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

Submission Title: Information Elements for efficient DL-TDoA

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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: Elaborate details on the IE needed to implement an optimized DL-TDoA in the context of a synchronous infrastructure.

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	It 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)	
Improved link budget and/or reduced air-time	The use of some IEs in the list will make it possible to diminish the number of bytes to be transmitted. Thus, less air-time usage is proposed.
Additional channels and operating frequencies	
Improvements to accuracy / precision / reliability and interoperability for high-integrity ranging	
Reduced complexity and power consumption	The solution proposed includes device-focused power consumption savings e.g. for battery-powered anchors.
Hybrid operation with narrowband signaling to assist UWB	The solution may operate either exclusively in band or in a synchronized way with narrowband systems.
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.

Requirements for an efficient DL-TDoA

To introduce an efficient DL-TDoA mechanism that meets multiple requirements:

a) Offering the means to build a fully synchronous infrastructure

b) Scalability across wide areas

c) Ability to share the UWB timeline with UL-TDoA

d) Optimizing the air time in order to comply with duty cycling constraints and maximize power efficiency

a) Enabling mixed infrastructures with both battery and mains powered anchors

Requirements for an efficient DL-TDoA

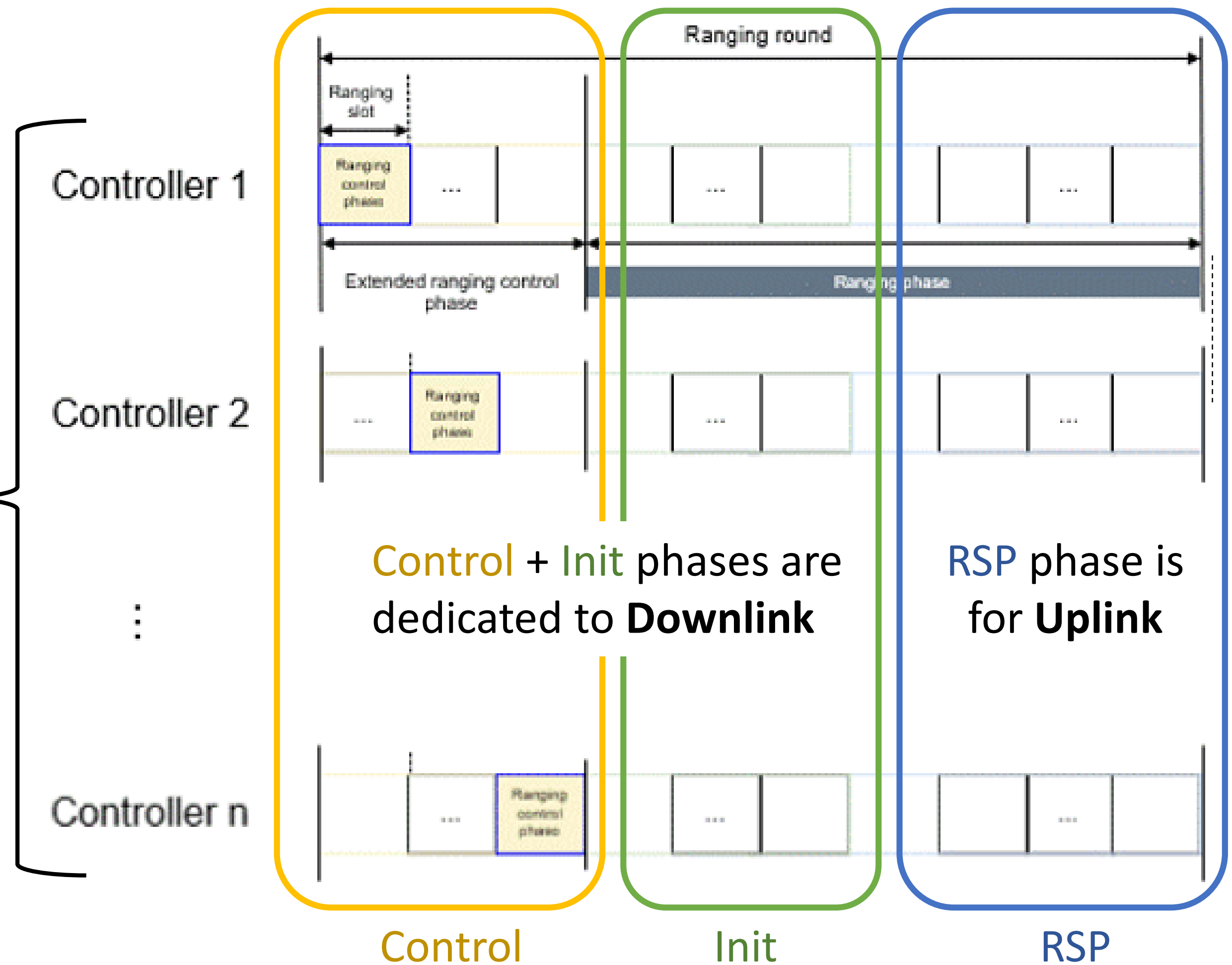
To introduce an efficient DL-TDoA mechanism that meets multiple requirements:

a) Offering the means to build a full synchronous infrastructure
    - XRCM IE: Ranging Control Message
b) Scalable across wide areas
    - XPos IE: Position of the satellite for downlink TDoA
c) Able to share the UWB timeline with UL-TDoA
    - XTxTime IE: Actual time of transmission, factoring the time shift
d) Optimizing the air time in order to comply with duty cycling constraints and maximize power efficiency
e) Enabling mixed infrastructures with both battery and mains powered anchors
    - XSync IE: Synchronization messages to correct the drift of battery powered anchors

Round for Scalable Synchronous Infrastructure

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

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



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XRCM IE Description

The XRCM (Ranging Control Message) specifies ranging round information at every xRCP.

Bits: 0	1	2	3	4-7	Octets:1
Ranging round type	IB scan activated flag	OoB availability flag	RSP listening	reserved	Slot index

XRCM IE description

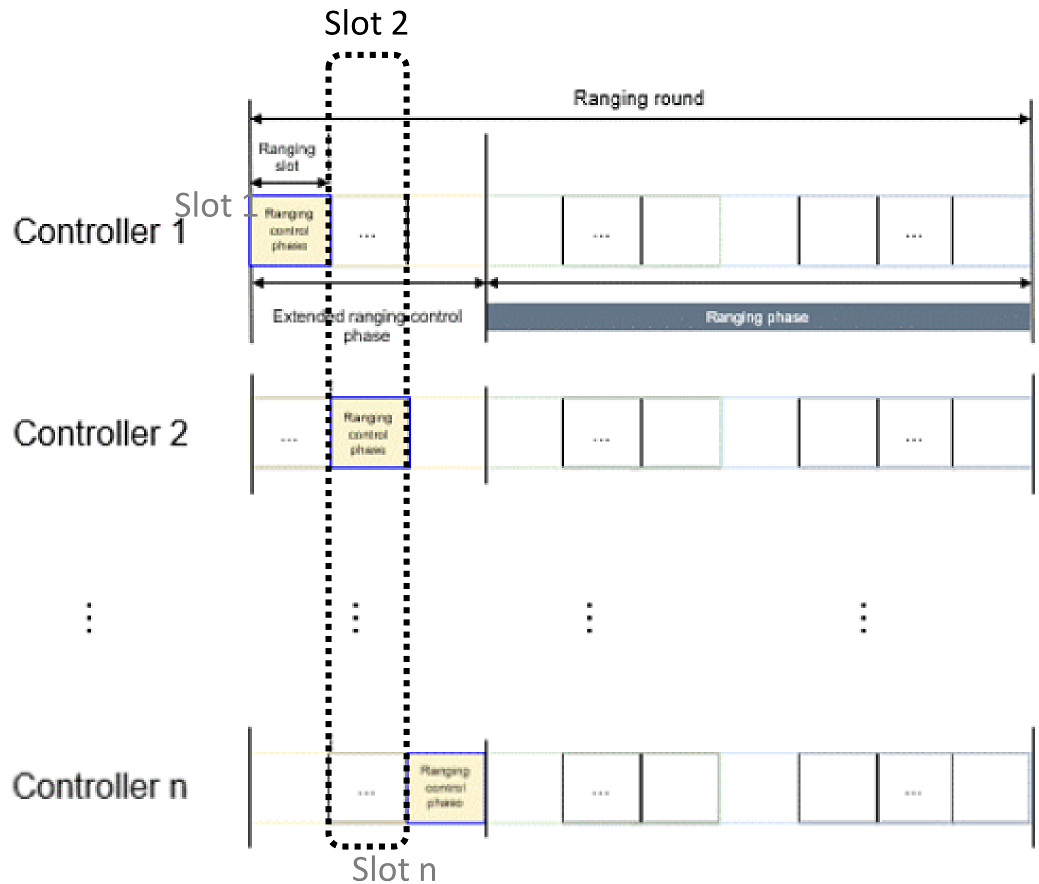
- Ranging round type: information for Uplink only. It details whether the Response part of the Ranging Phase should be used in TDMA mode (guaranteed time slots avoiding collisions) or in contention access mode.
- IB scan active flag and OoB availability flag: these flags are used to manage 2 different types of signalling, either In Band or Out of Band, or both. The IB-OoB signalling synergies are not detailed in this presentation.
- RSP listening flag is used for Uplink only. It is set to one if the controller is listening during the Ranging Response Phase.
- The other fields are reserved for future use and shall be set to zero for compatibility reasons.
- Slot index specifies the used slot for the RCM in the current ranging round, starting with zero.

XRCM is 4 bytes (including a 2-byte IE id)

XRCM IE Description

The Slot Index field of the XRCM (Ranging Control Message) tells which slot of the extended ranging control phase the message is sent. It allows a DL-TDoA receiver to find the beginning of the round.

Example with slot #2



XTxTime IE Description

The XTxTime IE (Transmit Timestamp IE) includes information about the Tx time of the sent message. It shall be added to each UWB message of the .

Octets: 5	2
Tx timestamp	Time shift

XTxTime IE description

The Tx timestamp field shall be set to the ranging counter value (in RCTUs) of the point in time when the message is sent.
The Time shift field shall be set to the value, compensating the error of the Tx timestamp, caused by an inaccurate Tx time related to any hardware constraints. It is a signed integer in two's complement in multiples of the RCTU.

Correct_Tx_timestamp = Tx_timestamp + Timeshift

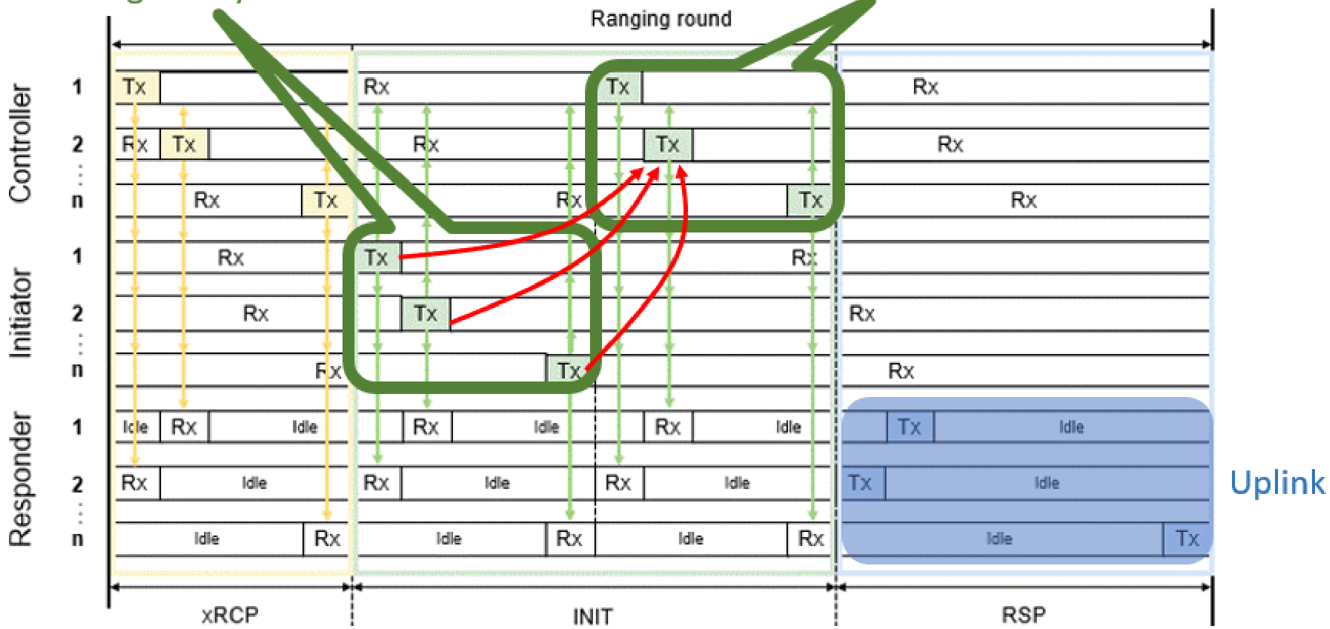
XTxTime IE is 9 bytes (including a 2-byte IE id)

XSync IE Description

The XSync IE allows Full Blown Satellites to monitor the drift of Battery Powered and other Satellites and advertise the measured drift so that all satellites can be used in the DL-TDoA implementation.

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



XSync IE Description

The XSync IE (Synchronization IE) is transmitted during the INIT phase, and in some cases, it can be transmitted, together with the XPos IE, during the extended ranging control phase. A message may include several sync info with different options (sync format). The XSync IE includes the following elements:

Bits: 0-4	5	6	7	Octets: variable
Sync List Length	Synchronization	Address Format	Reserved	Sync List

XSync IE Content field format

- The Sync List Length field shall be set to the number of entries present in the Sync List.
- The field Synchronization conveys the estimated status of the synchronization of the satellite. When set to zero, the device is not perfectly synchronized and additional information (XSync IE) from another device shall be sent to use the ToA from this device. When set to one, the device is estimated to be perfectly synchronized, and no compensation needs to be applied to use the ToA. If the XSync IE is not present in the UWB message, one should consider the satellite as being not perfectly synchronized.
- The Address format field describes the type of address used. If set to zero, the satellites short addresses shall be used in the Sync List, otherwise it includes the occupied slot number of a satellite instead.
- The reserved field shall be set to zero.

XSync IE Description

Each element of the Sync list shall be formatted in one of two possible ways depending on the Format field value:

If the Address Format field is set to *zero*, the single elements of the Sync List contain a 2-byte Address field (the short address) and a variable length Sync correction field.

Octets: 2	Bits: 0	1 / 2
Address	Sync correction size	Sync correction

Sync List element with Address Format 0

- The address field shall be set to the related satellites short address.
- The Sync correction size field specifies the number of bits used for the sync correction field as described in

Sync correction size value	Sync correction size
0	15 Bit
1	23 Bit

Sync correction size definition

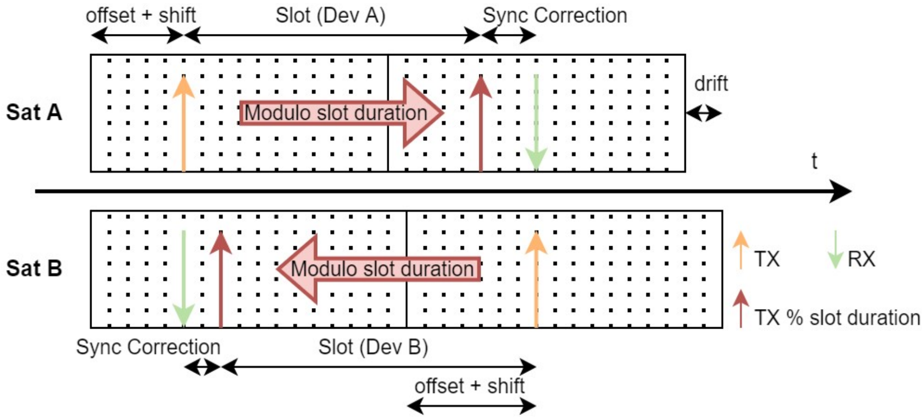
XSync IE Description

If the Address format field is set to *one*, the single elements of the Sync List contain a 5-bit Address field (the list address) and a 19-bit Sync correction field. This option may be applied, if there are installations of positioning systems, where there is only a maximum number of 32 satellites involved and it will then save 1-2 bytes per list element in such an implementation case.

Bits: 0-4	5-23
Address	Sync correction

Sync List element with Address Format 1

The list address shall be set to the time slot number in the ranging round of the corresponding satellite. The sync correction field shall be set to the time difference between own Tx and Rx of the related satellites message modulo the slot duration in multiples of the RCTU (see figure below). It is a signed integer in two's complement format.



XSync IE explanation

- The Sync correction is a number representing the time offset, shift and drift estimated by the transmitting FBS/MPS to other satellites. It represents a time difference between the ToA and the own transmission time. It shall be already pre-processed by the transmitting satellite device considering the knowledge of the propagation time to the related other satellite.
- The selection of the satellite to be considered in the Sync List is up to the implementer and is not part of this specification. The list length may be subject to constraints of the maximum payload length allowed for a specific mode of operation. The list length may impact the Quality of the DL TDoA localization precision.

The Xsync IE size corresponds to the number of sync elements and the size of each element depending on the Address Format and Sync correction size. Each Sync element is composed of an Address and a Sync correction depending on the Format.

6 bytes <= XSync IE size <= 158 bytes (including a 2-byte IE id)

Explanation:
Minimum would be a list of 1 element with 3 Byte + 1 Byte List Format + 2 Bytes IE id → 6 Bytes. Maximum would be a list of 31 elements of size 5 Byte = 155 Byte + 1 Byte List Format + 2 Bytes IE id → 158 Bytes.

Typical size in case a) (address format 0) would be a list of 10 elements of size 5 Bytes = 50 Bytes + 1 Byte List Format + 2 Bytes IE id → 53 Bytes.
Typical size in case b) (address format 1) would be a list of 10 elements of size 3 Bytes = 30 Bytes + 1 Byte List Format + 2 Bytes IE id → 33 Bytes.

XPos IE Description

The XPos IE (Position IE) can be sent by any satellite during the xRCP and the INIT phase.

Bit: 0	1	2	3	4-7	Bits: 20/35	20/36	16/25	0/8	0/8	0/8
Type	Elev present	Uncertainties	Expect other Type	reserved	X/Lon	Y/Lat	Z/Elev	UX	UY	UZ

XPos IE content

- The field Type is set to *one* if a **local** coordinate (X,Y,Z) is supplied and is set to *zero*, if a **global** coordinate (Lon, Lat, Elev) is supplied.
- The field Elev present is set to *one* if the Elev field is present in the IE. If this is set to *zero*, the Elev field value can be arbitrary or can be left out completely.
- The field Uncertainties is set to *one* when uncertainties are present in the IE, *zero* if not.
- The field Expect other Type is set to *one* if the satellite will send the other coordinate type in the future (relating to the coordinate Type that is transmitted within the current IE).

XPos IE Description

Bits: 0-19	Bits 20-39	Bit 40-55
X	Y	Z

Local coordinate coding

A local coordinate is coded in a total of 7 octets: The fields X,Y,Z are coded as signed integers (little endian, two's complement) with 1 cm resolution. This yields a Cartesian coordinate space of roughly (-5,5) x (-5,5) x (-0.3,0.3) kilometers in dimension.

Bits: 0-34	Bits 35-70	Bits 71-95
Longitude	Latitude	Elevation

Global coordinate coding

A global coordinate is coded in a total of 12 octets: The fields Longitude, Latitude, and Elevation are coded as signed integers (little endian, 2-complement).

- Longitude and Latitude both represent a signed fixed-point number with an implicit scaling factor of 10^{-8} resulting in 8 decimal places or a resolution of roughly 1.1mm. This yields a value range of -180 to 180 decimal degrees for longitude and -90 to 90 decimal degrees for latitude.
- Elevation represents the ellipsoidal height in Millimeters, resulting in a value range of roughly -15 to +15 kilometers. Global coordinates refer to the WGS84 (EPSG:4326) standard model.

XPos IE Description

Timing: An XPos IE may be sent at any time, local or global. The Expect other Type field signals if a receiver can expect the other coordinate format in the future. A receiver device should be able to cope with arbitrary sequences and timing and is responsible for mapping the local to the global coordinate system if required. For non-stationary installations (trucks etc.) the global coordinate of a satellite may change continuously.

The field UX, UY, UZ conveys the uncertainty values of X, Y and Z. Uncertainties are the unsigned distance values, so that probability (abs (True Coordinate - Coordinate) < distance) = 99.7%.

The uncertainty is encoded as described below – X standing here for the values of the unsigned 8 bits of uncertainty.

X	0-49	50-99	100-199	200-254	255
step (cm)	1	2	5	10	NA
from (cm)	1	52	155	660	NA
to (cm)	50	150	650	1200	>1200
distance formula	X+1	50 +2*(X-49)	150+5*(X-99)	650+10*(X-199)	

Uncertainty encoding

10 bytes <= XPos IE size <= 18 bytes (including a 2-byte IE id)

IB and OoB

- This presentation focused on the UWB aspects of Downlink TDoA.

- It listed the minimal amount of Information Elements required to perform DL-TDoA on a UWB Receiver exclusively.

There are optimization possibilities to benefit of external information that allow to trigger (anonymous) UWB DL-TDoA and support discovery. For example:

- Other location methods (GPS, BLE, WiFi) that can tell whether the receiver is inside an UWB DL-TDoA zone and then switch on/off the UWB DL-TDoA.
- Finely synchronized OoB as NB-MMS described in [6] (Hammerschmidt & al.)
- Standard OoB signalling (e.g. based on Bluetooth or 802.15.4)

Feedback welcome!

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?