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Analysis on MIMO Transmit Diversity Techniques for Ship Ad-hoc Network under a Maritime Channel Model in Coastline Areas

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ABSTRACT

For the purpose of providing high data rate real-time services, radio transmission technologies for ship ad-hoc network based on the Recommendation ITU-R 1842-1 are designed. In order to increase the link throughput of real-time services, in this paper, we investigate the performance of the SANET with the spatial transmit diversity techniques are employed. Based on the analysis of the packet error rate and throughput, we select the efficient multiple antenna schemes for SANET to improve the link reliability.

Key Words : ITU-R M.1842-1, Coastline Channel, MIMO, SANET, Link-level Simulation

Ⅰ. Introduction

Recently, there has been a gradual demand in maritime communications for various multimedia services, such as marine video surveillance and underwater video sensing. Without loss of generality, a satellite system is a good candidate for realizing multimedia services, especially for ships that rarely find other neighboring ships. However, when ships can easily locate neighboring ships, a satellite system becomes burdensome due to its remarkably high cost. The ship ad-hoc network (SANET)[1], maritime counterpart of the terrestrial vehicle ad-hoc network, thus needs to provide those diverse multimedia services in a maritime communications system. ITU-R M.184-1 was released as a recommendation that characterizes very high frequency (VHF) radio systems for data exchange in maritime mobile services[2].

In this paper, we investigate the link performance of SANET associated with several multiple antenna schemes, including, space time block coding (STBC), space frequency block coding (SFBC), cyclic delay diversity (CDD) 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 bit error rate (BER), packet error rate (PER) and throughput, we select the efficient multiple antenna schemes to be included in the next generation maritime communication system.

Ⅱ. Maritime Channel Model for SANET

The maritime VHF channel model for both open-sea and coastline areas is referred by Kim[3] and channel parameters are listed in Table 1. According to Table 1, we notice that the channel environment on a coastline is a two-path fading channel composed of the first Rician distributed path and the second Rayleigh distributed path. The relative delay of the second path is 5 μs, and its power decay is -3 dB. The mathematical description of a coastline two-path channel model is given as:

$$\begin{aligned} g_{i,k}(t) &= h_{i,k}^{Rician} + h_{i,k}^{Rayleigh} \\ &= \sqrt{\frac{M}{M+1}}\left(\sqrt{\frac{K}{K+1}} + \sqrt{\frac{K}{K+1}} h_{i,k}^{1}(t)\right)\delta(t) \\ &\quad + \sqrt{\frac{M}{M+1}} h_{i,k}^{2}(t)\,\delta(t-\tau), \end{aligned} \tag{1}$$

where $h_{i,k}^{1}(t)$, and $h_{i,k}^{2}(t)$ are two independent Rayleigh paths. $h_{i,k}^{1}(t)$ is used to generated the

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Table 1. Maritime channel model.

Scenario	Path Index	Delay Spread	K [dB]	Average Relative Power [dB]
Coastline	0	0	10	0
	1	5	0	-3
Open Sea	0	0	15	0

Rician path $h_{i,k}^{Rician}$ via the Rician K-factor. M is the normalization factor for two paths, and τ is the relative delay of the second path.

Ⅲ. MIMO Transmit Diversity Strategies for SANET

In this section, we discuss the spatial diversity strategies for SANET under a maritime channel model in coastline areas.

3.1 Space Time Block Coding (STBC)

For STBC, two successive symbols are formed in one sub-carrier. The 2-by-1 STBC coding scheme is described in Fig.1.

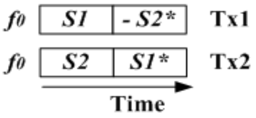

Fig. 1. STBC technique.

3.2 Space Frequency Block Coding (STBC)

For SFBC, two successive symbols are located over two different sub-carriers. The 2-by-1 SFBC coding scheme is described in Fig.2.

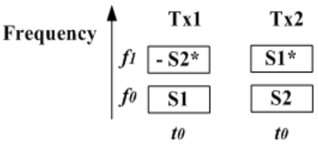

Fig. 2. SFBC technique.

3.3 Cyclic Delay Diversity (CDD)

CDD is a simple approach to exploit the frequency diversity in MC system. Hence, cyclic shift of the time domain signal corresponds to a frequency-dependent phase shift that can be extende extended to more than two transmit antennas with different cyclic shifts for each antenna. Consequently, the cyclic shift of the first antenna is set to zero and the signal is given as:

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

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:

$$s((t-\delta)\mathrm{mod}N) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} e^{-j\frac{2\pi}{N}k\delta} S(k)\, e^{j\frac{2\pi}{N}kt}, \tag{3}$$

3.4 Beam Forming (BF)

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:

$$w_t = \lambda_{\max}(H^H H), \tag{4}$$

where the eigenvector which corresponds tolargest eigenvalue $\lambda_{\max}$ of the channel covariance matrix is selected.

Table 2. Link-level simulation parameters.

Parameter	Value
Carrier Frequency	2.075 GHz
Bandwidth	100 KHz
Multiple Access	TDMA: 4 time slot / 1 TDMA frame
FFT Size	32
Subcarrier Spacing	2.7 KHz
Packet Length	64 Symbol
Modulation	16 QAM
Channel Coding	Turbo Coding (1/2)
Channel Model	2-path Coastline
Mobility	55.56 km/h (30 Knots)
Channel Estimation	2-D WFE

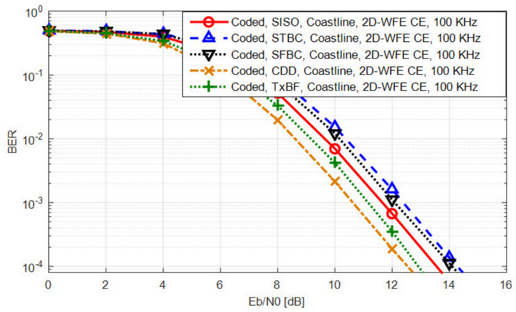

Fig. 3. BER performance of Tx diversity schemes employing to the SANET system.

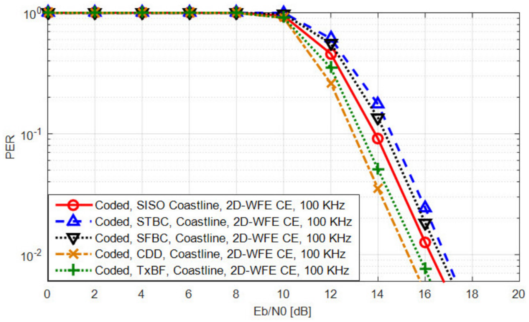

Fig. 4. PER performance of Tx diversity schemes employing to the SANET system.

Ⅳ. Link-level Performance Evaluation for SANET under Coastline Channel Model

In order to analyze the link reliability of the SANET system, the link-level simulations (LLS) are performed to check the BER, PER and throughput performances of various transmission diversity techniques such as STBC, SFBC, CDD and BF under the 2-path Coastline channel model. The simulation parameters are given in Table 2.

From the Fig. 3 and Fig. 4, it can be clearly seen that STBC and SFBC transmit diversity schemes has worst BER and PER performances than SISO scheme while CDD and Eigenvector TxBF schemes improve the BER and PER performances, respectively, under the 2-path coastline channel model

In terms of throughput in Fig. 5, STBC and SFBC transmit diversity schemes are inefficiunder the 2-path Coastline channel model. On the other hand, CDD and TxBF diversity techniques increase link reliability and achieve throughput gain over SISO in SANET environment. At 12 dB Eb/N0, the CDD and TxBF diversity schemes have 21.9% and 11.9% throughput gain.

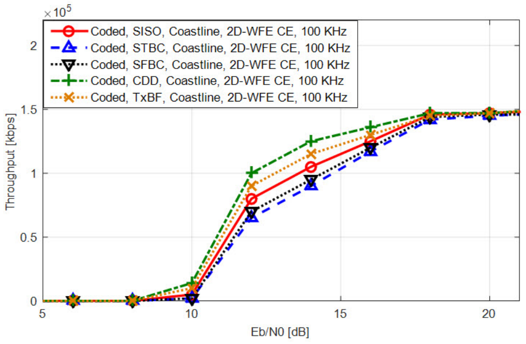

Fig. 5. Throughput performance of Tx diversity schemes employing to the SANET system.

Ⅴ. Conclusions

Based on LLS results, STBC and SFBC are not so efficient to perform under coastline channel model. On the other hand, CDD and BF are efficient schemes to enhance the link reliability as well as capacity under the coastline channel model. Moreover, CDD and Eigenvector TxBF diversity schemes show a significant PER gain of 1.15 dB and 0.65 dB at the target PER 10^{-2}, respectively.

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