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

Submission Title: TDMA scheme enabling industrial DL-TDoA and UL-TDoA scenarios
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Re: Call for contributions to IEEE 802.15 TG4ab
Abstract: Evolution of 802.15.4(z) to enable efficient industrial positioning systems
Purpose: Discussion of how to improve 802.15.4(z) to serve industrial positioning systems

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	Enables very high device densities while maintaining very low interference potential and high reliability in industrial/professional use cases.
Other coexistence improvement	
Backward compatibility with enhanced ranging capable devices (ERDEVs)	The proposed scheme is backward compatible with ERDEVs.
Improved link budget and/or reduced air-time	
Additional channels and operating frequencies	
Improvements to accuracy / precision / reliability and interoperability for high-integrity ranging	The proposed scheme is enabling increased reliability for industrial environments.
Reduced complexity and power consumption	
Hybrid operation with narrowband signaling to assist UWB	Allows off-loading device management to NB channels.
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 scheme supports adding low energy consumption anchor nodes in DL-TDoA.

- List of IEEE 802.15 SG4ab/TG4ab contributions related to the topic of TDMA/DL-TDoA systems (until 2021-12, ordered by date):

  - 21-01: 802.15.4z upgrade requirements for larger industrial scenarios. *Sven Zeisberg & Jean-Marie Andre,* [1]
  - 21-04: Reverse TDOA Applications and Technical Characteristics. *Zhenzhen Ye*, [2]
  - 21-09: Downlink TDOA (DL-TDOA) Location Service in 802.15. *Zhenzhen Ye*, [3]
  - 21-10: DL-TDOA positioning TDMA scheme. *Jean-Marie Andre & Sven Zeisberg*, [4]
  - 21-11: Beacon and Ranging Frames to Support Downlink TDOA (DL-TDOA) Location Service in 802.15. *Yongsen Ma & Zhenzhen Ye*, [5]

- Common assumptions in previous SG4ab/TG4ab TDMA and/or TDoA contributions from the different stakeholders:
  - block based TDMA frame structure based on 4z ranging block structure including multicast/broadcast synchronization information exchange time slots
  - additional Information Elements (IEs), location & timing information

- Proposed next step:
  - Based on the received inputs: define non-conflicting 4ab update proposals enabling future 4ab PHY/MAC to serve for the proposed TDMA/TDoA scenarios
  - Define a corresponding optional NB OoB channel (enabling optional traffic off-loading and energy efficient scheduling) by updating the NB IEEE 802.15.4 in parallel to updating 4z?

- Background:
  - Following up on presentations of Jan 21 [1] and Oct 21 [4]
  - Inspired by works of omlox v2 core-zone specification to build industry grade RTLS

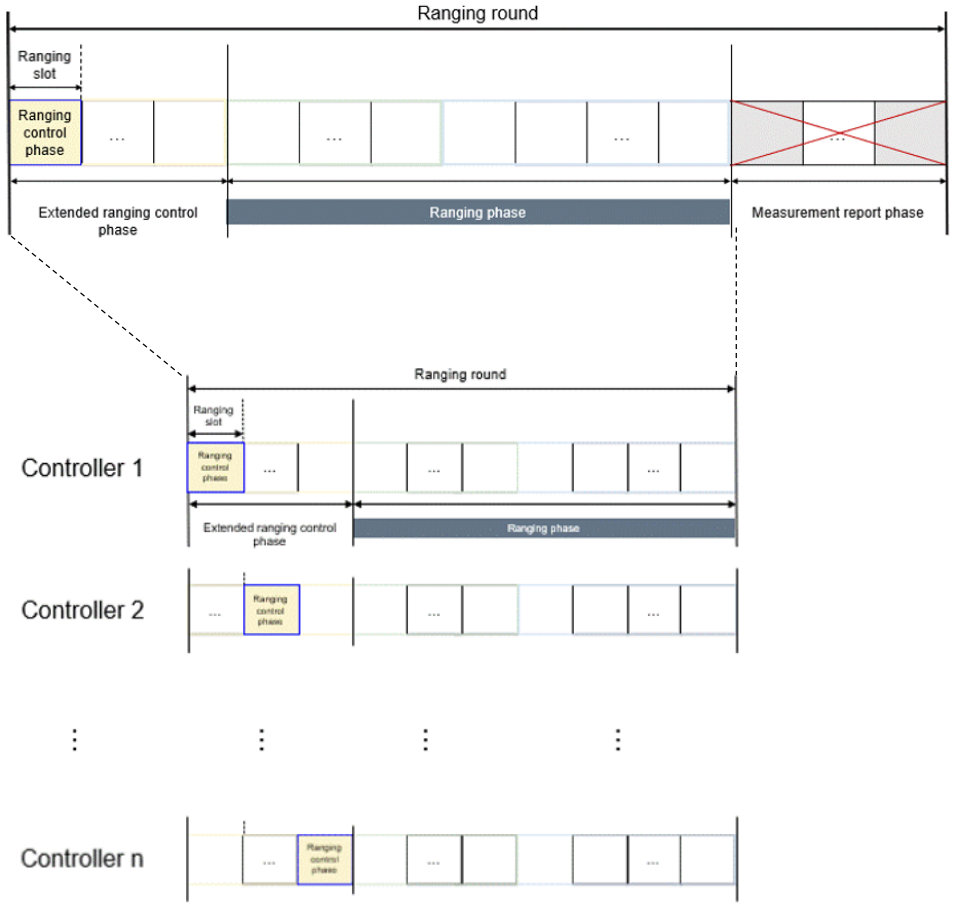
- In October 21 [4], we have described the principle of a scalable TDMA based solution for industrial positioning systems:
  - ✓ enabling DL-TDOA as well as UL-TDOA to simultaneously **co-exist**,
  - ✓ enhancing positioning **reliability** by avoiding ranging collisions,
  - ✓ allowing full featured **and battery powered** anchor nodes
  - ✓ based on the “creative deployment” of legacy 802.15.4(z) toolbox

- In this presentation, we are detailing our views in particular:
  - What part of 802.15.4z is used
  - What minimal additions we are proposing

Reminder on proposed round structure

802.15.4z round structure is kept:

- Report measurement phase is not used
- Ranging Control Phase is extended

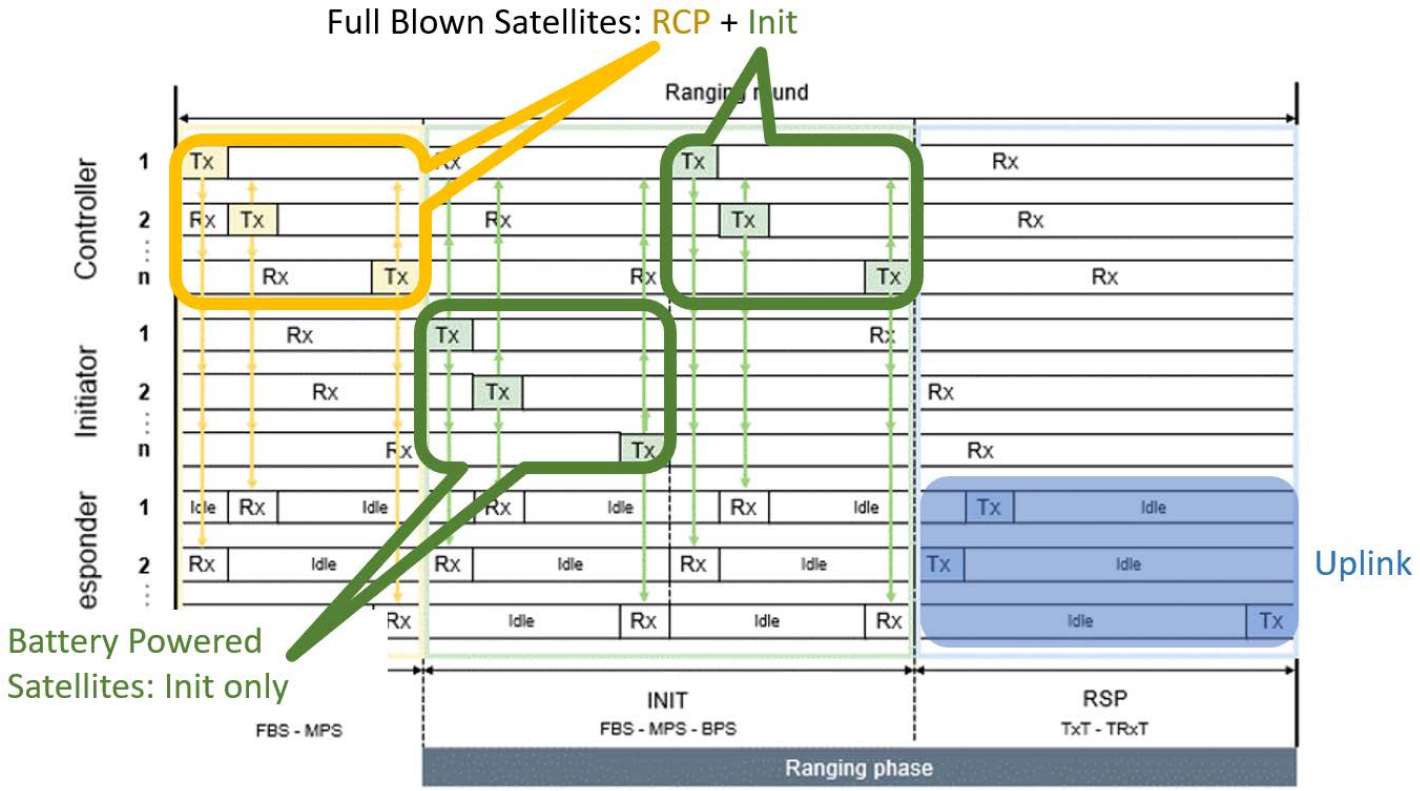


Extended Ranging Control Phase allows multiple controller to co-exist in a synchronous way

This is key for a non-zonal, scalable synchronous network

Reminder in Round Structure

Fixed anchors (aka Satellites) are transmitting during the (Extended) **Ranging Control Phase** and during the **Init part** of the Ranging Phase.
Mobile Tags are transmitting during the Response part of the Ranging Phase.



2 types of rounds organized in blocks

Two types of rounds are available:

- Rounds were the Response part of the Ranging Phase is sliced in time slots. Each time slot is exclusively assigned to one mobile tag to avoid collisions.
- Rounds were the Response part of the Ranging Phase is considered as a large time window that may be accessed on a contention basis by mobile tags.

Both round types share the same extended RCP structure and the same Init phase for the ranging, which enables a continuous DL-TDoA service.

The mix between these 2 types of rounds is organized at block level

Important: the propagation of synchronization is handled by the extended Ranging Control Phase available at every round. There is no geographical clusters, which ensures a fully scalable deployment of wide synchronous infrastructures

Evolution needed to achieve this

We are proposing to minimize the evolution of 4z to enable this kind of solutions:

Evolution 1: acknowledge the possibility to have extended ranging control phase to enable scalable synchronous infrastructure

Evolution 2: add a minimal number of Information Elements to address the management of such an infrastructure, and the elaboration of real time location systems

Use regular IEEE Information Elements

Regular 802.15.4z Information Elements are used to manage ranging

(note: RR and RDM IEs may be used out of band)

Sub Id value	Name
0x48	RRTI IE: Ranging Reply Time Instantaneous
0x49	ARC IE : Advanced Ranging Control
0x4b	RR IE : Ranging Round
0x4D	RCPS IE : Ranging Contention Phase Structure
0x51	RDM IE : Ranging Device Management
0x52	RRMC IE : Ranging Request Measurement and Control

Information Elements to be added

Additional Information Elements are needed for synchronization purposes and could be adopted in 802.15.4ab update:

- XRCM IE: Ranging Control Message (for Extended RCP): round description
- XTxTime IE: Actual time of transmission, factoring the time shift (HW delay)
- XSync IE: List of other satellites drifts as observed by one satellite
- XCFO IE: Exact reply time between Init and RSP as per responder clock
- XPos IE: Position of the satellite for downlink TDoA
- XOCM IE: OoB Control Message – to enable OoB/IB synchronization

Round Management

Extended RCP messages use XRCM IE

It is an extension of the regular RCM IE which offers precisions on the round:

- Whether the round is organized in guaranteed time slots (each time slot being assigned to one specific tag, thus avoiding collisions)
- Or it is made a large time window which will be accessed in contention

It specifies also whether the housekeeping (e.g. infrastructure, synchronization, devices) management is done out of band or in band (or both).

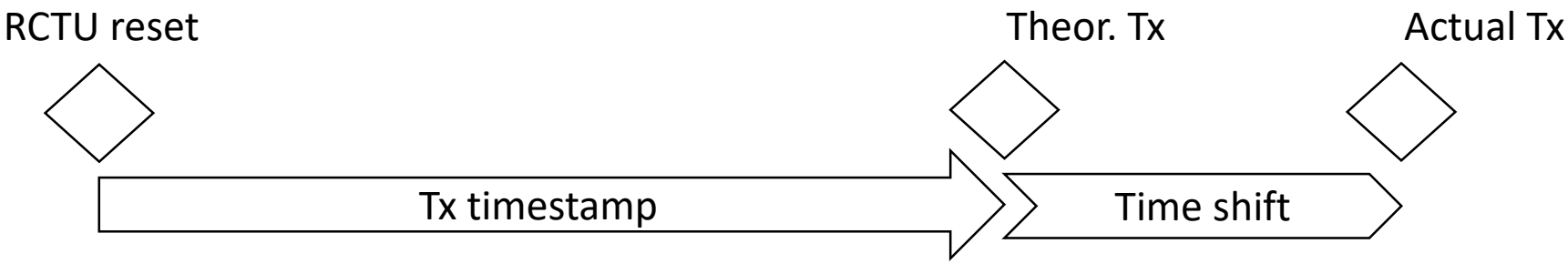
Synchronization Management

To enable accurate ranging algorithms, the exact time of transmission should be mentioned. In particular, the time shift linked to HW delay when processing a Tx.

The XTxTime IE includes:

- Tx timestamp (5bytes)
- Time shift (2 bytes)

Both are expressed in Ranging Counter Time Units

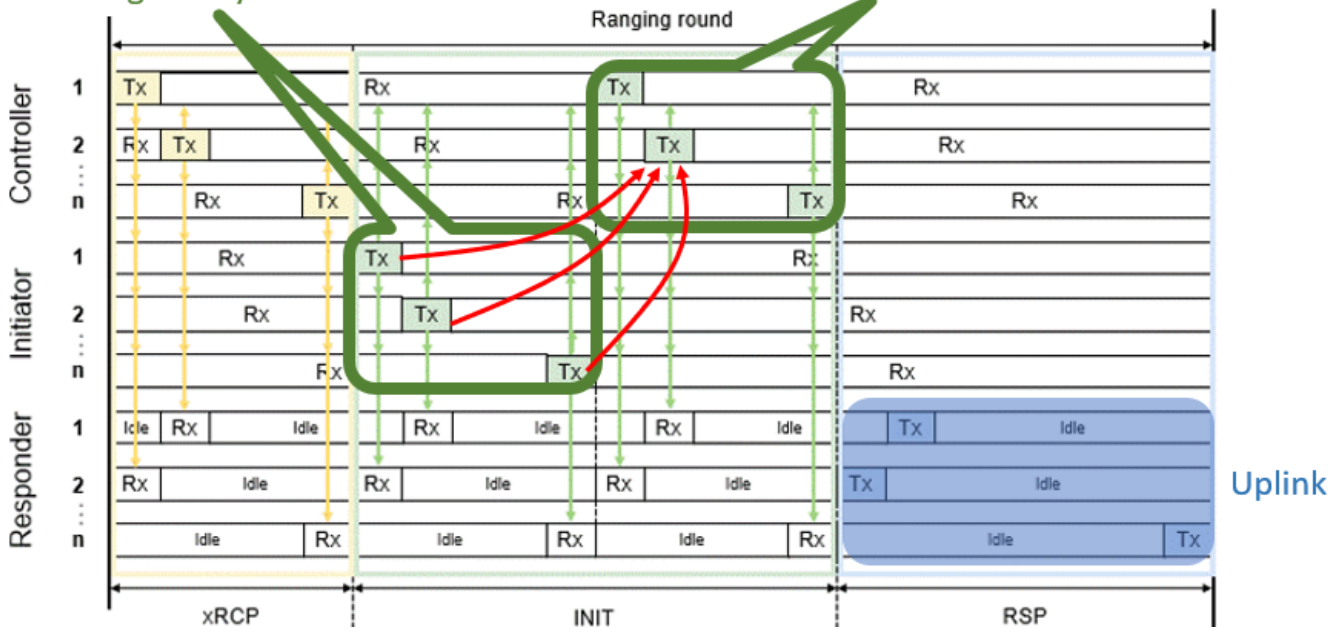


Synchronization Management

Dealing with power constrained anchors (aka Battery Powered Satellites) is possible, provided that other satellites advertise a measure of the drifts.
This is the main purpose of the XSync IE.

Battery Powered Satellites do not set their receiver at every round
=> Init messages may drift

Full Blown Satellites monitor the init messages of their neighbours and transmit a list of time corrections to be applied



DL-TDoA enablement

Each fixed anchor (aka satellite) is able to broadcast its (relative) position in band, which allows:

- Receive-only UWB devices to compute their own location without interacting with the infrastructure (zero intra system interference, zero tracking).
- This is assuming that the precise time relations between the selected relevant fixed anchors (aka satellites) is known to the UWB Rx only devices.

The Information Element to handle that is the **Xpos**, it contains:

- Coordinates of the transmitter may be expressed in local X/Y/Z coordinates or in Lon/Lat/Elev coordinates.
- Uncertainty information relating to these coordinates.

Note: Depending on scenario this information may be published in a list format via NB OoB in order to shorten the UWB payload while time stamp broadcasting.

DL-TDoA enablement continued

Each fixed location anchor (aka satellite) is broadcasting it's time offset to selected other anchors (satellites, which could be selected geographical or selected strong radio neighbors) in a list format in band, which allows :

- UWB tags to compute the precise relative time difference of Txtimes from several relevant selected fixed location anchors (aka satellites) in case these anchors would not have an ideal synchronization status.

The Information Elements to handle that are the **Xsync** and **Xcfo**, they contain: Information about the other satellites drifts as observed by one satellite as well as the exact reply time between Init and RSP as per responder clock.

Getting both, the knowledge of the (relative) fixed anchors position and relative timing, allows a receive-only UWB device to compute the own (relative) location without transmitting towards the infrastructure (zero intra system interference, zero unwanted devices tracking).

Synchronization Management: UL-TDoA

Mobile Tags may enable precise location algorithms by measuring accurately the reply time between:

- The timestamp of **a reference ranging initiation message**
- and the timestamp **of the ranging response message**

This allows to assess the CFO of a mobile tag precisely, and the satellite that has transmitted the ranging initiation can compute the frequency offset and share with the higher layer location server.

The XCFO IE includes the RRTI information (Ranging Reply Time Instantaneous) relating to one or several initiators. This allows to implement a two way ranging with one or several initiators within one transmission.

Beyond this presentation: IB-OoB sync.

This presentation focused on the UWB aspects of **Industrial use cases positioning** systems. It is assumed inherently, that UWB radio typically is used primarily for time / distance measurements and that other mechanisms are handled OoB deploying a NB channel. The NB channel is assumed to be an **O-QPSK** as defined in IEEE 802.15.4 operating at **a globally available band** (e.g. 2.4 GHz ISM band).

For example, an additional IE, XOCM (omlox OoB Control Message), describes the offset between the NB OoB system and the UWB system.

Another interest relevant of this group is the synchronization of IB and OoB radios. In this respect suggestions like the MMS PHY structure presented in [6] and related follow ups can be very interesting, especially if they allow to acquire a good synchronization with an optimized power consumption.

A **clock synchronous NB OoB** with the ability of **scheduled packet transmission** would enable collision free UL-TDoA transmission at UWB TDMA slot scheduling without energy consuming UWB reception at the mobile device.

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

Thank you for your kind attention.

Are there any questions?