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Experimental analysis of IEEE 802.15.4a CSS ranging and its implications

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ABSTRACT

The IEEE 802.15.4a Chirp Spread Spectrum (CSS), known to be resistant to electromagnetic disturbances, performs precise ranging. This work aims to analyze the performance and characteristics of CSS ranging in indoor environments under actual real-life conditions. The results indicate that unpredictable multipath effects due to surrounding deployment environments may cause unreliable ranging distances in indoor environments. This phenomenon may critically influence the positioning algorithm. To address this issue, this research proposes a simple scheme to estimate the reliability of measured distance.

1. Introduction

Location awareness is a key feature of mobile applications that are emerging in the pervasive computing era [1–3]. While the GPS is the best suited to implement location-aware systems in outdoor environments, it certainly has limitations indoors. Various technologies, such as ultrasound, Wi-Fi, Bluetooth, RFID, and inertial sensors, are used to develop indoor locating systems [4–9]. The Chirp Spread Spectrum (CSS) is a new radio technology for positioning systems. CSS is exploited by the IEEE 802.15.4a [10] standard that supports accurate ranging with low power consumption. CSS ranging has advantages over previous methods based on radio signals. Traditional localization systems based on Received Signal Strength Indicator (RSSI) [11,12] have problems such as high initialization cost, measurement errors, and security issues, which are not present with CSS. Furthermore, CSS ranging compromises the weaknesses of traditional ranging techniques using time of flight (ToF) for signal between two devices distance estimation error from hardware clock drift, and signal interference by Symmetrical Double-Sided Two-Way Ranging (SDS-TWR) [13]. Since the CSS spreads over the 2.4 GHz ISM band, the technique is conveniently merged with other wireless systems to provide location awareness.

Researchers have attempted to understand errors in distance measurement by using radio frequency, since the scheme does not require additional devices. Research has produced diverse types of filtering methods to complement errant positioning results [14–20] and algorithms [19,21–25] to detect or reduce non-line-of-sight (NLoS) influence. In particular, some researchers have paid particular attention to investigation of indoor localization systems using Ultra-wideband (UWB) [24,26–32]. Few studies, however, have examined the characteristics of CSS ranging in localization systems [14,33,34], which is the subject of this study. We analyze CSS ranging accuracy and measurement error in real environments to identify the characteristics of ranging results. We also endeavour to find a practical method to implement high-performance indoor localization systems based on CSS ranging.

This paper is organized as follows. Section 2 describes the background of CSS radio frequency and its ranging mechanism. In Section 3, we analyze the results of CSS ranging in real environments and show the relationship between Packet Reception Rates (PRR), Ranging Success Rates (RSR), and Automatic Gain Control (AGC) values. Section 4 proposes a simple scheme to determine the reliability of a measured distance at run time. We conclude the paper in Section 5.

2. Background

The IEEE 802.15.4a standard is an alternate physical layer standard of IEEE 802.15.4 that allows high communication throughput and precise ranging capability. The standard specifies two optional signaling formats based on UWB and CSS. The UWB PHY has designated frequencies in three ranges: below 1 GHz, between 3 and 5 GHz, and between 6 and 10 GHz. The CSS PHY is designated to the 2450 MHz ISM band.

The CSS uses chirp pulses for transmission over air. A chirp is a frequency-modulated pulse that changes monotonically from low to high value (Upchirp) or from high to low value (Downchirp) by Linear Frequency Modulated (LFM) signals with constant amplitude. Fig. 1 shows the signal forms of Upchirp and Downchirp. The

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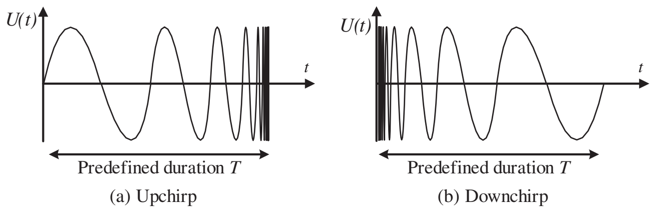

Fig. 1. Upchirp and Downchirp pulse.

LFM is based on *Frequency Spreading* and *Time Spreading* techniques. Chirp signals always fill out the total available bandwidth of the channel for transmission over a predefined duration, even if the data rate does not require full bandwidth. Narrow band noise does not significantly affect the transmission of the symbol, because the full bandwidth of the radio frequency channel is used. Thus, a sufficient amount of uninfluenced symbol energy remains to reach the receiver. Consequently, the chirp signal has a high resistance against disturbances [35].

A key advantage of CSS is robustness against multi-path fading. During signal transmission, echoes and reflections arise from environmental surroundings due to multi-path propagation.

In this situation, some frequencies will be amplified or attenuated, which may distort the signal on narrowband transmission systems. However, CSS is different in that the amplified and attenuated signals are in balance because the broadband technique integrates all energy shares [35]. The CSS characteristics are expected to improve the accuracy of ToF-based ranging techniques in indoor environments.

CSS ranging is a methodology using SDS-TWR [13] to overcome the inherent difficulties of ToF distance measurement. SDS-TWR, which is based on the Round Trip Time (RTT) methodology as illustrated in Fig. 2, uses the signal propagation delay between two nodes and the processing delay within a node. To estimate the signal propagation delay, Node 1 sends a ranging packet to Node 2, and expects an acknowledgement. Upon the reception of the acknowledgement, Node 1 estimates the signal propagation delay and the processing delay that is assumed to be equal on both nodes. Although the clock synchronization is necessary, the range estimation is affected by clock accuracy of two nodes, which can be eliminated by symmetrically performing additional ranging from Node 2 to Node 1. At the end of this procedure, two range values are determined and the accuracy of range calculation can be verified. Finally, an average of the two measurements is used to achieve a fairly accurate distance measurement between these two nodes.

Recently, various ToF-based ranging techniques [19–26,29,30] have become available for indoor localization systems, which specifically target fundamental problems such as NLoS propagation, multi-path fading, and hardware clock drifts. In this context, CSS is a viable solution. To date, studies on indoor CSS ranging with real experimental data have been insufficient, compared to studies done on UWB. In particular, the European research project PULSERS [36] has shown experiment results with range estimation errors for their UWB-based indoor localization system [24,27–30,37]. The experiments considered range measurements corrupted by thermal noise, multi-path fading, direct path (DP) blockage, and DP excess delay.

To implement an indoor localization system via CSS ranging, we should first understand the performance characteristics of the technology in real environments under realistic conditions. In the following, we present our experiment results and describe the characteristics of indoor CSS ranging.

3. Indoor ranging analysis

We experimented on CSS ranging between two nodes and analyzed how measurement error and its distribution changed with varying distances. We conducted experimental analyses to characterize the measurement error, because accurate prediction of the

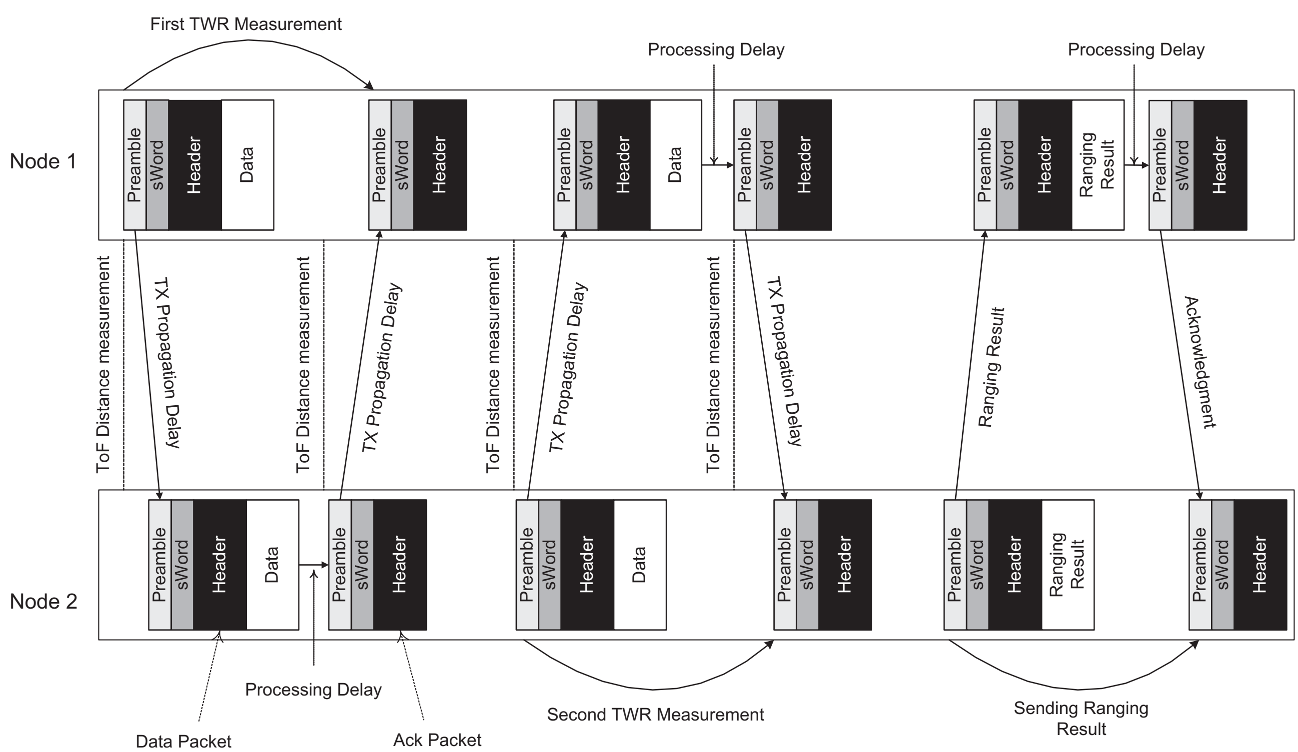

Fig. 2. Measuring distance with SDS-TWR.