# Poster Abstract: Ultra-Wideband Backscatter Towards General Passive IoT Localization

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## ABSTRACT

Typical passive internet of things (IoT) localization systems, such as those based on UHF RFID, adopt narrow bandwidth signal and bind the localization function with energy harvesting and communication waveform. Due to the signal bandwidth and waveform constraints, the systems can not meet crucial requirements of practical IoT use cases. In this poster, we identify the fundamental challenges and analyze why the existing systems fall short. Based on the analysis, we propose to adopt dual band backscatter design and identify different design choices on frequency band, waveform and tag modulation. Finally, we build an ultra-wideband FMCW signal based prototype UWB$^2$ to verify the feasibility of our proposal. Our results show that the system can achieve low tail error and realize one shot localization even under harsh multipath scenarios.

## CCS CONCEPTS

• **Networks → Network architectures**; • **Hardware → Wireless integrated network sensors**.

## KEYWORDS

UWB, FMCW, RFID, Localization, Internet of Things

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## 1 INTRODUCTION

Passive IoT localization acts as a game-changer for many applications. The asset management in data center, library, warehouse, etc., usually relies on the manual check by scanning the attached bar code. With accurate passive IoT localization, the intensive labor can be freed by automatically identifying and locating the objects. In virtual reality, the passive IoT localization could provide an alternative lightweight approach. A concrete example is the VIVE Tracker [1], which adopts active transmitter for movement tracking and requires an embedded battery with the cost of $100 for each tracking point. Passive IoT localization enables replacing the tracker with low cost, battery-free tags to make full body tracking more accessible. Many general applications in retail stores, factories, smart home etc., can be enabled by passive IoT localization [3, 4, 6].

Over the past few years, a number of passive IoT localization systems [2–5] were proposed to fulfill the requirements of the applications. It is tempting to think that the state-of-the-art systems with centimeter level precision rating can already thoroughly satisfy all the requirements of passive IoT applications. However, we argue that the widely studied backscatter based localization systems are still far away from acceptable for real-world use cases. None of the existing systems address all of the following challenges:

- **Low tail error:** In the real world deployment, the tail error of localization accuracy is a much more important metric than median error. The system should provide low tail error even under the harshest scenarios with prevalent strong multipath. A common problem in the existing papers is treating none-line-of-sight (NLoS) deployment as a multipath-rich deployment. NLoS usually means the signal strength of the line-of-sight path is lower but does not necessary means that prevalent strong multipath exists. The localization error under strong multipath is the main reason why long tail error exist which cannot be fixed by the works with limited bandwidth [2–4].
- **One shot localization:** The system should locate the position of nearby tag with one shot response. In large scale applications, the chance of collecting signals from a specific tag is quite low, especially for random accessed tags like RFID. If the system needs many rounds to locate many tags like [4], the localization will be too time consuming for real deployment scenarios, especially in a warehouse where hundreds or thousands of tags are needed to be read.
- **Low tag cost:** The tag needs to be cheap if the system targets large scale deployments. Millimeter wave based design such as [5] has the potential to address the previous challenges at the same time, but the requirement of millimeter wave antenna and components will lead to higher cost (tens of dollars per tag) compared to UHF RFID tag (several cents per tag).
- **No application specific assumption:** There should be no application specific assumption to the system which may hinder the general deployment. For example, an assumption that the tag must be static [4] will limit the applicable use cases.


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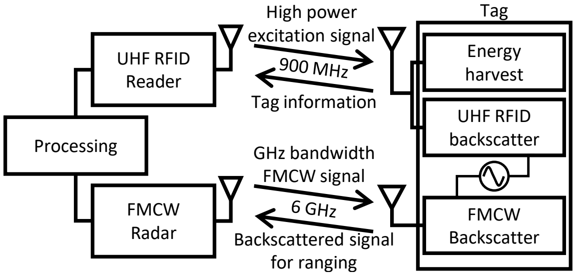


**Figure 1: System diagram of UWB$^2$.**

In this poster, we proposed UWB$^2$, the first GHz bandwidth backscatter system which can perform low tail error, one shot localization without application specific requirements.

## 2 UWB$^2$ DESIGN

We believe that the main reason why existing works cannot address all of the challenges at the same time is that they stick to the single band operation. Most projects [2–4] prioritize the consideration on the tag cost and thus use the UHF RFID signal in 900 MHz band for both data reading and localization. The issue will be that the available signal bandwidth is not wide enough to disentangle the multipath signals, i.e., the direct path cannot be differentiated from the multi-paths if the path length differs by less than 1.5 m (the range resolution corresponding to the 200 MHz sampling bandwidth extended to licensed band [4]). On the other hand, custom design [5] with higher carrier frequency may have enough bandwidth (*i.e.,* enough range resolution) for robust localization. But the tag cost will be high due to the requirements of additional power source (path loss of higher frequency is much larger and not being able to deliver enough power to the tag though wireless energy harvesting) and high frequency components.

Therefore, to address all of the challenges, UWB$^2$ adopts a dual-band design (Fig. 1) based on UHF RFID. More specifically, the powering and tag data reading function will be done by the existing UHF RFID design at low carrier frequency band, while the localization function is implemented in a higher frequency band where much wider bandwidth is available. Here, we will focus on the localization function design.

**Frequency band.** We picked the newly released 6 GHz band for the localization function. Specifically, FCC has released the 1.2 GHz contiguous spectrum in the 6 GHz band for indoor unlicensed use with up to 30 dBm EIRP.The bandwidth is 46× of the 900 MHz unlicensed band and even 5× of the 24 GHz unlicensed band. Combining with other U-NII bands at 5 GHz, the available bandwidth can be nearly 2 GHz. This would provide 15 cm range resolution, which means robust localization results can be achieved even in a multipath-rich environment. Only design in 60 GHz band may have larger bandwidth, but that high operating frequency is not ideal because of the much higher cost and shorter range.

**Ultra-wideband backscatter.** In UWB$^2$, an ultra-wideband (UWB) signal from tag is generated by backscattering a UWB excitation signal from the reader device. The key finding behind is that in backscatter communication, the bandwidth of the backscattered signal depends on both the excitation signal which acts as the carrier signal and the backscatter modulation on the tag. Although the backscatter modulation has to be narrow bandwidth due to the power limitation on the tag, the backscattered tag signal can still be an UWB signal when the excitation signal is ultra-wideband.

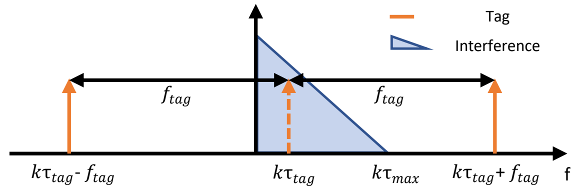


**Figure 2: FMCW processing result with tag signal.**

**UWB signal design.** Then UWB$^2$ adopts frequency modulated continuous wave (FMCW) signal as the UWB excitation signal due to the low complexity of the hardware, especially when the bandwidth is more than 1 GHz.

**Tag modulation.** UWB$^2$ introduces a careful tag modulation design with frequency shifting backscattering. Specifically, the tag applies a constant frequency $f_{tag}$ clock to the RF switch. As illustrated in Fig. 2, such modulation will move the tag signal far away from the interference introduced by TX to RX leakage and the indoor object reflection. Thus, the best signal to interference and noise ratio (SINR) can be reached for the longest reading range. This design ensures that the localization can be done within one FMCW period which meets the requirement of one shot localization.

**Ranging.** As shown in Fig. 2, after FMCW processing, the tag modulation will result in double side band signal at $f_1 = k\tau_{tag} - f_{tag}$ and $f_2 = k\tau_{tag} + f_{tag}$. Then the time of flight $\tau_{tag}$ can be calculated by $\tau_{tag} = (f_1 + f_2)/2$. Therefore, the range can be derived with a one-time inventory. Noting that the ranging method of UWB$^2$ does not need a preknown value of $f_{tag}$. Hence, the tag of UWB$^2$ can reuse the power and clock of UHF RFID tag. The only additional needs compared to existing RFID tag is an 6 GHz RF switch on the chip which does not introduce too much cost.

## 3 RESULT AND FUTHURE WORK

We implement a prototype of UWB$^2$ design and evaluate the ranging performance in multipath-rich environment. The system achieves a 90th percentile error of 14 cm in the harshest scenario, even without any additional super-resolution processing. The largest error is around 30 cm in the strong multipath environment and around 7 cm in the normal indoor environment with a stable sensing range of more than 5 m. We will further improve our design and thoroughly evaluate the system.

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