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Abstract

In the design of shore-to-shore and shore-to-vessel wireless links, the impact of the ray reflected on the surface is often neglected. It adds that, in some coastal areas, the geometry of the reflection changes over time due to tides. When choosing an antenna height for an inshore node, often the largest possible height is used, but this approach can lead to signal degradation. The two-ray model is the most fundamental path loss model to account for the contribution of the reflected ray. We carried out experimental measurements at the shores of a freshwater body to verify that the two-ray model can predict the major trends of the path loss experienced by a 2.4 GHz over-water wireless link. We focus on short-to-medium distance links, with antennas installed a few meters above surface. We observed considerable consistency between measurements and model estimates, leading us to conclude that the two-ray model may bring benefits when applied to the network design of over-water links affected by tidal variations, which is our end-goal.

Experimental evaluation of the two-ray model for near-shore WiFi-based network systems design

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***Abstract*—In the design of shore-to-shore and shore-to-vessel wireless links, the impact of the ray reflected on the surface is often neglected. It adds that, in some coastal areas, the geometry of the reflection changes over time due to tides. When choosing an antenna height for an inshore node, often the largest possible height is used, but this approach can lead to signal degradation. The two-ray model is the most fundamental path loss model to account for the contribution of the reflected ray. We carried out experimental measurements at the shores of a freshwater body to verify that the two-ray model can predict the major trends of the path loss experienced by a 2.4 GHz over-water wireless link. We focus on short-to-medium distance links, with antennas installed a few meters above surface. We observed considerable consistency between measurements and model estimates, leading us to conclude that the two-ray model may bring benefits when applied to the network design of over-water links affected by tidal variations, which is our end-goal.**

***Index Terms*—IEEE 802.11, path loss, radio propagation, RSSI, over-water, tides, two-ray, Wi-Fi, WLAN**

I. Introduction

Coastal marine and freshwater environments (e.g., around rivers, lakes or estuaries) have become common deployment locations for environmental monitoring and protection systems. Such systems may be composed of floating/vehicular nodes, e.g., buoys, ships, or unmanned surface vehicles (USVs), and static nodes deployed inshore (or moored to the dock), such as communication equipment and antennas for remote control of the vessels and data collection to the shore [1]. When designing and deploying such systems, the antennas of the static nodes are often placed at a fixed height with respect to the ground surface [2], at the highest possible point, in order to achieve the best link quality. However, this design option fails to account for key path loss and fading propagation phenomena that may degrade the received signal [3].

One of the main aspects affecting over-water communications is the impact of the ray reflected on the water surface. The two-ray propagation model [4] is one of the most established and convenient literature methods to describe that phenomenon, treating it as a geometrical problem dependent of the link distance and antenna height, among other parameters. The problem gets further aggravated at coastal areas for shore-to-shore and shore-to-vessel links, as tides impose a variation of the geometry of the reflection over time [3], [5]. In the literature, numerous works have explored the fundamentals of this model to explain the propagation of radio signal in other over-water conditions [6] but for long-range links that use much higher antennas. Recent experimental works focusing on short and medium-range link distances that use near-surface antenna heights present non-conclusive ideas about the fitting of the two-ray model to these particular settings [7]–[9].

In this work, we carried out an experimental campaign to evaluate the impact of the surface reflection on the received signal strength [indicator] (RSSI), specifically on shore-to-shore links of short and medium-range distances (< 200m) and for **two heights of antennas** up at a few meters above the surface (< 3m). In the set of link distances and antenna heights that we explore, the two-ray model predicts the occurrence of strong path loss attenuation (due to the reflected ray) at well-defined distances (also known as deep fades or dips in received power).

This preliminary work and results do not aim for an accurate numerical validation of the two-ray model, but for an empirical observation of the phenomenon captured by the model. This is to provide strength to the claim that the two-ray model can be safely used as a building block in more sophisticated network design methodologies that take into account the surface reflection and antenna-to-surface height variation over time. In turn, these will enable a more efficient operation of shore-to-shore and shore-to-vessel links, the latter of which can be used for exchanging data with and remote controlling moving nodes (i.e., buoys, ships, USVs). While the measurements were taken in a shore-to-shore link, the results are applicable to vessel-to-vessel links, as the height to water surface was kept constant and equal at both terminals.

II. Background on the Two-Ray Model

Consider a shore-to-shore link with distance d in which the transmitter and receiver antennas are installed at the same

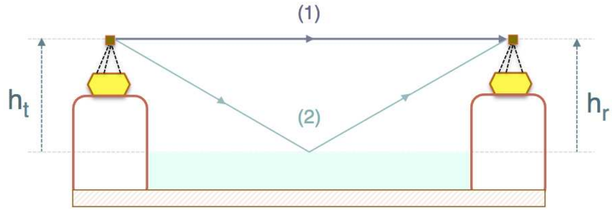

Fig. 1. The two-ray propagation model showing: (1) the direct line-of-sight (LoS) ray, and (2) the indirect ray reflected from the water surface.

height h=h_r=h_t to the water surface. The two-ray model describes the received signal strength as the interference of two copies of the transmitted signal, one that follows the line-of-sight (LoS) ray and a second that is reflected on the water surface. The interference between the two rays may be constructive or destructive depending on their phase; this, in turn, depends on the difference of the path lengths and, subsequently, on the antenna-to-surface height. Figure 1 shows a graphical representation of the two-ray propagation model.

Formally, the two-ray model describes the received power P_r is modelled as the contribution of the Friis [4] free-space path loss prediction and the second ray, resulting in the (simplified) formula:

$$P_r = \frac{\lambda^2}{(4\pi d)^2}\left[2\sin\left(\frac{2\pi h_t\ h_r}{\lambda d}\right)\right]^2 P_t G_t G_r \qquad (1)$$

where λ is the wavelength, P_t the transmitted power, and G_t and G_r the respective transmitter and receiver antenna gains.

In this paper, we aim to empirically show that the antenna height should indeed be a factor of relevance in the design of shore-to-shore links, and that the traditional rule-of-thumb (*higher-is-better*) neglects an important propagation effect that, in coastal areas, may have an additional time-variant behaviour as a consequence of tides.

III. RSSI Measurements in Shore-to-Shore Links

A. Setup

We set up a testbed at the shore of a large body of fresh water situated at the Porto City Park, in Porto, Portugal, to collect packet-based RSSI values. Two wireless network interface cards (NIC) were used, and installed as shown in Fig. 2 (a). The transmitter was kept at a fixed position at one side of the shore, while the receiver was placed at one of other 9 different positions, on the other side of the shore (Fig. 2 (b)); the receiver distance to the shore was kept constant at $\sim$ 1m. The receiver positions were chosen in order to generate a set of links distances within the range of interest,

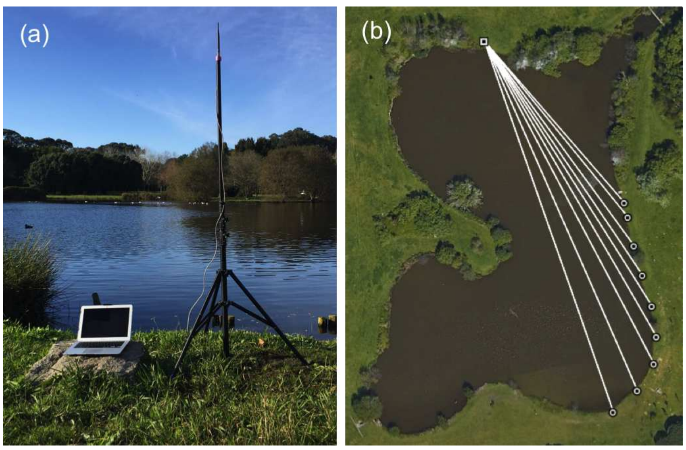

Fig. 2. The experimental setup showing: (a) a representative node deployment at the actual location, and (b) the set of links and nodes positions evaluated.

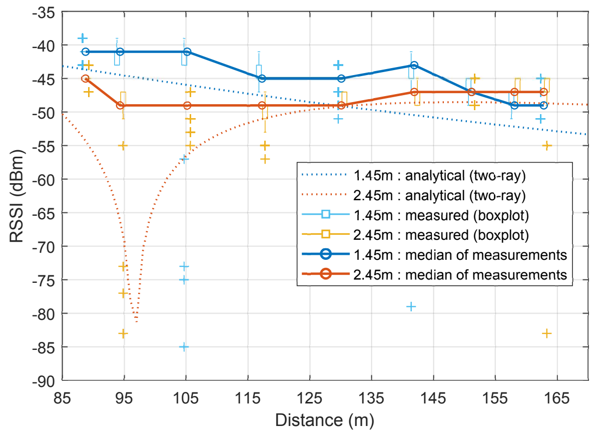

Fig. 3. Two-ray model RSSI estimates for two antenna heights (dotted lines) and field measurements at selected distances (per distance, two side-by-side boxplots [one per height], slightly offset to true distance and color-faded for readability; outliers shown as crosses); medians of measurements are connected (solid line).

namely: 88.75m, 94.33m, 105.2m, 117.28m, 130.11m, 141.9m, 151.17m 158.11m, 162.84m. The distances were obtained from the Google Earth tool. Regarding the antenna height to the water surface, we carried out measurements at two heights (for both the transmitter and receiver terminals): 1.45m and 2.45m. These were measured with a conventional measuring tape, to the best of our capabilities.

The wireless NIC in use was an Amiko WLN-880 coupled to a rubber duck, vertically positioned, omnidirectional antenna providing 5dBi gain in the 2.4 GHz band. All transmissions used channel 1 (2412 MHz) and default IEEE 802.11b (WiFi) configurations, namely: beacon frames sent periodically every $\sim$ 100ms, and at a fixed transmission power of 20dBm. At each distance and height, data collection lasted $\sim$ 3min.

B. Results & Discussion

Figure 3 presents the RSSI measurements collected utilizing the configurations above described, and the corresponding values predicted by the two-ray model (Eq. 1, in dBm). From these results, we highlight two particular features. First, the RSSI obtained with the antenna at 1.45m was on average higher than at 2.45m for distances up to 150m, after which the relationship is inverted. Second, we observed a considerable drop in the received power when the antenna is at 2.45m for the [90, 130]m range. These results are consistent with the behaviour produced by the two-ray model, that indicates: (i) an inversion of the antenna height that experiences the highest RSSI for the same distance (at 130m); and (ii) a considerable dip in received power for the 2.45m antenna height (between 80-120m).

While the measured and estimated patterns are similar, there is some numerical mismatch both on the received power and the distances at which the mentioned phenomena occur. This stems from two sources. First, the used methodology may have suffered from relevant limitations, namely regarding the accurate measurement of distances, heights and cable attenuation. A thorough revision of the methodology is necessary in future experimental campaigns to minimize such sources of error; nevertheless, that aims beyond the exploratory nature of the current measurements. Second, the two-ray model captures the impact of one of the main path loss components in near-surface communications (the reflected ray), but this is not the only propagation effect taking place. Other path loss effects such as other reflected rays and fading phenomena such as scattering also contribute to the received power, and may account for why the signal loss estimated for the 2.45m height around 95m, while it was observed, was not of the magnitude predicted by the model.

IV. Conclusion & Next Steps

This work presents an empirical study of radio signal propagation in near-surface/short-to-medium-range links deployed over freshwater. The results suggest that the two-ray model is capable of representing major trends in the path loss experienced by a wireless signal transmitted in over-water links. Consequently, we hypothesize and observe that antenna height adjustment is an effective design approach to improve the signal quality in this type of links, and that the two-ray model can effectively guide the design of over-water links. In the future, we will use this work as a building block towards the end-goal of creating new network design methodologies for shore-to-shore and shore-to-vessel that take into account surface reflections and their variation over time, in the case of coastal environments.

Acknowledgment

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