Tracking Resurgence of Ultra-Wideband – A Standards and Certification Perspective

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***Abstract*— In this paper we present the resurgence of Ultra-Wideband (UWB) as a highly accurate and secure ranging technology for IoT systems. We present a view of this resurgence from standards and certification perspective. UWB communication, based on impulse radio technology, was first standardized in IEEE 802.15.4a specification. IEEE 802.15.4a defined PHY& MAC mechanisms and a few ranging techniques for UWB communications. The latest amendment to the UWB standard happened in IEEE 802.15.4z. With improved accuracy and security enhancements introduced in IEEE 802.15.4z, UWB has emerged as preferred technology for ranging and positioning. FiRa Consortium builds upon and enhances the IEEE 802.15.4z specification. It defines other mechanisms to enable multiple use-cases of UWB. In this paper, we present the evolution of UWB standard, key developments of IEEE 802.15.4z that enabled resurgence of UWB as a preferred choice for ranging and positioning technology. We also present technology developed in FiRa Consortium, FiRa Consortium certification program and the next steps for UWB in the future.**

Keywords— Ultra-Wideband, Impulse Radio, IEEE 802.15.4z, FiRa Consortium

I. INTRODUCTION

Ultra-Wideband (UWB) is a wireless technology used for transmitting data over short distances and with a low power density. As the name suggests, the data is transmitted over a large bandwidth of about 500 MHz. One version of UWB, based on multi-band orthogonal frequency division multiplexing (MB-OFDM), was considered in the past for high speed data transfer with data rates up to 480 Mbps. WiMedia Alliance [1] was formed in 2002 with the intent of standardizing this version of UWB and certifying UWB products. However, the UWB for high speed data transfer did not gain as much popularity as expected and died out with Wi-Fi's success. Another variant of UWB called UWB impulse radio that uses extremely short UWB pulses became a front-runner for developing highly accurate ranging and positioning systems. In 2007, IEEE 802.15.4a [2] defined an impulse radio based UWB technology with focus on low power usage and highly accurate ranging capability, with an accuracy of within 1 metre. Recently in 2019, IEEE 802.15.4z [3], made amendments to the UWB standard adding more PHY mechanisms to improve the ranging accuracy within 10cm and enhance security at PHY, making ranging more secure and reliable.

In recent days, IOT ecosystems are becoming prevalent, more nuanced use cases involving multi-device experience are being conceived. With the reliable ranging technology offered by IEEE 802.15.4z, the ability to accurately and securely determine the distance of another device with an accuracy of ± 10 cms enables us to address numerous IoT use cases that can improve the quality of experience for the end user. For example, in an automotive scenario the ability to identify that the owner of the car is at a specific distance from the car door allows us to create an excellent experience of seamless access for the user of the car. As the user is approaching the car, about 10 meters away from the car, the car can flash its lights to help the user locate it in a parking lot. As the user walks further towards the car, the car starts its heating or cooling system to make the car comfortable to the user. As the user approaches the car door and is very close to the car, the door unlocks, mirrors open and seats adjust as per the user preference. Once the user is inside the car, ignition system starts. This is one example that illustrates how UWB based accurate ranging can help us develop a rich set of use cases. One can imagine the potential of this technology to open up interesting use cases in other service verticals like physical access security systems, location services, transit systems, banking and payment, gaming etc.

For the success of UWB ranging technology, Interoperability needs to be addressed. FiRa Consortium [4] is a standardisation and certification body that builds technology on top of IEEE 802.15.4z and ensures interoperability. FiRa Consortium defines requirements to enable many use cases of UWB. Technical requirements for PHY, MAC and higher layers to address the use cases are defined, interoperability is ensured and certification is done based on the requirements defined in FiRa Consortium. The certification program for the first version of PHY and MAC was recently launched.

In section II of the paper, we present UWB evolution, describe the advancements made in IEEE 802.15.4z to define UWB impulse radio PHY and MAC mechanisms for ranging. In section III, we present the standardization and certification efforts of FiRa Consortium to develop UWB ecosystem by defining requirements, technical specifications, providing interoperability and conformance testing, providing certification of UWB devices and creating the building blocks for developing applications in multiple service verticals. In section IV, we talk about the next generation UWB, which is being developed in IEEE in Task group TG4ab with the goal of improving link budget, introducing Narrow Band (NB) signalling tightly coupled with UWB and high data rate streaming.

II. ULTRA-WIDEBAND STANDARDISATION

IEEE 802.15 [5] is a working group in IEEE, which specifies technical standards for Wireless Personal Area Networks (WPAN). UWB standardization started with two task groups TG3a [6] and TG4a [7] in IEEE tasked with making amendments to 802.15 standard to provide alternate PHY specifications that would allow communication with precise ranging capability and low power usage. In TG3a, two technologies, namely multi-band orthogonal frequency division multiplexing (MB-OFDM) and direct sequence code division mutiple access (DS-CDMA), competed. However, TG3a task group fell apart with no consensus in the group for choice between the two technologies and no standard was defined. Based on one of the proposals in TG3a, UWB based on MB-OFDM was standardized in WiMedia. IEEE 802.15.4 [8] is a technical standard that defines the operation of low rate personal area networks. This standard defines various PHY and MAC specifications for low rate wireless personal area networks (WPAN). TG4a defined multiple PHY standards in IEEE 802.15.4a, one among which was impulse radio based UWB technology. Impulse radio based technology for UWB used very short pulses of about 2ns to transmit data. Short pulses result in a very large bandwidth of about 500MHz, which helps in detection of direct path in multipath environment and thereby improving the accuracy of ranging. TG4a also introduced ranging techniques to calculate the distance between devices. Subsequently in 2012, task group TG4f [9] defined a Low Rate Pulse Repetition (LRP) UWB PHY in the amendment IEEE 802.15.4f [10]. In 2018, Task group TG4z [11] was tasked to amend the UWB standards with specifications for enhancing security and improving ranging accuracy. This group has defined multiple enhancements to the PHY and MAC to enable secure and accurate ranging over UWB. Two variants of PHY defined in IEEE 802.15.4, were enhanced in this amendment, one based on the High Rate Pulse Repetition Frequency (HRP) and the other based on Low Rate Pulse Repetition Frequency (LRP). One major development in HRP-PHY is the introduction of scrambled Time stamp (STS), detailed in the next section. FiRa Consortium chose to build upon HRP-PHY for all the use-cases and certification. This paper will focus on HRP-PHY for developments related to PHY.

A. IEEE 802.15.4z

As mentioned in the previous section IEEE 802.15.4z amendment incorporated changes to PHY and MAC which enhanced security and improved accuracy of ranging.

1) Ranging enhancements

IEEE 802.15.4a, in 2007 introduced Single Sided Two way Ranging (SS-TWR). As shown in Fig 1, this method of ranging involves two transmissions. One packet is transmitted from *Device 1* to *Device 2*. *Device 2* responds with another packet. *Device 2* includes reply time in the form of time stamp in the packet. On reception of response, *Device 1* uses the round trip time T_{ROUND} as well as reply time, T_{REPLY} to determine the distance between the devices. SS-TWR has the disadvantage of erroneous calculation due to clock offsets in the two devices and internal delays in the device to start timing counters.

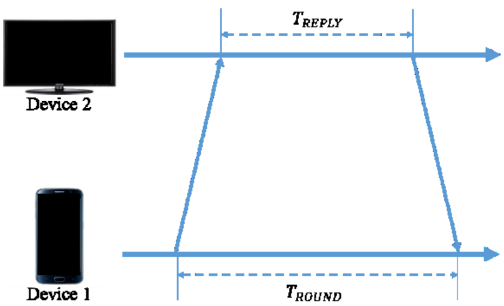

Fig 1. Single Sided Two way Ranging

The propagation time, T_{PROP} is estimated as

$$T_{PROP} = \frac{1}{2}(T_{ROUND} - T_{REPLY}) \quad (1)$$

Where T_{PROP} is the time of flight used to calculate distance. T_{ROUND} and T_{REPLY} are calculated independently by *Device 1* and *Device 2*. T_{PROP} and speed of light is used to calculate the distance between two devices.

IEEE 802.15.4z introduces Double Sided Two Way Ranging (DS-TWR) to mitigate ill effects of clock offset and internal delay in the devices. As shown in Fig 2, it uses four packets instead of two packets of exchange in SS-TWR. DS-TWR essentially is like two SS-TWR exchanges.

The time of flight, T_{PROP} is estimated as

$$T_{PROP} = \frac{(T_{ROUND1} \times T_{ROUND2} - T_{REPLY1} \times T_{REPLY2})}{(T_{ROUND1} + T_{ROUND2} + T_{REPLY1} + T_{REPLY2})} \quad (2)$$

Where T_{PROP} is the time of flight used to calculate distance. T_{ROUND1} , T_{REPLY2} and T_{REPLY1} , T_{ROUND2} are calculated independently by Device 1 and Device 2 respectively.

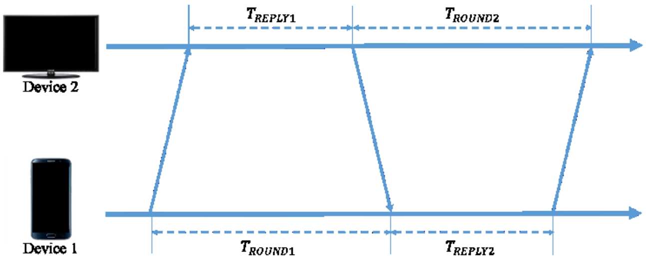

Fig 2. Double Sided Two Way Ranging

Another version of ranging technique called One-way ranging (OWR) was also introduced in IEEE 802.15.4a and enhanced in IEEE 802.15.4z. OWR however requires to have a common time across devices and an infrastructure of ranging devices to locate another device. OWR is based on time difference of arrival (TDoA) of packets from multiple sources to calculate distance.

If ranging happens between two devices, it is called one-to-one ranging. IEEE 802.15.4a only supported one-to-one ranging. IEEE 802.15.4z introduced support to multi-node ranging. In multi-node ranging one or more devices range with one or more other devices. This may be one-to-many or many-to-many ranging.

2) PHY enhancements for UWB ranging

IEEE 802.15.4 introduced a new set of length 91 ternary preamble codes for better synchronisation for HRP devices. At PHY, a HRP device also incorporates a Scrambled Time stamp Sequence (STS) [3]. This sequence is generated by an AES-128 based deterministic random bit generator. STS ensures that only valid transmitters and receivers know the correct key and data to generate the transmission sequence at transmitter side and for cross correlation on the receiver side to accurately determine the receive time. Thus the PHY itself provides a level of security that enables secure ranging. Based on the position of STS in the packet, IEEE 802.15.4z defines four types of packet formats. The 802.15.4z PHY supports Base Pulse Repetition Frequency (BRPF) and Higher Pulse Repetition Frequency (HPRF) modes for spreading and modulating the payload, with HPRF being introduced in the specification.

3) MAC enhancements for UWB ranging

IEEE 802.15.4z specification defines two types of devices, controller and controlee. The specification also defines two new roles, initiator and responder. Controller device is the one that configures ranging parameters and modes of operation and the controlee receives the configuration from the controller and configures itself. Either device can be an initiator or responder for ranging. An initiator device starts the ranging event by sending a ranging initiation message and the responder responds to it. Devices that support multiple antennas can measure Angle of Arrival that enables locating a device in a polar coordinate system relative to the device.

IEEE 802.15.4z also defines ranging block structure and two modes of ranging in multi-node ranging - interval-based mode and block-based mode. While interval-based mode allows for a flexible block period in a ranging session, in block-based mode, block period is assumed to be constant. FiRa Consortium mandates block-based ranging mode.

III. FiRa Consortium

IEEE 802.15.4z group has defined PHY and MAC of the UWB specification. However, for any technology to be successful in the market there is a need for developing the ecosystem through a multitude of use cases that make use of this technology and improve user experience. User adoption of the technology is directly dependent on how much of an impact it has over their lives and its ease of use. In order to ensure seamless interactions between UWB devices of multiple manufacturers in multiple service verticals, interoperability and certification of the devices is required. With this thought process in mind, in 2019, several companies including Samsung, NXP and HID Global came together to form the FiRa Consortium [4]. This consortium provides certification and testing of UWB devices by developing a FiRa Consortium certification program. The consortium is also developing common services & management layer specification and profile specifications. Currently, FiRa Consortium is defining requirements for use cases of physical access, untracked navigation, asset tracking, smart home, find something nearby and transit [14].

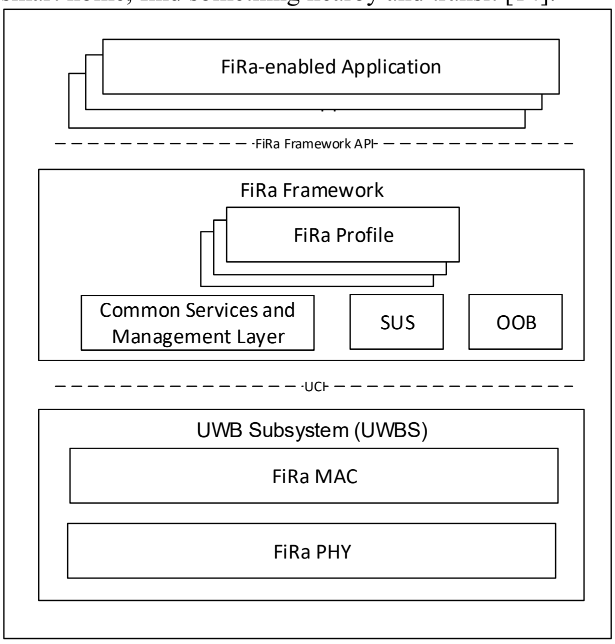

Fig 3. Simplified view of FiRa Device Architecture.

Many of the use cases being targeted by the FiRa Consortium, like physical access control and payment, may require a high level of security in the system. While the IEEE 802.15.4z task group has worked on enhancing the security at the PHY through mechanisms like scrambled time stamp (STS), enabling secure ranging and data transfer, FiRa Consortium has focused on enabling highly secure communication of key material between peer devices, secure storage of keys and secure configuration of the UWB radio. Many of the features being developed by FiRa Consortium, like secure channels, use of a secure element (SE) for storage, secure UWB service (SUS) and the applet (a small application run on the SE) are for this purpose. However, to enable markets that can accept a lower level of security, FiRa Consortium also supports a feature called reliable ranging, which does not require a shared secret between peer devices for generating the STS.

A simplified FiRa Device functional architecture is shown in Fig 3. It comprises of UWB Subsystem which typically resides on the UWB chip, FiRa Framework which runs on the application processor and FiRa-enabled applications. Some parts like applet run on SE (not shown in this figure for simplicity). To enable the FiRa Framework to communicate with the UWB subsystem, the UWB Command Interface (UCI) has been defined. FiRa Framework APIs provide easy to use interface to allow FiRa-enabled applications on the device to use the UWB capabilities of the device in a standardized way.

UWB subsystem comprises of FiRa Consortium defined PHY and MAC. FiRa Consortium is developing PHY and MAC requirements specifications based on the IEEE 802.15.4 and 802.15.4z specifications. These specifications capture important functional, performance requirements and behaviour of UWB devices for certification. These include:

– Detailed key derivation mechanism for STS generation

– Dynamic and Static STS

– Detailed requirements for block-based ranging mode

FiRa Consortium PHY and MAC requirements specifications also add features, which enhance UWB PHY and MAC defined in IEEE 802.15.4 and 802.15.4z specifications such as

– FiRa Consortium defined UWB messages for control configuration and reporting of measurement results

– Block striding - To skip ranging blocks when frequent ranging is not required

– Additional PHY parameter sets

– Integrity Check for ranging measurements in FiRa Device

FiRa Framework helps support various UWB applications. FiRa Consortium defines common service and management layer (CSML) specification, which is the core of FiRa Framework. Since the IEEE 802.15.4z specification does not specify in-band mechanisms for discovery and configuration of the UWB radio, CSML specification provides mechanisms for UWB discovery, as part of Out-of-band (OOB) specifications. Currently Bluetooth low energy (BLE) based discovery and configuration mechanism is defined. In the future, additional OOB mechanisms like Wi-Fi may be considered. As it is important to keep the keys, which are used for UWB ranging, secure, the specification provides detailed mechanisms for secure channel setup between peer devices. The secure channels are based on Global Platform SCP03[12] protocol and a variant of SCP03. ISO/IEC 7816-4:2020[13] based command set is used for data exchange over the secure channels. For secure storage of key material, FiRa Framework specifies the use of a hardware based SE. In the future, this will be extended to cover additional secure components like a trusted execution environment (TEE) and application processor (AP) based approaches. For interoperability, the specification defines the data model for exchange of information for setting up the UWB session. The data model includes information like UWB capabilities, UWB preferences, UWB configuration including session keys used during UWB ranging and UWB regulatory information. The data model can be extended to include profile specific information, which are defined by Profile specifications.

FiRa Consortium defines various FiRa Profile Specifications, which cater to various service verticals/use cases, such as physical access, navigation, smart home etc. Each of the profile specifications define the set of features required from various layers to support the use case. For example, some profiles may allow only use of Dynamic STS, which is required for high security. Profile specifications also define typical operational flows which enable interoperability. They also defines UWB configurations based on the use case. In addition, Profile specifications define profile specific data that needs to be exchanged between the FiRa Devices supporting a particular profile.

FiRa Consortium defines a FiRa Device and a FiRa Smart Device. A FiRa Device is based on Enhanced Ranging Device (ERDEV), as defined in IEEE 802.15.4z. A FiRa Smart Device is a FiRa Device that also implements the Framework API. FiRa specifications define reference APIs to allow various OS/platform vendors to provide APIs in their platforms, to allow 3rd party application developers to develop various FiRa-enabled applications. In future, OS-specific APIs may also be detailed as part of FiRa specifications. These APIs provide easy to use interface to allow applications on the device to use the UWB capabilities of the device in a standardized way. A FiRa Smart Device may host multiple FiRa-enabled applications, including those provided by 3rd parties, which may be installed by the user. A FiRa Device does not expose the Framework API but may use a proprietary interface to support specific applications provided by the manufacturer. This may be used in devices which are dedicated to a particular use case (e.g. a door lock), and does not require installation of applications by user.

FiRa Consortium also defines an applet to be installed and run within the SE. When instantiated with the application identification (AID) defined in the specification, it hosts the secure channel keys, UWB parameters like session ID and keys for different service providers. It also implements secure channel protocols and the means for a service provider backend to securely provision the application dedicated file (ADF).

FiRa Consortium has also developed PHY and MAC conformance and interoperability test specifications to enable a robust certification program. The FiRa Consortium certification program will be expanded to include the profile specifications for more use cases such as indoor positioning, payment ensuring interoperability.

IV. Next Generation Ultra-Wideband

IEEE Task group TG4ab, under IEEE 802.15.4, has been tasked with developing a next generation UWB, with the objectives of improving link budget by introducing new improved coding schemes, introducing interference mitigation techniques for improving coexistence, introducing a Narrow band signalling tightly coupled with UWB and enabling high data rate streaming using UWB. The Task group is currently accepting technical proposals from various members for addressing requirements of the PAR [15].

Setting up a UWB ranging session, has been a major challenge so far. Currently UWB uses an OOB technology like Bluetooth or Wi-Fi to setup a ranging session. In-band setup is power consuming and hence there is a need for narrow band signalling. Proposals from many companies have come into TG4ab, concentrating towards having a Narrow Band (NB) signalling radio or a wake up radio tightly coupled to UWB for control and setup of ranging.

Samsung has proposed a MAC scheme [16] for Narrow band coupling with UWB. We briefly discuss the proposal below. The proposal introduces a MAC scheme with NB tightly coupled to UWB to setup UWB ranging. The proposal introduces concepts of mirroring channel and a discovery channel. An NB channel mirrors UWB usage, and another NB channel helps in discovery of UWB devices and ranging setup. Fig 4 shows an example operation. Device discovery happens with exchange of three messages in discovery channel. The device next moves to mirroring channel to identify and reserve a free slot. Post reserving a free slot in the mirroring channel, the device comes back to setup the connection in discovery channel. To address collisions in both discovery and mirroring channels, we define a collision avoidance scheme introducing a set of delay timers and defining back off strategy.

There are also proposals for using Turbo codes, Low Density Parity Check (LDPC) codes for improved encoding. A spectrum of proposals for use cases ranging from low data rate to a very high data rate that include use cases of streaming real time audio are been discussed in the Task group. We expect the NG UWB specification coming out of TG4ab to bring in much needed enhancements to the UWB technology, addressing various requirements of the PAR successfully.

V. Conclusion

UWB as a technology finds a great potential for use in many use cases ranging from payment to device control, tracking to name a few. In a couple of years since formation of FiRa Consortium, many big players have joined the group and invested to develop UWB technology for various service verticals. With the solid technical foundation laid by IEEE 802.15.4z, large number of proposals coming in to improve UWB in TG4ab, and with FiRa Consortium developing new specifications for services, ecosystem development and certification programs, the stage is set for the UWB market to develop and flourish. We foresee a future where UWB would be ubiquitous and enjoy a global acceptance. Standardization and certification of this emerging technology thereby is very important to ensure the success and adoption on a global scale.

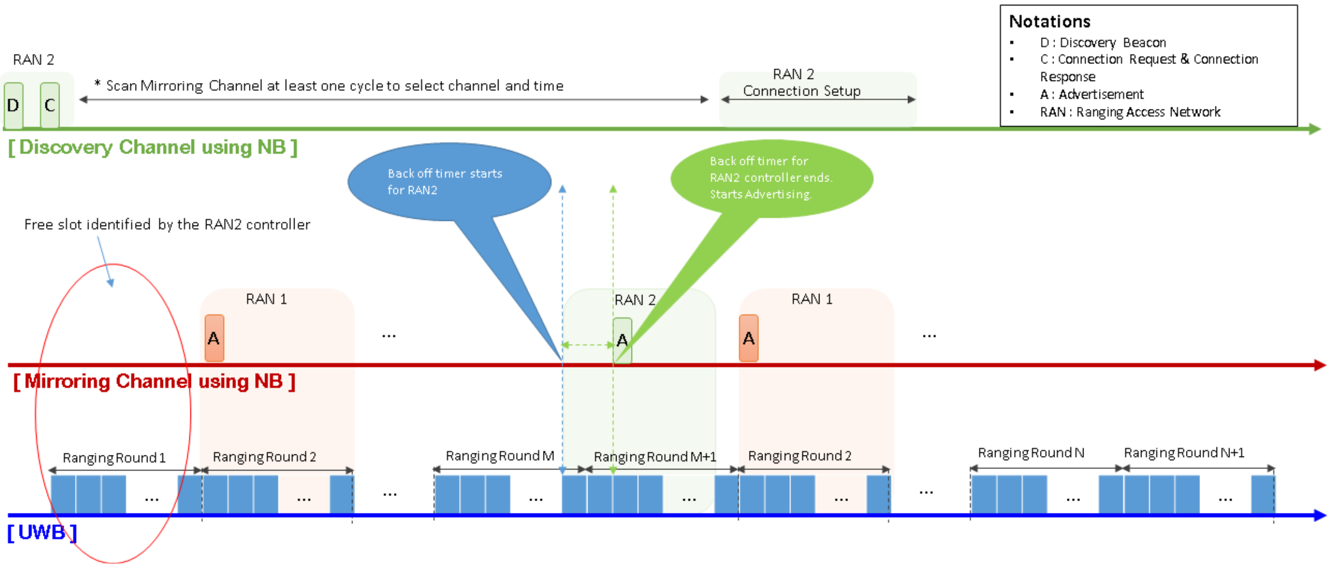

Fig 4. NB-UWB coupling MAC

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