Project: IEEE P802.15 Working Group for Wireless Specialty Networks (WSN)

Submission Title: Evolution of 4z enabling optimized many-to-many ranging for dense environments
Date Submitted: January 2023
Source: Jean-Marie André (ST microelectronics), Vincent van der Locht (SynchronicIT), Sven Zeisberg, Erik Mademann (ZIGPOS), Franz Lehman (TRUMPF)
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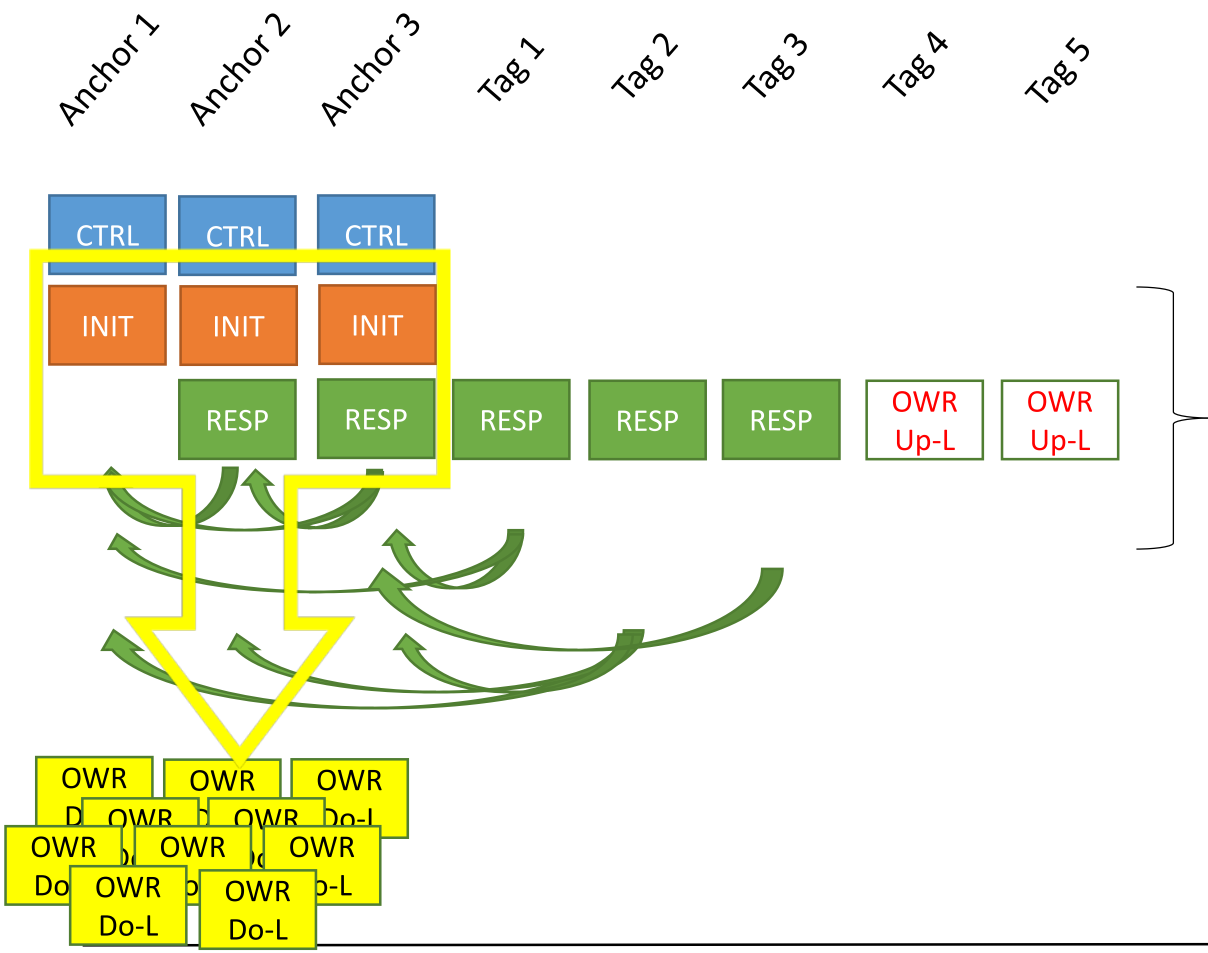
Re: Call for contributions to IEEE 802.15 TG4ab
Abstract: Evolution of IEEE 802.15.4z enabling efficient scheduled positioning systems
Purpose: Propose evolutionary extensions to IEEE 802.15.4z for scheduled ranging concerning ranging roles in slot assignments and initiator picking of responders.

PAR Objective	Proposed Solution (how addressed)
Safeguards so that the high throughput data use cases will not cause significant disruption to low duty-cycle ranging use cases	
Interference mitigation techniques to support higher density and higher traffic use cases	Reduce number of messages in dense positioning systems
Other coexistence improvement	Reduce signal aggregation
Backward compatibility with enhanced ranging capable devices (ERDEVs)	
Improved link budget and/or reduced air-time	reduce air-time by avoiding transmission duplication and or merging messages of various types
Additional channels and operating frequencies	
Improvements to accuracy / precision / reliability and interoperability for high-integrity ranging	
Reduced complexity and power consumption	Less messages will optimize power consumption in dense environments.
Hybrid operation with narrowband signaling to assist UWB	
Enhanced native discovery and connection setup mechanisms	
Sensing capabilities to support presence detection and environment mapping	
Low-power low-latency streaming	
Higher data-rate streaming allowing at least 50 Mbit/s of throughput	
Support for peer-to-peer, peer-to-multi-peer, and station-to-infrastructure protocols	The proposed scheme supports infrastructure-based positioning systems.
Infrastructure synchronization mechanisms	The proposed extension allows multiple synchronization schemes

Reminder on the slide presented last time



Cumulating multiple functions into one single UWB frame makes the whole system much more time-efficient (6 time slots vs 14) for dense ranging use cases

Sven Zeisberg, Jean-Marie Andre, et al.

Reminder on the structure described in 4z

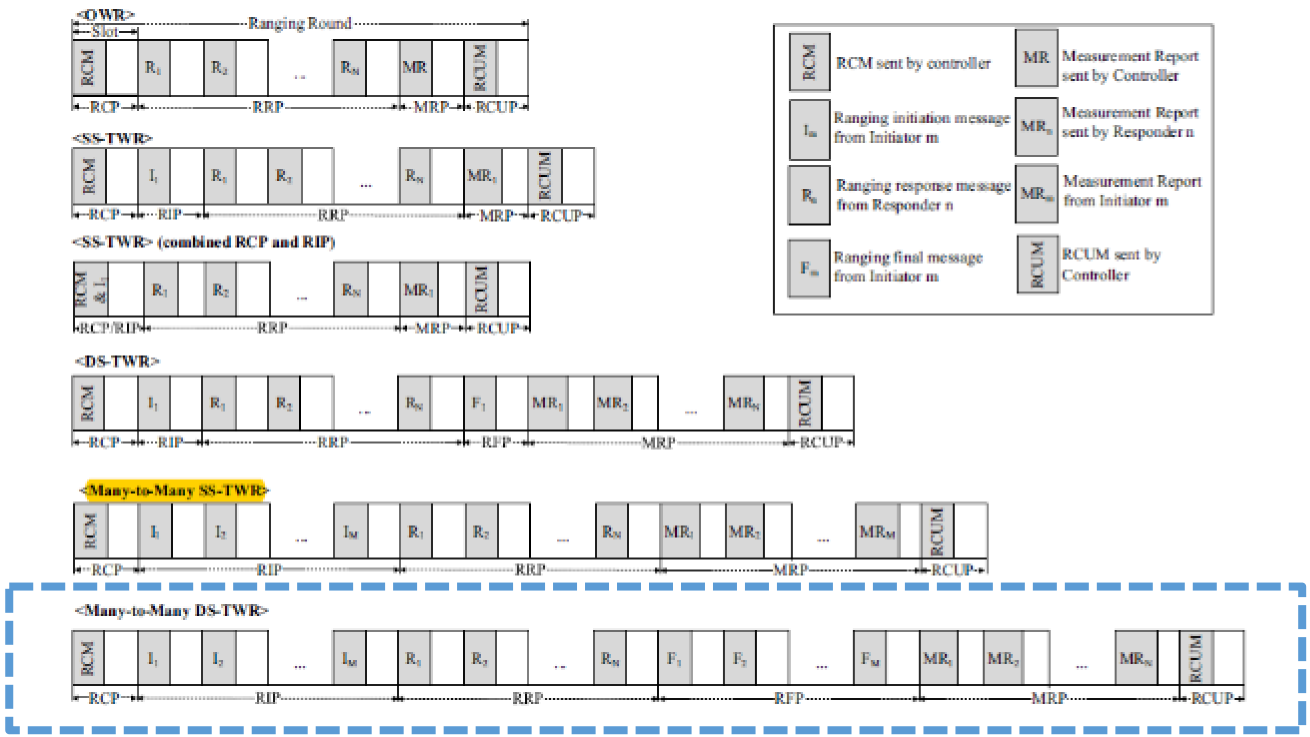


Figure 6-48l—Example timing diagrams for some different multi-device ranging use cases

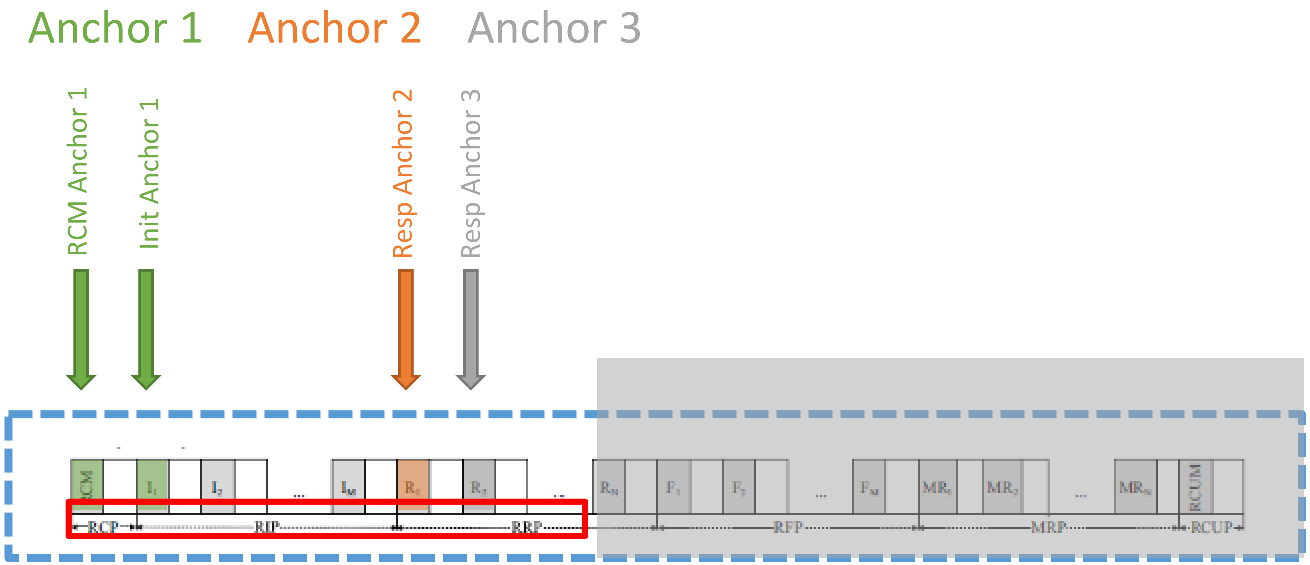
We have mapped the mechanisms presented last time on the Many to Many DS-TWR scheme

Reminder on the structure described in 4z

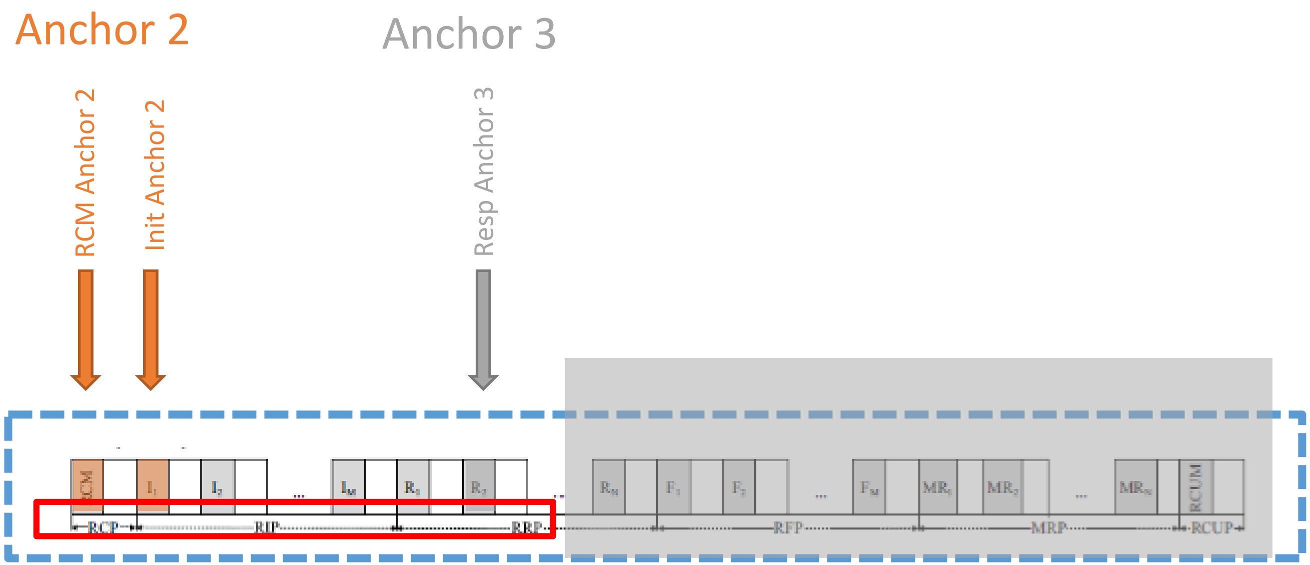
Figure 6-48l—Example timing diagrams for some different multi-device ranging use cases

We are considering the RCP, Init and Resp phases

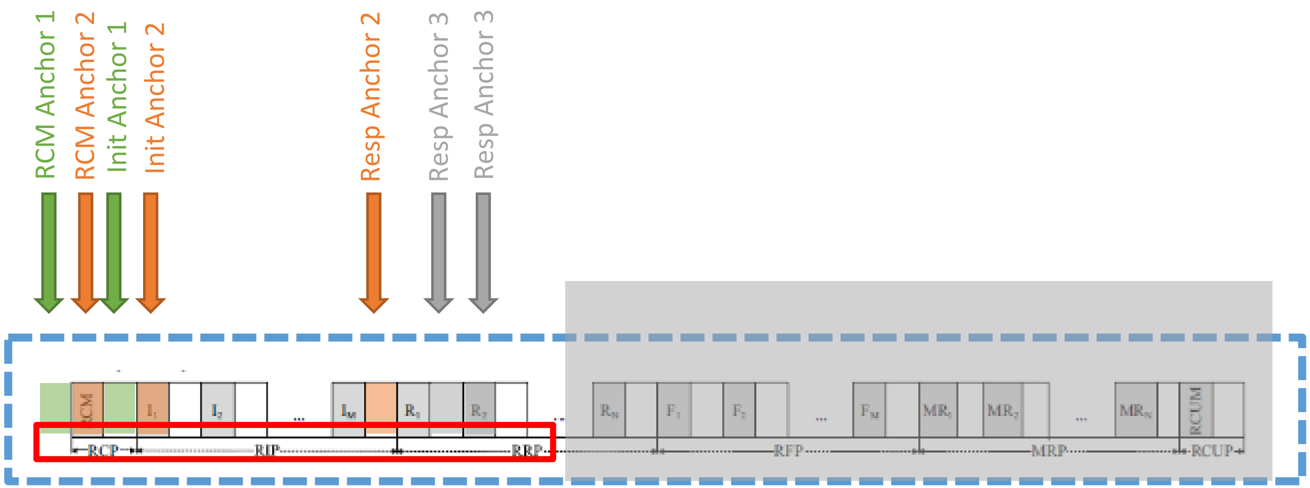
Ranging between 1st anchor and next anchors



Ranging between 2nd anchor and next anchor

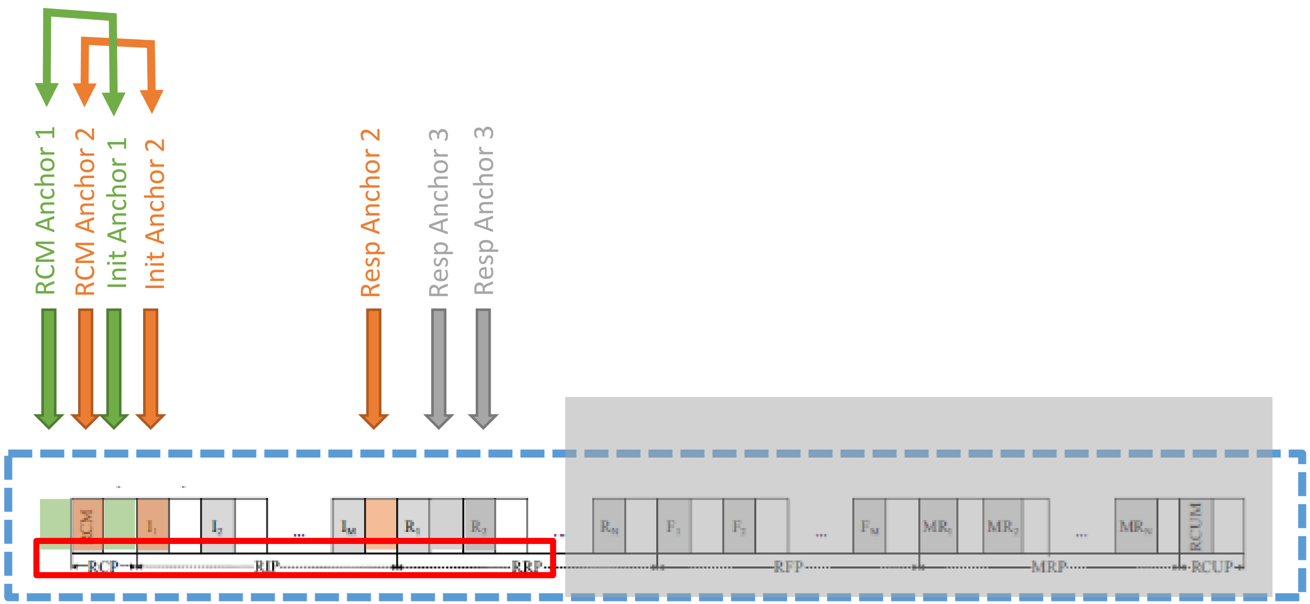


Both rangings on the same time structure



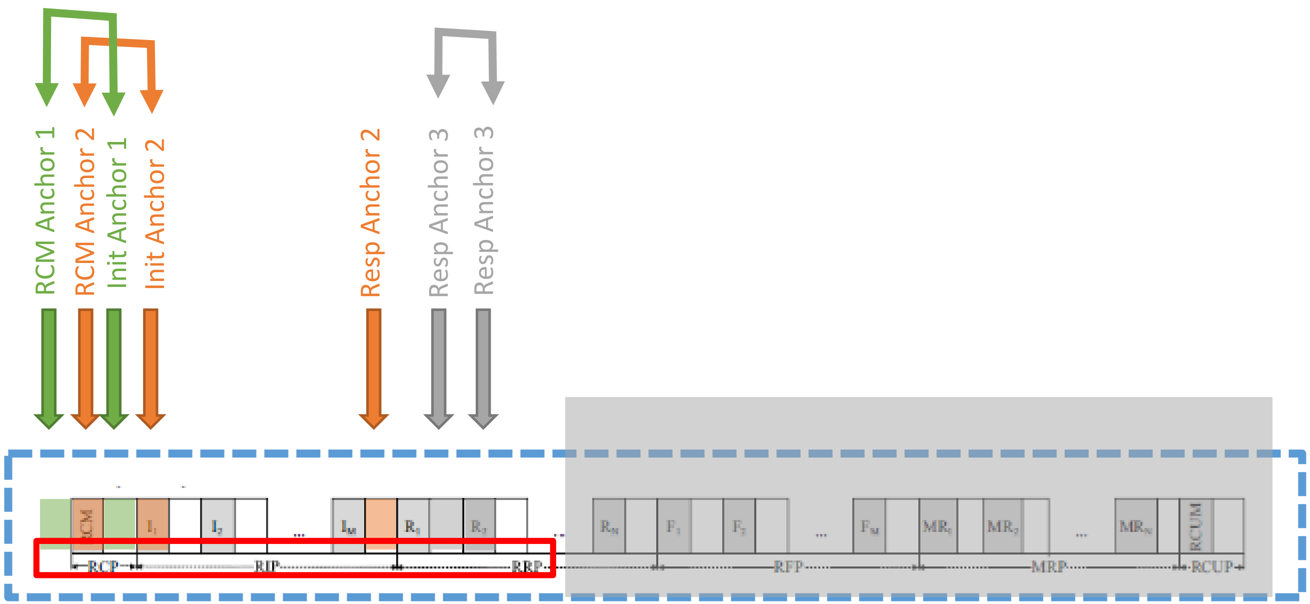
Mapping all messages on the same time structure highlights the duplication of messages
And stress the need for optimization

Optimization: merging messages



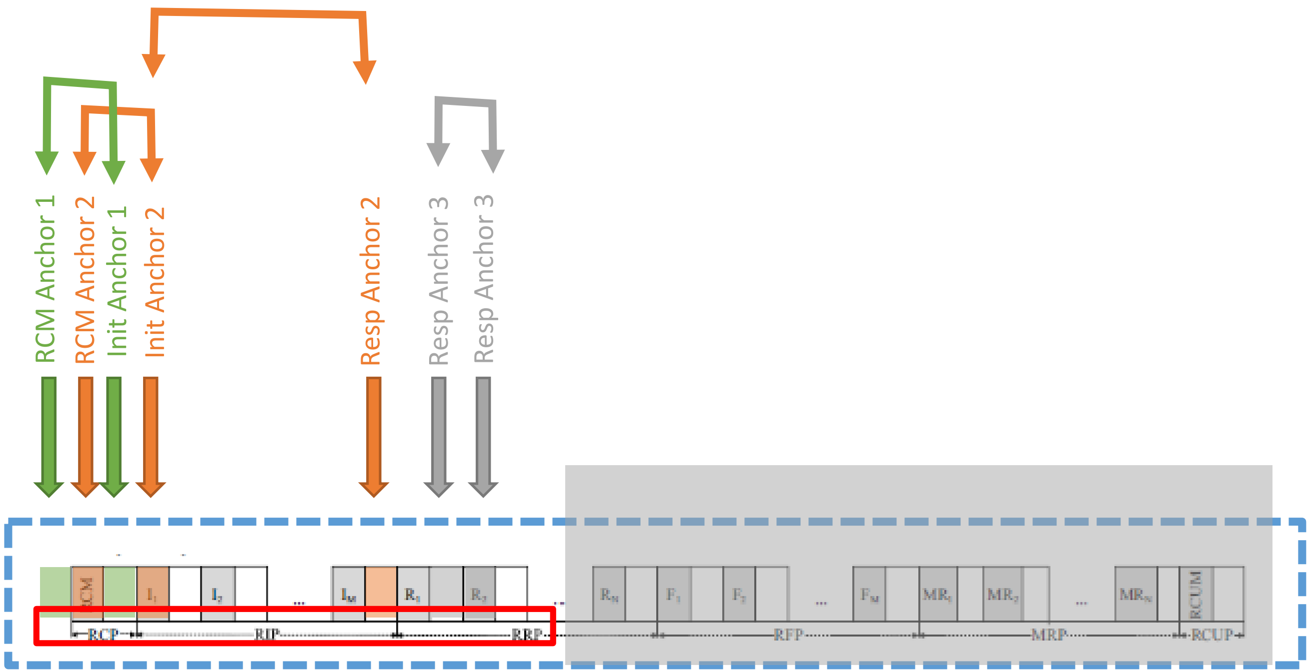
It is "4z compliant" to merge RCM and Init messages

Optimization: merging messages



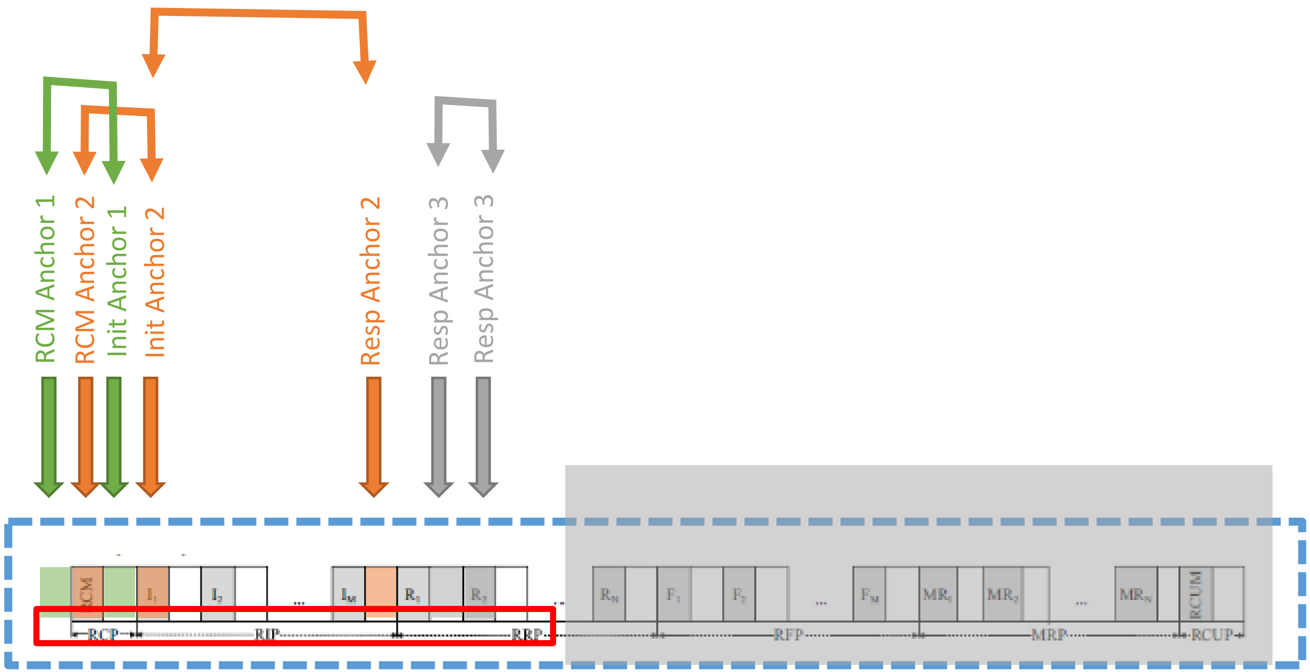
It is “4z compliant” to merge multiple Response messages

Optimization: merging messages



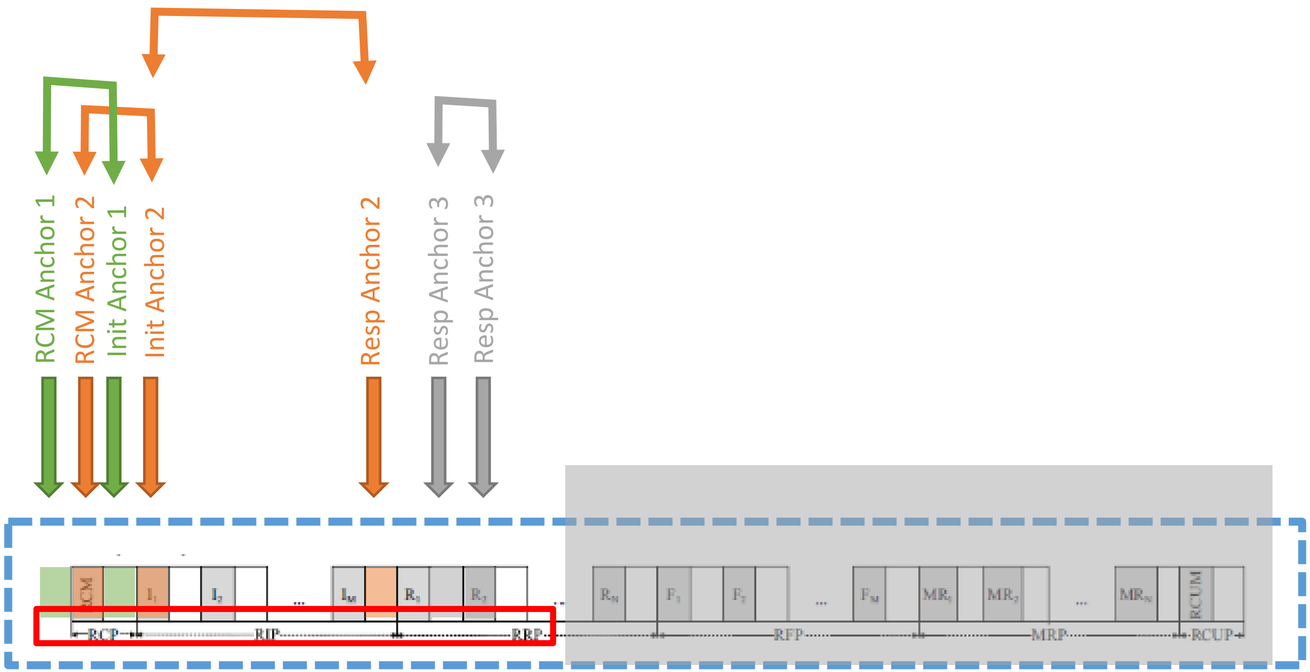
It is “4z compliant” to merge multiple Init and Response messages

Suggested evolution: merging all messages



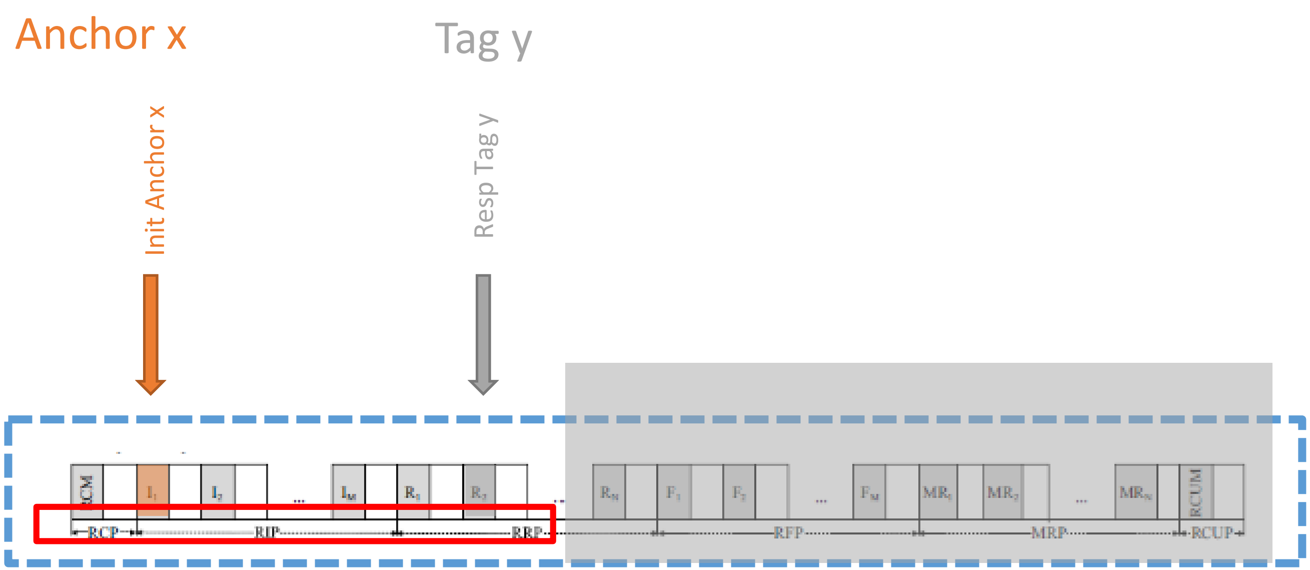
Merging RCM, Init & Response messages generates optimal use of the time within a round

Getting DL-TDoA for free



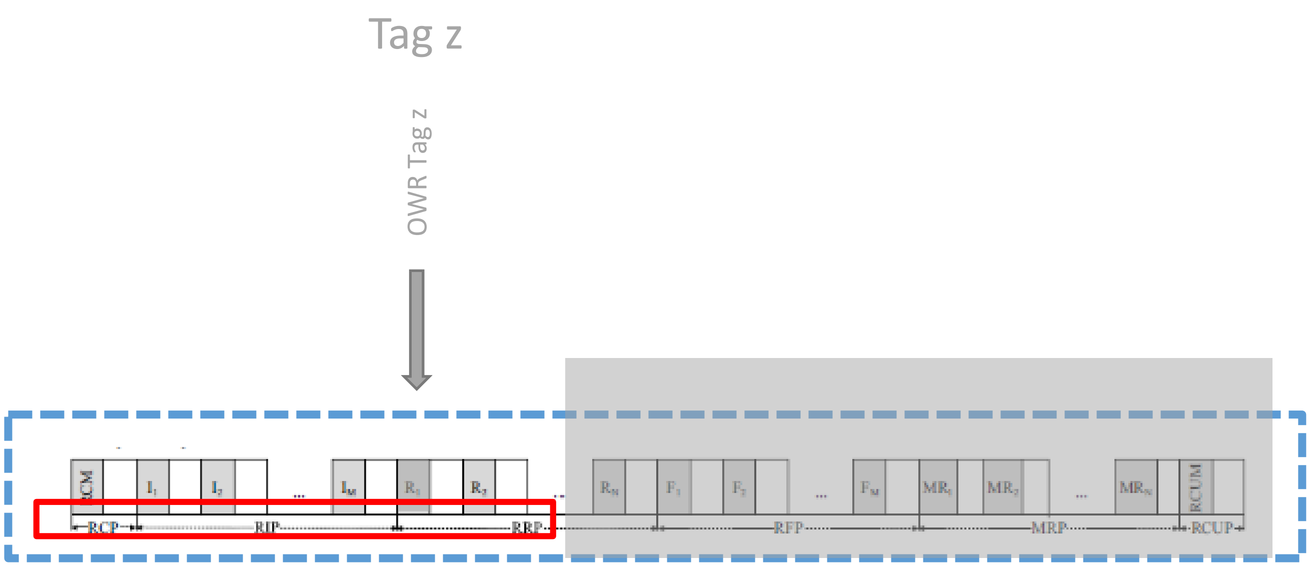
Overhearing these merged messages enables any receiver to implement DL-TDoA

Ranging between an anchor and a tag



This is regular ranging in a many-to-many configuration, it comes on top of anchors synch.

Extending the round for OWR transmissions



This is regular OWR and enables UL-TDoA implementations

Takeaway

Merging messages is the ultimate optimization of the round time structure
It enables anchor synchronization in a straightforward way

On top of this synchronization structure, multiple location algorithms can be implemented and co-exist:

- Regular many-to-many ranging between the set of anchor and responding tags
- DL-TDoA for any receiver that would take anchor messages as OWR
- UL-TDoA for any transmitter that would send OWR messages in the remainder of the round

References

[1] Sven Zeisberg, Jean-Marie André: *802.15.4z upgrade requirements for larger industrial scenarios*. IEEE 15-21-0066-00-04ab, 2021-01-20, IEEE 802.15 SG4ab

[2] Zhenzehn Ye: *Reverse TDOA Applications and Technical Characteristics*. IEEE 15-21-0223-00-04ab, 2021-04-27, IEEE 802.15 TG4ab

[3] Jean-Marie André, Sven Zeisberg: *DL-TDOA positioning TDMA scheme*. IEEE 15-21-0530-00-04ab, 2021-10-19, IEEE 802.15 TG4ab

[4] Zhenzehn Ye : *Downlink TDOA (DL-TDOA) Location Service in 802.15*. IEEE 15-21-0488-00-04ab, 2021-09-15, IEEE 802.15 TG4ab

[5] Yongsen Ma, Zhenzhen Ye: *Beacon and Ranging Frames to Support Downlink TDOA (DL-TDOA) Location Service in 802.15*. IEEE 15-21-0616-01-04ab, 2021-11-16, IEEE 802.15 TG4ab

[6] J.S. Hammerschmidt, Ersen Ekrem, Eren Sasoglu, Xiliang Luo: *Narrowband assisted multi-millisecond UWB*. IEEE 15-21-0409-00-04ab, 2021-07-20, IEEE 802.15 TG4ab

[7] Jean-Marie André (ST microelectronics), Sven Zeisberg (HTW), Vincent van der Locht (SynchronicIT), Frank Stephan (ZIGPOS), Andreas Schumacher (TRUMPF): *TDMA scheme enabling industrial DL-TDoA and UL-TDoA scenarios*. IEEE 15-22-0077-00-04ab, 2022-01-2, IEEE 802.15 TG4ab

Thank you for your kind attention.

Are there any questions?

IEEE P802.15
Wireless Specialty Networks

Project	IEEE P802.15 Working Group for Wireless Specialty Networks (WSNs)
Title	15.4 MAC evolution to support air time efficient multi-mode many-2-many ranging – based on Technical Specification Framework for 802.15.4ab
Date Submitted	16th Januar 2023
Source	[Sven Zeisberg, Erik Mademann, Zigpos] [sven.zeisberg @ zigpos.com] [Jean-Marie Andre, ST microelectronics] [jean-marie.andre @ st.com] [Vincent van der Locht, SynchronitIT] [Franz Lehmann, TRUMPF]
Re:	Developing technical content for 15.4-2020 MAC evolution to support air time efficient multi-mode many-2-many ranging
Abstract	This document provides inputs for editing the draft 4ab standard in order to enhance the 15.4(z) MAC enabling air time efficient multi-mode many-2-many ranging. Inputs are provided in a backward compatible evolutionary approach and are focused on (i) allowing interleaved multi-purpose time slots in scheduled multi-mode ranging mode as well as (ii) enabling free choice of responders while picking initiators in scheduled many-2-many ranging. Further, the existing TSCH slotframe approach is proposed to be applied also for another O-QPSK based additional special application space, which is introduced and which is called “NB Ranging Support Service”.
Purpose	Provide input for technical content for the draft 802.15.4ab
Notice	This document has been prepared to assist the IEEE P802.15 and is based on the Technical Specification Framework for 802.15.4ab provided by Ben Rolfe in document 15-21-0442-00-04ab-technical-specification-framework. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein.
Release	The contributor acknowledges and accepts that this contribution becomes the property of IEEE and may be made publicly available by P802.15.

Technical Specification Framework

For 802.15.4ab

1. Overview

2. References

[0] IEEE 802.15.4-2020

[0b] IEEE 802.15.4z-2020

[1] Jean-Marie André, Sven Zeisberg, Erik Mademann: Evolution of 4z enabling optimized many-to-many ranging for dense environments. IEEE 802.15-22-0471-00-04ab, 2022-09, IEEE 802.15 TG4ab

[2] Sven Zeisberg, Jean-Marie André: 802.15.4z upgrade requirements for larger industrial scenarios. IEEE 15-21-0066-00-04ab, 2021-01-20, IEEE 802.15 SG4ab

[3] Jean-Marie André, Sven Zeisberg: DL-TDOA positioning TDMA scheme. IEEE 15-21-0530-00-04ab, 2021-10-19, IEEE 802.15 TG4ab

[4] J.S. Hammerschmidt, Ersen Ekrem, Eren Sasoglu, Xiliang Luo: Narrowband assisted multi-millisecond UWB. IEEE 15-21-0409-00-04ab, 2021-07-20, IEEE 802.15 TG4ab

[5] Jean-Marie André (ST microelectronics), Sven Zeisberg (HTW), Vincent van der Locht (SynchronicIT), Frank Stephan (ZIGPOS), Andreas Schumacher (TRUMPF): TDMA scheme enabling industrial DL-TDoA and UL-TDoA scenarios. IEEE 15-22-0077-00-04ab, 2022-01-2, IEEE 802.15 TG4ab

3. Definitions, acronyms, and abbreviations

3.1 Definitions

Multi-Mode Ranging scenario: within a single ranging round the ranging anchor nodes support several different ranging modes at the same time.

3.2 Acronyms and abbreviations

RSS Ranging Support Service

MMR Multi-Mode Ranging

DOP Dilution of precision

4. Format conventions

5. General description

In this contribution four backward compatible MAC sublayer evolution proposals (A,B,C,D) are described, which all target the same goal to enhance air time efficiency in dense multi-mode ranging (MMR) scenarios with fixed ranging infrastructure installations. Selected proposals can be also beneficial deploying single-mode ranging scenarios. All of the proposals have been motivated in previous contributions [1,2,3,4,5] to the TG4ab group and are now in this contribution detailed and provided in a suitable format to support integration into the draft 4ab text document.

First an example scenario description is provided, which provides a frame for motivating all the four proposed MAC evolution proposals. Afterwards the four proposed enhancements are explained based on this scenario description.

5.1 Scenario description

In certain dense ranging environments like manufacturing halls or logistics centers, many items (via attached tags at proximity) are to be tracked, and multiple location tracking solutions need to be implemented (e.g. DL-TDoA, UL-TDoA, TWR) at the same venue [1][2] running at the same time.

Multiple sequences of ranging procedures may be required simultaneously:

- Ranging between anchors in order to keep them synchronous, or to verify status etc.
- Ranging between anchors and diverse tags to run various location algorithms simultaneously (e.g. TWR, UL-TDoA, DL-TDoA, …)

The example environment can be dynamic in terms of shadowing/fading as well as in terms of interference, but a high robustness of the ranging procedures is still targeted to support important processes, such as professional/industrial production or logistics, in a reliable manner. Furthermore the scenario needs to be scalable to larger areas with several tens or several hundreds of anchor nodes.

The scenario foresees mainly scheduled channel access to minimize the probability of intra system collisions, but there is also contention based channel access possible during certain dedicated periods.

5.2 Enhancement A: Optional single slot/message accommodation of control+init+resp or init+resp roles in many-2-many MMR

To accommodate as many as possible simultaneous ranging schemes, it is suggested to allow several messages of various types to be merged into one single UWB frame. This maximizes the use of available time slots [1].

In the example environment the deployment of several kinds of anchor nodes can be helpful supporting the MMR scenario in order to enable high user densities, a good air time efficiency and a good dilution of precision (DoP).

In such a scenario, within a single ranging round the ranging anchor nodes support several different ranging modes at the same time. The different ranging modes operate quasi-simultaneous and serve different purposes (i.e., different use-cases requiring specific performance/behavior characteristics) in parallel at a single area of coverage.

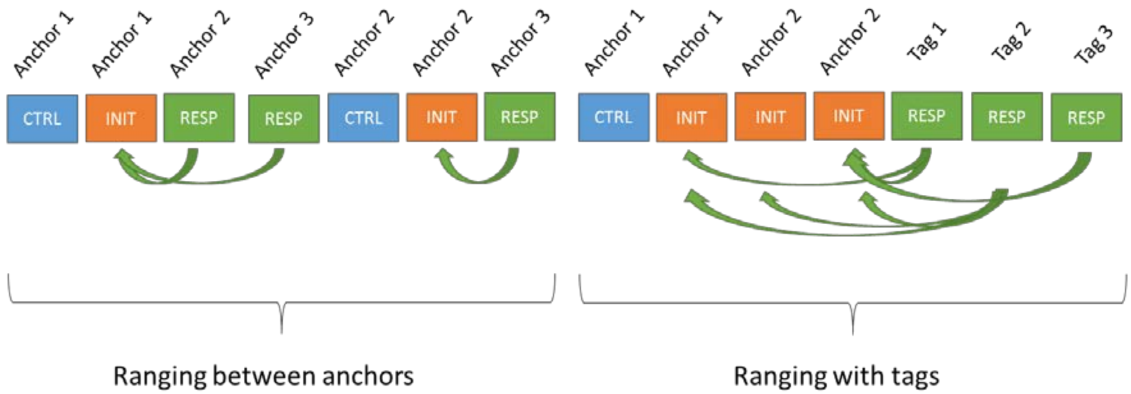


Figure 1: Multiple rangings scheduled sequentially.

As an example, this way, e.g., the time synchronization between ranging anchor nodes can be realized with a many-2-many TWR scheme, where at the same time the synchronization frames exchanged between the ranging anchor nodes can be utilized by some UWB receive-only tags to calculate their position based on down-link time difference of arrival algorithms.

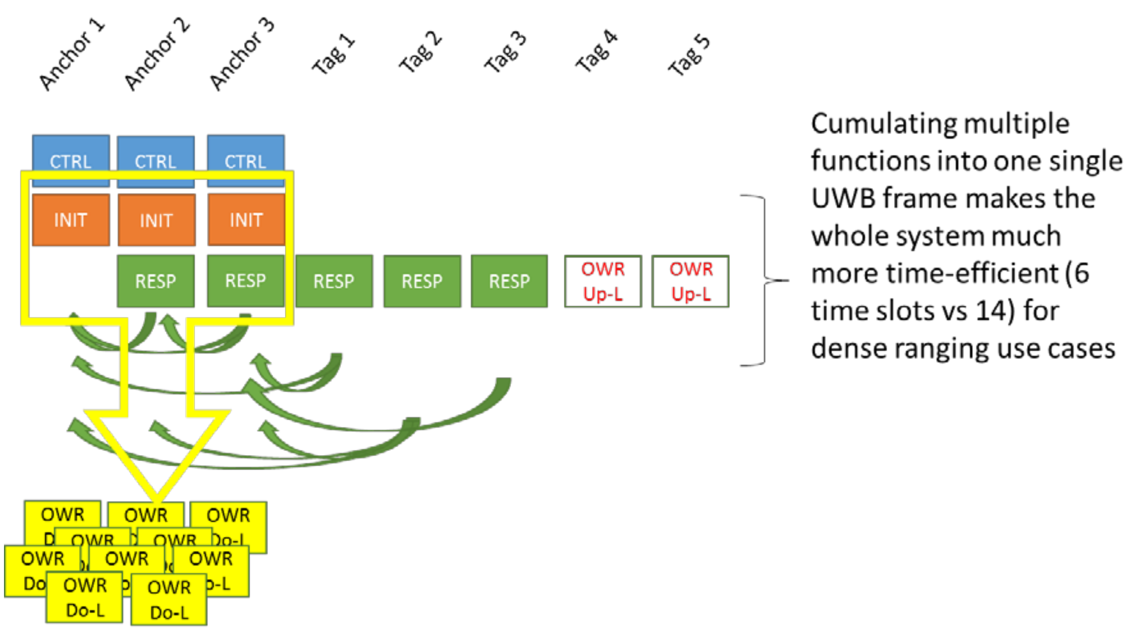


Figure 2: Multiple rangings organized simultaneously.

Furthermore, the frames exchanged for such purposes can be deployed also at the same time as command and initiator messages for starting a scheduled two way ranging with another type of tags in the same vicinity [Figure 2].

The example illustrated in Figure 1 and Figure 2 demonstrates the air time saving potential of such message merging. This has advantages in terms of air time efficiency, radio coexistence and fulfilling regulatory requirements in terms of duty cycle limitations and last but not least providing a better service quality to various diverse user requirements at a single service coverage area.

The existing IEEE 802.15.4z-2020 [0b] standard foresees already an implementation of the role merging principle for messages in a few selected occasions:

- Non-deferred reports: a single message carries the response to an initiation message as well as the report part
- RCM & Initiation roles can be merged into one single message in general
- DS-TWR realization with 3 messages: the 2nd message carries the role of responder and initiator

It can be concluded, that the concept of multiple roles for messages is already existing in IEEE 802.15.4z [0b] . There, in section 6.9.7.2. it is mentioned, that "…, each ranging round may be composed of an RCP, an RP, and an MRP, where each of these phases may consist of multiple slots. In practice, it may be possible to merge some phases." However, the focus for explicit examples has been on merging Ranging Initiation Phase (RIP) with Ranging Control Phase (RCP) so far.

Currently the IEEE 802.15.4-2020 [0] standard only foresees for scheduled ranging to identify ranging phase time slots explicitly as either initiator or as response time slots. The existing standard foresees further, that there is only one single command, initiation and response phase each scheduled subsequently within a single ranging round. It is not yet explicitly described in the standard, that it is also possible to merge initiation and response time slots nor to merge command, initiate and response time slots in MMR scenarios.

It is proposed here to mention explicitly extending the already mentioned RCM/Initiation merging to a possible RCM/Initiation/Response merging in single slots.

In order to ensure backward compatibility the assignment of initiator or responder roles for slots still need to be in place for RDM IE, if not scheduled by a higher layer. Depending on the mandatory part of the message the slot shall have the role assignment either initiator or responder and may contain as optional component the other one functionality as well.

(These extensions/clarifications can be helpful for many-2-many MMR use cases, e.g., in dense DL-TDoA scenarios anchors message exchanges.)

5.3 Enhancement B: Optional free selection of initiators in many-2-many responses

The example scenario forms a dynamic environment, therefore it can not be known beforehand, if a certain anchor can receive a message from another certain anchor in the vicinity. The receiving anchor (which could be any one anchor except of the transmitting anchor itself at a certain slot) will receive a number of initiation messages from selected surrounding anchors depending on the current shadowing and interference situation. Due to the many-2-many nature of the ranging round it may be sufficient if it picks only a subset from them and includes it's time relations to each member of this subset into a single response message. In order to keep the UWB response frame payload reasonably short only a certain relevant subset should be picked. Besides the many-2-many condition there is also the second constraint of the scenario, which is the MMR nature. Here we are leveraging the fact, that the many-2-many TWR messages between the anchors can be processed at the same time as OWR messages for DL-

TDoA devices. If there would be perfect time sync between anchors only the initiation messages of the TWR would be sufficient for the OWR of the DL-TDoA device. For the more general case of assuming certain non-ideal sync between anchors, it is important, that the DL-TDoA device can also receive the responses of the TWR anchor sync ranging procedure. And here it becomes now important that the responses subset should address most of the neighbor anchors, which can be received by a DL-TDoA device at a certain position.

Allowing the responder to pick its initiators, to which it will include responses in its message, allows the system to adapt to temporary link distortions and to keep the UWB frame still reasonably short.

5.4 Enhancement C: Optional sending multiple RCM messages in a ranging round

Increase robustness and support scalability by optionally sending multiple “copies” of an RCM in a many-2-many ranging round. The challenging environment in the dynamic example scenario with temporary shadowing and interference can better be coped with by deploying a diversity strategy in terms of sending the RCM from several anchor nodes. The contents in terms of scheduling information etc. would be the same. Other anchors as well as tags may be able to receive only a subset of anchors on the vicinity.

This proposal constitutes a transmit diversity. We propose that each RCM can be combined with an initiation and with an anchor position information in a single UWB frame. This allows any other than the first slot user in the round to already insert a response information reacting to previously sent initiation messages in its own RCM+Init message.

5.5 Enhancement D: Optional O-QPSK Ranging Support Service using slotframes

Slotframes have been introduces in 15.4 originally for TSCH operation as a more flexible option of organizing scheduled channel access than the rather rigid Superframe structure defined for the conventional beacon-enabled mode. The advantage of slotframes is the ability to freely define the number of slots per frame between 0 and 0xFFFF (64k) and to be able to freely define the size of a time slot in terms of micro seconds between 0 and 0xFFFFF (ca. 1s). There is no limitation to multiples of the power of 2. Furthermore, the transmission of a beacon for each slotframe is optional and alternatively the time organization is done by other means [0].

5.5.1 Maximize battery time for scheduled UL-TDoA tags by enabling UWB TXonly by using loosely coupled O-QPSK for communication and rough time slot synchronization

An out of band communication with low resource consumption avoids UWB reception at the portable tag device and providing at the same time a coarse time synchronization. Accuracy should be in the order of a few micro seconds for typical scheduled UWB UL-TDoA schemes. The coarse timing could be achieved by aligning UWB time slots and OOB transmission schedule. Therefore a contention free access without CSMA-CA is required for the OOB time synchronization messages.

5.5.2 Optimize the Dilution of Precision (DoP) and diversity gain for the DL-TDoA tags by enabling battery powered anchor (BPA) nodes, which are basically UWB TXonly by using loosely coupled O-QPSK for communication and rough slot synchronization

An out of band communication with low resource consumption avoids UWB reception at the BPA device and providing at the same time a coarse time synchronization to schedule the UWB DL-TDoA initiation messages of the BPA. Accuracy should be in the order of a few micro seconds for typical UWB slot sizes in DL-TDoA schemes. See previous paragraph for OOB channel access for synchronization messages.

5.5.3 Keep the UWB channel free for ranging frames/slots by off-loading of uncritical management/cmd&control communication from UWB to out-of-band communication deploying O-QPSK in order to keep the number of UWB communication/cmd&control frames low

Network maintenance, such as discovery, joining, resource allocation messages can be exchanged out-of-band (OOB), if sufficient OOB communication bandwidth is available. OOB coverage need to be at least equal to UWB coverage. No strict time or frequency synchronization is required between OOB and UWB for this purpose.

5.5.4 Keep the UWB frames short by off-loading of uncritical management/cmd&control communication from UWB to out-of-band communication deploying O-QPSK

Ranging management, such as slot allocation, resource allocation requests, can be exchanged out-of-band, if sufficient OOB communication bandwidth is available. OOB coverage need to be at least equal to UWB coverage. No frequency synchronization is required between OOB and UWB subsystems for this purpose, but time-wise an alignment of the control phase of the scheduled UWB ranging round and the OOB is desirable.

6. MAC Functional Description

Proposed enhancements of existing standard(s):

6.1 802.15.4, add section 5.2.9: Ranging Support Service (RSS) in section 5.2. Special application spaces

The RSS portions of this standard are designed to implement a network infrastructure and portable devices that enable the support of ranging services performed by dedicated ranging devices. Therefore scheduled as well as event based channel access is required with a fine time granularity and flexibility. Time structures for communication are defined by the Ranging Service to be supported.

6.2 802.15.4, 5.7.1.3: Slotframes …change text in this section to make sure the slotframes concept can be used also in RSS but not necessarily with channel hopping

In a TSCH PAN and in RSS PAN, the concept of the superframe is replaced with a slotframe. The slotframe also contains defined periods of communications between peers that are either CSMA-CA or guaranteed, but the slotframe automatically repeats based on the participating devices' shared notion of time. Unlike the superframe, slotframes and a device's assigned timeslot(s) within the slotframe can be initially communicated by beacon, but are typically configured by a higher layer as the device joins the network. Because all devices share common time and channel information, devices may hop over the entire channel space to minimize the negative effects of multipath fading and interference and do so in a slotted way to avoid collisions, minimizing the need for retransmissions. Both of these features are desirable for operation in a harsh industrial environment.

6.3 802.15.4, 6.2.6: rename the heading from "TSCH slotframe structure" to "Slotframe structure" and adapt to contents of section 6.2.6. so, that RSS and TSCH are appropriately reflected

6.4 Change in 6.2.6.2.: Absolute slot number (ASN)

It may be beaconed by devices already in a ~~TSCH~~ PAN, allowing new devices to synchronize. It is used globally by devices in a ~~TSCH~~ PAN as the frame counter …

6.5 Change in 6.2.6.3.: Links

From:

"The physical channel, CH, in a link is calculated as follows:" …

To

"For RSS the physical channel is selected by a higher layer. For TSCH the physical channel, CH, in a link is calculated as follows:" …

6.6 802.15.4z, section 6.9.7.1: correct the sentence

from

"The RDM IE can be omitted from the R**D**M in the case where the roles and transmission schedule is pre-determined or conveyed via some out-of-band mechanism."

to

"The RDM IE can be omitted from the R**C**M in the case where the roles and transmission schedule is pre-determined or conveyed via some out-of-band mechanism."

6.7 802.15.4z, section 6.9.7.2: change definition of RCM in order to allow several copies of the RCM to be send subsequently by several (controller/control transmit diversity) nodes

from

“Ranging Control Message (RCM): A message transmitted by a controller in Slot zero, the first slot of a ranging round to configure ranging parameters.”

to

“Ranging Control Message (RCM): A message transmitted by a controller in Slot zero, the first slot of a ranging round, or additionally transmitted by other devices in other ranging slots after Slot zero in case there will be more than one RCM copy transmitted in a ranging round. ”

6.8 802.15.4z, section 6.9.7.2: change definition of RCP allowing several copies of the RCM to be send subsequently be several (controller/control transmit diversity nodes) nodes

from

“Ranging Control Phase (RCP): A phase in which the controller sends an RCM.”

to

“Ranging Control Phase (RCP): A phase in which a controller and optionally other devices (e.g. functioning as controller transmit diversity node(s))send RCM(s).”

6.9 802.15.4z, section 6.9.7.2: change definition of RRP allowing responders to address within a single slot/frame several initiators

from

“Ranging Response Phase (RRP): A phase in which the responder(s) send their response message(s)

to the initiator.”

to

“Ranging Response Phase (RRP): A phase in which the responder(s) send their response message(s)

to the initiator**(s)**.”

…to be continued

7. MAC frame formats

7.1 802.15.4, section 7.4.4.2: replace TSCH synchronization IE wit Slotframe Synchronization IE

Throughout the section replace “TSCH Synchronization IE” with “Slotframe Synchronization IE” to reflect that this IE is used not only by TSCH but by all Slotframe user.

7.2 802.15.4, section 7.4.4.3: replace “TSCH Slotframe and Link IE” with “Slotframe and Link IE”

Throughout the section replace “TSCH Slotframe and Link IE” with “Slotframe and Link IE” to reflect that this IE is used not only by TSCH but by all Slotframe user.

7.3 802.15.4, section 7.4.4.3: replace “TSCH Timeslot IE” with “Timeslot IE”

Throughout the section replace “TSCH Timslot IE” with “Timeslot IE” to reflect that this IE is used not only by TSCH but by all Slotframe user.

7.4 802.15.4z, section 7.4.4.36: change definition of ARC IE allowing multi-mode ranging (MMR) schemes

The Ranging Round Usage field is currently two bit and all four options are used to define one out of four ranging scheme for the current ranging round. See table 7-52c.

Table 7-52c—Values of Ranging Round Usage field in the ARC IE

Ranging Round Usage field value	Selected ranging round use
0	One-way ranging (OWR), see 6.9.1.2.5
1	Single-sided two-way ranging (SS-TWR), see 6.9.1.2.2.
2	Doube-sided two-way ranging (DS-TWR), see 6.9.1.2.3.
3	Ranging ancillary information exchange, see 6.9.10.

In order to be backward compatible one would need to indicate, if such an exclusive table is valid or not. One could imagine to realize this by using the reserved value of “3” from the Multi-node mode field of the ARC IE or the Reserved bits 4-7 in the Content Control Field of the ARC IE (see Figure 7-106d).

Bits: 0	1	2	3	4–7
RBDP	RRDP	RSDP	SIP	Reserved

Figure 7-106d—Content Control field of the ARC IE

Here the second option is proposed. It is proposed to allocate Bit 4 of the Content Control Field to indicate, if an additional field is present, which one would call “multi-mode field”. If this Bit 4 is set to

“0”, then there is no multi-mode operation and the table 7-52c is valid indicating that only one out of the ranging round usages takes place in the current round. If Bit 4 is set to “1” it indicates, that a multi-mode usage is taking place in the current ranging round and that a MM field is present in the ARC IE, where the specific multi-mode usage of the round is coded.

A one octet optional MM field is proposed for this reason after the Session ID field in the ARC IE.

Bits: 0–1	2–3	4–5	6	7	8	9–14	15	Octets: 1	0/3	0/1	0/2	0/4	**0/1**
Multi-node Mode	Ranging Round Usage	STS Packet Config	Schedule Mode	Deferred Mode	Time Structure Indicator	RCM Validity Rounds	MMRCR	Content Control	Ranging Block Duration	Ranging Round Duration	Ranging Slot Duration	Session ID	**Multi Mode**

Figure 7-106c—ARC IE Content field format

This field allows to code 256 different multi-mode operation scenarios, where the basic multi-mode scenario 0x00 is assigned to the presence of SS-TWR and OWR in the same round. *Further modes to be harmonized with different multi-mode usage scenarios.*

… to be continued

8. Annex

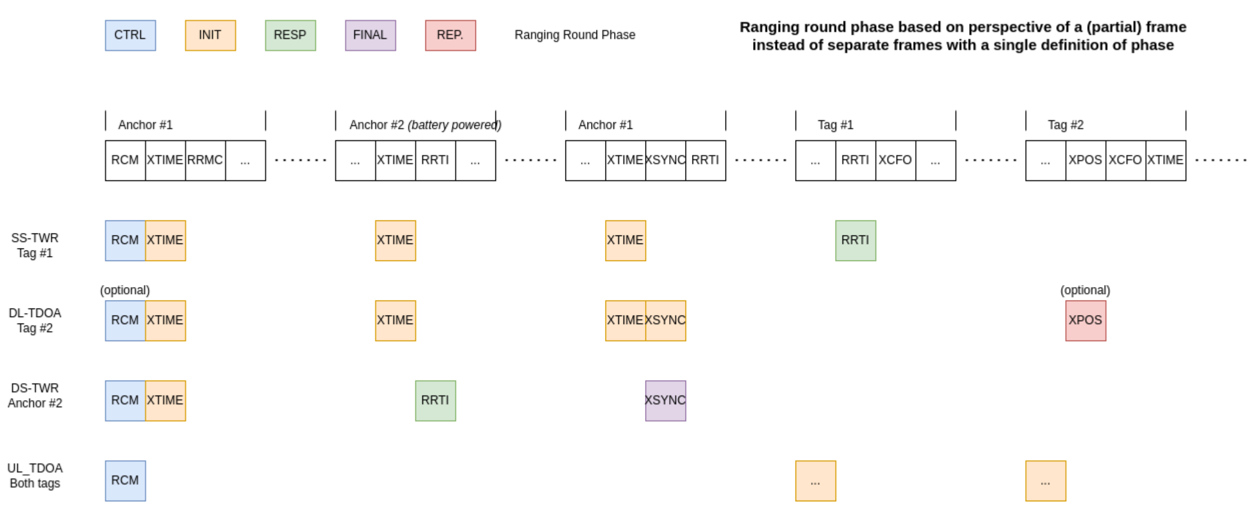


Figure 8-1: Different perspectives from different Ranging methods using same message sequence.