UWB Physical Layer Adaptation for Best Ranging Performance within Application Constraints

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CCS Concepts

•Computer systems organization → Sensor networks;

Keywords

UWB; Indoor Localization; Physical Layer Configuration

ABSTRACT

Indoor localization has been a hot area of research for many years. There are many research proposals and commercial products which can accurately locate moving objects inside the buildings. Wireless communication signals have been a good alternative for existing indoor localization solutions due to their accurate results and scalability. Ultra-wideband signals can locate objects with less than 5 cm error in the reasonably inexpensive price. Despite very accurate localization achievable by UWB based systems, building a robust and reliable indoor localization system based on UWB signals remains as a challenge. In this paper, we investigated the impact of different channel configuration parameters on the robustness of UWB-based indoor localization. Based on conducted experiments, we proposed an efficient algorithm to find the best setting for UWB communication channel to meet accuracy, power, and air utilization requirements. We evaluated the performance of our framework in real-world environment scenarios, and our results show an average 20% reduction in range errors achieved by our proposed method through proper setting of UWB physical layer parameters.

1. INTRODUCTION

Tracking assets and people has many potential applications in safety, security, improving worker's performance, and making asset and workplace management more effective. GPS is a well-known tracking and localization technology. In outdoor environments, GPS works reasonably well. In indoor environments, GPS does not work well. There are many research proposals and commercial solutions for indoor localization utilizing different types of wireless networks and IMU sensors.

Ultra-wideband radios have recently become popular in localization research. The very large bandwidth of UWB signals boosts the communication data rate up to 1 Gbps. Also, UWB signals are sent in the form of short pulses which makes them resilient to multipath fading. Features like high center frequency, resilience to multipath fading and low power consumption makes the UWB signals a perfect choice for many applications including indoor localization.

Despite very accurate results achieved by UWB-based techniques to track objects with errors less than 5 cm [16], building a robust UWB-based indoor localization system is challenging. The accuracy of localization with UWB technology depends on the propagation characteristics of the unique circumstances of a deployment. To achieve best ranging performance one can set the transmission power and frame length to the maximum possible but that approach is not suitable in some applications. For instance, increasing frame length, decreases the location update rate (due to interference) which is not desired in most of tracking applications. There are no tools or methodologies to determine the best configuration for UWB communication to increase ranging quality while limiting power consumption and air utilization within application constraints. Without those tools and methodologies, it is difficult to achieve accurate and efficient UWB-based localization while meeting application constraints in power and latency. Dynamics in wireless propagation environment requires re-discovery of best settings, thereby making the problem or robust indoor localization even more challenging.

One of the major problems that threatens the robustness of UWB based indoor localization systems, is short coverage due to noise interference and attenuation from obstacles. In our work, we propose a framework to make UWB localization more robust and resilient to attenuation and noise. We implement an efficient algorithm to find the best setting for the UWB channel which gives the best ranging performance while it meets power consumption and air utilization requirements. Our solution changes the parameters of the UWB channel to improve the quality of ranging which makes the whole localization system more reliable and robust. The proposed method can be used during the deployment phase to find the best channel setting and also during online ranging once the quality of ranging drops due to changes in the environment. We proposed a simple technique to monitor the ranging performance and trigger the proposed method to change the UWB channel setting if the quality of ranging

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drops below a certain threshold.

Our contributions in this work can be summarized as the following:

- Investigated the impact of changing UWB communication channel configuration on accuracy and robustness of UWB-based indoor localization system.
- Designed a framework to monitor the quality of ranging and change the configuration of UWB physical layer to improve the ranging accuracy while maintaining power consumption and frame duration restrictions.
- Evaluate the performance of the system in a real-world environment using DW1000 UWB transmitters.

2. RELATED WORK

The literature on UWB based indoor localization techniques can be divided into two major topics: First path detection techniques and error detection techniques. The following paragraphs elaborate on both areas in more details and cover state-of-the-art work in UWB indoor localization.

2.1 First path detection in UWB

Time-of-Arrival (ToA) is a critical concept in wireless indoor positioning systems. The general idea here is that considering the constant speed of the signal through the air, accurate measurement of signal's flight time provides an accurate estimation of distance between sender and receiver nodes. The challenging part is accurately timestamping signal's ToA. It is essential to mention that the speed of light through air is approximately $3 * 10^8 m/s$ which means even one nanosecond error in ToA measurements will cause 30 cm error in estimated distance. Two most common categories of previous work to identify ToA are maximum likelihood (ML) techniques and energy-based methods.

2.1.1 ML-based First Path Detection

Correlation between sent and received signals is utilized in ML techniques. The goal is finding the optimum propagation time which maximizes the correlation between sent and received signals. Experiments have shown that ML estimators can achieve to the Cramer Rao Lower Bounds (CRLB) in the high-SNR region [2]. In addition to the correlation between sent and received signals, the similarity between uplink and downlink also has been utilized to estimate the most likely propagation time for the signal [17]. However, ML estimators require processing the signal at very high sampling rates which makes them inapplicable in most of the low power embedded system implementations.

2.1.2 Energy-based First Path Detection

Energy-based ToA detection algorithms utilize the power of the received signal as an indicator to leading edge of the signal [3]. The basic idea is sampling the received signal and detecting the first sample which has higher power than a particular threshold as the leading edge of the signal. Although the accuracy of energy-based first path detection techniques is not as good as ML estimators, they are much easier to implement. The first sample that passes the threshold is considered as the first path and is used to measure ToA.

The real challenge in energy based leading edge detection techniques is selecting the proper threshold. There are many research work that tried to propose a suitable threshold based on the signal and noise characteristics. The lowest complexity approach is monitoring a massive amount of data and finding the best threshold value to set for deployment [8]. Threshold also can adaptively change based on the maximum and minimum energy level in the signal [11],[14]. A proper threshold value should be designed depending on the received signal characteristics, the operating condition, and the channel characteristics. The ambient noise floor is an important factor in detecting the first path. SNR can be utilized [15] to find the best threshold to mark the leading edge of the signal. Due to their simplicity and excellent performance, energy detection-based first path detection algorithms are used in current UWB-based indoor localization systems including DW1000 chip which is most dominant UWB-enabled chip used in indoor localization [5].

The general rule of thumb in UWB ranging is that higher power UWB frames provide more accurate ranging since the gap between the first path and ambient noise will be bigger which means it would be easier for the receiver to detect the first path. IEEE802.15.4-11 [10] which standardizes the low power UWB communication suggested few adjustable parameters for UWB physical layer which provides the capability of changing transmitted frame's power and duration. Effectiveness of changing these UWB physical layer settings to improve communication quality has been investigated before[7] and the results show 30% to 40% of improvements in packet reception rate under interference by changing the UWB physical layer settings.

To the best of our knowledge, there is no previous study on impact of different UWB physical layer settings on ranging performance and quantize each configuration's ranging improvements. Our solution finds the optimum physical layer setting which meets the power consumption and frame duration requirements of the application and at the same time minimizes the ranging errors.

2.2 UWB Localization in the Real World

Recent advances in embedded system design and development have made the inexpensive UWB transmitters available for public usage. Despite the huge body of work in UWB system design, in most cases evaluations have been done through simulations. There are few works [18, 12, 9, 13] who tried to deploy UWB systems in the real world and report their performance. Overall, based on those reports, in the situations with clear Line-of-Sight (LoS) between two nodes, the UWB indoor localization systems are very reliable with centimeter-level accuracy in locating objects but in the locations with high levels of noise floor or crowded areas which LoS signals are not available, there is a huge performance drop in localization performance including lots of blind spots (places that system cannot locate the object) even in short ranges.

In summary, the research community has been successful to propose highly accurate UWB-based wireless indoor localization, but robustness and reliability of such systems still require a lot of attention.

3. UWB BASICS

IEEE802.15.4-11 standardized use of low power UWB signals in wireless sensor networks. In this section, we briefly explain basics of UWB communication and go through UWB physical layer parameters defined by this standard.

Table 1: UWB Channels Supported by DW1000 [5]

Channel #	Center Frequency (MHz)	Bandwidth (MHz)
1	3494.4	499.2
2	3493.6	499.2
3	4492.8	499.2
4	3493.6	1331.2
5	6489.6	499.2
7	6489.6	1081.6

3.1 Center Frequency and Bandwidth

UWB signals are referred to signals that their bandwidth is bigger than 20% of their center frequency. Although this general definition can be applied to many frequency ranges but most popular center frequencies for UWB signals are in range of 3 GHz to 10 GHz and according to IEEE 802.15.4 standard [10], the minimum bandwidth for each UWB channel is 500 MHz.

3.2 UWB Channel Configuration

UWB communication link has to be configured properly before being used for localization or communication purposes. Fundamental factors in UWB links are explained in this section. It is essential to mention, in this section we focused on the parameters which are supported by DW1000 chip [5].

- Center Frequency: The IEEE 802.15.4 standard UWB PHY defines 16 different channels; the ones supported by DW1000 have been summarized in Table 1. Since different channels face different levels of ambient noise, proper selection of center frequency has a critical role in the robustness of system.

- Preamble Length: UWB packet begins with a synchronization header which contains the preamble and Start of Frame Delimiter (SFD). During message reception phase, the receiver searches channel to observe the preamble and once the preamble is detected, the receiver looks for SFD symbols. The moment the receiver detects the first SFD symbol is timestamped as ToA for the message. Higher robustness and range after increasing the length of preamble comes at the price of consuming more energy and spending more time sending each message.

- Pulse Reputation Frequency (PRF): The PRF is one of the basic characteristics of radio systems. In simple terms PRF defines the amount of time interval between sending two consecutive pulses. After sending the first pulse, the transmitter is not sending new pulses for a time period which gives the receiver enough time to hear the reflections of the first pulse. The required time between sending of each pulse is a function of the system's desired range. Higher PRF values generate more pulses in constant amount of time, and thus higher radio energy, which are detectable in longer distances. UWB standard defines 16 MHz and 64 MHz as standard PRF values for communication.

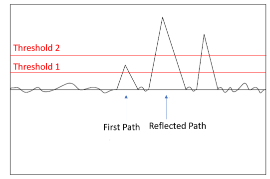


Figure 1: Threshold for Minimum Received Signal Power

- Preamble Code: Depending on the channel and PRF, IEEE 802.15.4 standard defines a choice of two or four preamble codes. These preamble codes are designed in a way that they have a low cross correlation with each other with the intention that separate channels with different preamble codes can work simultaneously without interfering with each other.

- Data Rate: IEEE 802.15.4 standard has defined three different data rates (110 kbps, 850 kbps, and 6.8 Mbps) for UWB communication.

3.3 UWB-based Localization Challenges

The challenging part in ToA calculation is proper selection of the threshold for the minimum gap between signal's power and noise. Smaller gap between first path power and noise floor increases the chance of misclassification of noise as the first path signal. On the other hand, higher threshold values, increase the chance of not finding the firth path signal. This phenomenon is shown in Figure 1 where *Threshold 2* is not a suitable choice but *Threshold 1* is able to detect proper first path.

Not being able to receive the first path signal is not the only problem, the other problem is that Non-Line-of-Sight (NLoS) signal is not distinguishable from LoS on the receiver side. For instance in Figure 1, in the case that the system is using *Threshold 2* value, the receiver can not spot the real first path and will consider reflected signal (second peak) as the first path. There is no practical way for the receiver to realize that the measured distance is wrong due to detection of NLoS signal as LoS.

4. DESIGN

To make UWB-based indoor localization systems more robust, the best configuration for UWB channel which meets accuracy, power consumption, and air utilization requirements is selected through an efficient search algorithm. Features like preamble length and frequency channel have a significant impact on the robustness of the UWB positioning system. Higher preamble length means better robustness but with the cost of consuming more energy and having higher air utilization. In addition, lowering down the receiver's threshold for received signal power, will increase coverage of the system but at the same time increases the chance of detecting noise as the first path signal in the environments with higher levels of noise. The effectiveness of changing these settings is directly related to the amount of power in the reflected signal. In this section, we study the impact of changing each of the above mentioned UWB physical layer settings on the accuracy of localization solution.

4.1 Building the Dataset

Table 2: UWB Physical Layer Parameters (Supported by DW1000) - 252 possible combinations

Parameter	Values
Frequency Channel	1,2,3,4,5,7
Pulse Repetition Frequency (PRF)	16 MHz, 64 MHz
Preamble Length (symbols)	64,128,256,512 1024,2048,4096
Date Rate	110 kbps, 850 kbps , 6.8 Mbps

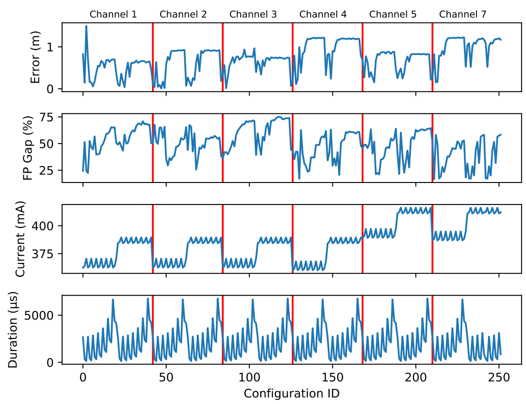


Figure 2: Average ranging error, first path gap, current consumption and frame duration across all 252 UWB Physical Layer Configurations

UWB physical layer has several adjustable parameters which are listed in Table 2 alongside with the list of their potential values. Overall, DW1000 chip supports 252 different configurations ($6 channels \times 2 PRFs \times 7 preamblelengths \times 3 datarates$) for UWB physical layer. To estimate ranging error associated to each configuration, we conducted experiments in 2 different locations (inside an academic building and also a coffee shop with lots of furniture). In each experiment, a pair of UWB nodes (Decawave EVB1000) are placed in the distance of 10 m from each other. They both try all the 252 different configurations for UWB physical layer and under each configuration, two-way ranging algorithm is conducted for 200 times. Figure 2 shows the ranging error, the gap between first path signal and ambient noise $((firstpathpower - ambientnoise)/firstpathpower)$, transmission and reception current (mA) and frame duration (μs) for all the 252 configurations averaged based on the data collected in both of the locations.

The main purpose of figure 2 is to show the impact of changing configuration of UWB channel on ranging accuracy. We use error values measured in this phase to assign an error to each of the configurations. Later on, our algorithm uses this information to find the best configuration for UWB communication and ranging. We need to mention, all the frame duration and power consumption measurements in this paper are based on the tool [4] provided by Decawave company which exactly measures current consumption and duration for each packet based on the channel's setting. Power consumption is a general limitation in wireless sensor networks including UWB based indoor lo-

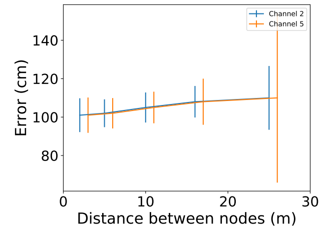


Figure 3: Ranging error across different distances

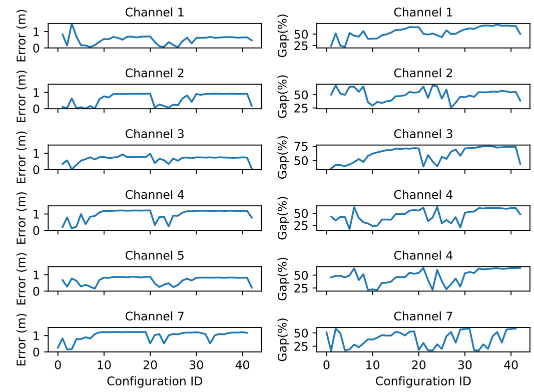


Figure 4: Gap between first path and noise has direct relationship with observed ranging error

calization. Also, there are regulatory restrictions on maximum transmission power in UWB communication. Frame duration is also important since it impacts interference and reliability of communication.

To decide about the distance to put nodes during our data collection (10 m), we conducted a simple experiment. In this experiment, we used 2 nodes (Tag and Anchor). We configure our UWB radios to use channel 2 and increased the distance between tag and anchor (2 m, 5 m, 10 m, 16 m, and 25 m) and measured amount of error reported by them in different distances. We repeated the same experiment with channel 5. Figure 3 summarizes the results.

It can be seen in Figure 3 up to 20 m distance, the ranging performance does not change significantly as we increase the distance between nodes. Based on this observation, we decided to put 2 nodes in 10 m distance during data collection phase to build our dataset.

As it is shown in Figure 2, changing the physical layer has some impact on ranging performance but what could be the reason? As mentioned in the previous section, energy detection algorithm is used inside DW1000 chips to mark the first arriving pass, which means the difference between the first arriving path's power and ambient noise has direct relationship with the accuracy of ranging. In figure 4, we focus on the relationship between the first path gap and ranging error across different channels.

Figure 4 supports our earlier hypothesis. Across different channels, ranging error goes higher once the gap between first path and the ambient noise decreases. This observation gives us the idea of improving the ranging performance by changing channel setting. For example noise pattern is different across different channels which means changing the center frequency can reduce the ranging error. Also, longer preamble length provides more power in the received signal

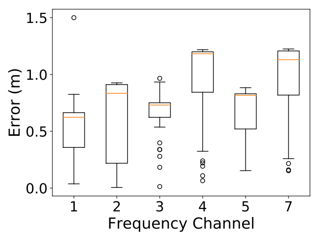


Figure 5: Ranging error across different frequency channels

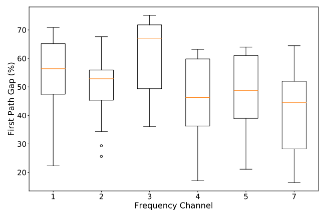


Figure 6: Gap between first path power and noise across frequency channels

which means higher first path power gap.

4.2 UWB Physical Layer Parameter's Impact on Ranging

In the following paragraphs, the impact of changing each of the factors on the final accuracy of UWB-based localization system has been investigated using the data we collect in our dataset. In all the experiments, off-the-shelf EVB1000 chips [6] are utilized as anchor and tag nodes.

4.2.1 Frequency Channel

The first analyzed factor is frequency channel. Figure 5 shows the average error measured in estimating the distance to the TAG node using different frequency channels (average of 4000 ranging per channel). As it is shown in Figure 5, lower frequencies provide more accurate and reliable (less deviated) results.

Figure 6 shows the amount of gap between the noise floor and first path signal in different frequency channels. As it is shown in figure 6, the amount of noise floor in different frequency channels varies a lot which is reasonable considering the distribution of noise in different frequency channels. This observation helps us to justify different ranging performances across different frequency channels.

4.2.2 Preamble Length

The second parameter to be considered to change in UWB physical layer is the preamble length. Figure 7 shows the average error (more than 4000 ranging measurements per preamble length) in estimating the distance to the TAG node while changing the preamble length. As we expect, increasing the length of preamble from 128 symbols to 1024 symbols significantly decreases the error but after 1024 symbols increasing the preamble length does not have noticeable impact on reported accuracy. On the other side increasing preamble size will increase the length of message which means it will increase the amount of time required for the system to transmit the message (higher energy consumption and lower location update rate). Figure 8 shows the amount of time required for sending messages with different preamble lengths (with 30 bytes of data payload). Based on the results from these two experiments, changing preamble length is one of the key features of the designed solution to increase the robustness of the system. We need to mention, looking at Figure 8, increased ranging performance comes with the price of increased frame duration which means higher air utilization. To emphasize on importance of air utilization in UWB communication, we need to mention that, in IEEE802.15.4-11 standard, the default Medium Access Control (MAC) for UWB communication is ALOHA [1] which is based on random access to the medium (UWB signals are very low power compared to background noise which makes CSMA protocols impractical in UWB communications [10]). In the case of long frames, the chance of collision and interference goes higher which reduces the robustness of the UWB based localization and communication technique.

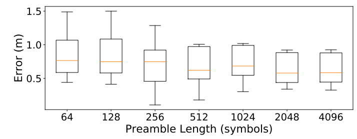


Figure 7: Ranging error across different preamble lengths

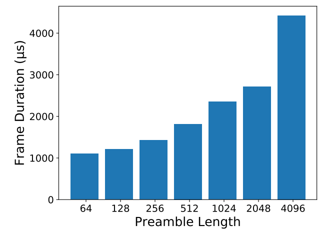


Figure 8: Frame duration across different preamble lengths

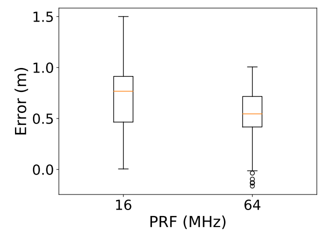


Figure 9: Ranging error across different PRFs

4.2.3 Pulse Repetition Frequency

The third channel configuration parameter is PRF value. Figure 9 shows significant improvement by changing the PRF value from 16 MHz to 64 MHz in estimating the distance to a tag.

4.2.4 Preamble Code

Preamble code is another configurable parameter in UWB communication link. As it can be seen in Figure 10, changing the preamble code in the same frequency channel does not have a significant impact on the accuracy of estimated location.

4.2.5 Data Rate

The last configurable metric is data rate. Figure 11a shows the impact of changing the data rate on final accuracy of ranging. As shown in Figure 11a changing the data rate does not have a noticeable impact on the final accuracy of the system but on the other hand, Figure 11b indicates the

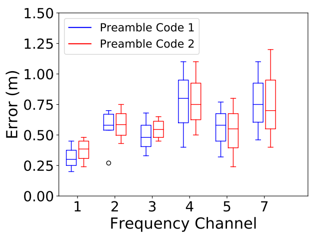
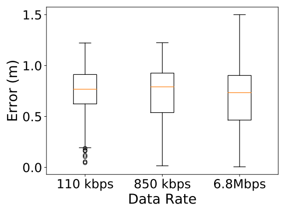
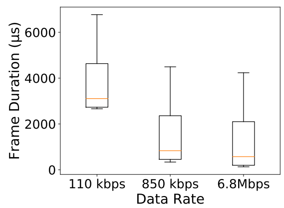


Figure 10: Ranging error across different preamble codes



(a) Ranging error across different data rates



(b) Frame duration across different data rates

Figure 11: Impact of data rate on ranging error and air utilization

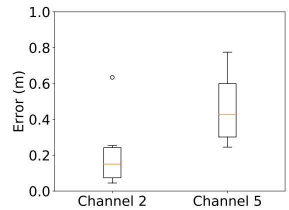
fact that increasing the data rate will significantly decrease the frame duration which means reduced air utilization in higher data rates.

4.2.6 Frequency Channel Vs. Preamble Length

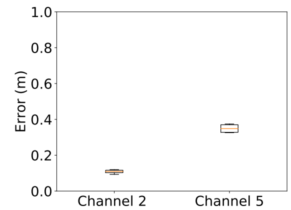
As mentioned in previous paragraphs frequency channel and preamble length have high impacts on average error. In order to compare the impact of each of them, we designed a simple experiment. A pair of tag and anchor points were placed in the distance of 20 m, in non-light of sight condition. We changed channel setting (preamble length and frequency channel) and measured average error. Figure 12 shows the impact of changing the frequency channel and also preamble size on the reported accuracy. The general fact that can be inferred from figure 12 is that increasing preamble length has a lower impact on accuracy of measurements (25% error reduction) compared to increasing the frequency channel (50% error reduction). In all the cases, increasing preamble length makes the measurements more stable. On the other hand, channels with higher frequencies have more accurate results but with higher chances of NLoS measurements.

4.3 Detect Low Quality Ranging

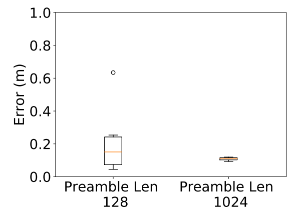
The environment has a significant impact on the UWB ranging error. Interference and attenuation change the UWB channel characteristics which change ranging performance. As mentioned earlier, our proposed solution can improve the ranging performance by changing the channel setting, but, we need to have an indicator of low quality ranging to trigger the search algorithm. DW1000 chips utilize energy detection algorithm to find the first path which means the distance between the first path's power and ambient noise can be used as ranging quality indicator. Figure 13 shows the amount of gap between first path power and noise in different ranging error ranges from our dataset. It is shown in Figure 13 that if we want to keep the error range below 20 cm, the gap between first path and noise should be bigger than 50%. We decided to use threshold of 50% as an indicator of low quality ranging. In other words, if the gap between first path power and ambient noise is smaller than 50% of first



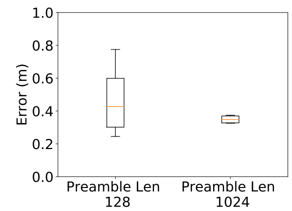
(a) Preamble Length = 128



(b) Preamble Length =1024



(c) Channel = 2



(d) Channel = 5

Figure 12: Impact of frequency hopping compared to increasing the preamble length

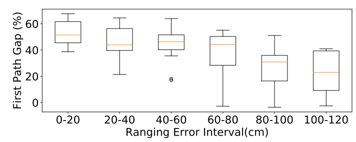


Figure 13: Observed gap between first path power and noise in different ranging error intervals

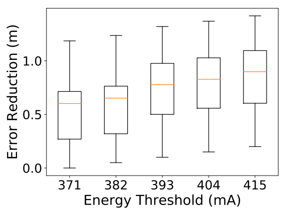
path power, our framework marks the ranging as low quality ranging and in the case of seeing multiple consecutive low quality ranges, it will trigger the search algorithm to change the UWB physical layer setting.

4.4 Proposed Search Algorithm to Find Best Physical Layer Configuration

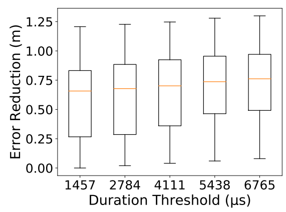
Impact of changing each of the configuration parameters on final accuracy of the system has been investigated in previous sections. The simplest way to change the channel configuration is running a brute-force search algorithm and test the error based on all the possible combinations of values for configuration parameters. In this case, the search space would be 252 different settings. In our framework, considering the impact of each factor on final robustness, accuracy, energy consumption and delay, an efficient search algorithm proposed. Based on our measurements, we proposed Algorithm 1 to change the setting of the channel to improve the robustness considering trade-offs between data rate, power consumption, error rates, and robustness.

Algorithm 1 Find The Best Physical Layer Configuration

$Configs \leftarrow AllAvailableConfigurations$
$P_{th} \leftarrow MaxAllowedPower$
$D_{th} \leftarrow MaxAllowedFrameDuration$
$PC \leftarrow PotentialConfigurations$
$PC_{filtered} \leftarrow \{Config \in PC, Config_{power} \leq P_{th}$ **and** $Config_{length} \leq D_{th}\}$
for all $C \in PC_{filtered}$ **do**
  $C_{error} \leftarrow$ Estimate ranging error
end for
$C_{min} \leftarrow \{C, C_{error} \leq allConfigs \in PC_{filtered}\}$
return C_{min}



(a) Only consider power consumption threshold



(b) Only consider frame duration threshold

Figure 14: Effectiveness of proposed search algorithm on ranging

The proposed algorithm first finds the configurations which satisfy energy and time constraints. As we showed in previous sections, changing channel settings will change power consumption and frame duration. Based on the desired application, user can define thresholds for maximum power consumption preferred per ranging activity and also maximum duration of time per packet. Packet length has two direct impacts on the ranging. First, the packet length identifies the power consumption. It is obvious longer packets require longer transmission and reception which means higher power consumption. Frame duration also is important in air utilization. If the packets are too long, the air utilization goes up and causes lots of interference problem among the UWB nodes. We need to find a configuration which meets both the requirements and also minimizes the error rate.

5. EVALUATION

In this section, we first evaluate effectiveness of proposed algorithm on reducing ranging errors and next, we study the impact of changing UWB physical layer configuration on 2D localization (3 anchors and 1 tag).

5.1 Ranging Quality in Proposed Solution

To evaluate the effectiveness of the suggested technique, we perform simulations using our collected dataset. In each round, we randomly select a configuration to be the starting configuration, then run proposed search algorithm over all the 252 settings in our dataset, to find best configuration in which power consumption and frame duration are below the power consumption and frame duration of current configuration and ranging error is the minimum among the rest of configurations. Figure14 shows reductions achieved by running our proposed search algorithm to find best possible configuration which satisfies either power consumption or frame duration thresholds. The results are achieved by running the simulation for 100 times. Figure 14a shows the reductions in ranging error by only considering power consumption threshold and Figure 14b illustrates error reductions happened by only considering frame duration threshold. Figure 14, shows as much as we have higher power consumption or frame duration thresholds, there is more room for error reduction. Another interesting fact is that increasing power consumption threshold has more potential to reduce ranging errors compared to frame duration threshold.

5.2 Localization with Different Physical Layer Configurations

In this section, we conducted few experiments to evaluate effectiveness of the proposed algorithm on accuracy and robustness of UWB-based indoor localization technique. In our experiments, we used TREK1000 [19] system provided by Decawave. The solution contains four DW1000 based modules (EVB1000) providing UWB transmissions conforming to IEEE 802.15.4a standard. We deployed three nodes as anchor nodes inside an academic building and tracked the fourth node while someone just holding it and moving across a predefined path. We conducted the experiment with 4 different configurations which are summarized in Table 3. As mentioned in earlier sections, preamble size and PRF are two most important factors which have direct impact on accuracy and coverage of UWB localization system. In these experiments, we change both PRF and preamble size to evaluate their impact on final accuracy and robustness of system. Figure 15a shows the trajectory as green lines and reported locations for each configuration. The important fact is by increasing the preamble length, the location update rate is reduced but the reported locations are more accurate.

Table 3: UWB Physical Layer Configurations Selected for the Evaluation

Config #	Frequency (MHz)	PRF	Preamble Length	Data Rate
1	3493.6	16 MHz	128	110 kbps
2	3493.6	64 MHz	128	6.8 Mbps
3	3493.6	16 MHz	1024	110 kbps
4	3493.6	64 MHz	1024	6.8 Mbps

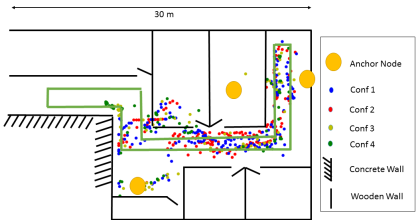
Another interesting fact from figure 15a is that configuration 4 which has 1024 symbols as preamble length and 64 MHz as PRF value increases the robustness of the system by covering more places. Figure 15b shows average reported error in locating the object with each of the configurations. We calculated the minimum distance of each point to the trajectory and considered it as error in estimating the location. Figure 15b shows the average error for each configuration. As expected, configuration 4 has the smallest value of the error.

Finally, Figures 15a and 15b prove that changing configuration of channel will improve the robustness of indoor localization system.

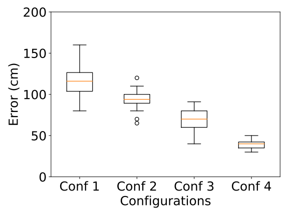
6. DISCUSSION

UWB wireless technologies can be used both for localization and data communication. The optimal setting for localization application may be different from the optimal setting for communication application of UWB. In our current work, we focused on indoor localization and changing the channel setting in a way to increase the robustness of localization at the cost of reducing the efficiency and speed of data communication. Different UWB applications may make different tradeoffs in settings depending on their combination of localization and data transfer goals.

The designed framework will be executed during deployment of the system and it finds the best performing settings. It also can continue monitoring the performance of the localization and update the setting during runtime via a central or distributed protocol. In localization algorithm, tag communicates with each anchor in a separate message which means it can utilize different setting to communicate with



(a) Tracking moving target with different physical layer configurations



(b) Error in each configuration

Figure 15: Localization with different physical layer configurations

each anchor node. The channel setting can be exchanged between tag and anchor during a simple handshaking protocol, in fact, we used this technique in our evaluations.

7. CONCLUSION

Wireless indoor localization using ultra-windband signals is one of promising technologies to solve problem of locating moving objects inside the buildings. In this paper, we propose a novel framework to improve the robustness of UWB localization systems by changing the UWB channel setting in an efficient and fast way. Through extensive real-world implementations using DW1000 UWB transmitters, we verified effectiveness and robustness of our proposed framework. We showed impact of different UWB channel settings on the ranging performance and proposed an algorithm to utilize these differences to increase robustness of UWB-based indoor localization systems.

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