth of 50 kHz and 100 kHz are finalized.

Key Words : SANET, Receive combining, Transmit diversity, Beamforming, MIMO

Ⅰ. Introduction

It is well known that the wireless networks over sea are not well developed. The existing communication systems over sea, such as automatic identification system (AIS) [1], only provide low data rate non real-time services such as ship identification, positioning, and email, etc. Also, the cost will be high for the services with the requirements of high data rate and low delay through satellite. Based on the survey of existing maritime wireless communication systems and the ongoing projects, we realize that there are still many challenges and open problems in the current status of R&D. The existing maritime wireless systems are designed for the maritime environment only, therefore the network architectures and frame structures of maritime radio networks and terrestrial radio networks are not compatible to each other. When delivering the data from current maritime communication networks to the backbone terrestrial networks, the communication delay and deployment cost of maritime wireless communication system in current status may be serious problem.

In order to provide real-time services with higher data rate such as multi-media services and video games etc., advanced radio transmission technologies such as OFDM and MIMO techniques are required for the ship ad-hoc network (SANET). The application of OFDM and MIMO techniques can improve the system throughput and increase the robustness of wireless data-link. In our former works, we set up the radio transmission techniques (RTTs) for SANET, which is considered for the next generation maritime communication system[2]. The channel compensation and coding techniques for the

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RTT of VHF (very high frequency) band SANET are also presented.

In this paper, we investigate the SANET associated with the several multiple antenna schemes, including receive combining (RC), transmit diversity (TD), and beamforming (BF). However, not all of them can effectively enhance the link performance of the SANET due to the nature of highly correlated maritime wireless channel. According to the analysis of packet error rate (PER), we select the efficient multiple antenna schemes to be included in the next generation maritime communication system. Additionally, the optimal MCS levels for the single carrier (SC) SANET with the bandwidth of 25 kHz, and the multi-carrier (MC) SANET with the bandwidth of 50 kHz and 100 kHz are finalized.

The remaining part of this paper is organized as follows. Section II presents the correlated MIMO channel for SANET, and spatial diversity strategies under the SANET correlated MIMO channel is described in section III. The applicability of BF to SANET is discussed in Section IV, and conclusions are given in section V.

Ⅱ. Correlated MIMO Channel for SANET

The correlation factor is widely used to characterize the similarity of the diversity branches, which is given by:

$$C_{x,y}=\frac{E\{x,y\}-E\{x\}E\{y\}}{\sqrt{(E\{x^2\}-E\{x\}^2)(E\{y^2\}-E\{y\}^2)}}, \tag{1}$$

where x and y represent the received signal from two different receive antennas, and $E\{.\}$ represents the expected value. As discussed in [3], the measured correlation factor is displayed in Fig.1, showing that the correlation factor is approaching 1 after 312 seconds of the boat's trip, corresponding to a distance over than 2km from sea shore. The measurements is analyzed by two receive antennas with an internal spacing of 1.865m. Additional measurement parameters are illustrated in Table.1. According to Fig.1, the channels will be highly correlated when the boat is far from the transmitter (more than 2km), and the channel diversity will be too small to be exploited. Consequently, throughout the paper, we use the correlation factor of C = 0.9 for the performance investigation of multiple antenna schemes on SANET.

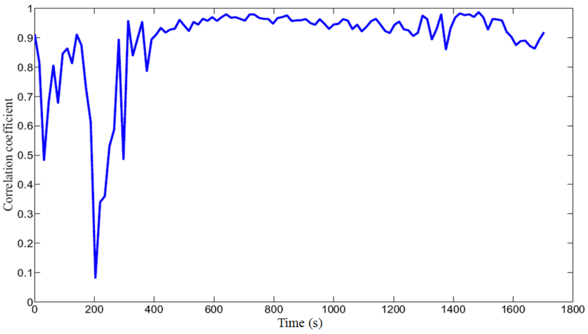


Fig. 1. Correlation factor derived from the measurements.

Table 1. Parameters for channel correlation measurement.

Carrier frequency	2.075 GHz
Chirp bandwidth	20 MHz
Transmitting power	33 dBm
Maximum resolvable delay	10.24 μs
Delay resolution	50 ns
Doppler resolution	4 Hz
Maximum resolvable Doppler shift	±128 Hz
Number of TX antenna	1
Number of RX antennas	2
TX antenna height	~6.5 m
RX antenna height	~23 m
RX antenna spacing	1.865 m
Maximum route distance	15.5 km
Temperature	2 °C
Wind speed	2 m/s
File size	500 MB

The correlated channel matrix H_c with a m-by-m MIMO configuration can be generated as

$$H_c=nR^{1/2}H, \tag{2}$$

where $n=\frac{1}{\sqrt{m[(1+(m-1)C^2)]}}$ is the normalization factor. $R^{1/2}$ is the symmetric matrix with all diagonal elements of one and other off-diagonal elements of C. $H=(h_1,h_2,...h_i...h_m)^T$, where $1\le i\le m$, is a MIMO channel matrix composed of independent channel h_i.

Ⅲ. Spatial Diversity Strategies under SANET Correlated MIMO Channel

3.1. Receiver Diversity of Equal Gain Combining (EGC) and Maximal Ratio Combining (MRC)

To improve the link reliability of the SANET, we consider the receiver diversity schemes first. For EGC, the received signals r from the different antennas are added together as

$$r = \sqrt{E_s}\sum_{n=1}^{n_r} h_n s + n_0 \tag{3}$$

where E_s is the transmitted symbol power, assuming that the average power is normalized to unity. s is transmitted signal, h_n represents the channel at the n-th receive antenna, and n_0 is the white Gaussian noise[4]. By assuming a perfect carrier and timing synchronization, the zero-forcing (ZF) strategy can be used for channel equalization (CE) to obtain the decision d as

$$d_{EGC} = \sqrt{E_s}\sum_{n=1}^{n_r} h_n^{-1} h_n s + h_n^{-1} n_0 . \tag{4}$$

EGC is easier to implement, but results in a minor SNR loss compared with MRC.

To maximize the received SNR, the branch weights are chosen as h_n^{*}, where $*$ denote the conjugate transpose. In this case, the signal is combined as

$$\begin{aligned} r &= \sqrt{E_s}\sum_{n=1}^{n_r} h_n^{*} h s + h_n^{*} n_0 \\ &= \sqrt{E_s}\sum_{n=1}^{n_r} \| h_n \|^{2} s + h_n^{*} n_0 . \end{aligned} \tag{5}$$

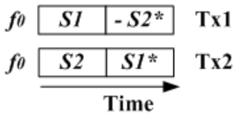
This scheme is known as maximum ratio combing (MRC), for the reason that it maximizes the output SNR. Then the decision d after channel equalization can be obtained by using ZF as

$$\begin{aligned} d_{MRC} &= \sqrt{E_s}\sum_{n=1}^{n_r} \| h_n \|^{-2} \| h_n \|^{2} s \\ &+ \| h_n \|^{-2} n_0 . \end{aligned} \tag{6}$$

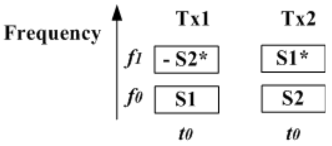
According to (6), combiner SNR is the sum of each branch SNR which maximizes the overall output SNR at the receiver.

3.2. Transmitter Diversity of Space-time Block Coding (STBC), Space-frequency Block Coding (SFBC), Space-time-frequency Coding (STFBC), and Cyclic Delay Diversity (CDD)

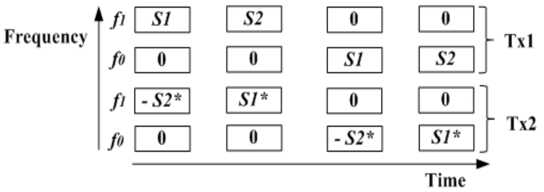
Transmitter diversity has received significant gains to provide link reliability [5], hence STBC, SFBC, and STFBC are considered to be implemented into the SANET. The 2-by-1 STBC/SFBC/STFBC coding schemes are described in Fig.2. For STBC-OFDM, two successive symbols are formed in one sub-carrier. While in SFBC-OFDM, they are located over two different sub-carriers. In the case of STFBC-OFDM, two successive OFDM symbols are transmitted by two sub-carriers for each antenna in different time slot.



(a) STBC-OFDM coding scheme.



(b) SFBC-OFDM coding scheme.



(c) STFBC-OFDM coding scheme.

Fig. 2. STBC, SFBC, and STFBC coding schemes.

Moreover, CDD is a simple approach to exploit the frequency diversity in OFDM system. In case of OFDM transmission, a cyclic shift of the time domain signal corresponds to a frequency-dependent phase shift that can be extended to more than two transmit antennas with different cyclic shifts for each antenna [5]. Consequently, the cyclic shift of the first antenna is set to zero and the signal is given as

$$s(t)=\frac{1}{\sqrt{N}}\sum_{k=0}^{N-1}S(k)\,e^{j\frac{2\pi}{N}kt}, \qquad (7)$$

where N is the FFT size and k denotes the sub-carrier index. $s(t)$ and $s(k)$ represent the signals in time and frequency domain, respectively. In other branches, the signals are cyclically shifted by specific shift δ in time domain. Thus, we have the transmit signal from each branch as

$$s((t-\delta)\mathrm{mod}N)=\frac{1}{\sqrt{N}}\sum_{k=0}^{N-1}e^{-j\frac{2\pi}{N}k\delta}S(k)\,e^{j\frac{2\pi}{N}kt}, \qquad (8)$$

After cyclic delay, a cyclic prefix is inserted to avoid inter-symbol interference (ISI) for multipath channel. Due to the simplicity and the efficiency of CDD, it can also be an effective candidate to improve the link reliability of SANET MC system.

3.3. Link-level Performance of Spatial Diversity Strategies under SANET Correlated MIMO Channel

In this part, we discuss link-level performances of spatial diversity strategies under the SANET correlated MIMO channel. We consider the scenario where ships move on the sea at the maximum speed of 30 Knots. The systems under test are single-carrier (SC) system (25 kHz bandwidth) with the modulation of pi/4 DQPSK and pi/8 DQPSK, and multi-carrier (MC) system (50 kHz bandwidth) with the modulation of 16QAM. More details of parameters can be found in [2], e.g., the carrier frequency is 2.075GHz and ship mobility is 30 Knots. To observe the coded performance, the channel coding of r = 1/2 convolutional coding (CC) is applied for the MC system [2], and the correlated MIMO channel is generated based on the 1-path Rician fading channel with the K_{factor} value of 15 dB [2]. The antenna configurations employed for spatial diversity strategies are : 1-by-2 for EGC/MRC, 2-by-1 for STTD (SC system) and STBC/SFBC/STFB (MC system), and 4-by-1 for CDD.

3.3.1. Spatial Diversity Strategies for SC System

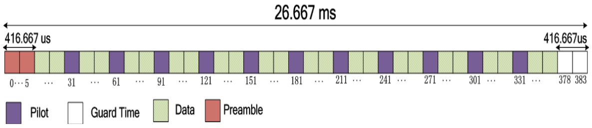
The SC SANET system given in [2] has a frame structure with a preamble of 6 symbols, a guard time of 6 symbols (which is necessary for synchronization purpose and to accommodate the round-trip delay), and a traffic data of 372 symbols.

We investigate the EGC performance for the SC system as illustrated in Fig.4. Since the DQPSK is employed for SC system, no pilot is required for CE [2]. Then (4) can be performed as

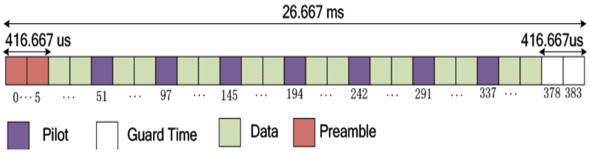
$$d_{EGC}=\sqrt{E_s}\sum_{n=1}^{n_r}h_n s+n_0. \qquad (9)$$

From Fig.4, we observe that the receiver diversity can not efficiently improve the PER performance mainly due to the highly correlated SANET wireless channel (C = 0.9).

For space-time transmit diversity (STTD) technique, which works in a same manner as STBC for MC system, orthogonal 2-antenna Alamouti code is applied by grouping two symbols into one Alamouti block and diagonally disposing them into an 2-antenna transmission scheme as illustrated in Fig.2(a). In this case, due to the use of STTD encoding, the pilots are required for CE at receiver side, so the frame structure of the SC system in [2] is modified to be with pilots as in Fig.3.



(a) 7-pilots allocated



(b) 11-pilots allocated

Fig .3. Pilot insertion for the SANET SC system.

Fig.4 also shows the PER for the SC system with STTD. According to Fig.4, we observe that the performances of uncoded pi/4 DQPSK and pi/8 DQPSK (which perform well without CE) decrease dramatically when STTD is implemented. This is mainly due to that the CE is required when the STTD is applied, and the CE with less number of pilots leads more errors when the channel variation is aggressive during a comparatively long symbol period for the SC system. Moreover, link performance applying transmit diversity becomes worse due to the correlation property of the channel, that is, though the power is divided to each link of transmit diversity, diversity gain by transmit diversity techniques is not achieved due to the highly correlated nature of the SANET MINO channel.

Because the channel coding is not applied for SC system, we do not implement CDD for the SANET SC system.

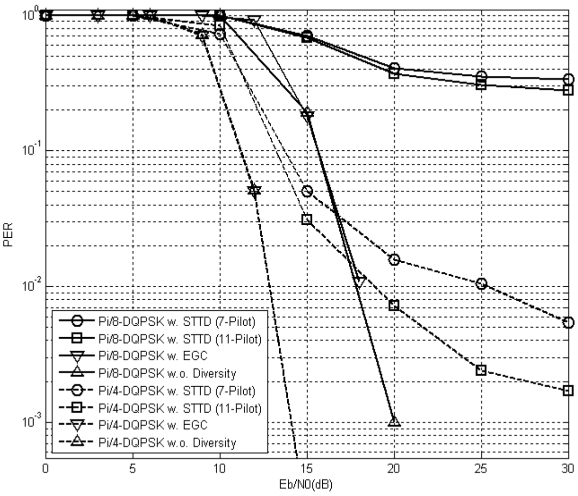


Fig. 4. PER of the SANET SC system with STTD and EGC.

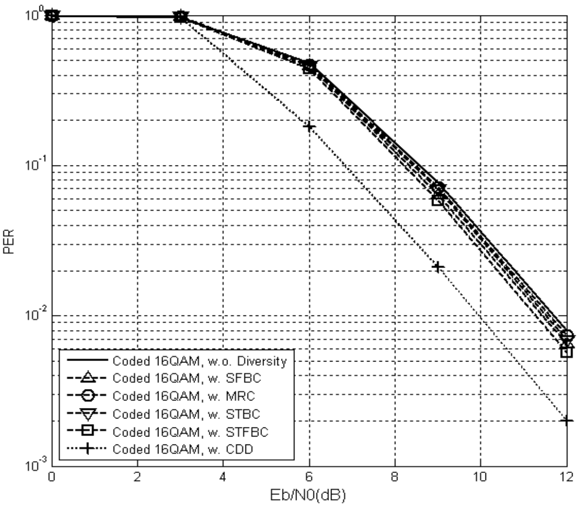


Fig. 5. PER of the SANET MC system with MRC, STBC/SFBC/STFBC, and CDD.

3.3.2. Spatial Diversity Strategies for MC system

For MC SANET system given in [2], the modulation of 16QAM along with the r = 1/2 convolutional channel coding is implemented. The details of pilots structure and the CE performance with ZF can be found in[2]. Fig.5 gives the PER for MC system (50kHz) associated with the spatial diversity strategies, i.e. MRC, STBC/SFBC/STFB, and CDD. Since the MC systems have a relative short symbol duration, which leads less channel variation in the time domain over a symbol period, compared with SC system, all the spatial diversity strategies can achieve gains. However, only CDD shows remarkable gain of 1.7dB at the target PER of 10^{-2}. That is, except CDD, the performances of other diversity strategies can not be exploited potentially under the highly correlated SANET MIMO channel. In addition, we also investigate the CDD along with the MRC. However, CDD plus MRC scheme does not show efficient improvement of the link performance. Of special note, the specific shift δ for CDD in the time domain is set as 1/8 FFT interval length[2].

Ⅳ. Application of Beamforming to SANET

In order to improve the link reliability of the SANET system, we further consider the adoption of antenna arrays. The beamfoming (BF) can provide a powerful method for increasing the link capacity even under the highly correlated wireless channel. Generally, there are three criteria to select optimal weights of BF[6].

Minimum Mean Square Error (MMSE) : It minimizes the error between the beamformer output and the desired signal.

Let $s(t)$ denotes the desired communication signal, and $\{u_i(t)\}_{i=1}^{N_u}$ denotes the interferers. Let further assume that the desired signal arrives at the array with a spatial angle θ_0 and i-th interferer signal arrives with an angle θ_i. The array output is represented by

$$\boldsymbol{x}(t) = s(t)\boldsymbol{v} + \boldsymbol{u} = \boldsymbol{s} + \boldsymbol{u}, \tag{10}$$

where v is the array response vector for the desired signal with K array elements,

$$\boldsymbol{v} = [1, e^{j.d.\sin\theta_0}, \ldots, e^{j.(K-1).d.\sin\theta_0}]. \tag{11}$$

The sum of all the interfering signal vectors u becomes

$$\boldsymbol{u} = \sum_{i=1}^{N_u} u_i(t)\boldsymbol{\eta_i}, \tag{12}$$

and η_i is the array response vector for the i-th interferer,

$$\boldsymbol{\eta_i} = [1, e^{j.d.\sin\theta_i}, \ldots, e^{j.(K-1).d.\sin\theta_i}]. \tag{13}$$

The weights are chosen to minimize the mean-square error between the BF output and the reference signal as

$$|\epsilon(t)|^2 = [|d^H(t)| - |\boldsymbol{w}^H \boldsymbol{x}(t)|]^2. \tag{14}$$

Taking the expected value of both sides, we have

$$E\{|\epsilon(t)|^2\} = E\{|d(t)|^2\} - 2\boldsymbol{w}^H\boldsymbol{r} + \boldsymbol{w}^H\boldsymbol{R}\boldsymbol{w}, \tag{15}$$

where $\boldsymbol{r} = E\{d^H(t)\boldsymbol{x}(t)\}$ and $\boldsymbol{R} = E\{\boldsymbol{x}(t)\boldsymbol{x}^H(t)\}$. Taking the gradient vector of (15) with respect to w equal to zero,

$$\frac{d(E\{|\epsilon(t)|^2\})}{dw} = -2\boldsymbol{r} + 2\boldsymbol{R}w = 0. \tag{16}$$

Then, we can have the optimal weighting vector as

$$w_{opt} = \beta \boldsymbol{R}_u^{-1}\boldsymbol{v}, \tag{17}$$

where $\beta = \frac{E\{|d(t)|^2\}}{1 + E\{|d(t)|^2\} v^H \boldsymbol{R}_u^{-1} v}$ and $\boldsymbol{R}_u = E\{uu^H\}$.

Maximum Signal-to-interference Ratio (MSINR) : The weights can be chosen to directly maximize the signal-to-interference ratio (SINR), and the optimum weights of MSINR can be given as

$$w_{opt} = \beta \boldsymbol{R}_u^{-1}\boldsymbol{v}, \tag{18}$$

where $\beta = \frac{E\{|d(t)|^2\}}{SIR} v^H w$.

Minimum Variance (MV) : When the desired signal and its direction are both unknown, it ensures a good signal reception to minimize the output noise variance. The weights of MV can be given as

$$w_{opt} = \beta \boldsymbol{R}_u^{-1}\boldsymbol{v}, \tag{19}$$

where $\beta = \frac{g}{\boldsymbol{v}^H \boldsymbol{R}_u^{-1} v}$. If g=1, the response of the beamformer is often termed as the minimum variance distortionless response (MVDR)[7].

Basically, those three criteria aim to give the weight vector w which is based on the statistics of the signal vector received at the array. The objective of this weight vector is to yield the beamformer response with respect to a prescribed criterion, so that the output contains minimal contribution from noise and interferers.

4.1. Beamforming Schemes for SANET

Since the SC and MC SANET systems are reference signal based systems that fulfill the criteria of MMSE BF [2], for the receiver beamforming (RxBF), we decide to use the first criteria, i.e., MMSE BF.

Additionally, Eigenvector beamforming algorithm is widely used to find the channel with maximum gain. Thus, we use the eigenvector BF as the transmitter BF (TxBF) for the SANET system. The weighting vector w_t for the eigenvector TxBF is calculated as

$$w_t = \lambda_{\max}(\boldsymbol{H}^H H), \tag{20}$$

where the eigenvector which corresponds to the largest eigenvalue $\lambda_{\max}$ of the channel covariance matrix is selected[8].

4.2. Proposed Transceiver with the BF Schemes

Since the CDD, MMSE RxBF, and Eigenvector TxBF are efficient schemes to enhance the link reliability for SANET, in this section, we propose two transceiver structures with the implementation of those three schemes.

The first is for the SANET SC system, where both the MMSE RxBF and eigenvector TxBF are implemented. And the second is for the SANET MC system, where the CDD is additionally implemented along with the use of MMSE RxBF and eigenvector TxBF. The proposed block diagrams of these two transceivers are illustrated in Fig.6 and Fig.7, respectively.

As shown in Fig.6, we use four array elements for both TxBF and RxBF. The eigenvector TxBF weight is multiplied at each branch after the DQPSK modulation, and the MMSE RxBF weight is multiplied at each brach before the DQPSK demodulation. To obtain the weights of the eigenvector BF, the singular value decomposition (SVD) is used to find the eigenvector corresponding to the maximum eignvalue of the channel covariance matrix.

In the case of the SANET MC system, the four-by-four array configuration is also used. As illustrated in Fig.7, at the transmitter side, the transmit signal is multiplied by the eigenvector BF weight after the modulation in the frequency domain, and then cyclically shifted by specific shift δ in the time domain. At the receiver, the MMSE RxBF weight is multiplied at each branch after the P/S process of the MC system in the frequency domain.

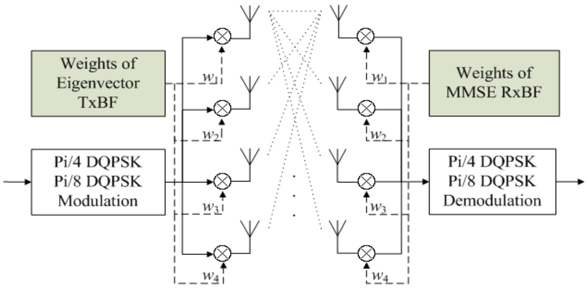


Fig. 6. The proposed BF transceiver for the SANET SC system.

4.3. Link-level Performance by the Proposed Transceiver Structure

We perform link-level simulation (LLS) in order to verify the performance of the proposed transceiver structures. In our simulation, we assume a scenario with one desired signal ($\theta_0 = 90$ degree) and two interferers ($\theta_1 = 45$ degree and $\theta_2 = 135$ degree) as illustrated in Fig.8, where each of them has a -10 dB power compared with the desired signal. The details of parameters, such as carrier frequency, ship mobility, correlated MIMO channel model, and modulation type for BF simulation can be found in Section 2 and 3. Fig.9 shows the PER performance of the proposed transceiver for the case of SANET SC system, and Fig.10 for the SANET MC system.

According to Fig.9, TxBF, RxBF, and the scheme with both of them implemented can improve the PER performance, respectively. Since the MMSE BF is designed to reduce the effect of interference signal, it outperforms the eigenvector BF, which is

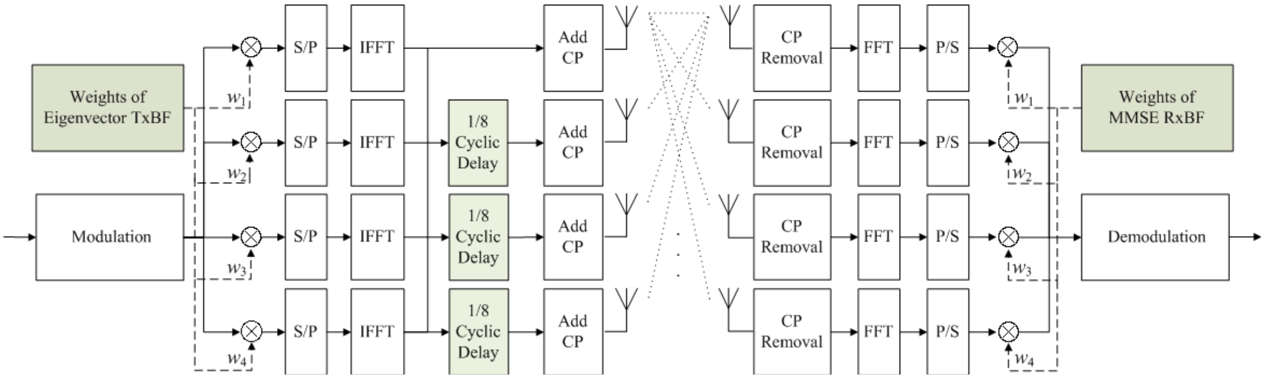


Fig. 7. The proposed multiple antenna transceiver for the SANET MC system.

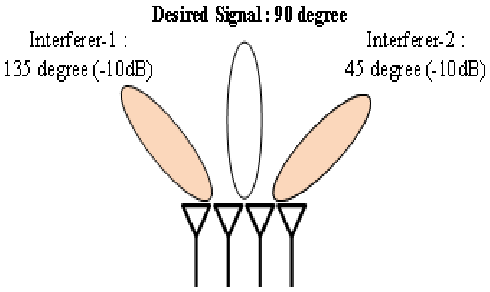


Fig. 8. Scenario of desired signal and two interferers.

used to achieve the maximum gain of the channel, under the scenario with two interferers existing. The proposed scheme with both TxBF and RxBF implemented can obtain the best PER for the modulations of pi/4 DQPSK and pi/8 DQPSK. It achieves target PER 10^{-2} at 13 dB for pi/4 DQPSK, and 16 dB for pi/8 DQPSK, respectively.

Fig.10 illustrate the PER of the proposed transceiver for the SANET MC system (50 kHz). Same as in Fig.9, the scheme with both TxBF and RxBF implemented performs better than the other cases. However, by adding CDD, the system performance can be further enhanced. That is, more than 1 dB gain is achieved at the target PER of 10^{-2} when the CDD is introduced. Note that, compared with Fig.4 and Fig.5, the PER performances of Fig.9 and Fig.10 are deteriorated mainly due to the introduction of the interferers.

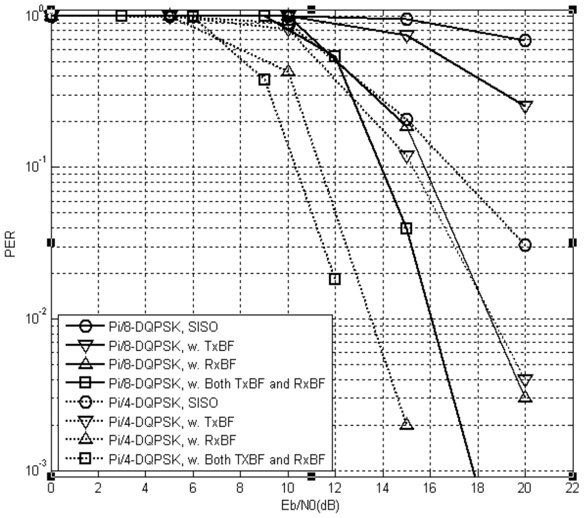


Fig. 9. PER of the proposed transceiver for the SANET SC system with two interferers.

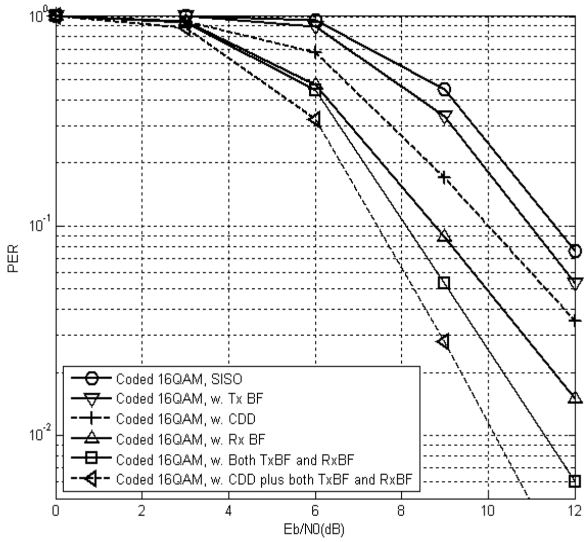


Fig. 10. PER of the proposed transceiver for the SANET MC system with two interferers.

4.4. Optimal MCS Level Selection with Multiple Antennas

In the previous section, two interferers are introduced for the comparison of two BF algorithms, that is, the MMSE BF is aimed to overcome the effect of interferers while the eigenvector BF tries to obtain maximum channel gain. In order to give a fair comparison, in this section, we do the modulation and coding scheme (MCS) level

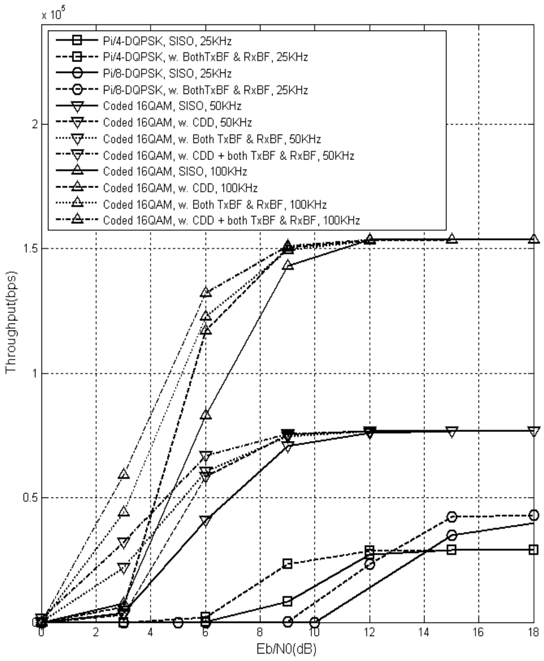


Fig.11. Overall throughput for the SANET system without two interferers.

Table 2. Optimal MCS level selection (without interferers).

	Bandwidth	FFT Size	SNR Range	Modulation	Channel Coding	Transceiver Structure
SC System	25 kHz	-	0 ~ 13 dB	Pi/4 DQPSK	NO	Combined BF
			Over 13 dB	Pi/8 DQPSK	NO	Combined BF
MC System	50 kHz	16	0 ~ +∞	16 QAM	CC (r = ½)	Combined BF & CDD
	100 kHz	32	0 ~ +∞	16 QAM	CC (r = ½)	Combined BF & CDD

selection for SANET SC and MC systems without the interferers. The average throughput concerned in MCS level selection can be calculated by using long-term PER as below.

$$Throughput = \frac{(1-PER)\cdot n_{bit-packet}}{T_{packet}(s)}\cdot r \qquad (21)$$

where $n_{bit\text{-}packet}$ is the number of bits in a packet, T_{packet} is 1-packet time duration, and r is the coding rate.

Fig.11 illustrates the overall throughput for the SANET system. According to Fig.11, we observe that for the SC SANET (25 KHz), the pi/4 DQPSK and pi/8 DQPSK SISO throughputs have a cross point at 14 dB. This is mainly due to that though the PER ($\approx 2\times10^{-4}$) of pi/8 DQPSK at 15 dB is much lower than the case of pi/4 DQPSK (≈ 0.192), the spectrum efficiency of pi/8 DQPSK can overcome this PER deficiency to increase the throughput. Furthermore, when the BF transceiver is implemented, the throughputs can be improved dramatically after 9 dB mainly due to that the channel gain has been achieved by the eigenvector TxBF. For the MC system, the transceiver structure of CDD plus combined BF always achieves the highest throughput in the both 50 kHz and 100 kHz systems. That is, the throughput improvement for MC system is not only due to the channel gain achievement via TxBF but also comes from the transmit diversity gain of CDD. Based on Fig.11, we make Table. 2 as the optimal MCS level selection for SANET. According to Table. 2, for the SC system, pi/4 DQPSK with the scheme of the combined BF should be chosen before 13 dB due to the less phase errors compared with pi/8 DQPSK. Thereafter, the pi/8 DQPSK with combined BF transceiver structure maximizes the system throughput. For the MC system, the transceiver with CDD plus combined BF improves the performance over all SNR range.

Ⅵ. Conclusions

This paper aims to propose effective transceiver structures for SANET system to improve the link reliability. Thus, we investigate state-of-art spatial diversity strategies for the SANET systems, including RC, TD, and BF. Due to that the SANET MIMO channels are highly correlated, RC and TD techniques such as, EGC, MRC, STBC, SFBC, and STFBC are not so efficient to work with SANET systems. The BF, on the other hand, performs effectively for SANET system under such maritime channel. Therefore, we investigate the eigenvector BF at the transmitter and MMSE BF at the receiver for SANET system. The simulation results show that the MMSE BF is efficient to overcome the effect of interferers while the eigenvector BF can improve performance via obtaining the maximum channel gain. Since the time division duplex (TDD) is used in SANET [2], eigenvector TxBF may not be implemented because we can use RxBF weights at the Tx side through channel reciprocity.

Additionally, the CDD is another efficient scheme along with the use of channel coding under the highly correlated maritime channel. Via the implementation of the CDD, more than 1 dB gain can be achieved at the target PER of 10^{-2} for the SANET MC system. Based on the PER performances, the optimal MCS level selections are finalized for the SANET systems.

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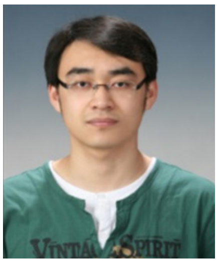

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