Poster: Increasing the Reliability of Concurrent UWB Transmissions over Complex Channels

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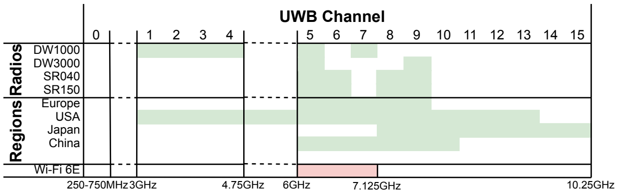
Abstract

Due to hardware limitations and legal restrictions, very few frequency channels are usable when developing applications based on ultra-wideband systems. As this hinders the adoption of this increasingly popular technology, the IEEE 802.15.4 standard introduces the concept of *complex channels* in order to create multiple orthogonal channels within the same frequencies. However, concurrent transmissions on different complex channels are known to be unreliable and lead to a high packet loss. In this poster, we propose a novel method to increase the reliability of concurrent transmissions on complex channels *by altering the radio's clock frequency offset*. Preliminary results show that the packet reception rate of concurrent transmissions on several complex channels remains close to 100 % when increasing the relative clock frequency offset of the devices by more than 5 ppm.

1 Introduction

Due to its high bandwidth and excellent time resolution, ultra-wideband (UWB) technology allows for cm-level ranging accuracy. Therefore, since the introduction of the IEEE 802.15.4a standard in 2007, the popularity of UWB for building location-aware Internet of Things (IoT) applications has soared. This success also led to an increasing amount of UWB devices being commercialized: companies such as Apple, Google, or Samsung have recently integrated UWB radios into their smartphones. To support such a high number of devices, separate frequency channels are needed to reliably communicate without interference. Unfortunately, *the number of channels available for UWB systems is limited.*

Limited number of available channels. The IEEE 802.15.4 standard foresees 16 physical channels with center frequencies between 500 MHz and 10 GHz (see Fig. 1). However, in order to mitigate interference among different technologies, institutions such as the FCC or CEPT restrict the usage of certain frequencies. For example, only five UWB channels (5 to 9) can currently be used in Europe. The lack of frequencies is exacerbated by the fact that UWB has to compete with other radio technologies in certain frequency bands, with Wi-Fi 6E being a well-known example of technology severely affecting UWB communication performance [1]. Moreover, existing UWB hardware typically supports only a fraction of the channels foreseen by IEEE 802.15.4. While Decawave's DW1000 radio – which has driven most of the recent UWB research – supports six channels [2], its successor, the Qorvo DW3000, supports only two channels. Another recent UWB radio, the NXP SR150, can only operate on four channels.



		0		1	2	3	4		5	6	7	8	9	10	11	12	13	14	15
Radios	DW1000			🟩	🟩	🟩	🟩		🟩		🟩								
	DW3000								🟩				🟩						
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	SR150								🟩	🟩		🟩	🟩						
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	Japan											🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	China								🟩	🟩	🟩	🟩	🟩	🟩					
	Wi-Fi 6E								🟥	🟥	🟥								

Figure 1: List of UWB frequency channels available in different regions and supported by popular off-the-shelf radios.

Limited reliability of complex channels. In order to increase the number of available channels, the IEEE 802.15.4 standard suggests the usage of so called *complex channels*. A complex channel (CC) is defined as the combination of a physical channel and preamble code. Preamble codes are chosen with a low cross-correlation, in order to allow simultaneous transmissions on the same physical channel. Unfortunately, this channel separation is known to be unreliable [2], leading to inter-channel interference. Vecchia et al. have reported packet loss rates between 47 % and 58 % using two concurrent transmitters on different complex channels [4]. Due to this high unreliability, complex channels are not usable by IoT applications that require a high energy efficiency and cannot tolerate a high number of retransmissions.

Contributions. In this work, we show a novel approach, leveraging the potential of altering the clock-frequency offset (CFO) between UWB devices to improve the reliability of concurrent transmissions over different complex channels and hence significantly increase the number of available orthogonal channels. After illustrating the main idea (§ 2), we report initial results showing the effectiveness of the proposed approach (§ 3).

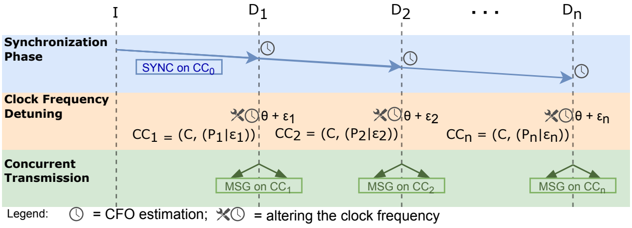


Figure 2: Sketch of the proposed approach when considering concurrent transmitters operating over n complex channels with different CFO adjustment values (ε_i).

2 Working Principle

We propose a scheme that leverages the ability of UWB radios to measure the CFO between devices and adjust their clock frequency in order to increase the reliability of concurrent transmissions over different complex channels.

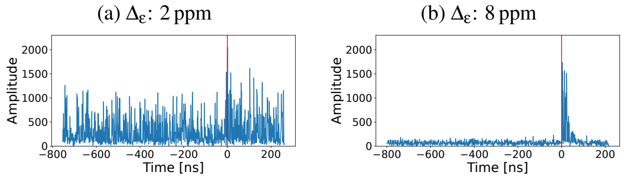
Consider the scenario illustrated in Fig. 2: n devices receive on a given complex channel (CC_0) a synchronization message sent by an initiator I running with a clock frequency θ. Upon reception of a message, each device estimates the relative CFO to the initiator, and alters its own clock frequency in order to match θ. We then extend the definition of preamble code *by associating a CFO adjustment value* ε_i *to each preamble code value* P_i. A complex channel is hence defined as a combination of physical channel (C) and a preamble code ($P_i|\varepsilon_i$). Based on the complex channel assigned for transmission, a device will detune its clock frequency by ε_i. For example, the clock frequency of n concurrent transmitters operating on $CC_1, \ldots, CC_n$ will be detuned w.r.t. θ by $\varepsilon_1, \ldots, \varepsilon_n$, respectively. As we show in § 3, when considering concurrent transmissions over n complex channels, if the minimum difference between the CFO adjustment value of two complex channels (Δ_ε) is ≥ 5 ppm, the transmissions will be received with a packet reception rate (PRR) close to 100 %, i.e., $\forall i, j \in \{1, \ldots, n\} : |\varepsilon_i - \varepsilon_j| \geq 5\,\text{ppm} \Rightarrow \text{PRR} \approx 100\%$.

Note that, in practice the synchronization phase may be omitted for inherently-synchronized networks, as can be found when using flooding or IEEE 802.15.4 TSCH.

3 Preliminary Evaluation

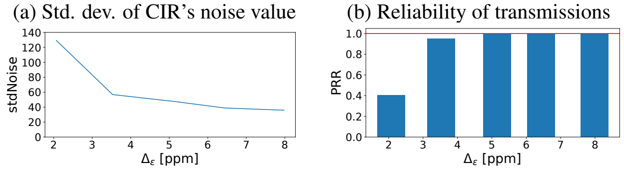
To show the effectiveness of the proposed approach, we use five Qorvo DWM1001-DEV boards [2] located in an office environment that is part of a larger UWB testbed facility at our premises [3]. One node acts as *initiator* (I) sending a `SYNC` message over CC_0 to four nodes, who act as concurrent *responders* over different complex channels ($CC_0, \ldots, CC_3$).

Upon reception of the `SYNC` message, each responder estimates its current CFO in relation to the initiator using the carrier-recovery integrator value provided by the DW1000 radio. Using the trimming feature provided via the radio's `FS_XTALT` register, the responder can set a specific CFO. The latter is adjusted based on the ε_i associated to the employed complex channel, with the clock frequency of the initiator θ being the reference value for all responders. After this step, the radio is configured to the assigned complex channel, and the responders concurrently transmit their message using the radio's delayed transmission feature, which allows synchronized transmissions with an accuracy of 8 ns [2].


(a) Δ_ε: 2 ppm

(b) Δ_ε: 8 ppm

Figure 3: CIR recorded in the presence of concurrent transmissions over multiple complex channels as a function of Δ_ε.


(a) Std. dev. of CIR's noise value

(b) Reliability of transmissions

Figure 4: Impact of Δ_ε on the CIR's noise value (a) and on the reliability of concurrent transmissions (b).

After sending the `SYNC` message, I is configured to receive messages on the same complex channel (CC_0), and to record the PRR, channel impulse response (CIR), and additional debug info such as the standard deviation of the CIR's noise value (*stdNoise*). All devices use channel 4 with a pulse-repetition frequency of 64 MHz, and we set $CC_0 = (4, (9, 0))$, $CC_1 = (4, (10, \Delta_\varepsilon))$, $CC_2 = (4, (11, -\Delta_\varepsilon))$, and $CC_3 = (4, (12, 2 \cdot \Delta_\varepsilon))$. We then study the PRR and the *stdNoise* received at I as a function of Δ_ε by performing 10.000 concurrent transmissions.

Experimental results. Our evaluation results confirm the findings from Vecchia et al. [4] concerning the unreliability of complex channels when not altering the radio's CFO. Specifically, Fig. 3 shows that the CIR received with a low Δ_ε (2 ppm) is much noisier than the one taken with a higher Δ_ε (8 ppm). This trend can also be seen in Fig. 4a, which shows a noise reduction by up to 72 % when increasing Δ_ε from 2 to 8 ppm. Fig. 4b further shows the improvements in reliability: when using $\Delta_\varepsilon \geq 5$ ppm, the PRR measured at I is consistently around 100%.

4 Conclusions and Future Work

Our preliminary results confirm the feasibility of the proposed approach. In the future, we plan to experimentally prove its effectiveness for different UWB platforms, PHY settings, and RF environments, as well as with a higher number of complex channels. We also aim to investigate the impact of the proposed approach on the ranging accuracy, as an increasing noise may deteriorate performance. Our ultimate goal is to embed the proposed principle into existing UWB networking stacks employing TSCH or flooding, showing its benefits for real-world applications.

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5 References

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