The Performance Analysis of Diversity Technologies for Underwater Moving Channel Environments Using Experimental Data

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Abstract – In this paper, we have analyzed the performance of diversity technologies using experimental data recorded from mobile underwater channel environments in order to analyze the usability of MIMO techniques in underwater channel environ-ments. After analyzing the experimental data we found out that high diversity gain should not be expected when using a stationary transmitter with a stationary array of receivers in swallow underwater channels.

I. INTRODUCTION

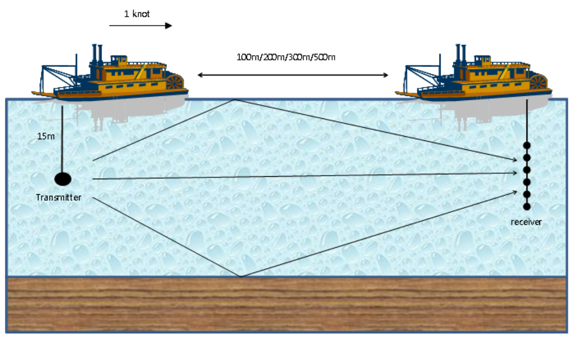
Recently, underwater sensor networks (USNs) and underwater mobile ad-hoc networks (MANETs) have been widely studied for oceanic monitoring applications. Such applications require high data rate performance with low bit error rates (BER). However, in underwater channel environments, the transmitted data highly suffers path-loss along with the effect of multipath fading. Along with this, recently, Multiple Input Multiple Output (MIMO) techniques have been widely studied for the purpose of increasing data rates with more reliable communications in rich multipath scattering underwater acoustic channel environments for USNs and underwater MANETs [1-2].

Typically, MIMO techniques have been applied to the field of wireless communications where urban environments introduce rich multipath effects. It is well known that the performance of MIMO systems depend highly on the correlation between signals received from multiple adjacent receivers. Therefore, in previous work, we showed analysis of the performance of diversity technologies using experimental data to see how MIMO techniques can benefit underwater acoustic communications when both the transmitter and receiver were stationary. We also introduced in previous work that the high diversity gain should not be expected when using a stationary transmitter with a stationary array of receivers in swallow underwater channels [3].

In this paper, we analyze the performance of diversity techniques using experimental data recorded from mobile underwater channel environments. Our experiments were performed at the sea near Geoje Island, South Korea in November 2009.

II. MEASUREMENTS

In order to analyze the usability of diversity techniques, we collected data from two ships, which have array sensors, and analyzed the performance using the collected data. Figure 1 shows the overview of experiments with pictorial view of equipments and ships used in the experiments. As shown in figure 1 (a), we used one sensor for the transmitter and six sensors for the receiver, in the experiments.



(a) Transmission / Reception Scenario

(b) Transmitting equipments

(c) Receiving ship

Figure 1. Overview of experiments with pictorial view of equipments and ships used in our experiments.

Figure 2 shows the transmitter and receiver that were used in the experiments. As shown in figure 2, we transmitted the signal using single sensor and the receiver has six sensors. The distance between array sensors was 0.5 wavelengths, 1 wavelength, and 2 wavelengths. Therefore the distances between the first receiver and the sixth receiver are 2.5 wavelengths (for 0.5 wavelengths between receivers) and 10 wavelengths (for 2 wavelengths between receivers). In the experiments, the transmitting ship moved towards the receiving ship at the speed of 1 knot.

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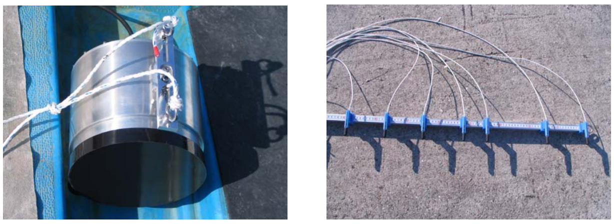


(a) Transmitter (b) receiving array

Figure 2. Transmitter / Receiver used in the experiments.

Figure 3 shows the transmitting equipments and receiving equipments used in the experiments

(a) transmitting equipments (b) receiving equipments

Figure 3. Transmitting equipments and receiving equipments used in the experiments

Figure 4 shows the geographical map of where the data collection experiments took place in November 2009.

Figure 4. Geographical map of where the data collection experiments took place at November 2009.

In our experiments, we transmitted data at a rate of 5Kbps using BPSK modulation with 25KHz carrier frequency via a single transmitter (see Table 1). The transmitted signals propagated underwater channel environments, where multipath reflections from the surface and bottom of the ocean existed. The data was finally received using multiple receivers that consist of a linear array of six receivers. We note that the collected multi-channel receiving data was stored in data files with a sampling rate of 200Ksps.

We varied the distance between the transmitting and receiving ship by 100m, 200m, 300m, and 500m for different tests and the distance between multiple receiving sensors in the array as 0.5 wavelengths, 1 wavelength, and 2 wavelengths.

Table 1. Transmitting parameters.

	BPSK
Carrier frequency	25KHz
Symbol rate	5Ksps
Symbol length	1023
Pulse shaping filter length	20
Roll-off factor	0.35

To analyze the fading characteristics and the diversity gain, the received data was averaged into local means and were subtracted [3] and finally we compute the local average power of the fading signal for every 5,000 samples (25 msec).

After estimating the fading characteristics, we analyzed the spatial correlation coefficient with the first receiver as follows in order to analyze the usability of diversity techniques in moving underwater channel environments.

$$\rho = \frac{E[r_1 r_m] - E[r_1]E[r_m]}{\sqrt{\left(E[r_1^2] - E[r_1]^2\right)\left(E[r_m^2] - E[r_m]^2\right)}}$$

Where $E[\cdot]$ denotes expectation, r_1 represents the estimated fading characteristic of the first sensor, and r_m represents the estimated fading characteristic of the m*th* sensor.

III. EXPERIMENTAL RESULTS

Figure 5 shows the fading characteristics of the received signals when the distance between sensors were 0.5 wavelength each. Note that the distance between the transmitting ship and the receiving ship was 100m. Specifically, in Figure 5, plot (a) represents the fading characteristics received at the first sensor and plot (f) represents the fading characteristics received at the sixth sensor (furthest away from the first). From Figure 5, one can see that the fading characteristics of the received signals are very similar over all six sensors. Additionally, the correlations of the channel characteristics with the first sensor are very high.

Figure 6 shows the fading characteristics of the received signals when the distance between multiple receivers was 1 wavelength each and the distance between the transmitting and the receiving ship was 100m. Figure 6, indicates that the correlations of the channel characteristics with sensor 1 are high in this case as well.

Figure 7 shows the fading characteristics of the received signals when the distance between multiple receivers was 2 wavelengths each and the distance between the transmitting and the receiving ship was 100m.

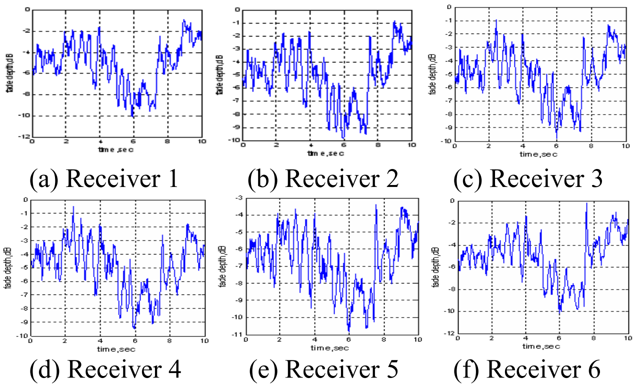


Figure 5. Fading characteristics that are estimated from the received signal when the distance between sensors are 0.5 wavelength (the distance between the transmitting ship and the receiving ship was 100m).

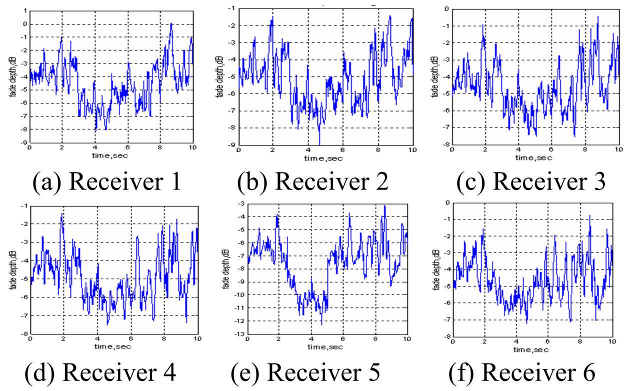


Figure 6. Fading characteristics that are estimated from the received signal when the distance between sensors are 1 wavelength (the distance between the transmitting ship and the receiving ship was 100m).

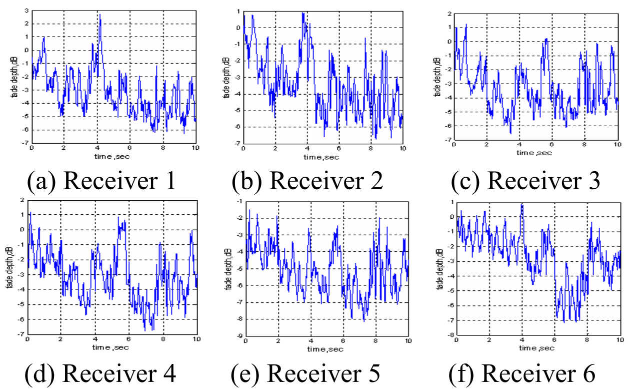


Figure 7. Fading characteristics that are estimated from the received signal when the distance between sensors are 2 wavelengths (the distance between the transmitting ship and the receiving ship was 100m).

Figure 7 show that the fading characteristics of the received signals become uncorrelated as the distance between sensors are increased. Especially, when the distance between sensors are more than 8 wavelengths, the correlation with sensor 1 becomes less than 0.3.

Figure 8 shows the fading characteristics of the received signals when the distance between multiple receivers was 0.5 wavelengths each and the distance between the transmitting and the receiving ship was 300m. Figure 8, indicates that the fading characteristics of the received signals are also similar over all six receivers. Also one can notice that the correlations of the channel characteristics with sensor 1 are high.

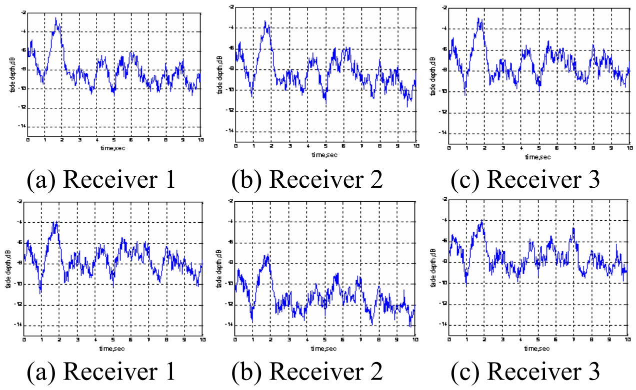


Figure 8. Fading characteristics that are estimated from the received signal when the sensors are 0.5 wavelength apart (the distance between the transmitting ship and the receiving ship was 300m).

Figure 9 shows the fading characteristics of the received signals when the distance between multiple receivers was 1 wavelength each and the distance between the transmitting and the receiving ship was 300m. Figure 9 show that the correlations of the channel characteristics with receiver 1 are high in this case as well.

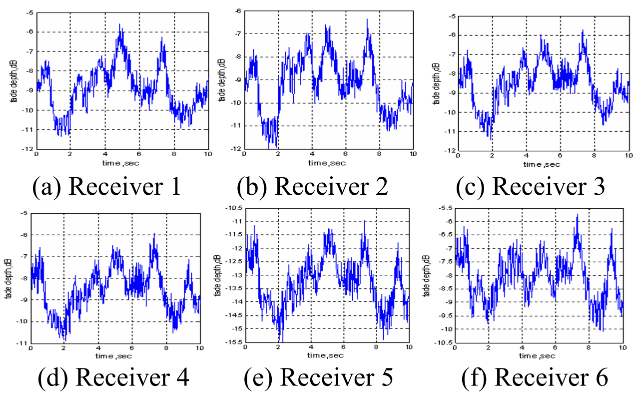
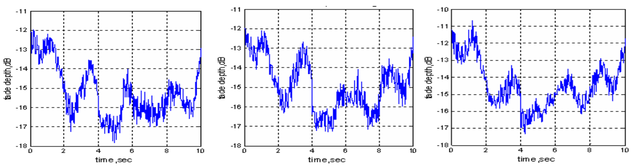
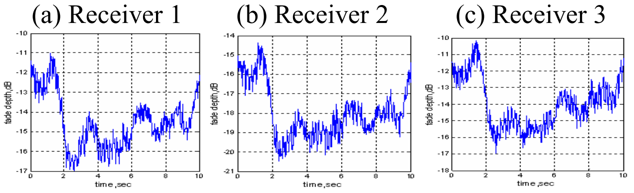


Figure 9. Fading characteristics that are estimated from the received signal when the sensors are 1 wavelength apart (the distance between the transmitting ship and the receiving ship was 300m).

Finally, Figure 10 shows the fading characteristics of the received signals when the distance between receivers was 2 wavelengths apart and the distance between the transmitting and the receiving ship was 300m. We notice from Figure 10 that the fading characteristics of the received signals become uncorrelated as the distance between the receivers are increased.



(a) Receiver 1 (b) Receiver 2 (c) Receiver 3



(d) Receiver 4 (e) Receiver 5 (f) Receiver 6

Figure 10. Fading characteristics that are estimated from the received signals when the sensors are 2 wavelengths apart (the distance between the transmitting ship and the receiving ship was 300m).

In our experiments, we fixed the environmental variables and performed each experiment ten times. We estimated the correlation of the received signals at each sensor with that of the first sensor and averaged all ten trials.

Table 2 and Table 3 show the averaged correlations of fading characteristics with the first sensor when the distance between the transmitting ship and the receiving ship was 100m and 300m respectively.

Table 2. Correlations of fading characteristics with first sensor (the distance between the transmitting ship and the receiving ship was 100m).

Sensor Number	Correlation		
	0.5 wavelength	1 wavelength	2 wavelength
2	0.9170	0.8609	0.6861
3	0.8168	0.6974	0.4190
4	0.7900	0.5508	0.3675
5	0.7550	0.4522	0.2982
6	0.6415	0.4220	0.2864

Table 2 and Table 3 show that the correlations of the received signals are high when the distance between sensors are close, regardless of the distance between the transmitter and the receiver. However, when the distance between sensors are further apart (10 wavelengths), and the distance of the transmitting ship and the receiving ship is 100m, then the received signals are independent.

When the distance of the transmitting ship and the receiving ship is 300m, the correlation of the received signals increase slightly, but still can benefit from diversity gain.

While we did not have the chance to take measurements with any distances larger than 10 wavelengths in these sets of experiments, the results obtained until now lead us to conjecture that the increasing distance between receivers (i.e., more than 10 wavelengths) can lead to larger diversity gain in underwater moving channel environments.

Table 3. Correlations of fading characteristics with first sensor (the distance between the transmitting ship and the receiving ship was 300m).

Sensor Number	Correlation		
	0.5 wavelength	1 wavelength	2 wavelength
2	0.9512	0.8964	0.7283
3	0.8214	0.7620	0.6457
4	0.8038	0.7194	0.5506
5	0.7051	0.6985	0.4469
6	0.6304	0.6225	0.4030

IV. CONCLUSIONS

In this paper we have analyzed the performance of diversity technologies using experimental data in order to analyze the usability of MIMO techniques in underwater moving channel environments. We collected data from various situations (different distance between the transmitting ship and the receiving ship, and different sensor spacing) and estimated fading characteristics using received signals.

After analyzing the estimated fading characteristics, we found out that the distance between multiple sensors should be at least 10 wavelengths apart to take advantage of the diversity gain in underwater moving channel environments and we also infer using our experimental results that the same argument will stand for the case where multiple transmitters are used with a single receiver as well.

ACKNOWLEDGEMENT

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