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Improving WiFi communication with surface nodes at near-shore on tidal waters

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Abstract

Wireless radio links deployed in aquatic areas (e.g., sea, rivers, lakes, estuaries) are affected by the conductive properties of the water surface, strengthening signal reflections and increasing destructive interference. Recurrent natural phenomena (e.g. tides or waves) cause shifts in water levels further impairing propagation over water surfaces. In this work, we aim to mitigate the detrimental impact of tides on link quality by providing tailored link distance/height-design regions that minimize average path losses. We focus on line-of-sight (LOS) over-water links between onshore stations and different types of surface nodes, namely AUVs, buoys, or USVs, using 2.4 GHz and 5 GHz frequency bands. Analytical results targeting mission data transfer scenarios demonstrate that the proposed method outperforms, in both frequency bands, the common practice of placing (i) onshore antennas at the largest possible height and/or (ii) surface nodes at a short but arbitrary distance from the shore. A longer version of this summary was presented at IEEE/MTS OCEANS 2021.

Improving WiFi communication with surface nodes at near-shore on tidal waters

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***Abstract*—Wireless radio links deployed in aquatic areas (e.g., sea, rivers, lakes, estuaries) are affected by the conductive properties of the water surface, strengthening signal reflections and increasing destructive interference. Recurrent natural phenomena (e.g. tides or waves) cause shifts in water levels further impairing propagation over water surfaces. In this work, we aim to mitigate the detrimental impact of tides on link quality by providing tailored link distance/height-design regions that minimize average path losses. We focus on line-of-sight (LOS) over-water links between onshore stations and different types of surface nodes, namely AUVs, buoys or USVs, using 2.4 GHz and 5 GHz frequency bands. Analytical results targeting mission data transfer scenarios demonstrate that the proposed method outperforms, in both frequency bands, the common practice of placing (i) onshore antennas at the largest possible height and/or (ii) surface nodes at a short but arbitrary distance from the shore. A longer version of this summary was presented at IEEE/MTS OCEANS 2021.**

***Index Terms*—maritime communication, over-water, path loss, propagation, tidal fading, tides, two-ray, wireless, WiFi.**

I. Introduction

Wireless radio data links are nowadays a common infrastructure support for remote maritime operations [1]. Modern monitoring and/or control systems operating in aquatic environments (e.g. offshore aquaculture, surveillance, oceanographic research) are gradually adopting radio-frequency (RF) communication technology for data transfer. Yet, achieving reliable RF communication performance in water environments is still challenging because of the multiplicity of factors impacting the over-water channel [2]. The conductive properties of the water medium and the relatively flat surface make radio signal reflections stronger, potentially causing severe interference due to multi-path. Natural water movements, such as tides and waves, further impair signal propagation by reducing the signal strength and superimposing additional fading effects.

The influence of tides on the link quality is particularly noticeable near the shore and when one of the terminals does not keep a fixed height w.r.t. the water surface. The so-called *tidal fading*, i.e., the recurrent impact of tides on the mean path losses experienced in a link, is shown to be tremendously detrimental at specific combinations of link distance and antenna height [3], [4] as predicted by the two-ray propagation model [5]. Conventional methods to counteract tidal fading often rely on classical diversity techniques, e.g., space-diversity or frequency-diversity , thus generally requiring additional communication resources (e.g., a second receiver hardware), which may not always be available or feasible.

Research on this topic is - in general - scarce and mostly focused on the long-range case, i.e., kilometric distances, thus not being directly applicable to the near-shore case. More concretely, the impact of tidal fading on line-of-sight (LOS) shore-to-surface links is often ignored, despite being a quite common issue, e.g. when onshore stations communicate with surface vehicles or mooring nodes, over the duration of a tidal cycle. Typical use cases for such a link setting may include coastal monitoring and/or maritime data off-loading operations by buoys, unmanned surface vehicles (USVs) or autonomous underwater vehicles (AUVs) coming to the surface, that perform sporadic or continuous communication with an onshore gateway (see Fig. 1).

In this work, we target over-water RF links between onshore stations and stationary surface nodes at near-shore, separated by tens to hundreds of meters. We assume that these links are deployed over tidal waters, which effectively change the relative antenna-to-surface height solely of the onshore station, but not of the floating nodes. Then, we aim at optimizing the positioning of the nodes and the height of the involved antennas from a tidal fading perspective. The objective is to minimize average path losses under given tidal conditions, thus providing an improved communication experience (e.g. for mission data transfer). To this purpose, we investigate the LOS shore-to-surface channel and we propose a method to determine the distance/height-design regions of best performance. We carry out this analysis for two frequency bands, namely 2.4 GHz and 5 GHz, concluding that our method is dominant, in both bands, against the common practice of placing (i) onshore antennas as high as feasible and/or (ii) floating nodes at a short but arbitrary distance. A longer version of this study including an experimental campaign using WiFi technology can be found in [6].

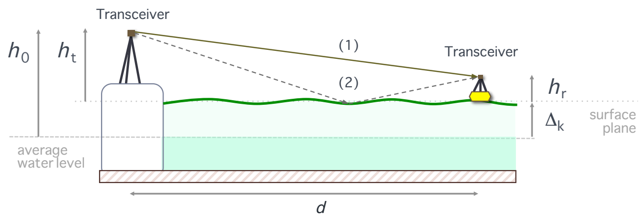

Fig. 1: The two-ray model showing: (1) the direct LoS ray, and (2) the indirect ray reflected from the surface when experiencing a water level variation of Δ_k.

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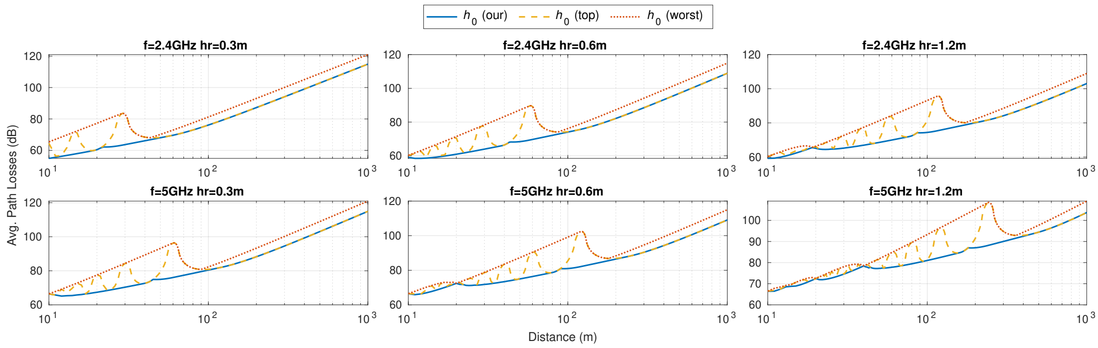

Fig. 2: Link average path loss experienced over a given tidal range as a function of the link distance when using: our antenna-height design method (solid blue), the largest possible antenna height (dashed yellow), or for benchmarking purposes, the 'worst' antenna-height (dotted red), i.e. the one performing with the maximum attenuation within the h_0 range.

II. Problem Formulation

Consider the over-water link of distance d depicted in Fig. 1, wherein one transceiver act as a transmitter Tx, and is installed at a nominal height h_0 w.r.t. a long-term average water level, and the other act as a receiver Rx, and is at a constant height h_r w.r.t. the water surface. Then, consider a tidal pattern causing a water-level variation Δ_k which influences the relative antenna-to-surface height of the transmitter h_t, i.e., $h_t = h_0 + \Delta_k$.

Assuming that the large-scale fading is well-described by the two-ray model, the attenuation of the received signal strength (in dB) when incorporating Δ_k can be formalized as:

$$L_{2ray} = -10\log_{10}\left(\frac{\lambda^2}{(4\pi d)^2}\left[2\sin\left(\frac{2\pi h_r(h_0+\Delta_k)}{\lambda d}\right)\right]^2\right)$$

where $\lambda = c/f$ is the signal wavelength with c being the speed of light and f the operating frequency.

The problem of finding the nominal antenna height of the transmitter h_0 that minimizes the average path losses experienced over a finite number of Δ_k values of a given tidal range can be adapted from [7] and formally expressed as:

$$\begin{aligned} \underset{h_0}{\text{minimize}} \quad & \frac{1}{N}\sum_{k=1}^{N} L_{2ray}(d, h_0, \Delta_k) \\ \text{subject to} \quad & \Delta_k \in [\Delta_L, \Delta_H],\ \forall k \in [1, N], \\ & h_0 \in [h_0^{min}, h_0^{max}] \end{aligned}$$

where $N \in \mathbb{N}$ is the number of steps of the discretized tidal range where the optimization expression is evaluated; Δ_k is the water level variation at the k^{th} step within the tidal range $[\Delta_L, \Delta_H]$; and $[h_0^{min}, h_0^{max}]$ is the h_0 feasibility region.

III. Evaluation

Setup. We explore the range of distances $d \in [10, 1000]$ m while optimizing h_0 within $[3, 6]$ m. We assume the use of Wi-Fi in the 2.4 GHz and 5 GHz bands and a set of receiver antenna heights $h_r = \{0.3, 0.6, 1.2\}$ m characterizing standard surface nodes, namely AUVs, buoys and USVs, respectively. Finally, we consider the tidal range $[-0.5, 0.5]$ m and step-size $\Delta_k = 0.1$ m.

Results. Fig. 2 depicts the average path loss as a function of $Tx - Rx$ distance obtained by our antenna-height design method (solid blue line) and using the largest feasible height (dashed yellow line). For reference, we contrast both against the worst case scenario (dotted red line), i.e., the antenna height within the h_0 feasibility range that leads to the maximum overall attenuation. The results show that our method is always better (or equal) than using the antenna on the top, being, in general, able to offer improvements w.r.t. an arbitrary (worst) link design. In contrast, if the top antenna height is chosen, careful positioning of the surface node is needed, otherwise, the only criteria of using a short distance will not guarantee the best performance.

IV. Summary & Conclusion

This work analyzes the optimal combination of link distance and antenna height for improved communication between an onshore station and a surface node over tidal waters. We consider two WiFi frequency bands and varying link configurations with multiple antenna heights, and we show that our method offers lower average path loss than the common practice of using (i) onshore antennas at the largest possible height and/or (ii) surface nodes at a short but arbitrary distance. In the extended paper we have also addressed the best positioning of different surface nodes, namely buoys, AUVs and USVs, given specific tidal ranges and a specific onshore antenna height. Finally, we have also included an experimental validation.

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