Improving short to medium range communication over water tides: Why does height matters?

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***Abstract*—Modern observation systems can be composed by heterogeneous entities (e.g., buoys, surface vehicles, on-shore sensors, etc.) that rely on dependable communications for coordination and data collection, often provided by over-water radio-frequency (RF) links. In tide-affected water bodies, RF links at fixed height from the shore can experience the so-called *tidal fading*, a cyclic time-varying tide-induced interference. To mitigate it, the classical space-diversity reception technique (i.e., the use of two or more receiver antennas positioned at different heights) is often applied, commonly combined with the consideration of having one of the antennas at the largest possible height. Yet, this approach does not always ensure the best performance. In this work, we focus on static over-water links of short to medium range distances that use antennas installed at a few meters above surface. We leverage the geometrical basis of the two-ray model to investigate the optimal single-antenna height design that minimizes overall average path losses over a given tidal range. We then extend this analysis to incorporate a second receiver antenna and identify its optimal antenna height. Analytical results show that our method considerably outperforms the more classical approach, thus enabling superior (average) link capacities. A longer version of this summary was presented at IEEE OCEANS 2020.**

***Index Terms*—maritime networks, over-water, space-diversity, tidal fading, tides, two-ray,**

I. Introduction

Maritime and underwater observatories are growing in complexity and can be often perceived as sophisticated distributed systems requiring dependable communication solutions. As buoys, ships, unmanned surface (and aerial) vehicles and nodes onshore must articulate tightly towards a common goal, technologies ensuring reliable and timely transfers of data and control information are critical [1]. Dependable connectivity in maritime conditions is being addressed e.g. in the AQUAMON project [2], dedicated to monitor a salt-water estuary. Wireless radio-frequency (RF) links are still the natural option to support much of the over-water communication of such systems [1][2], but they are subject to a multiplicity of factors that affect signal propagation [3]. The flat and conductive properties of the water medium make signal reflections stronger and this can lead to severe destructive interference. The natural water movements (e.g., tides, waves) add extra propagation effects (both path loss and fading), thus increasing design complexity [4].

The impact of tides on the link quality becomes particularly aggravated when at least one of the terminals does not keep a fixed height to the water level. Due to the varying geometry of the ray reflected on the water surface over the tidal cycle, the quality of the received signal can be greatly degraded due to severe destructive interference with the line-of-sight (LoS) ray during periods of the cycle. To counteract such an issue, the classical space-diversity reception technique, i.e., the use of two (or more) receiver antennas at different heights, is often applied [5], commonly combined with placing one of the antennas at the highest possible position. The method has demonstrated to be effective since early works reported in the literature [6] and until more recent years [7]. However, the focus is almost exclusively in long-range distances. The case of over-water links of short-to-medium-range distance that use antennas close to the surface (and within the magnitude order of the tidal range) is a barely explored but borderline scenario [8][9], which challenges the applicability of the classical technique.

This paper addresses static over-water links, affected by tides, operating over relatively short distances (e.g, few hundred meters) with antennas installed a few meters above surface. We investigate the optimal single-antenna height design that minimizes large-scale fading (path loss) over a given tidal height range. We then extend the analysis to a second receiver antenna and identify its optimal height. Analytical results suggest that our approach considerably outperforms the classical technique, thus enabling superior (long-term) broadband link support. We invite the reader to check a longer version of this work in [10].

II. Background & Problem Formulation

The impact of tides and surface reflections on the receive signal strength of over-water links can be well-described by the geometry of the two-ray model [8][9]. This model takes the resulting signal strength on the receiver side as the vectorial sum of two copies of the same transmitted signal arriving at the receiver from two different paths: (1) a direct line-of-sight (LoS) path between the transmitter and the receiver, and (2) an indirect path reflected from surface. In the static links design, the tide-induced water level oscillation can be incorporated

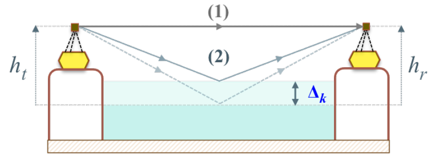

Fig. 1: The two-ray model showing: (1) the direct LoS ray, and (2) the indirect ray reflected from the surface when experiencing a water level variation of Δ_k.

in the model as a small variation (Δ_k) that influences the relative antenna-to-surface heights, thus changing the second path length, but keeping the LoS path unaffected (Fig. 1).

A. *Optimal antenna-height design*

Consider an over-water (shore-to-shore) link as the one presented in Fig. 1, where both transmitter and receiver antennas are installed at the same height w.r.t. an average water level, i.e., h=h_t=h_r, and separated by a distance d. Then, consider a tidal pattern causing a water level variation which influences the nominal antenna-to-surface height in Δ_k. By assuming the large-scale fading of such link is well-described by the two-ray model [11], the attenuation of the link (in dB) when incorporating the effect of tides can be formally expressed as:

$$L_{2ray} = -10\log_{10}\left(\frac{\lambda^2}{(4\pi d)^2}\left[2\sin\left(\frac{2\pi(h+\Delta_k)^2}{\lambda d}\right)\right]^2\right)$$

The problem of finding the optimal antenna height h that minimizes the (average) path losses experienced over all possible $\pm\Delta_k$ values of a given tidal range can be formalized as:

$$\begin{aligned} \underset{h}{\text{minimize}} \quad & \frac{1}{N}\sum_{k=1}^{N} L_{2ray}(\Delta_k) \\ \text{subject to} \quad & \Delta_k \in [\Delta_L, \Delta_H],\ \forall k \in [1, N], \\ & h \in [h_{min}, h_{max}] \end{aligned}$$

where $N \in \mathbb{N}$ is the number of (steps) values of the discretized tidal range where the optimization expression is evaluated; Δ_k is the (signed) value of the k^{th} step, valid within the respective lower (Δ_L) and higher (Δ_H) maximum deviations of the tidal range (w.r.t. h); and $[h_{min}, h_{max}]$ is the h feasibility region.

III. Evaluation

Setup. Consider a shore-to-shore link of distance $d = 100$m, $f = 2.4$GHz (i.e., $\lambda = 1/f$), that uses both transmitter and receiver antennas at the same (nominal) height, $h_t = h_r = h$. Assume the link is affected by a given tidal pattern which can deviate the nominal antenna-to-surface height h within a range of $[-1, +1]$m. Then, in order to avoid tides reach the antennas, assume the minimum design height is $h = 2$m. A maximum of $h = 4$m is assumed as cost/deployment constraint.

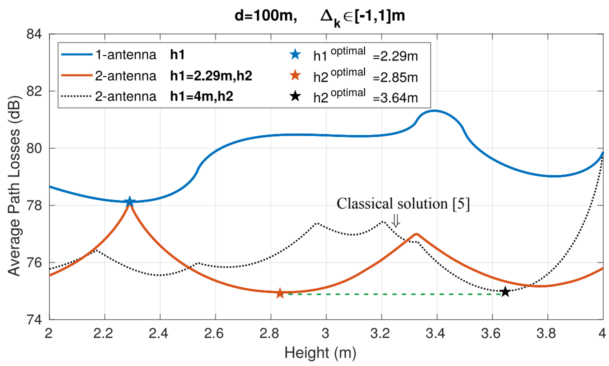

Fig. 2: Link average path loss over a given tidal range as a function of the antenna height when using: (blue) **1 antenna**; (orange) **2 antennas**, one of them at the optimal single-case height; and (dotted) **2 antennas**, one of them placed at the top. The star symbols mark the antenna heights at which reception experiences minimal average attenuation. The arrow symbol indicates the antenna height (and path loss) for the classical space-diversity approach: using one antenna at the top, and the other at a given spacing according to [5].

Results. First, we obtained the (single) optimal antenna-height using our method and compared its performance against the largest feasible height (here, $h = 4$m). Fig. 2 presents the link attenuation experienced at each possible height; which corresponds to the average path losses over the given tidal range. Fig. 2 shows that our method can use a considerably lower antenna height, i.e., $h = 2.29$m, while improving average attenuation. We extended the method to incorporate a second antenna, assuming the first one is placed at the optimal (single-antenna) height. The second position is chosen as the one providing the largest improvement w.r.t. to the previous overall obtained attenuation, i.e., $min[L_{2ray}^{ant.1}(\Delta_k), L_{2ray}^{ant.2}(\Delta_k)]$. This is depicted by the orange curve in Fig. 2. We compare this method against the classical two-antenna space-diversity technique, i.e., one antenna set at the highest point, while the other distances at a convenient antenna-height that avoid simultaneous deep fades [5].

The dotted black line in Fig. 2 shows the case when one of the antennas is at the largest possible height, while the second one is chosen based on our method. This sub-optimal approach obtained an overall attenuation comparable to our (optimal) two-antenna method, but using much higher antenna positions.

IV. Conclusion & Next Steps

This work proposes a novel method for antenna-height design on short-to-medium range over-water links affected by tides. The method allows finding the height at which the minimum average path loss is experienced over a given tidal range. Simulation results suggest that our method outperforms both (i) the common rule of using the largest possible antenna height for the single-antenna case, as well as (ii) the classical space-diversity approach when using two receiver antennas. In future work, we aim at refining the method using different distributions of water level variations (e.g., over a year-period), as well as to evaluate the impact of this method on the average link capacities of over-water Wi-Fi network systems.

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