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Fading Statistics Characterization of Shallow water Acoustic Communication Channel

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1. Introduction

The underwater acoustic channel is a time-varying multipath fading channel. The time variability of multipath is caused mainly by the boundary fluctuation and the propagation medium property time variability. In shallow water, the former is more important comparing to deep water in which refraction paths in medium is also important. The coherent components of multipath arrivals to receiver from various paths interfere with each other and cause constructive and destructive interference in received signals. This induces change of signal-to-noise ratio (SNR)[1,2].

The envelope amplitude statistics of receiving signal which defines the time varying multipath fading channel is very important for underwater acoustic communication system design and performance analysis. The shallow water channel was found to be a non-Rayleigh or a non-Rician distributions even if the statistics of each path such as a direct path and a surface reflected signal shows a Rician distribution[3].

In this study, the fading statistics in shallow water are characterized as function of frequency which is not parameterized in previous studies.

2. Statistical models for fading channels

In time variant channel as a result of change in the structure of the medium, the equivalent low pass receiving signal is give as

$$r_l(t) = \sum_n \alpha_n(f_c, t) e^{-j2\pi f_c \tau_n(t)}, \quad (1)$$

Where f_c is a carrier frequency and $\alpha_n(f_c, t)$ and $\tau_n(t)$ are the attenuation factor and the propagation delay of *n*th path, respectively. If there are a large number paths in channel, and the process is zero mean, then the envelope of the channel response has a Rayleigh distribution and the phase is uniformly distributed. This may be the case of deep water with a high degree of physically inhomogeneous medium. However, if there are a few strong time independent paths such as in shallow water, eqn. (1) reduces to

$$\begin{aligned} r_l(t) &= \sum_n \alpha_n(f_c, t) e^{-j2\pi f_c \tau_n(t)} \\ &= \sum_{m=1}^{M} \alpha_m(f_c) e^{-j2\pi f_c \tau_m} + \sum_n \beta_n(f_c, t) e^{-j2\pi f_c \tau_n(t)} \quad (2) \\ &= \alpha(f_c) + \sum_n \beta_n(f_c, t) e^{-j2\pi f_c \tau_n(t)} \end{aligned}$$

Where α_m and τ_m are the time independent attenuation factor and the time independent delay, respectively and $\alpha(f_c)$ represents a frequency dependent non-centrality parameter. In this case, the channel may represent the Ricean fading distribution. The frequency dependent non-centrality parameter $\alpha(f_c)$ depends on a degree of the surface roughness and a destructive or a constructive interference level between strong multi-paths[4,5].

2. Experiment

The experiment was conducted in about 20 m depth ocean near Geoje island in Korea on Aug. 6, 2014. The ranges between the transmitter and receiver are set to be about 100, 200, 400, and 800 m and the depth of receiver and transmitter are set to be 10 and 7 m, respectively. Linear frequency modulated (LFM) of 13 to 19 kHz bandwidth was transmitted for 5 ms with 1s interval to measure multipath intensity profile (MIP) and multipath interference pattern. PN signal of 13 to 19 kHz bandwidth was also transmitted for 30s to measure the fading statistics.

3. Results and discussions

The channel impulse response was analyzed by MIP which is given by matched filtering the received signal with the transmitted signal. **Fig. 1** shows the MIPs of 100, 200, 400, and 800 m Tx-Rx ranges. The first strong signals are pretty stable at four ranges. The surface reflected signal is shown clearly in 100 m range but not in other three ranges. The surface reflected signals of other three ranges are lumped together with the direct signal.

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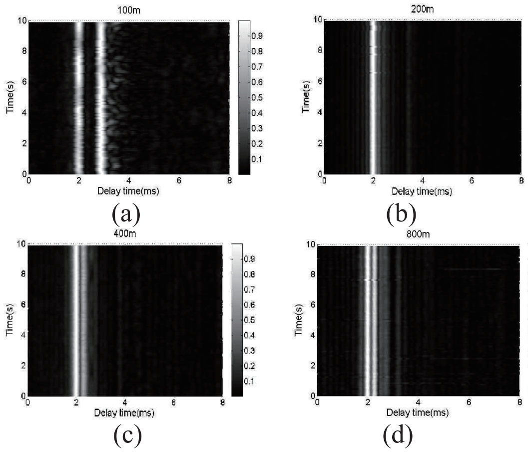

Fig. 1 Measured channel impulse responses as a function of the delay time and geo-time: (a) 100 m; (b) 200 m; (c) 400 m; (d) 800 m.

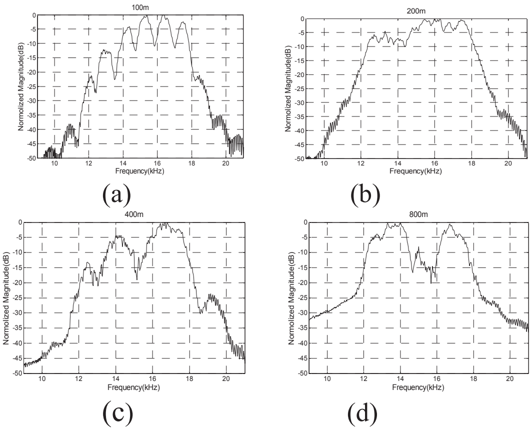

Fig. 2 Normalized receiving signal spectra of LFM signals for four Tx-Rx ranges: (a) 100 m; (b) 200 m; (c) 400 m; (d) 800 m.

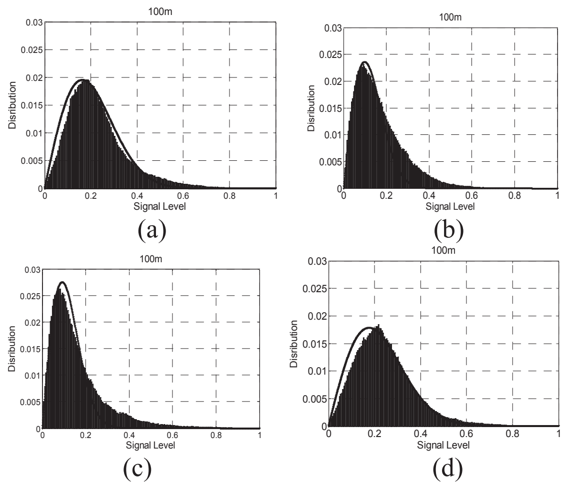

Fig. 3 Probability density of amplitude envelope of 12, 14, 16, and 18 kHz with 100 Hz bandwidth for 100 m Tx-Rx range: (a) 12 kHz; (b) 14 kHz; (c) 16 kHz; (d) 18 kHz.

The receiving signal spectra or interference patterns for given ranges are shown in **Fig. 2. Fig. 3** shows probability densities of 12, 14, 16 and 18 kHz with 100 Hz bandwidth for Tx-Rx range of 100 m. The probability density function is approximated as Rayleigh distributions for 16 kHz. As shown in Fig. 2(a) for Tx-Rx range of 100 m, the 16 kHz corresponds to dip frequency in interference pattern. The probability density functions of 12 and 18 kHz were found to be approximated as Rice distribution. Rayleigh distribution relates to dip or destructive interference frequency and Rice distribution relates to maximum frequency or constructive interference frequency. The statistical distribution characteristics analysis for other frequencies and Tx-Rx ranges is ongoing but it is found that the statistics depends on frequency dependent multipath interference pattern. The mean and the standard deviation of the statistics depend on sea surface roughness and frequency.

4. Conclusions

LFM and PN signal with 13 to 19 kHz bandwidth are used to characterize the multipath fading statistics. The receiving signal envelope statistics depends on frequency and range due to the distinct strong multipath signals and their interference. Rice or Rayleigh distributions depend on actually whether there are strong coherent multipath signals. As shown in eqn. (2) and Fig. 2, frequency and range dependent constructive or destructive interference determines whether fading statistics becomes Rice or Rayleigh distribution, respectively.

It is concluded that underwater acoustic channel fading statistics depends strongly on carrier frequency and Tx-Rx range if there are strong distinct multipath.

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