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Wireless Channel Models for Maritime Communication

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Abstract: *Due to the blue economy's rapid growth, maritime communication plays a significant role in broadband maritime operations. In order to provide broadband data service to the sea area, there has been an increasing interest in using higher frequency bands in addition to MF/HF/VHF bands. The two primary types of channels for an air-ground-sea communications network are air-to-sea (for communication links from, for instance, aircraft-based base stations or relays) and near-sea-surface (for communications from land to ship, ship to land, or ship to ship). The modelling of these maritime channel links is different from conventional terrestrial wireless channels in many ways because of the unique characteristics of the maritime propagation environment, such as sparse scattering, sea wave movement, and the ducting effect over the sea surface. This will have a significant impact on the transceiver.*

Keywords: Sparse Scattering, Sea Wave Movement**,** Ducting Effect

I. INTRODUCTION

The maritime economy has been steadily expanding over the past few decades. While new maritime activities like oil exploitation, environment monitoring, and tourism have emerged, industries like fishery and transportation have continued to develop. Higher data rates and more dependable wireless communications are needed for all of these. the automatic identification system (AIS), the navigational telex (NAVTEX) system, and the developing VHF data exchange system (VDES) (communication system that operates between ship, shore stations, and satellites on AIS) are examples of satellite-based and/or customised communication systems operating in the MF/HF/VHF bands. which significantly improves its capacity to provide high-speed data coverage for a large area, suffers from some significant propagation problems.

II. LITERATURE SURVEY

A. Integrated Wireless Networking Architecture for Maritime Communications

This paper suggests an integrated wireless networking system made up of a mobile ad hoc network, a cellular mobile communication network, and a satellite mobile network to help mobile users on ships communicate effectively in offshore areas at sea. The proposed system's general system architecture as well as pertinent network components are described. The suggested system can support more terminal types, lower the cost of network deployment and calling, and give mobile users more comprehensive maritime services. Mobile users on ships need to be assisted with efficient communications and services at any sea area as ocean fishery and transportation develop. Single sideband (SSB) shortwave radio, VHF (Very High Frequency) radio, and other technologies are currently available for use on ships.

B. High Speed Maritime Wireless Mesh Network

This article presents the TRI-media Telematic Oceanographic Network (TRITON) project, which aims to develop a high-speed and low-cost maritime communication system. The article includes information pertaining to background studies, high-level architecture, network feasibility, maritime communication environment, technology developments, prototype implementations and link performance measurements.

The motivation for this project stems from the fact that there is an increasing need for low-cost and high-speed maritime communication, with demands mainly coming from regulatory and crew welfare needs. The system also considers the use of an intelligent middleware to allow communications to switch back to a satellite link in cases where neighboring ships are sparse or at locations far away from mesh base stations. Protocol enhancements to both the Medium Access Control (MAC) and networking layers and a hardware design that features multiple transceivers and the implementation of antenna switching to counter sea wave reflection and rocking problems are presented.

C. Quality Service Provisions For Maritime Communications based on Cellular Networks

Considering the increase of communication requirements from marine users, more studies try to introduce terrestrial wireless communication techniques into maritime communications to improve communication qualities. However, different communication scenarios introduce challenges for the application of terrestrial techniques to maritime networks. Furthermore, the communication coverage requirement is much larger than that of terrestrial networks, while the quality of service (QoS) requirement of marine users is expected to be like that on land, which makes network design more complicated. The scenario of coastal networks based on cellular techniques is modeled mathematically, based on which the performance of such a network is analyzed and closed-form expressions of network performance are presented. To guarantee the QoS requirements of users, an antenna selection scheme is proposed, which can form a virtual service cloud.

D. Enabling Broadband Internet AccessoOffshore Using Tethered Balloon

The growth of the Blue Economy has been boosted by a set of traditional and new activities including maritime transportation, fisheries, environmental monitoring, deep sea mining, and inspection missions. These activities are urging for a cost-effective broadband communications solution capable of supporting both above and underwater missions at remote ocean areas, since many of them rely on an ever-increasing number of Autonomous Surface Vehicles (ASV), Autonomous Underwater Vehicles (AUV) and Remote Operated Vehicles (ROV), which need to transmit large amounts of data to shore. The BLUE-COM+ project has considered the usage of helium balloons to increase the antenna height, and overtake the earth curvature and achieve Fresnel zone clearance, combined with the use of sub-GHz frequency bands to enable long range communications. In this paper we present the results obtained in three sea trials. They show that the BLUECOM+ architecture is capable of supporting human and system activities at remote ocean areas by enabling Internet access beyond 50 km from shore, live video conference calls with the quality of experience available on land, and real-time data upload to the cloud by ASVs, AUVs and ROVs using standard access technologies with bitrates above 1 Mbit/s.

II. METHODOLOGY

3.1 The Maritime Radio Propagation Environment

It is the type of the air-ground-sea maritime communication network . In general ,a near user can be directly served by the terrestrial base station. As the distance becomes larger, the use of relay nodes such as dedicated vessels or high altitude platforms (air craft situated 17-22km form the ground) are needed.

3.2 Instability

It mainly caused by sea wave movement .It is due to gravitational pull of the moon and the sun. Even if the user is motionless at a fixed location. Such instability induced by waves would lead to periodic variations to the height. Accordingly, the influence on the onboard receivers can be divided into two parts, namely the linear motions and the rotational motions in the corresponding directions. These motions will determine the variations in the received signal strength.

The incoming wavefronts encounter more scattering and/or reflections due to the rough sea conditions. In this case, the simplified two-ray model has to be modified with the help of the so-called Karasawa's model which accounts for:

1) The variation of the sea surface height when calculating the amplitude of the main reflection path

2) Multiple scattered components stemming from irregular sea surface, which are characterized by dividing a large sea surface area into several small-sized regions and each corresponds to a individual scattering path. With these manipulations, the Karasawa's model is able to describe more precisely the multipath fading and path loss in the presence of rough sea conditions .

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3.3 Evaporation Ducting Phenomenon

The atmospheric ducting effect has been long noticed, and intensively investigated especially for radar systems and military communications. The ducting effect is caused by the refractivity changing at different heights of the atmosphere, which is caused by the change of atmospheric pressure, temperature and humidity etc.

According to the differences in the appearance heights and formulation conditions, there exists three typical types of atmosphere ducts: the surface duct (including the evaporation duct), the surface-based duct, and the elevated duct. As shown in the figure 3.1,the trapping effect in the evaporation duct layer.

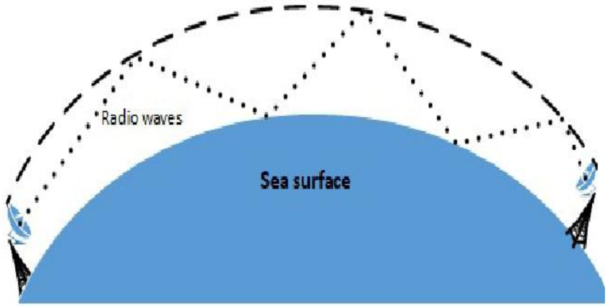

Figure: Evaporation Duct Layers

3.4 Sparsity

In maritime channel sparsity contain two aspects sparse scattering and sparse user distribution. Sparse scattering is nothing but scattering of electromagnetic wave form the atmosphere which was transmitted by antenna .Sparse scattering holds for almost all the channels like air –to-sea, land-to-ship ,ship-to-ship. Besides that in the number of multipath components (MPCs), sparsity also holds in the angle domain. For example, the LOS path and the sea-surface reflection path in the two-ray model may come from similar angular directions.

The angle difference between these two paths decreases as the Tx-Rx distance increases. When multiple antenna arrays are deployed at the transmitter and/or receiver, this will lead to high correlation between the antenna elements, and The three features described above will affect both the air-to-sea and near-sea-surface channel links in Fig. 1. In the following, we will describe the modeling of these two types of channel links considering these features

III. AIR-TO-SEA CHANNELS

We know the common three features of the maritime environment are sparsity , instability and ducting. There are some most distinctive properties of the air-to-sea radio propagation, as well as their impacts on the channel and therefore result in notable differences in the channel modeling. Herein, we highlight some most distinctive properties of the air-to-sea radio propagation, as well as their impacts on the channel.

IV. PHYSICAL PROPAGATION CHARACTERISTICS:

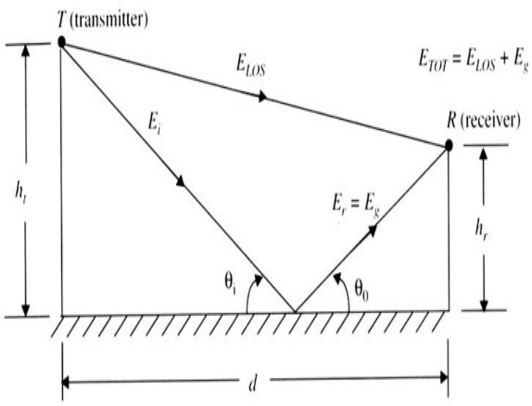

Figure: Propagation between transmitter and receiver.

Generally the LOS path and the surface reflection path are two dominant Form the curved –earth two ray(CE2R) model .we will consider transmission and receiver point. When the signal is transmitted from the transmitter there would be a 2 ray propagation. From the figure 3.2

Which are line of sight(LOS) and NLOS (non line of sight) or multiple path propagation .The multiple path propagation leads to superposition of the multiple signalsAn air-to-sea tapped delay for CE2R model can be represented by

$$h_{2Ray}(t, \tau) = \delta(\tau - \tau_0(t)) + \alpha_s(t) \exp(j\phi_s(t))\, \delta(\tau - \tau_s(t))$$

Where $\tau_0(t)$=Delay, $\alpha_s(t)$ = attenuation.

$$h_{Ray}(t, \tau) = h_{2Ray}(t, \tau) + z_3(t)\, a_3(t) \exp(j\phi_3(t))\, \delta(\tau - \tau_3(t))$$

where a_3, τ_3, and ϕ_3 are the time-varying amplitude, propagation delay, and phase shift of the third multipath component, respectively . Here, z_3 is generated from a random process that controls the occurrence possibility of the third multipath component.

V. KEY PARAMETERS OF THE AIR-TO-SEA CHANNEL

In this subsection, we highlight some measurement results for various key parameters of the air-to-sea channels, including the path loss, the root mean square-delay spread (RMS-DS) and the Rician *K* -factor. The readers are referred for a more detailed description of the latest results.

5.1 Path Loss

As discussed, the air-to-sea channel can be approximated by a classic two-ray or three-ray model. In this case, due to the destructive summation of the two or three independent rays with different phases, the channel will meet deep nulls at certain Rx positions as confirmed The deep nulls appear with higher probability in the maritime environment due to its sparse nature, while for the inland air- to-ground channels, the path loss curve would be smoother with rich scattering.

It will cause due to the destructive summation of the two or three independent rays with different phases. Two factors that may affect the path loss model need to be considered in the air-to-sea propagation environment.

1) *Earth curvature:* In maritime communications, usually long coverage distance expected.

2) *Ducting effect:* Although the height of the transmitter is generally higher than the duct layer.

A general path loss model for the air-to-sea channels, following the classic logarithmic path loss model .Is represented by

$$PL(d)|_{dB} = PL(d_0) + 10n\log_{10}\frac{d}{d_0} + X\sigma + \varsigma F$$

5.2 Root Mean Square Delay Spread (RMS-DS)

In the case that the air-to-sea channel is dominated by the two-ray components, the RMS-DS is usually small, especially for high aircraft altitudes . When the third ray cannot be ignored, the RMS-DS of the air-to-sea channel will be significantly affected by the sea wave condition and the existence of the duct layer: First, as described in the previous subsection, higher sea state level may decrease the occurrence probability of the third ray in (1), and consequently, decreases the RMS-DS. Second, in the presence of the duct layer, additional rays may arrive at the receiver from small grazing angles, which may substantially increase the RMS-DS as compared to that measured inland.

VI. NEAR SEA –SURFACE CHANNELS

6.1 LOS Transmission

LOS transmission is the most common communication scene of short-range maritime activities, including coastal traffic and near-sea fishery. The LOS path exists when the Tx-Rx distance is relatively short. Geometrically, the largest distance that can support LOS transmission can be calculated by

$$D_{LOS} = \sqrt{{h_t}^2 + 2h_tR} + \sqrt{{h_r}^2 + 2h_rR}$$

where ht and hr are the heights of the Tx and Rx antennas, respectively, and R is the $Earth\ radiu.$

6.2 Empirical Path Loss Models

It is important to have an accurate large-scale path loss model so that the transmitter can set its power accordingly to support long-range maritime communications. For this purpose, one straightforward approach is to use the well-known empirical path loss models with necessary modification to fit the maritime environment.

VII. TWO-RAY AND THREE-RAY PATH LOSS MODELS:

Although the empirical path loss models can efficiently predict the *average* signal strength in the maritime environment, they fail to fit the *local oscillations* resulted from the destructive summation of sparse multipath signals. To address this problem, the ray trajectory-based path loss models geometrically identify the trajectories of the most dominant rays arrived at the receiver. Accordingly, the phase shift of each ray is characterized and considered in the path loss calculation, therefore providing a better description of the local peaks and nulls of the received signal strength. Using the two-ray model, the path loss in dB at distance d can be calculated by the formula

$$L(h_t, h_r, d) = -10log_{10}\left(\left(\frac{\lambda}{4\pi d}\right)^2 \left(2\sin\left(\frac{2\pi}{\lambda}\frac{h_t h_r}{d}\right)\right)^2\right)$$

where ht and hr are the Tx and Rx antenna heights, respectively, and λ is the carrier wavelength.

Using the three-ray model, the path loss in dB at distance d can be calculated by the formula

$$L(h_t, h_r, h_e d) = -10log_{10}\left(\left(\frac{\lambda}{4\pi d}\right)^2 (2(1+\Delta))^2\right)$$

where $\Delta = 2\sin\left(\frac{2\pi h_t h_r}{\lambda d}\right)\sin\left(\frac{2\pi(h_{e-}h_t)(h_{e-}h_r)}{d}\right)$ and he is th effective height of the evaporation duct.

VIII. RESULTS AND DISCUSSION

8.1 Sparsity

Both the air-to-sea and near-sea-surface channels exhibit the sparse property. There are three ways to look at sparsity:

1) Sparse multipath component distribution (MPCs)
2) AOA/AOD distribution that is sparse
3) a dispersed user location distribution.

The applicable channel models are summed up as follows for the first aspect, depending on how many MPCs are being taken into account:

models that combine two and three rays: The two dominant MPCs of the channel are only taken into account by the two-ray model as being the LOS path and a specular reflection path. The three-ray model may be used to describe the near-sea-surface channel in the range of distances and the air-to-sea channel when the sea surface is rough by adding a third ray (dbreak , dLOS). In certain applications, the two-

In Next word prediction the proposed system utilizes the Stupid Back Off algorithm that, combined with weighted value, builds a list of likely next words. It depends on the N-gram frequencies, the highest frequency for the top five words increases or is matched. Later, it combines the sequences of probability of sequences of words to get the maximum probability of predicting the word. It can be seen that performance increases with the increment of N in the N-gram model. As a result, the straightforward way to assess the used language model is by mapping its accuracy.

The Location-Dependant Feature

Different user locations may result in completely different model structures in the maritime environment, which is distinct from the inland environment where typically only path loss is impacted. The crucial location-dependent parameters are, specifically, the Tx-Rx distance in the near- sea-surface channels and the grazing angle in the air-to-sea channels. List the appropriate channel models for three typical scenarios with various Tx-Rx distance ranges for the near-sea-surface propagation, as follows:

LOS Spreading for the d-d break: The two-ray model can be used to model the large-scale path loss and locate the deep-null points in the channel link when the sea surface is calm. The two rays represent, respectively, the LOS propagation and specular reflection paths. When sea levels are high, the choppy.

True Research Topics in Maritime Wireless Channels

In this section, we discuss the future research topics from the following two aspects:

The impacts of channel features in maritime communication system design. The development of more sophisticated maritime channel models.

Impacts of Maritime Channels in Communication Design

In the maritime environment, it may face more challenges in communication design than the terrestrial systems. First, in order to guarantee long-distance communications, chan- nel state information (CSI) of the intended user is necessary for the transmitter to properly concentrate its power. Accurate and prompt CSI acquisition could be difficult in maritime communications due to

1. Large feedback delay caused by long Tx-Rx distance
2. Poor channel condition caused by link mismatch, deep nulls, and high path loss.

To address the feedback problem, statistical and outdated CSI-aided transmission schemes could be applied in maritime communications to improve the channel estimation performance, the sparsity feature of the channel can be exploited to concentrate the resource only on the channel's dominant components. Besides the instantaneous CSI, the location information can be conveniently obtained in maritime communication systems, thanks to the implementation of the AIS system which regularly updates the vessels' locations at the central controller. Recalling that the mar- itime channels are location-dependant and the vessels move slowly, the location information is especially important and can be utilized in long-term CSI based transmission design. Liu *et al.*creatively utilized the location-based large- scale CSI to design hybrid precoding, power allocation, and user scheduling strategy, which have opened up a new direction for maritime communication system design.

Development of Novel Maritime Channel Models

The creation of more complex maritime wireless channel models is another area of research. The majority of current measurements and modelling strategies are based on the single antenna setup, according to the literature review. The modelling of spatial channel properties, such as the spatial correlation between nearby antennas and the eigenvalue distribution in a MIMO channel matrix, is crucial when MIMO systems are deployed.

However, these still require additional research in the maritime setting. Due to its capacity to form extremely sharp beams in the intended direction, massive MIMO technology is also anticipated to be used to support long-distance maritime communications. The far field assumption typically used in conventional MIMO channel models may no longer be valid for massive MIMO channel modelling due to the large array size.

IX. CONCLUSION

We have performed a thorough analysis of the modelling techniques and measurement successes for maritime wireless channels in this paper, including both the air-to-sea and near-sea-surface channel links. From the perspectives of large-scale path loss, small-scale fading, as well as other crucial channel parameters like the Rician K -factor and the delay spread, the literature's previous findings have been compiled. We came to the conclusion from the literature review that the two most distinguishing characteristics of maritime wireless channels can be summed up as sparse and location-dependent. We also discuss the potential effects of these special features and the corresponding difficulties they may present for the design of maritime communications. Additionally, we talk about the creation of more complex maritime wireless channel models.

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