First Steps in Benchmarking the Performance of Heterogeneous Ultra-Wideband Platforms

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***Abstract*—The recent gain in popularity of ultra-wideband (UWB) technology and the rapid development of new-generation transceivers triggered by the IEEE 802.15.4z amendment has led to a large number of UWB systems being deployed and to an increasingly heterogeneous ecosystem. This growing heterogeneity calls for quantitative performance comparisons across different hardware platforms on a large scale, so to identify their strength and weaknesses and to verify whether heterogeneous devices can interact with each other seamlessly. Additionally, the recent opening of the 6 GHz band has raised major concerns in the UWB community, as Wi-Fi 6E is now allowed to operate in the same unlicensed spectrum used by UWB devices. Therefore, the ability to examine and compare the performance of different UWB platforms in presence of Wi-Fi 6E interference is key to develop robust and dependable solutions. In this paper, we describe our first steps towards the development of a large-scale testbed facility that allows us to benchmark and shed light on the performance of different UWB platforms in the absence and presence of cross-technology interference, as well as on their interoperability. We further present preliminary results comparing the communication performance of old- and new-generation UWB platforms, namely the Decawave DW1000 and Qorvo DW3000, as a function of different physical layer settings and with or without co-located Wi-Fi 6E activity.**

***Index Terms*—Experimental evaluation; Decawave DW1000, Qorvo DW3000, Interference, IoT, Performance, Testbed, UWB, Wi-Fi 6E.**

I. INTRODUCTION

Recently, ultra-wideband (UWB) has gained increasing attention in both industry and academia thanks to its superior time-domain resolution. UWB has indeed become one of the most popular choices for developing indoor positioning systems, with applications ranging from the automotive sector (e.g., secure vehicle access) and industrial domain (e.g., asset tracking) to smart healthcare (e.g., assisted living, medical monitoring) and other IoT use cases [1].

This increased popularity has materialized in several hundred millions UWB device shipments in 2021 alone [2], and in a large number of players entering the UWB market. For example, established companies such as Apple and NXP Semiconductors have started integrating their chips into vehicles and smartphones, whereas a plethora of UWB system providers such as Zebra Technologies, Ubisense, Kinexon, and Sewio has emerged, fuelling the adoption of UWB services [3]. As a consequence, the UWB ecosystem has now become *much more diverse*, which represents a radical change compared to the last decade, when only a handful ultra-wideband chips and platforms were commercially available.

The need for benchmarking. This growing heterogeneity in the UWB landscape raises the need for quantitative performance comparisons across different platforms, so to identify their strengths and weaknesses. Such a benchmarking activity would not only facilitate the platform selection process for developers, but would also foster competition between manufacturers and further increase the adoption of UWB technology.

Comparing old- and new-generation UWB chips. To date, nearly the entire body of experimental UWB research has revolved around Decawave's (now Qorvo) DW1000 chip [4], one of the first and few UWB platforms compliant to the IEEE 802.15.4a standard that could be readily found off-the-shelves in the past years [5]. Following the increasing standardization efforts around UWB technology [1], new-generation UWB platforms have emerged, such as Qorvo's DW3000 [8] and NXP's Trimension [9], [10]. These platforms offer similar features as the DW1000 to ensure backwards compatibility, but also support new functionality and embed several improvements in the transceiver design. It is hence interesting to benchmark their performance and compare it with that of old-generation hardware under the same settings.

Understanding the role of PHY settings. The IEEE 802.15.4 standard allows to fine-tune a large number of physical layer (PHY) settings, which are known to have a strong impact on communication performance and ranging [5], [11]. Whilst the impact of these settings has been largely investigated experimentally on the DW1000 chip, it is yet to be confirmed whether the same trends apply on different platforms. Moreover, new-generation chips often support a larger set of possible values for each PHY setting (e.g., the DW3000 radio offers many more preamble symbol repetitions than those supported on the DW1000), and quantifying how different the performance is for these new values would also be valuable.

Analysing the resilience to external interference. The advent of Wi-Fi 6E represents a major threat for UWB-based systems, as the latter share the same spectrum and operate at a significantly lower power than Wi-Fi devices [12]. Therefore, benchmarking the communication and ranging performance of different UWB platforms in the presence of Wi-Fi 6E traffic is interesting to shed light on their resilience to cross-technology interference – a promising research avenue as UWB is experiencing this challenge for the first time [13].

Testing the interoperability across platforms. With a growing number of UWB systems being deployed, concerns about inter-technology interference from co-located UWB networks keep increasing. It is hence important to systematically test how co-located UWB networks coexist, and whether heterogeneous UWB devices can correctly interact (e.g., towards the creation of collaborative coexistence strategies).

Our contributions. In this work, we take the first steps towards the creation of a testbed facility allowing us to benchmark the performance of heterogeneous UWB platforms, and perform initial experiments shedding light on how old- and new-generation UWB transceivers perform in absence and in presence of Wi-Fi 6E interference as a function of different PHY settings.

Experimental infrastructure. To this end, a first obstacle we have to overcome is the lack of public UWB testbeds supporting multiple UWB platforms. Although a few testbeds embedding UWB nodes exist [14]–[17], they are often only available to on-site researchers

[1]The UWB physical layer has been first standardized by the IEEE 802.15.4a working group back in 2007 [6]. Over the years, the standard was revised several times, until the most recent extension, known as IEEE 802.15.4z [7]. The latter was formalized in August 2020 in order to support new features and to meet the increasing demand for secure and robust localization systems.

and/or are homogeneous, i.e., they only make use of a single UWB platform (typically the Decawave DW1000). Our aim is instead to create an infrastructure that can support an arbitrary number of platforms, that allows a seamless integration of new hardware, and where heterogeneous devices are deployed in close proximity, so to enable a direct performance comparison of different platforms.

Head-to-head performance comparison of old/new chips. We then make use of the aforementioned testbed facility to compare the performance of the well-established DW1000 radio with that of its successor, the DW3000. First, we investigate the interoperability of both radios and examine their communication performance in absence of interference (Sect. III-A). We then quantify the impact of Wi-Fi 6E interference on both platforms and explore the influence of different Wi-Fi bandwidths and frequency configurations in detail (Sect. III-B).

The paper proceeds as follows:

- We detail the architecture of our heterogeneous testbed (Sec. II).
- We exploit the testbed's capabilities to compare the performance of the DW3000 and DW1000 transceivers (Sec. III).
- We recap our contributions and discuss future work (Sec. IV).

II. Experimental Infrastructure

In this section, we present our initial work towards a testbed facility that allows to benchmark multiple heterogeneous UWB platforms. After deriving a set of goals and requirements (Sec. II-A), we describe its architecture (Sec. II-B) and services (Sec. II-C), as well as give details about the current testbed deployment (Sec. II-D).

A. Goals and requirements

In order to tackle the challenges arising with the increasing adoption of UWB technology, we want to design a testing infrastructure that facilitates the development and benchmarking of new protocols and allows to compare the performance of different UWB platforms. We identified the following challenges to overcome along this way.

Testing UWB systems at scale. With the increasing number of UWB systems being deployed, the need for scalable UWB solutions has emerged and a lot of effort has been put into the design of solutions mitigating inter-technology interference. We thus want to support a large number of devices, so to enable experimental research on UWB systems in challenging, highly cluttered environments.

Integrating heterogeneous UWB platforms. Given the growing diversity in the UWB ecosystem, the support of multiple heterogeneous platforms is required to evaluate and compare their performance. This requires the support of different interfaces. For example, some UWB devices (such as the NXP SR150 and SR040 [18]) provide a FiRa-standardized UWB command interface (UCI) to directly access radio-related features via a serial interface, while other platforms (e.g., Qorvo DW1000 and DW3000, NXP OL23D0) host a microcontroller unit (MCU) that controls the UWB radio and thus require the ability to program the corresponding MCU via a debug probe.

Simple integration. Despite hardware-specific differences, the integration (or replacement) of new platforms should be simple and agnostic to the underlying interface. Furthermore, it should be possible to place devices in close proximity, so to enable a head-to-head comparison of different platforms based on the same environment.

Hardware-agnostic user interface. The testbed needs to provide a unified way to access and control attached devices, as well as to retrieve diagnostic data and logs. To enable an easy development of new UWB devices, it should be possible to monitor the devices remotely and in real-time.

Cross-technology interference. The ability to investigate the impact of external interference on UWB systems is important for future research, given the recent standardization of Wi-Fi 6E, which operates in the same unlicensed spectrum. Therefore, it is necessary to enable the generation of predefined, repeatable Wi-Fi 6E traffic patterns within the experimental infrastructure.

B. Architecture

Similar to other testbeds [19]–[22], our approach also follows a hierarchical structure. The overall testbed architecture is depicted in Fig. 1a. A *testbed server* forms the central backbone of the experimental infrastructure, as it is connected to a large number of aggregators as well as to the sources of Wi-Fi 6E traffic. Among others, the testbed server allows users to remotely access and control all deployed nodes via a number of aggregators.

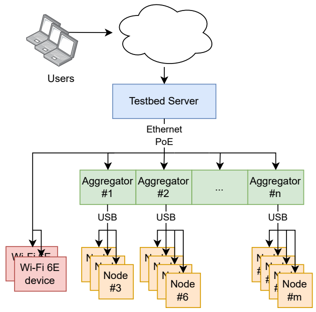
Aggregators manage the deployed UWB nodes and decouple node-specific hardware details from the core infrastructure. We therefore deploy Raspberry Pi 4 devices, due to their low cost and high availability. They are connected to the testbed server via Ethernet and can easily be added to the infrastructure thanks to their Preboot Execution Environment (PXE) and Power over Ethernet (PoE) capability. PXE allows the aggregators to boot from the testbed's network and minimizes deployment efforts, while PoE minimizes the need for additional cables on the infrastructure site. The easy deployment of these components allows for an efficient scaling of the testbed. Each aggregator can host multiple *nodes* that are connected and powered via USB: this enables also quite some freedom during node deployment. For example, nodes can be placed in very close proximity (so to enable head-to-head comparisons), or can be spaced apart so to cover larger areas. Fig. 2 gives a flavour of our current deployment, where three different UWB platforms are attached to an aggregator (Raspberry Pi 4).

C. Tools and services

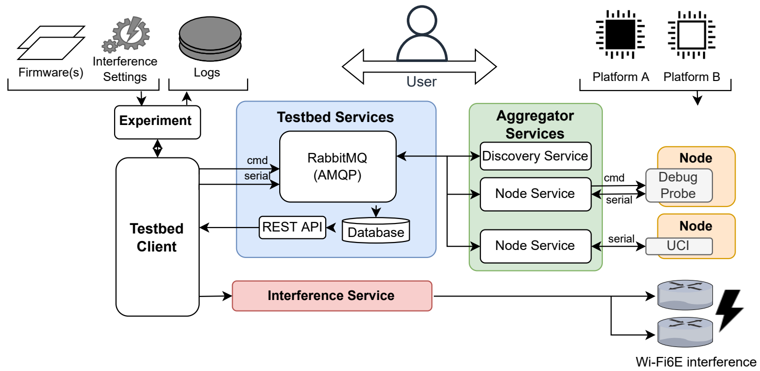
The experimental infrastructure includes a set of tools and services that allow users to access the nodes transparently (i.e., without the need of detailed knowledge about the underlying infrastructure). Fig. 1b illustrates the different services that jointly provide a unified way to run experiments on heterogeneous nodes. For each experiment, users can specify a set of firmwares or UCI commands for the corresponding nodes, as well as an optional interference pattern to be generated by the Wi-Fi 6E devices surrounding the UWB nodes. Additionally, users can monitor the nodes' status and serial interface in real-time or collect the corresponding data for later analysis.

Testbed client In order to run an experiment, our testbed facility includes a hardware-agnostic command line tool called *testbed client*. This client, written in Python, provides primitives to program, reset, or forward UCI commands to attached nodes regardless of the deployed target platform. Furthermore, it allows to access the nodes' serial interfaces and to control the generation of external interference. Finally, it offers commands to obtain status information of any component within the experimental infrastructure.

Testbed services. This status information is stored in a PostgreSQL database located on the testbed server. The database can be accessed using a dedicated REST API and contains information regarding the status and availability of the testbed components. The server further integrates RabbitMQ, an open-source implementation of the advanced message queing protocol (AMQP). It provides efficient, reliable real-time communication among the different components and connected users. The RabbitMQ message broker is used to



(a) Overall architecture



(b) Tools and services

Fig. 1: Structural and functional overview of our experimental infrastructure. The architecture based on the use of aggregators allows the system to scale (a). Several tools and services provide users with an unified and hardware-agnostic way to run experiments (b).

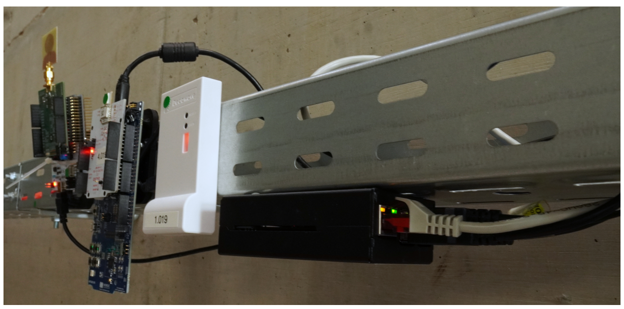


Fig. 2: Three different UWB platforms attached to an aggregator.

forward the serial communication from the users to the nodes and vice versa. Furthermore, status information of the components as well as the control commands are distributed by the broker.

Aggregator services. The need for a scalable and flexible infrastructure is tackled by the use of aggregators, which manage the deployed UWB nodes and decouple node-specific hardware details from the testbed's core functionality. For each node, aggregators assign a *node service* that provides a suitable interface to the target platform and forwards the commands from (and to) the testbed server's RabbitMQ message broker accordingly. UCI-based nodes can be accessed directly via the serial interface, whereas MCU-based platforms can be controlled via debug probes (*e.g.,* J-Link, ST-Link or DAPLink). Thanks to this structure, our testbed is able to support a large number of different platforms. Furthermore, aggregators make it possible to quickly add or remove nodes on demand using a dedicated *discovery service*. This service monitors all attached nodes, dispatches node services for new nodes, and observes their status. Furthermore, it assigns each node a unique ID derived from its USB serial number. Nodes can thus be deployed quickly, while also rearranging the nodes is possible without additional (re-)configuration efforts.

Interference service. To allow a benchmarking of UWB platforms in the presence of cross-technology interference, we deploy Wi-Fi 6E devices in the testbed infrastructure and make them accessible using an *interference service*. The latter is a script that allows to adjust certain Wi-Fi6E related parameters, such as bandwidth, center frequency, or transmission power. To generate Wi-Fi 6E traffic, the interference service relies on the `iperf` tool, which creates UDP streams at different bitrates (i.e., to vary the channel occupancy) and leads to a high reproducibility.

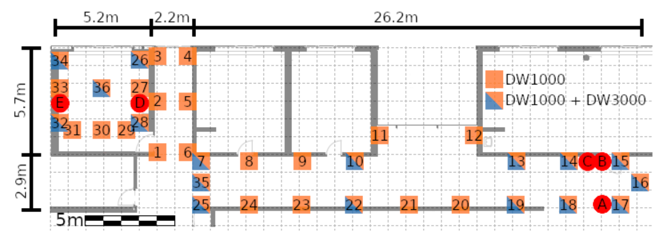


Fig. 3: Map of the UWB nodes currently installed in our testbed. Squares 1–36 denote the position of the UWB nodes. Circles A–D mark the position of Wi-Fi 6E routers.

D. Current deployment

We have deployed the experimental infrastructure as described above in our research facility across an area of roughly 350 m^2. Currently, our permanently-mounted installation includes two different platforms and consists of 53 nodes. 36 of these nodes are based on the MDEK1001 platform, a development kit employing the Qorvo DWM1001C radio [4]; 17 of them are co-located with nRF52833 boards hosting a DW3110 radio of the DW3000 family [8]. The positions of the nodes are highlighted in Fig. 3 by colored squares.

The deployment aims to provide varying real-life scenarios to test the UWB systems. The setup currently consists of two main scenarios. The OFFICE scenario (nodes 26–34 and 36) represents a typical room environment, which can be used to investigate real-time location system (RTLS) systems in a realistic setup. The nodes deployed in the CORRIDOR section (nodes 1–25 and 35) allow to leverage the distance to investigate the impact of varying signal strengths and multi-hop scenarios. Due to the obstructed line-of-sight of nodes 1–6 to the other nodes, the testbed can also be used to investigate non-line-of-sight conditions. Note that several of the squares in Fig. 3 are half green and orange: this indicates that DW1000 and DW3000 nodes are placed in very close proximity, so to enable direct comparisons about their performance.

We have also deployed five DR6018 routers employing Wi-Fi 6E-compliant Qualcomm QCN9074 modules: these are used to generate external interference throughout CORRIDOR and OFFICE, as marked in Fig. 3 by red circles. The Wi-Fi 6E routers allow to investigate the impact of interference in different environmental scenarios. Routers Ⓐ, Ⓑ and Ⓒ offer the possibility to create multi-client scenarios and allow to assess the impact of Wi-Fi 6E at large distances. Routers Ⓔ and Ⓓ, on the other hand, resemble a scenario where UWB nodes and Wi-Fi 6E devices are co-located in the same room.

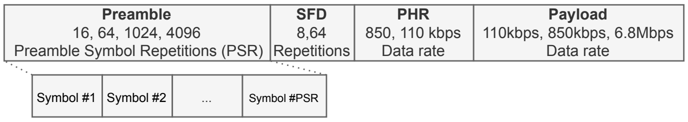


Fig. 4: Structure of an IEEE 802.15.4-compliant UWB frame.

III. Comparing the Performance of DW1000 and DW3000

We make use of the aforementioned testbed infrastructure to perform a comparison of the popular DW1000 radio with its successor, the DW3000. To this end, we run several experiments in both absence (Sec. III-A) and presence of Wi-Fi 6E interference (Sec. III-B).

A. Performance in absence of interference

We start our performance analysis by comparing the reception performance in absence of interference. Previous work [5] has experimentally investigated the role of the UWB PHY settings, as defined in the IEEE 802.15.4a standard. An IEEE 802.15.4a-compliant frame consists of a preamble, a start-of-frame delimiter (SFD), a physical header, and a payload, as shown in Fig. 4. There exist a large number of settings to adjust each of the frame parts in order to tune the communication performance. For example, the length of the preamble can be adjusted using the preamble symbol repetitions (PSR) value, which specifies the number of symbols that are transmitted repeatedly. Großwindhager et al. [5] have shown that those settings have a strong impact on packet reception in UWB systems based on the DW1000. Our aim is thus to investigate whether the same observations apply to the new-generation DW3000 radio. We further want to examine whether the DW1000 and DW3000 can interact seamlessly and if there are significant differences in the communication performance between the platforms.

Experimental setup. Unless otherwise specified, we carry out the experiments on the co-located DW1000 and DW3000 nodes placed in the CORRIDOR. We assign node 16 as a transmitter and let it broadcast 3×2500 packets in a 8 Hz interval with a 16 byte payload, while the remaining nodes report the corresponding number of receptions and/or error codes to the testbed server. All nodes are configured according to the IEEE 802.15.4 UWB standard [6]. We use a pulse repetition frequency of 64 MHz, a data rate of 6.8 Mbps and let the devices operate on UWB channel 5 (i.e., at a center frequency of 6.495 GHz), as this is the only channel that is supported by both the DW1000 and DW3000. The UWB transceivers come pre-calibrated with a recommended transmission power gain, that is supposed to be within the regulatory boundaries. Due to the lack of calibration equipment, we rely on the Qorvo user manual to set the transmission power to the recommended default value for each platform, which should correspond to the maximum transmission power that stays within regulatory limits.

Packet reception as a function of the PSR. We investigate the packet reception depending on the PSR, as this parameter has been shown to affect the reception performance significantly [5]. According to the UWB standard, the PSR can be either 16, 64, 1024, or 4096. Both the DW1000 and the DW3000 do not support a PSR of 16, but offer additional values. We thus select PSR values of 64, 128, 256, 512 and 1024 in the following experiments. According to the Decawave's API guide [23], an optimized receiver configuration for the DW1000 at PSR=64 is recommended. For PSR=64, we thus run experiments with both default and optimized settings. To investigate the impact of the PSR, we obtain the packet reception rate (PRR) for different PSR settings while reducing the transmission power gain of the transmitting node to simulate attenuation within the channel. More specifically, we vary the transmission power gain between 0 and -6 dB on the DW1000 in 1 dB steps. A value of 0 dB corresponds to the default transmission power, while -6 dB is the minimum value supported by the DW1000. The DW3000 supports more gain settings and we thus perform measurements between -6 and -18 dB, as the effects of different PSR settings are more pronounced at these values. In order to explore the differences among the platforms, we compute the average PRR for all DW1000 and DW3000 nodes separately and repeat the experiment with different transmitters.

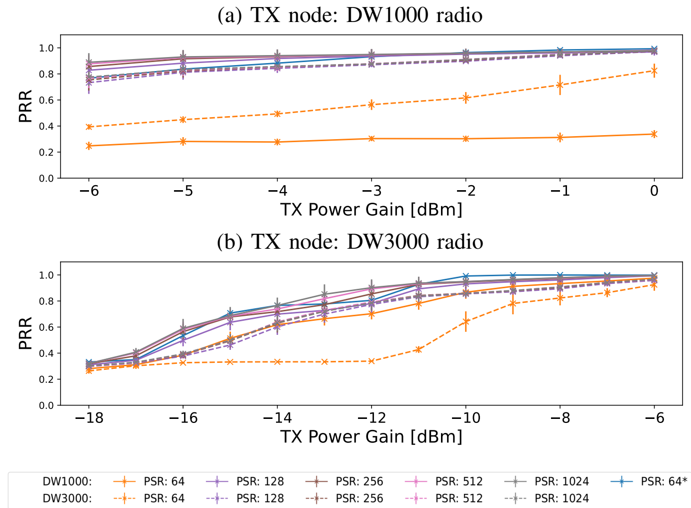


Fig. 5: Average PRR for DW1000 and DW3000 receivers as a function of the transmission power at different PSR settings. PSR 64* refers to the optimized receiver configuration of the DW1000.

Impact of the PSR. Fig. 5 shows the average PRR for different PSR settings when using the DW1000 (a) or the DW3000 (b) as transmitter. Both experiments confirm the results from [5], showing that larger PSR values increase the communication robustness. This applies to both DW3000 and DW1000 nodes, as they exhibit a higher PRR with larger PSR settings. Interestingly, the performance of the DW3000 transmitter with 64 PSR is significantly higher than that of the DW1000 using a default configuration. For the latter, the average PRR never exceeds 32% and 85% when receiving with the DW1000 and DW3000, respectively. For the DW3000, the PRR reaches more than 95% for both receivers. Using the optimized receiver configuration, the performance of the DW1000 improves significantly, outperforming the DW3000 with a PRR up to 100%.

Differences in communication performance. The results from Fig. 5a further suggest that the DW1000 has a slightly better reception performance: for a PSR of 1024, the PRR is hardly affected ($\geq$ 98%) for any attenuation, while the DW3000 experiences a decrease in the PRR from an attenuation of 3 dB onwards. A similar trend applies regardless of the employed transmitter (see Fig. 5b) and PSR setting (excluding a PSR value of 64). Please note that all our experiments confirm that the DW1000 and DW3000 are able to receive each others' messages in a correct and seamless manner, i.e., they are fully interoperable.

B. Performance in presence of interference

We next compare the performance of the DW1000 and DW3000 in the presence of Wi-Fi 6E interference. A recent study has shown that UWB devices can suffer from severe packet loss in the presence of

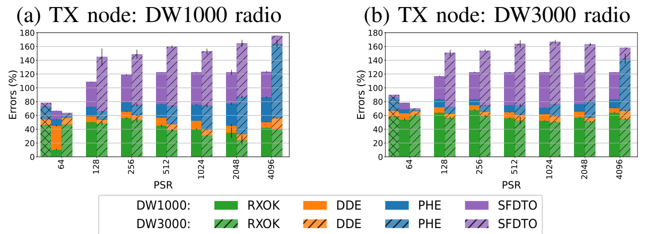


Fig. 6: PRR and reception errors for different PSR settings. The additional bar for PSR 64 refers to the DW1000's optimized configuration.

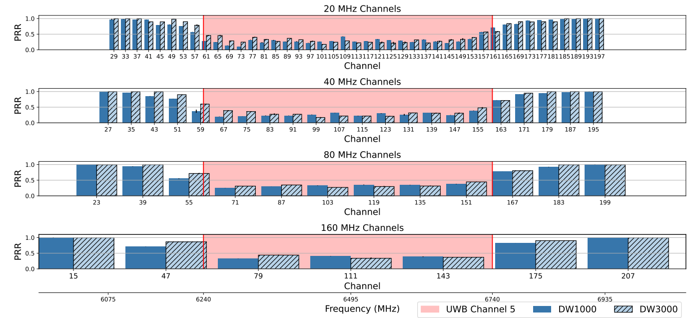


Fig. 7: UWB PRR under interference of different Wi-Fi 6E channels. Red lines mark the borders of UWB channel 5.

interference and observed that specific PSR settings are more robust than others [12]. We are thus interested in investigating if the presence of Wi-Fi 6E traffic also affects the reception of the DW3000 radio, if one platform is more robust than the other, and how the impact differs depending on different PSR and Wi-Fi 6E settings.

Experimental setup. We run experiments as described in Sec. III-A while inducing Wi-Fi 6E interference using our experimental infrastructure. More specifically, we used `iperf` to generate a UDP stream with an average of 100 Mbps between devices Ⓐ and Ⓑ. The Wi-Fi 6E devices are configured to operate at their highest permitted transmission power and on channel 111, which is located in the center of UWB channel 5 at 6.945 GHz and has a bandwidth of 160 MHz.

Impact of Wi-Fi 6E interference at different PSR settings. A recent study [12] has shown that the PSR has significant impact on the PRR under interference. The authors identified a PSR of 256 as the optimal trade-off between i) a large PSR increasing the reception robustness, and ii) a short PSR decreasing the packet air-time and, consequently, the likelihood of a collision with Wi-Fi 6E frames. To investigate whether this trend holds also true for the DW3000 platform, we obtain the number of successful receptions as well as reception errors depending on the PSR. We distinguish between SFD timeouts (SFDTO), occurring when a preamble symbol but no SFD has been detected after $(PSR + 1 + length(SFD) - PAC\ size)$, physical header errors (PHE), occurring when the SFD but not the physical header has been detected, and data decoding errors (DDE), indicating errors in the payload. Successfully received frames are identified as RXOK. Fig. 6 gives the accumulated errors and successful receptions related to the number of transmitted packets for different PSRs. Again, we compute the average across all DW1000 and DW3000 separately, and exchangeably use a DW1000 and DW3000 node as the transmitter. To compare our results with [12], we examine the same PSR values (i.e., 64, 128, 256, 512, and 1024) and run additional experiments with PSRs of 2048 and 4096.

Fig. 6a shows the results for a DW1000 transmitter and confirms the findings in [12]. A PSR of 256 yields the highest reception rate for both receivers with a PRR of 56% and 53% for the DW1000 and the DW3000, respectively. Interestingly, very large preambles (e.g., PSR of 4096) are advantageous in presence of interference. The reason might be that, due to the long duration, receivers are able to recover from a wrongly classified Wi-Fi 6E frame within the preamble and can subsequently receive the UWB packet. The trends for a DW3000 transmitter, shown in Fig. 6b, are similar, yet reveal differences between the DW1000 and DW3000 platforms. The DW1000 still performs best at a PSR of 256, while the DW3000 achieves the highest reception rate at a PSR of 64. This is due to the improved performance of the DW3000 at a PSR of 64 (as observed in Sec. III-A) in combination with a decreased time-on-air that allows to transmit UWB packets in the gaps of consecutive Wi-Fi 6E frames. Our experiments further indicate that the DW3000 is more susceptible to wrongly classify Wi-Fi 6E packets as UWB preamble, an effect that has been shown in [12]. In Fig. 6, this is visible as the accumulated errors exceed 100% (i.e., the number of reported errors and successful receptions exceeds the number of transmitted packets). Misclassified packets may appear either as SFDTO, when mistaken for preamble symbols, or as PHE, if an interfering packet in the preamble is interpreted as SFD. On average, the DW3000 reports 119% more SFDTO and PHE compared to the DW1000, which suggests that the number of falsely classified Wi-Fi 6E frames is significantly higher [2]. Additionally, the slight advantage of the DW1000 in terms of reception rate observed in III-A is confirmed in these experiments.

Impact of the Wi-Fi 6E bandwidth and center frequency. We next compare the performance under Wi-Fi 6E interference depending on different Wi-Fi 6E channel and bandwidth configurations. Wi-Fi 6E channels are located in the 6 GHz band and a large number of those overlaps with the 500 MHz wide UWB channel 5. Wi-Fi 6E allows channel bandwidths of 20, 40, 80, or 160 MHz. A recent study [12] has shown that Wi-Fi 6E interference has the strongest impact if Wi-Fi traffic makes use of the channels close to the UWB center frequency, but that even partially overlapping Wi-Fi 6E traffic and the narrow 20 MHz channels lead to packet loss. We are therefore interested in showing at which spectral distance Wi-Fi 6E has to operate such that the UWB devices are unaffected and whether the DW1000 and DW3000 behave differently in these scenarios.

To this end, we select the DW1000 as a transmitter (using the same setup as described before and a PSR of 1024) and successively alter the channel configuration of the Wi-Fi 6E device. This way, we create a channel map of the 6 GHz spectrum, where each entry corresponds to the PRR of the DW1000 and DW3000 under Wi-Fi 6E interference on the given channel. Fig. 7 shows the results of channels between 6.015 and 6.975 GHz. The shaded area indicates UWB channel 5 (i.e., the region where it formally overlaps with Wi-Fi 6E channels).

As expected, the impact of Wi-Fi 6E is strongest when the Wi-Fi channel is located close to the UWB center frequency. This is evident for each Wi-Fi 6E bandwidth configuration and applies to both the DW1000 and DW3000 platform. The impact is less severe when Wi-Fi 6E operates towards the far end of the UWB channels. However, even if the channels *do not overlap*, the packet reception is affected. For example, even when using Wi-Fi channel 51, which is nominally 15 MHz away from the lower boundary of UWB channel 5,

[2] We confirm this finding by observing the reception errors solely based on Wi-Fi 6E interference (i.e., without UWB transmissions) for different PSR settings. Over a duration of 7 minutes, up to 2095 SFDTO (PSR=256) and 1823 PHE (PSR=4096) are detected on average by the DW3000 CORRIDOR nodes. In comparison, the DW1000 devices accumulate up to 984 SFDTO (PSR=128) and 403 PHE (PSR=64 with optimized receiver configuration).

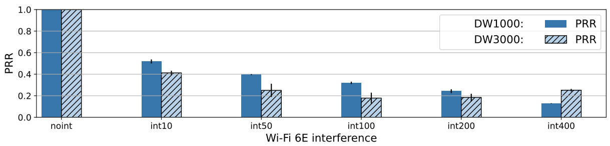


Fig. 8: Impact of different interference patterns in OFFICE.

we still observe a packet loss of 24% and 10% on the DW1000 and DW3000, respectively. In this regard, the DW3000 performs better than the DW1000, as it requires a nominal distance of 65 MHz to obtain a PRR of 99% (e.g., at channel 173), while the DW1000 achieves this only at a distance of 165 MHz (e.g., channel 193).

Impact of Wi-Fi 6E interference in harsh environments. Finally, we explore the radios' performance in a highly-cluttered dense environment where interference is generated close by. We repeat the previous experiments in OFFICE using node 36 as transmitter and devices Ⓓ and Ⓔ to generate Wi-Fi 6E traffic. After checking for consistency without interference, we induce `iperf` traffic with different bitrates (10, 50, 100, 200 and 400 Mbps) on channel 111 and obtain the average PRR of all nodes located in OFFICE. The results shown in Fig. 8 emphasize that the performance of both DW1000 and DW3000 is severely compromised in harsh scenarios where UWB and Wi-Fi 6E devices are located in the same room.

IV. Conclusion and Future Work

In this work, we describe our steps towards a multi-platform testbed infrastructure that allows to explore and compare the performance of different UWB platforms experimentally. We implement this experimental infrastructure and use it to benchmark the performance of two popular UWB platforms in absence and presence of Wi-Fi 6E interference. To go beyond these experiments and to provide a powerful tool for future research on UWB systems, we plan to enrich our infrastructure with several features.

Public access. While there exist many publicly available large-scale testbeds for Internet of Things applications (*e.g.,* FlockLab [19], Indriya [21], D-Cube [22]), there is still a need for public testbeds targeting UWB. Furthermore, the node density of common Internet of Things (IoT) testbeds is often not sufficient for benchmarking RTLS applications. We therefore aim to make the experimental infrastructure accessible for public use in the future. To this end, we plan to improve the user interface and implement automatic scheduling of remote experiments.

Integration of heterogeneous platforms. To address the increasing variety of UWB platforms on the market, we are working on integrating devices from different manufacturers in our infrastructure. Among these, there are established manufacturers such as NXP (with their SR150 [10] and SR040 [9] chips), or 3db [24] (with their transceiver based on low rate pulse (LRP) UWB). This integration work will allow us to systematically benchmark different UWB technologies and platforms, and to shed light on their relative performance.

Automation of experiments. Testbeds such as D-Cube [22] have shown the benefit of automated testing. The ability of binary patching simplifies the realization of consecutive tests with changing parameters. Furthermore, it allows the evaluation of firmwares in different scenarios, without the need of altering the source code. Thereby, we could automate the test of firmwares from external sources.

Emulating repeatable and accurate interference patterns. As the availability of Wi-Fi 6E hardware was still limited at the time of construction of our testbed, our options for interference generation have been limited. In the future, we plan to integrate an approach suggested in [20], where the Wi-Fi cards' monitor mode is used to generate recorded real-world Wi-Fi traffic in a repeatable way. Moreover, we want to provide more challenging and diverse multi-client scenarios by deploying additional Wi-Fi 6E hardware.

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