Capacity Analysis for Broadband Communications on Sea

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***Abstract*—Maritime communication currently changes from analog to digital in the VHF band. The limited bandwidth of 100 kHz in the VHF band results in low data rates of a maximum of 100 kbit/s in a region of several of to 70 kilometers. Alternative solutions could be the access to 3G or 4G cellular communication systems which offer data rates of up to tens of megabits. However, these access schemes are designed for a very limited coverage of several hundreds of meters for mobile users and are seldom available on the sea. Therefore, in the ITS band at $5,85$ GHz a broadband channel of 20 MHz is defined for maritime applications. In this paper we analyze the communication capacity depending on the different antenna heights and different distances between transmitter and receiver.**

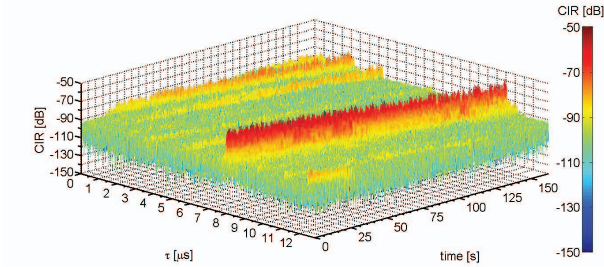

Fig. 1: A snapshot of the time variant channel impulse response.

I. Introduction

Maritime broadband communications nowadays uses two different ways to communicate depending on the environment. On the open sea the broadband communication links operate between the vessels and the satellites to overcome the limited coverage of terrestrial links. Communication satellite systems offer a broadband and high data rate link, but suffer from the huge footprint and therefore, only a portion of the overall data rate is reasonable for a single vessel. Close to the shore the vessels may benefit from the cellular mobile radio links that exist anyhow for terrestrial users. However, the continuous tremendous increase of the data rate over the evolution of the cellular generation from the 2nd (GSM) to the 3rd (UMTS) and now to the 4th generation (LTE) come with a cost. The coverage zones on land that also cover part of the sea have shrunk for each new generation significantly. Therefore, a new broadband solution that guarantees high data rates with large coverage zones close to the shore is needed to cope with the increasing demands on sea. The demand for high data rates increases by novel on sea applications such as telehealth and telematic. In this paper we analyze based on the data of our channel measurement sounding campaign [1] the potential throughput on sea which enables such applications in the coastal areas and for smaller seas even everywhere.

Novel applications which have a crucial impact also on safety on sea is telemedicine. The bidirectional video streams from the vessel demand a megabit data link ($>$ 1 MBit/s) for high resolution and low latency ($<$ 100 ms) to avoid dropouts.

An application which is rapidly exploiting the potential of higher data rates is telematic. The increase of data that is requested by land-side controlled applications that monitor and control, e.g. the engine of the vessel, or other cargo related objects increases continuously. More specifically dredging companies have been tracing their progress in the past locally, but nowadays they intend to move the working place away from the vessel. The demand of high data rate especially in areas with very limited infrastructure raises the need for wireless communication systems over the sea.

The importance of observing and controlling the (e.g. telematic) functionalities is gaining nowadays in many intelligent transport systems importance. Therefore, the European Telecommunications Standards Institute (ETSI) proposes within its technical report [2] a wireless communication system with a bandwidth of 20 MHz and a transmit power of 20 dBm. Furthermore, by significant antenna gains on both ends the EIRP increases to 62 dBm.

II. Line of Sight - K Factor

For line of sight (LoS) conditions the K-factor is an important parameter describing the fast fading characteristics of the channel [3]. It is often assumed that the Rician K-factor (KRICE) equals the power ratio of the LoS component and the other MPCs. However, the KRICE is a characteristic parameter of the Rician amplitude distribution and it is conventionally related to the narrowband [4]. Even when it is used to describe the amplitude characteristics of the first delay bin in wideband channel, it does not have a strict correspondence to the LoS component [3]. Therefore, we distinct and analyze the impact in power that multipath components (MPCs) have, the multipath K factor KLOS is defined as

$$K_{LOS} = 10log\frac{E(H_{LOS})}{E(H_{MPC})}[dB] \quad (1)$$

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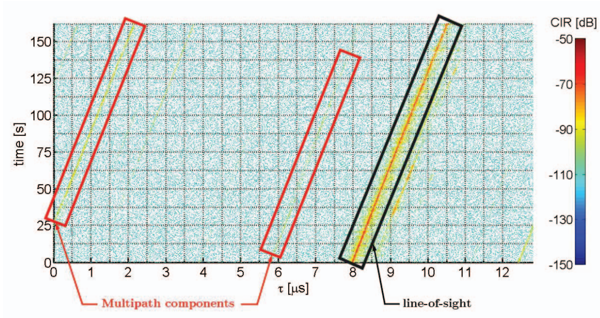

Fig. 2: A snapshot of the time variant channel impulse response with dedicated multipath components.

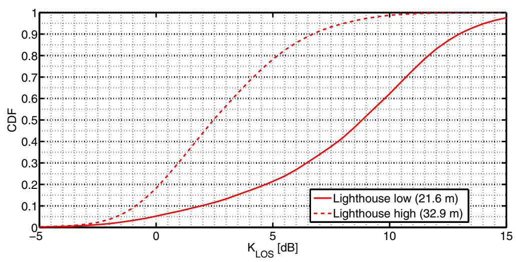

Fig. 3: K_{LoS} from the lighthouse.

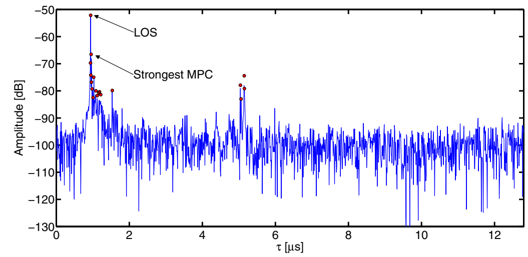

Fig. 4: Channel impulse response from the lower part of the lighthouse with some local reflections.

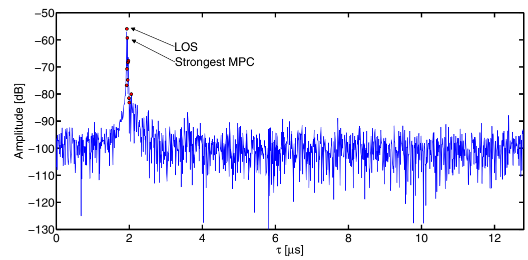

Fig. 5: Channel impulse response from the higher part of the lighthouse with less local reflections.

Fig. 1 shows a snapshot of 150 seconds of the channel impulse responses at a distance of around 6000 m from the transmitter. The different multipath components are visualized in a 2-dimensional plot in Fig. 2.

III. Time Dispersion

Mean delay and RMS delay spread used to design the communication links, which give a measurement of performance degradation due to ISI in the system.

Mean delay and RMS delay spread are calculated for each snapshot of the CIR. The mean delay $m_D(t_k)$ and the RMS delay spread $\sigma_R(t_k)$ are calculated

$$m_D(t_k) = \frac{\sum_{n=0}^{N-1} \tau_n \gamma(|h_\tau(t_k,\tau_n)|^2)}{\sum_{n=0}^{N-1} \tau_n \gamma(|h_\tau(t_k,\tau_n)|^2)} \tag{2}$$

and

$$\sigma_{RMS}(t_k) = \sqrt{\frac{\sum_{n=0}^{N-1}(\tau_n - m_D)^2 \gamma(|h_\tau(t_k,\tau_n)|^2)}{\sum_{n=0}^{N-1} \tau_n \gamma(|h_\tau(t_k,\tau_n)|^2)}} \tag{3}$$

The delays are related to the first detectable propagation path at $\tau_0 = 0$. To detect the multipath components we represent the threshold by the Gamma function $\gamma(x)$.

For each snapshot k, the N samples of the CIR that exceed the noise threshold are considered for the calculation of the time dispersion parameters.

The cumulative distribution function (CDF) of the mean delay is plotted in Fig. 7 and of the RMS in Fig. 8.

The scenarios are split into two groups according to the location of the RX. The results for the different RX antenna height for the lighthouse scenario are shown in red (in both Figures 8 and 7) and for the hotel scenario are shown in green. As a result, the time dispersive parameters increase as the RX antenna height decreases. This trend in time dispersive parameters can be explained by the results of the PDP. The higher the RX antenna, the higher the probability that MPCs with larger delay have higher power. Therefore, the time dispersive parameters (that are calculated based on the PDP) should become larger, as shown in Figures 8 and 7. A physical explanation might be given by the analysis of the environment. The height of the buildings along the coast and in the surrounding area is below 30m. Therefore, from the lower floor in the lighthouse (21.6m) more reflections can be observed, from the highest antenna position less reflected paths are present and the captured multipath signals corresponds generally to scattered paths, so they have lower power.

IV. Capacity Analysis

The capacity of the time varying wideband channel in the single-input single-output (SISO) case under the constrains of a bandwidth B can be given by

$$C = \frac{1}{N}\sum_{i=1}^{N} \log_2(1 + \rho H_i \cdot H_i^*) \text{ in (bits/s/Hz)}, \tag{4}$$

where N is the number of sub-carriers, ρ is the averaged signal-to-noise ratio (SNR) and H_i is the normalized sampled channel frequency responses for each carrier i. Based on the channel measurement data, a direct evaluation on the wideband channel capacity can be performed. The measured channel frequency response $\boldsymbol{H} = [H_1, H_2, \ldots, H_N]^T$ can be used to estimate the SNR and, therefore, to calculate the wideband

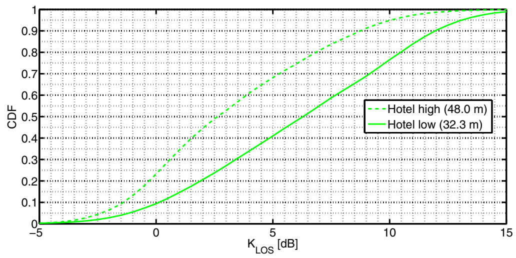

Fig. 6: K_{LoS} from the hotel.

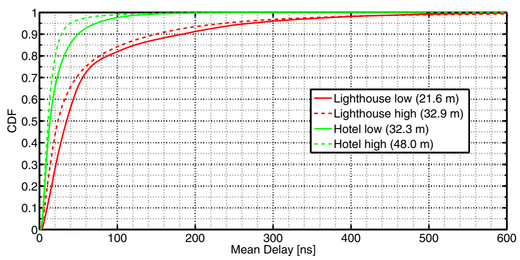

Fig. 7: Mean delay for different antenna heights on land.

channel capacity C. The design of a new broadband maritime radiocommunication system requires the understanding of the propagation channel and its wideband characteristics. To gather information about the broadband maritime channel, the German Aerospace Centre (DLR) performed a channel measurement campaign in the Baltic Sea. These measurements were conducted using a channel sounder at 5.2 GHz with a bandwidth of 100 MHz, with the transmitter mounted on a ship and the receiver located on land. Based on the measurement results we characterized the maritime wideband radio channel. For this purpose, wideband channel characteristics and the capacity analysis depending on different antenna heights are analysed.

In the following we calculated based on eq. (4) the capacity for different antenna heights on land. From this we derived the potential data rates for a 20 MHz channel and different shore stations.

Figure 9 - 12 shows the performance analysis for the different antenna heights on land with a 20 MHz broad data link. The data rates are around 20 and 30 MBits/s for distances higher than 5 km. In our case the EIRP was 48 dBm due to limitations by the license giver. With an additional 14 dB margin compared to the ETSI recommendation which states 62 dBm we can expect a range of more than 30 km offering still a stable data rate of above 10 MBits/s. To confirm this we are investigating this in our ongoing second channel measurement sounding campaign to understand what we can expect close to and especially beyond the horizon.

V. Conclusions and Outlook

In the future besides higher data rate shorter latency of the communication link will have a substantial impact on the success of telematic applications. Autonomous ships require

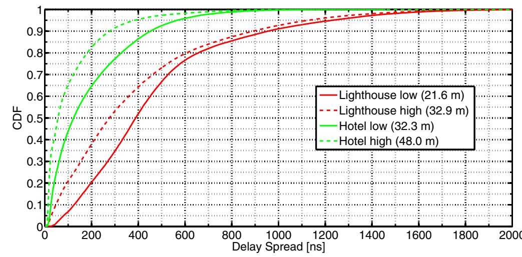

Fig. 8: Root mean square delay for different antenna heights on land.

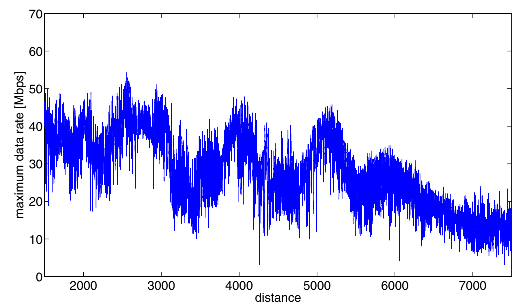

Fig. 9: Higher lighthouse floor (30 m)

a stable and a high data throughout of the wireless channel. In this paper our analysis focuses on the characteristics of the wireless channel effects over the open sea in the C-band at different distances. We derived the K-factor and provided analysis of the multipath components. Further, we analyzed the root mean square delay spread and the mean delay. Based on the outcome and the different antenna heights of the receiver on land we analyzed the potential capacity that a wireless communication system could exploit for a 20 MHz bandwidth.

References

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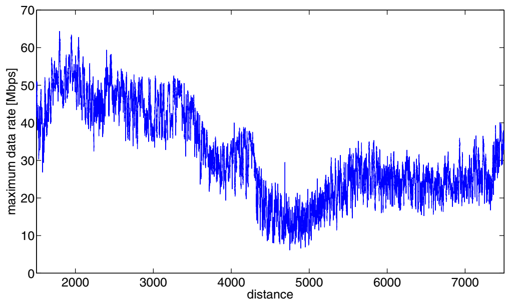

Fig. 10: Lower lighthouse floor (16 m)

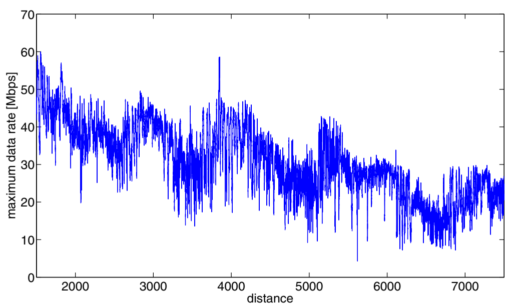

Fig. 11: Higher hotel room (48 m)

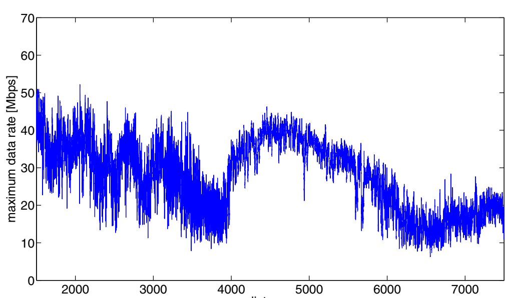

Fig. 12: Lower hotel room (30 m)