Poster Abstract: Runtime Adaptation of PHY Settings for Dependable UWB Communications

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ABSTRACT

IoT localization systems based on ultra-wideband (UWB) technology require dependable communication links to reliably acquire and efficiently share the timestamps in the network. The communication performance of UWB radios, however, is still largely unexplored and strongly affected by the employed physical layer settings. In this work, we analyze the role of different UWB physical layer settings and propose a scheme that adapts them at runtime in order to maintain a highly reliable link while minimizing energy consumption. The proposed adaptation scheme exploits the channel impulse response provided by the UWB transceiver to estimate the link quality and to extract information about the surrounding environment, such as the presence of destructive interference.

1 INTRODUCTION

Ultra-wideband (UWB) transceivers provide a much higher bandwidth than traditional low-power wireless IoT technologies, which results in a superior time-domain resolution allowing for accurate localization. To date, the main focus of the IoT research community has been on algorithms that maximize the localization accuracy of UWB systems [3]. Most of these works, however, ignore that (i) time-based localization systems require dependable communication links to reliably acquire and efficiently share the timestamps in the network and that (ii) UWB radios are considerably more energy-hungry than narrowband IoT transceivers such as BLE.

The role of UWB PHY settings. Off-the-shelf UWB radios such as the Decawave DW1000 allow to fine-tune PHY settings such as channel, bandwidth, preamble symbol repetitions, pulse repetition frequency, and data rate. These settings have a significant impact on the reliability and energy efficiency of communications. Unfortunately, the community has not yet characterized and quantified this impact in detail. Getting a thorough understanding of how (and how much) each setting influences UWB's communication performance is a necessary first step to build dependable IoT systems.

Adapting UWB PHY settings at runtime. With such an understanding, one can indeed employ the PHY settings of radio transceivers as tuning knobs towards a reliable and energy-efficient UWB communication and localization. UWB systems currently employ static PHY settings defined at setup time [2], which makes them incapable of reacting to fluctuating signal power due to changes in the surrounding environment (e.g., presence of destructive interference). Hence, there is a stringent need to detect changes in the environment and to automatically adapt the system at runtime accordingly. This, however, requires a link state indicator tailored to UWB that captures both the link quality and the environmental state (e.g., presence of destructive interference, absence of line-of-sight).

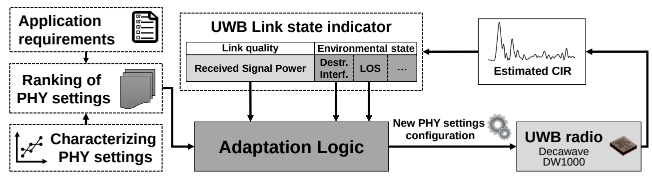

Figure 1: Overview of the proposed adaptation scheme.

We describe next a novel scheme that adapts UWB PHY settings at runtime in order to maintain a highly reliable link while minimizing energy consumption. The proposed scheme exploits the channel impulse response (CIR), i.e., information about reflections from walls and scattering from other objects, provided by UWB radios to estimate the link quality and to extract information about the surrounding environment. After describing the main design components of the proposed scheme in Sect. 2, we present a preliminary experimental evaluation of its performance in Sect. 3.

2 PROPOSED ADAPTATION SCHEME

Fig. 1 shows an overview of the proposed adaptation scheme. First, a ranking of PHY settings is derived based on the application requirements and on an experimental characterization of their impact on the reliability and efficiency of UWB communications (Sect. 2.1). Second, an UWB link state indicator provides information about the link quality and the environmental state (Sect. 2.2). In the case of a reduced signal power or a change in the surrounding environment, the logic adapts the PHY settings according to the derived ranking.

2.1 Impact of PHY Settings

Low-cost IEEE 802.15.4-compliant UWB transceivers provide five different PHY parameters to fine-tune the performance: *channel*, *bandwidth*, *preamble symbol repetitions (PSR)*, *pulse repetition frequency (PRF)*, and *data rate*.

We have characterized each of these PHY settings by connecting two UWB transceivers with an SMA cable and a tunable attenuator. Fig. 2 shows for example the packet reception rate (PRR) over the attenuation level for the lowest (110kbps) and highest data rate (6.8Mbps) supported by the DW1000 radio. On the one hand, it shows that the lowest data rate reduces the sensitivity of the receiver by 5.5dB, which is a variation sufficient to transform a

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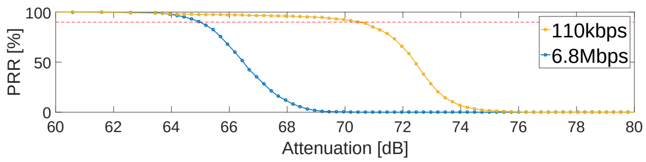

Figure 2: Packet reception rate (PRR) as a function of attenuation and data rate [1].

useless link into a highly reliable one. On the other hand, the lower data rate results in an about 64x higher energy consumption due to the longer transmission. Table 1 summarizes the results of our characterization, showing the impact of each UWB PHY setting on the reliability and energy efficiency of communications.

Table 1: Trade-off between reliability and energy efficiency.

Change in PHY setting	Reliability	Energy efficiency
Higher PSR	-	↓↓↓↓
Higher PRF	↑	↓↓
Lower data rate	↑↑↑↑	↓↓↓↓
Lower carrier frequency	↑↑↑	↑
Higher bandwidth	↑↑	↓

2.2 Link state indicator

Adapting PHY settings at runtime requires to assess the quality of a link continuously. Based on this information, the adaptation logic can trigger the change of a PHY setting in the case of a degrading link. To estimate the link quality, we make use of the CIR derived by UWB transceivers, which provides information about the multipath propagation consisting of reflections from walls and other objects.

Deriving environmental state. Due to the high bandwidth, UWB transceivers are less affected by multipath fading than narrowband radios. Still, at longer distances the line-of-sight (LOS) component may still overlap with multipath reflections. This can result in destructive interference and hence heavily degrade a communication link. Detecting the presence of destructive interference is possible by analyzing the CIR. Fig. 3 shows two CIRs acquired with the DW1000 transceiver. One CIR refers to a highly reliable link with a clear LOS (blue, solid); the other one was derived when the LOS was overlapping with a reflection from the wall, causing a deep fade due to destructive interference (green, dashed). It is evident that, in the case of destructive interference, the amplitude of the LOS component drops significantly, while the amplitude of the multipath reflections remains constant. Hence, keeping track of the LOS and multipath signal energy ratio can provide an efficient mechanism to detect destructive interference.

Deriving the link quality. To estimate the received signal power (RSP) and the quality of the link, we use the integral of the entire CIR. We derive empirically a threshold RSP_{TH} at which the packet reception rate (PRR) drops below 90% and use this to signal the adaptation logic that a change to a more robust setting is needed. Similarly, we derive a second threshold RSP_{EE} signaling the adaptation logic that the link margin is sufficiently high to switch to a more energy-efficient (but less robust) PHY settings configuration.

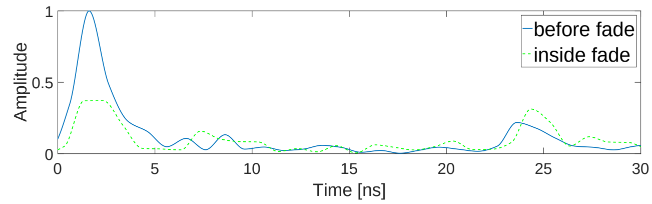

Figure 3: Channel impulse response acquired inside a fade due to destructive interference (green, dashed) and before a fade (blue, solid) [1].

3 PRELIMINARY EVALUATION

We evaluate the performance of the proposed scheme experimentally by exposing two UWB nodes to dynamic environmental conditions. Towards this goal, we program a tunable attenuator with the pre-defined attenuation sequence shown in Fig. 4 (top), and compare the packet reception rate of the two nodes when using static PHY settings and our adaptation scheme. Fig. 4 (middle) shows the results: whilst the use of static settings results in a significant packet loss over time, the proposed adaptive scheme allows to sustain a PRR always higher than 98%. Fig. 4 (bottom) shows the received signal power over time: the thresholds RSP_{TH} (red solid) and RSP_{EE} (red dotted) are used by the adaptation logic to trigger a change in the PHY settings configuration. We have further observed that the proposed adaptation scheme increases the energy efficiency over time and that it promptly detects the presence of destructive interference and triggers a change of PHY settings. These preliminary results demonstrate that the proposed adaptation scheme effectively increases UWB's communication performance.

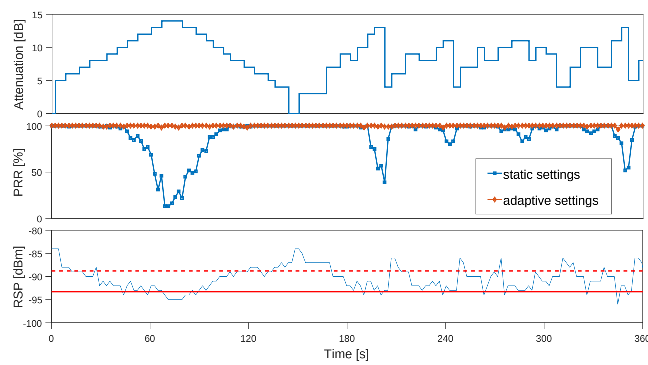

Figure 4: Evaluation of the adaptation scheme showing the attenuation sequence (top), packet reception rate (middle), and the received signal power (bottom).

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