How to build omlox products

A guide to air device integration

omlox

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Foreword from PROFIBUS and PROFINET International – PI

Enhancing Industry 4.0, think big!

30 years ago, I was delivering a speech to the European Railways organization explaining how a cellular network designed for consumers[1] could enable mission critical services for train collision avoidance and traffic improvement. As a young engineer, I was very impressed by the number of translators involved in the debates and the huge conference room in Brussels.

The author 30 years ago:
Jean-Marie André – Head of UWB Product Marketing STMicroelectronics and working group leader core zone

This impression however was misleading.

The actual impressive part was that European travellers would be faster and safer thanks to a technology designed for consumers, as a simple convenience.

The impressive part was the incredible engineering works that were considered to turn a “just-good-enough” technology into a “lifesaving” service.

Since then, consumer and industry-grade tools & technologies incestuous relationship has kept growing, driven by the same force: plug-and-play. Plug a consumer phone into a factory and locate it instantly. Plug a tracking system in a shopping mall, a hospital or a train station and serve both customers and hospitality managers.

Borders have since long blend, between industry-grade, mission-critical systems and massive consumer uses. First-come, first-served. With omlox, industry has taken the lead for indoors location tracking services, its actors (you!) now have a chance to scale way beyond the shop floor…

Go ahead and do it!

[1] GSM cellular networks, now referred in history books as 2G are now covering most of the planet.

Foreword by Fraunhofer IOSB-INA

"Integrate future-proof positioning today, …
… don't get lost"

omlox is the standard for future in- and outdoor positioning in the industrial context. By leveraging omlox, businesses can unlock a myriad of economic and technological potentials across a wide range of products and services. Integrating omlox into your products ensures that you stay competitive.

With omlox, you can make your products easily locatable, enhance their interoperability, and generate additional value. This not only secures a competitive edge but also ensures that you are not left behind in the rapidly evolving market landscape.

Moreover, omlox ensures that your products are not just part of a standalone system but are interoperable with devices and systems from various vendors. It bridges the gap between digital data and real-world applications, ensuring that your products can seamlessly integrate into existing ecosystems and future advancements. In industrial applications your omlox enabled products may enhance the Industry 4.0 experience and create unique selling propositions for your existing and new customers.

However, integrating omlox comes with its set of challenges. These include familiarizing yourself with a new standard, suitable chips, and making necessary software and hardware adjustments. This guideline is designed to help you navigate these challenges effectively. It provides comprehensive information, simplifies the initial steps, and highlights the relevant areas you need to focus on. Additionally, it offers a better estimation of the efforts required for integrating omlox into your products.

Take advantage of this opportunity to revolutionize your products and make them future-proof. By integrating omlox, you ensure that your products remain competitive in an increasingly connected world. Embrace the future of positioning technology with omlox and take the lead in innovation and efficiency…

… and don't get lost!

Prof. Dr.-Ing. Jürgen Jasperneite
Director of Fraunhofer IOSB-INA

Management Summary

Indoor localization technologies, especially those leveraging ultra-wideband (UWB), offer transformative advantages for industrial operations. Precise indoor positioning enables real-time tracking of assets, enhances automation, and optimizes workflow efficiency. omlox stands out as an open locating standard that not only provides high accuracy and reliability but also ensures interoperability across different systems and vendors. By integrating omlox into products, companies can significantly improve operational efficiency, reduce costs, and foster innovation.

However, the integration of omlox technology into products involves a series of challenges. Engineers and development teams must navigate complexities such as selecting appropriate hardware components, ensuring software compatibility, adhering to regulatory standards, and achieving seamless interoperability within a broader ecosystem. These challenges necessitate a structured approach to ensure that the final products not only meet technical specifications but also perform reliably in real-world industrial environments.

This "How to build omlox Products" document serves as a comprehensive guide to support developers in overcoming these challenges. It provides a short overview of the omlox standard, its basics functionalities and relevant standards. It covers crucial areas such as hardware integration, offering insights into selecting and incorporating the right components. In software integration, the guide provides valuable guidelines for developing firmware, explaining methods for accurate position, determination and highlighting the benefits of combining these with sensor data. The document also stresses the importance of continuous testing and offers recommendations for tools and techniques which can help to ensure robust integration. Additionally, it addresses regulatory compliance and outlines the certification process managed by PROFIBUS & PROFINET International (PI), ensuring device interoperability within the omlox ecosystem.

The primary goal of the document is to provide developers with valuable insights and practical guidance for integrating omlox technology into their products. While it offers significant support, it does not claim to be exhaustive. Nevertheless, by following these guidelines, developers can enhance compliance, interoperability, and performance, thereby improving industrial operations through advanced location-based services.

List of abbreviations

API	Application Programming Interface
BPRF	Base Pulse Repetition Frequency
BPS	Battery Powered Satellite
BLE	Bluetooth Low Energy
CAP	Contention Access Period
CE	Conformité Européenne (European Conformity)
DL-TDoA	Downlink Time Difference of Arrival
EMC	Electromagnetic Compatibility
ETSI	European Telecommunications Standards Institute
FBS	Full Blown Satellite
FCC	Federal Communications Commission
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
GTSW	Guaranteed Time Slot Window
HPRF	High Pulse Repetition Frequency
IB	In-Band
IC	Integrated Circuit
IE	Information Element
IEEE	Institute of Electrical and Electronics Engineers
IEC	International Electrotechnical Commission
IP	Ingress Protection
ISM	Industrial, Scientific, and Medical
ISO	International Organization fo Standardization
IMU	Inertial Measurement Unit
JSON	JavaScript Object Notation
LTS	Laboratory Test Setup
LTW	Large Time Window
µC	Microcontroller
MAC	Media Access Control Layer
MPS	Mains Powered Satellite
MQTT	Message Queue Telemetry Transport
Multiple TWR	Multiple Two-Way Ranging
OAD	omlox Air Device/s
OCZS	omlox Core Zone Specification
O-QPSK	Offset Quadrature Phase-Shift Keying
OoB	Out-of-Band
OTA	Over-The-Air
OTL	omlox Test Laboratory
PCB	Printed Circuit Board
PICO	PROFIBUS & PROFINET International Certification Office
PHY	Physical Layer
PI	PROFIBUS & PROFINET International
REST	Representational State Transfer
RFID	Radio Frequency Identification
RF	Radio Frequency
RoHS	Restriction of Hazardous Substances
RTLS	Real-Time Location Systems
RToF	Reconstructed Time of Flight
RxT	Receiver Tags

RWTS	Real-World Test Setup
SLAM	Simultaneous Localization and Mapping
SUT	System Under Test
TDoA	Time Difference of Arrival
ToF	Time of Flight
TRxT	Transceiver Tag
TxT	Transmitter Tags
UL	Underwriters Laboratories
UL-TDoA	Uplink Time Difference of Arrival
UWB	Ultra-Wideband
WiFi	Wireless Fidelity
XOCM	omlox OoB Control Message
xRCP	Ranging Control Phase

Introduction

This chapter outlines the fundamentals of omlox air device integration, with a focus on engineers and development teams interested in integrating omlox functionalities in their products. It explains the role of locating technology as enabler for Industry 4.0 and introduces the elements of the omlox architecture. The chapter concludes with an overview of air device integration, emphasizing its impact on enhancing industrial operations through location-based services.

Locating as a universal enabler for Industry 4.0

Real-time locating systems (RTLS) facilitate the implementation of track and trace applications, location-based automation, and efficient operations and maintenance tasks, significantly optimizing asset utilization and process automation. Therefore, locating technology has been used in numerous areas for years, particularly with Global Navigation Satellite Systems (GNSS). It is a versatile tool that can be applied in various fields. GNSS, such as GPS (Global Positioning System) or Galileo, are used to determine position data in outdoor environments. Professional applications in logistics and numerous other fields around the globe can use the global satellite infrastructure to acquire real-time position data of objects and use it in application-specific software systems.

In addition to GNSS (for outdoor use only), a range of wireless and vision-based technologies can be used for indoor positioning, enabling precise positioning in a variety of ways. Here, UWB technology distinguishes itself through high location accuracy, reliability, and low power consumption, ideal for industrial environments where precision and robustness are necessary. UWB technology utilizes e.g. time-of-flight measurements to pinpoint locations to within a few decimeters. In comparison to other wireless locating technologies, such as Bluetooth Low Energy (BLE), WiFi (Wireless Fidelity), Radio Frequency Identification (RFID), and GNSS, as well as vision-based technologies, such as cameras with Simultaneous Localization and Mapping (SLAM) algorithms, UWB offers superior accuracy and reduced maintenance due to its low power needs.

The potential of these technologies, particularly UWB localization, as described above, is not yet fully harnessed because there is no one-size-fits-all solution for indoor localization technology, and different use cases require different technologies. Flexibility and interoperability are key requirements for a future-proof indoor locating system setup.

omlox – the open locating standard

The omlox architecture overcomes the limitations (proprietary) of traditional indoor locating systems by providing a standardized, flexible, and interoperable solution that eliminates vendor lock-in and reduces costs. This open standard allows for seamless integration of different systems, enhancing operational efficiency and setting the stage for future advancements. It bridges the gap between digital data and real-world applications, fostering innovation and reducing implementation risks.

Having established the omlox architecture as a new standard that enhances interoperability and efficiency, the following detailed exploration of its architecture provides insight into its components and architecture. This technical overview illustrates how various locating technologies are integrated within the omlox architecture to achieve a comprehensive and scalable solution.

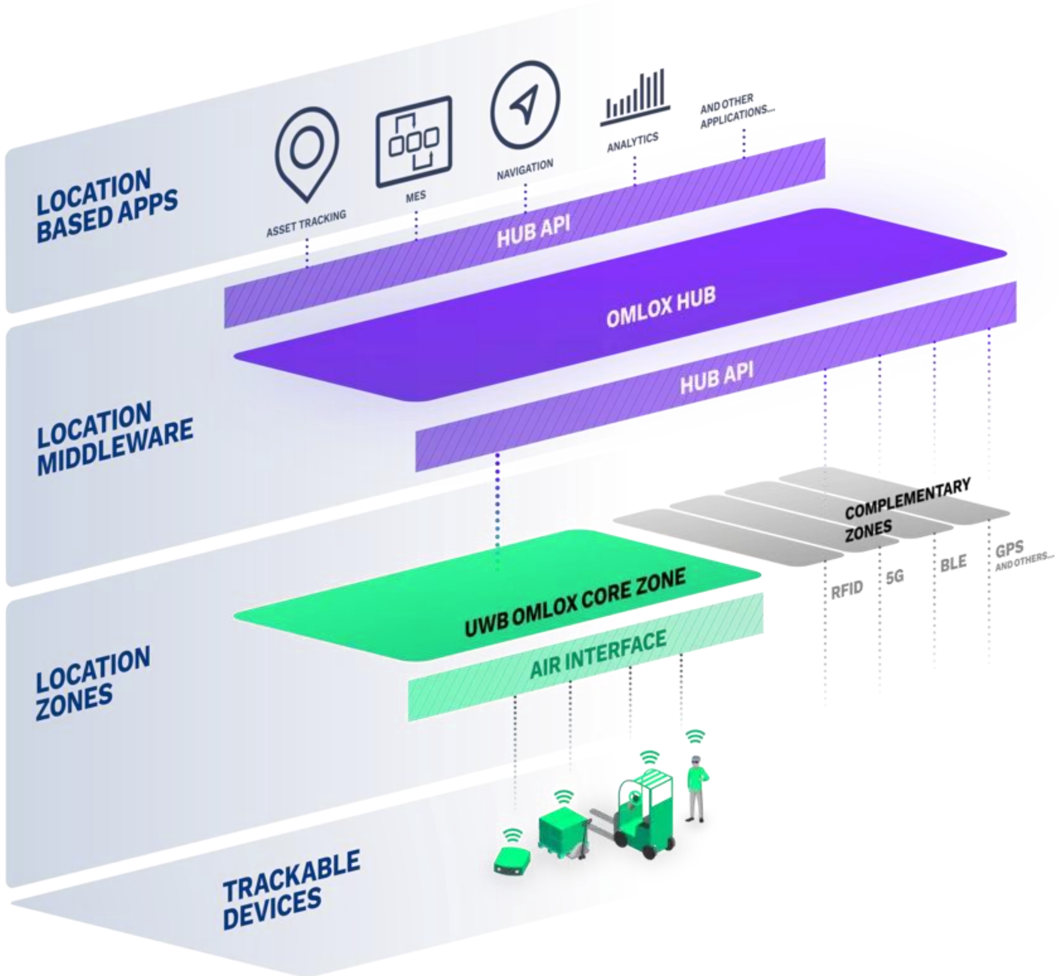

Figure 1: The omlox architecture [1]

Part of the omlox architecture is the omlox core zone, which uses UWB technology for robust and accurate localization, as shown in Figure 1.

The core zone is comprised of fixed infrastructure elements, referred to as satellites, and mobile devices, which are referred to as tags. The communication protocol (the omlox air-interface) between tags and satellites is specified by the omlox core zone specification (OCZS). This enables both satellites to determine the position of tags (i.e., tracking) and tags to locate themselves (i.e., self-location), similar to the concept of GNSS devices where the position is calculated directly on GNSS device side. Since omlox-certified satellites as well as omlox-certified tags implement this joint air-interface, tags can easily and quickly discover the presence of an omlox core zone satellite infrastructure and register themselves for tracking. This plug-and-play interoperability across devices from different vendors allows flexible configurations and scalable extensions of RTLS.

In addition to the omlox core zone, there are complementary zones (see Figure 1) that support various other technologies, including WiFi, BLE, RFID, 5G, vision-based systems, and satellite-based GNSS technologies such as GPS and Galileo. These technologies are standardized by the relevant authoritative bodies. The omlox hub facilitates the integration of the location data generated by the respective zones into a unified format. Furthermore the data from complementary zones can be used to enhance a trackable's position through sensor fusion.

Another part of the omlox architecture is the omlox hub. It acts as the middleware that standardizes and consolidates location data from the core and complementary zones. It provides standardized application programming interfaces (APIs) for data access, supporting REST (Representational State Transfer) API, WebSocket API, and MQTT (Message Queue Telemetry Transport), and uses a JSON (JavaScript Object Notation) based data model for ease of integration and customization. This hub decouples the application layer from the specifics of the underlying positioning technologies, enabling technology-agnostic and vendor-independent solutions for indoor and outdoor tracking.

Applications that interface with the omlox hub span a variety of use cases and take advantage of features supported by the hub, such as georeferencing and spatial operations. Georeferencing translates local coordinate data into a global coordinate reference system, while spatial functions include geo-fencing and collision detection, which use standardized APIs. Geo-fencing refers to the management of spatial boundaries, and collision detection calculates the proximity between moving objects.

The omlox standard is governed by PI, which ensures adherence to industry standards and promotes interoperability among different real-time locating systems and devices. This standardization initiative increases the flexibility, scalability and interoperability of location-based solutions in the industrial sector, promotes the introduction of UWB technology and enables the integration of different location technologies into coherent, standardized systems [1].

Air device integration for omlox

The term air device integration typically refers to the process of connecting and incorporating wireless devices into a network or system, allowing for seamless communication to enhance functionality and user experience. In the context of omlox, the term describes the integration of omlox core zone capabilities directly into products, tools, or devices, to extend their functionality by making them trackable or giving them tracking capabilities. This significantly enhances the use and management of such assets, allowing for real-time tracking of their location and usage. The integration of omlox core zone capabilities into vehicles, industrial equipment, and high-value tools, such as power tools in professional environments, not only reduces the rate of loss but also enables better asset management and utilization. The dissemination of the OCZS across various products fosters a common functionality that can be leveraged across different industrial sectors.

Integrating omlox core zone functionality directly into new products during the manufacturing process, rather than retrofitting omlox tags later, offers substantial benefits. Direct integration ensures that the omlox core zone capabilities are seamlessly incorporated into the product design, potentially reducing the complexity and cost of subsequent modifications. Moreover, it enables manufacturers to standardize the tracking capabilities across their product lines, enhancing the overall value proposition of their offerings to the industries that heavily rely on precise and reliable asset tracking.

Finally, the development of omlox air devices (OAD) designed for multiple use cases will enable the omlox architecture to grow. With many customers designing omlox products with different functionalities, such as satellites and tags, the architecture can support a wider range of industrial and commercial applications, from asset tracking in logistics to personnel monitoring in safety-critical environments.

This introductory exploration of OAD interface within the omlox architecture sets the stage for a deep dive into the specific aspects of integrating omlox technology. The subsequent chapters will detail the technical intricacies, application scenarios, and strategic considerations involved in the development and integration of OAD. From detailed engineering guidelines to case studies illustrating real-world implementations, these sections aim to provide comprehensive insights and practical advice for effectively leveraging omlox core zone standard.

Basics and relevant standards

The OCZS specifies the communication of the omlox devices i.e. satellites and tags in terms of device management, network organization and synchronization and measurement methods used for localization of tags. This ensures cross-vendor compatibility. As shown in Figure 2, the OCZS describes two interfaces: the UWB radio protocol (also known as in-band (IB) radio) and the out-of-band (OoB) radio protocol. Due to the emission limits, the UWB radio protocol is mainly used for time and distance measurements. All other communication processes are usually transferred to a separate, less restricted narrowband OoB radio protocol [2] [3] [1].

Both protocols are based on global standards of the IEEE (Institute of Electrical and Electronics Engineers) Standards Association and therefore benefit from technical stability and interoperability with other, higher-level standards. The following standards are used in detail:

The **OoB protocol** is based on the IEEE 802.15.4-2020 standard for low-rate wireless networks. On this standard, the OCZS introduces an OoB radio (IEEE 802.15.4-2020 O-QPSK (Offset Quadrature Phase-Shift Keying), §12) that uses the ISM (Industrial, Scientific, and Medical) band at 2.45 GHz. The specification defines all the necessary device management procedures, from device detection and ranging to over-the-air updates. Different channels can be used to operate different cells (see section below on OoB controllers) [2] [3].

The **IB protocol** is based on the IEEE 802.15.4z. This standard was released as an amendment of the IEEE 802.15.4-2020 standard in August 2020 and defines a set of PHY- (Physical Layer) as well as MAC- (Media Access Control Layer) features and configuration options, spanning pulse shape, pulse rates, modulation, frame structure, etc. This feature set enables UWB solutions with a focus on range, security and power consumption. omlox offers a choice of two UWB channels for implementation. It is also possible to set up devices that support both. The UWB channel 3, operating in the **4 GHz low-band (therefore called omlox air 4)** with a center frequency of 4492.8 MHz in high pulse repetition frequency (HPRF) mode, is optimized for performance and range. On the other hand, UWB channel 9, operating in the **8 GHz high band (therefore called omlox air 8)** with a center frequency of 7987.2 MHz in Base Pulse Repetition Frequency (BPRF) mode, is

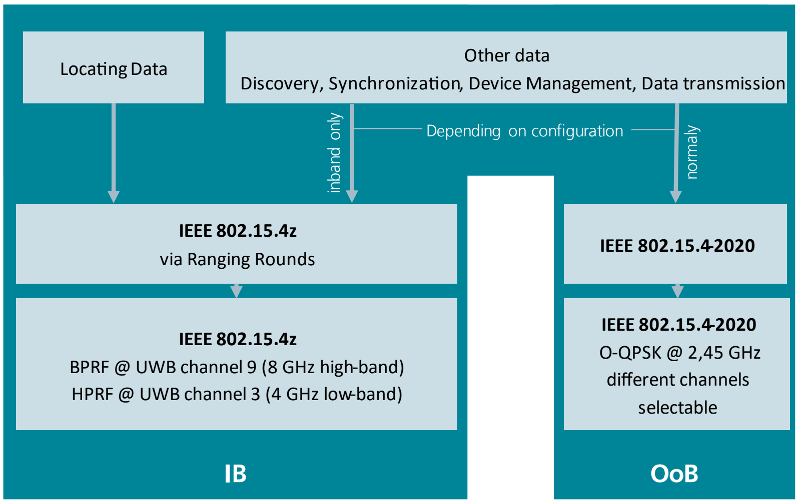

Figure 2: Systematic overview of data transmission via different interfaces (IB and OoB) of the omlox standard and the standards used.

chosen when broader compliance with global regulations is required [2] [3].

Time structure

The time structure of **IB communication** is derived from the so-called **Ranging Rounds** defined in the IEEE 802.15.4z standard (see Figure 3). The OCZS specifies 150 time slots per Ranging Round with a respective length of 0.833 ms each. In one slot only one specific device (i.e. satellite or tag) is allowed to transmit, thus avoiding collisions. In addition to the IEEE 802.15.4z standard, omlox combines 8 ranging rounds into one ranging block (1 sec.). The time structure of **OoB communication** uses the **superframes** defined in IEEE 802.15.4-2020. Thereby, an OoB superframe is aligned and synchronized with an UWB ranging round. In omlox, several superframes are combined in a structure called hyperframe, which is aligned to a ranging block [3].

omlox ranging round

In IB communication, each **omlox ranging round** consists of three consecutive phases, as shown in Figure 4 [3]:

1. An extended Ranging Control Phase xRCP of 16 slots assigned to controller satellites (see description below) that sequentially propagate synchronization signals across the network
2. An Initiation Phase of 32 slots assigned to satellites that transmit downlink ranging messages (see description below) to tags
3. A Response Phase consists of 102 slots allocated for tags to transmit uplink ranging messages. Because not every tag transmits in each ranging round, the number of slots is not the limit for the possible number of tags.

Regarding the response phase, a ranging round can be set up as a **Guaranteed Time Slot Window (GTSW)** or **Large Time Window (LTW)** depending on the system composition, whereby the ratio of GTSW and LTW ranging rounds in a ranging block may vary (see table 12. in OCZS). In a GTSW ranging round, the tags have a permanently assigned time slot (until the tag releases this slot) in which they transmit. This guarantees a deterministic tracking behavior but requires exact time synchronization of the tag with the infrastructure. In an LTW ranging round, loosely synchronized tags can communicate with the satellite infrastructure; however, it should be noted that in this mode package collisions are possible and there is no determinism. Clear Channel Assessment methods specified in [IEEE Std 802.15.4z] can be used to avoid collisions [3].

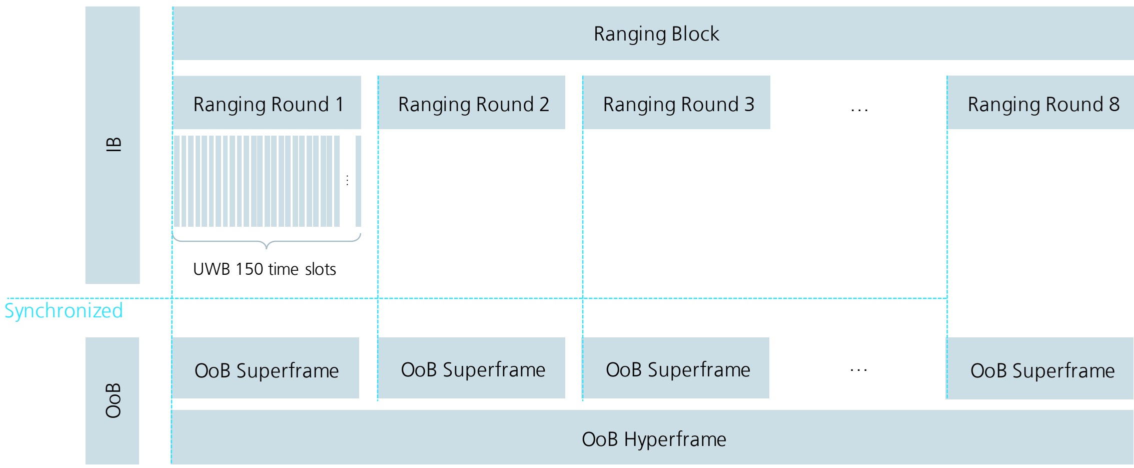

Figure 3: Time structure and alignment of IB- and OoB communication

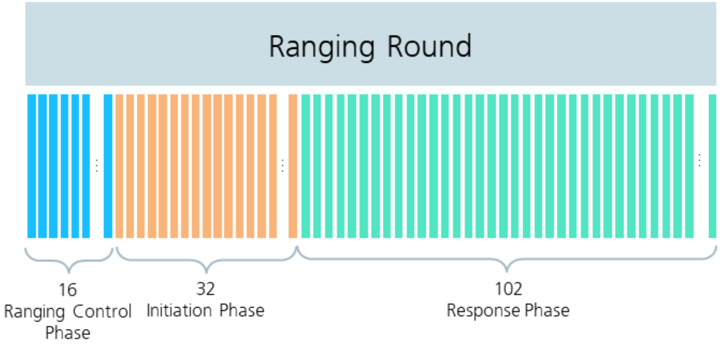

Figure 4: Phases of an IB omlox ranging round

Superframe

An OoB superframe is divided into two phases (see Figure 5), the extended (contention free) XOCM phase (XOCM stands for omlox OoB Control Message) and a OoB Contention Access Period (CAP). During the XOCM phase each OoB controller (specially assigned configurations of specific satellites, for further information see OCZS) shall transmit commands or data to be sent to a device. In the OoB CAP each device may transmit its data packet. The type of data that is sent is described in the following section [2].

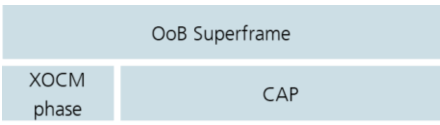

Figure 5: Phases of OoB superframe

Data structure

The exchange of information elements (IEs) between devices in the defined time slots and time windows is a crucial aspect of communication. These IEs are embedded in data frames that comply with the IEEE 802.15.4-2020 standard (frame type 1). This data structure is used for both IB and OoB communication. The omlox core zone uses IEs from the IEEE 802.15.4z standard, but also defines additional omlox-specific IEs. The choice of whether information is transmitted via the IB channel or the OoB channel depends on its function, which is determined by the omlox standard. Time and distance measurements are transmitted via the IB channel, while other communication is typically handled via a separate, less restricted narrowband OoB radio protocol. In cases where communication in the 2.4 GHz band is restricted, the omlox standard enables IB only communication, in which all data is transmitted exclusively via the IB interface [3].

Other MAC payloads that are not part of the OCZS are not interpreted by the omlox core zone satellites and are transported transparently (with additional metadata such as source address and timestamp) to the higher-level software on the upper layer side. Therefore, manufacturers also have the option of transmitting product-specific information at the MAC level, which is then forwarded to the HUB level via the satellite infrastructure [3].

Device types

The omlox air interface essentially distinguishes between two types of devices. On the one hand, the so-called satellites, which are fixed devices with known coordinates for position determination and form the infrastructure for localization. On the other hand, there are so-called tags, whose position needs to be estimated.

The OCZS provides different variants for both the satellites and the tags. Depending on the constellation, different measurement methods can be implemented. In the following, the respective satellites and tag types are first briefly introduced and then the intended measurement methods of the OCZS are presented [3].

Satellites

There are three types of satellites: Full Blown Satellite (FBS), Mains Powered Satellite (MPS), and Battery Powered Satellite (BPS). The FBS strives for perfect synchronization, is connected to a power source without power constraints, and collects data for higher layers. The MPS needs also a power source without power constraints and strives for perfect synchronization but does not collect data for higher layers. The BPS is battery-powered, has synchronization constraints, and does not collect data for higher layers but synchronizes at larger intervals than FBS and MPS.

The roles of the satellite types differ in their tasks. The FBS synchronizes the network, participates in the initiation phase, and collects data from tags. The MPS also synchronizes the network and participates in the initiation phase but does not collect data from tags. With a BPS, the satellite density can easily be increased, improving the accuracy and coverage of the system. To do this, it takes part in the initiation phase and serves as an additional time reference for tags. By reducing its reception window, it extends its battery life [3].

Tags

OCZS defines three types of tags based on different use cases and requirements. A Transceiver Tag (TRxT) can both transmit and receive. These tags are particularly useful as they enable the measurement of time of flight (ToF) data for ranging on the satellite side by responding to initiation messages from satellites. Transmitter Tags (TxT), on the other hand, only transmit and allow satellites to measure the time difference of arrival (TDoA) of their transmissions. Receiver Tags (RxT) only receive and measure the TDoA of initiation messages from surrounding satellites.

Depending on the tag type, different measurement methods (see following section) can be implemented. The main distinguishing features are whether a self-localization or a localization via the satellite infrastructure takes place. Furthermore, a distinction can be made based on the ratio of the energy requirement and the possible accuracy of localization [3].

Measurement methods

Localization involves two steps: Ranging and Positioning. During Ranging, the distance between nodes (tags and satellites) is measured based on the ToF or TDoA principle and the location of the tag is calculated. The OCZS features four measurement methods (see Figure 6) that can be simultaneously deployed by an omlox satellite infrastructure. For each tag, one of the following measurement methods can be chosen. For each measurement method, the OCZS also specifies accuracy and a reliability value that must be maintained in the interaction between satellite infrastructure and tag. Compliance is checked as part of the certification process (see chapter Certification). An overview of the measurement methods is given in Table 1 [2] [3].

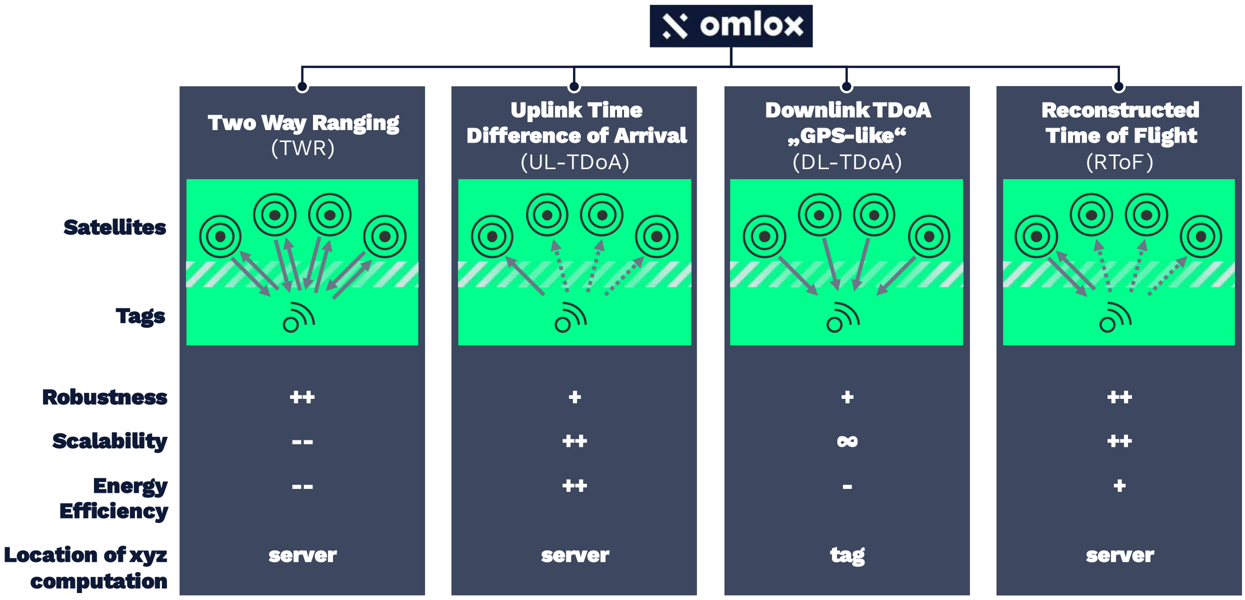

Figure 6: OCZS measurement methods [2]

Table 1: Measurement methods [3, 2]

Measurement methods	Description
Multiple Two-Way Ranging (multiple TWR)	The Two-Way Ranging mode enables precise position determination through repeated handshakes between a tag and several satellites. Therefore, a transceiver tag is required. Based on a time-of-flight principle this mode allows for accurate distance measurement from the tag to multiple satellites. Once all distances are known, the upper layer can use multilateration to compute the tag's coordinates. While this mode is highly accurate, it is energy-intensive and has limited scalability regarding the number of simultaneously tracked tags.
Uplink Time Difference of Arrival (UL-TDoA)	The Uplink Time Difference of Arrival (UL-TDoA) is an energy-efficient method for determining the position of tags. These tags periodically send a signal (blink) that is received by surrounding satellites. Since the satellites are synchronized, they can calculate the tag's position based on the time difference of arrival of the signals. Therefore, a transmitter tag is sufficient.
Reconstructed Time of Flight (RToF)	The Reconstructed Time of Flight (RToF) methode is an energy-optimized Two-Way Ranging method that depends on a single handshake between a tag and one satellite. This handshake is also received and processed by other surrounding satellites. Due to the synchronization of the satellites, it is possible to compute the time of flight among all the satellites involved. A transceiver tag is therefore required.
Downlink Time Difference of Arrival (DL-TDoA)	DL-TDoA, also known as "GPS mode," is a tag-centric GPS-like method designed to support an unlimited number of mobile devices. It exclusively uses the signals received from satellites to allow tags to calculate their position. Therefore, a receiver tag is sufficient. The tags analyze the differences in the arrival times of multiple satellite signals received at a single tag location. The position calculation is carried out directly on the tag, so that a higher energy and computing effort is to be expected on the tag side.

Hardware integration

Integrating hardware components for OADs requires careful consideration of various elements to ensure optimal performance and compliance. Typical components of an omlox device include the integrated circuits (ICs) responsible for UWB and OoB communication, the antenna for signal transmission and reception, the power supply to ensure consistent operation, and other supporting elements such as sensors and connectors. This chapter covers key aspects of hardware integration, including antenna options and restrictions and selection of suitable ICs providing a comprehensive overview to facilitate successful implementation.

Basic Structure of an OAD hardware

As previously described, for the implementation of an OAD, the possibility must be created to communicate over two channels (IB and OoB). This can be implemented as shown in the example design in Figure 7, so that each radio frequency (RF) chip handles communication for one channel. Also essential is the control of these ICs as well as data processing and routing of the different IEs. For this task, a microcontroller (µC) is provided in the example design. Depending on the selection of components, an external oscillator can be added as a clock to ensure the necessary synchronization for communication with other OADs and to enable precise time measurement, which is required for distance measurements that are implemented through signal travel time determination. These functions form the core of every OAD.

Depending on the type of OAD (i.e. tag or satellite), additional peripheral devices can be connected to the µC. In the case of a tag, for example, a rechargeable battery including an energy management unit could be provided. Other control elements such as buttons or LEDs for control and feedback options are also conceivable. In the case of a satellite, which is only part of the overall infrastructure, further possibilities for communication with a locating engine must be created, which manages the satellites and determines the position.

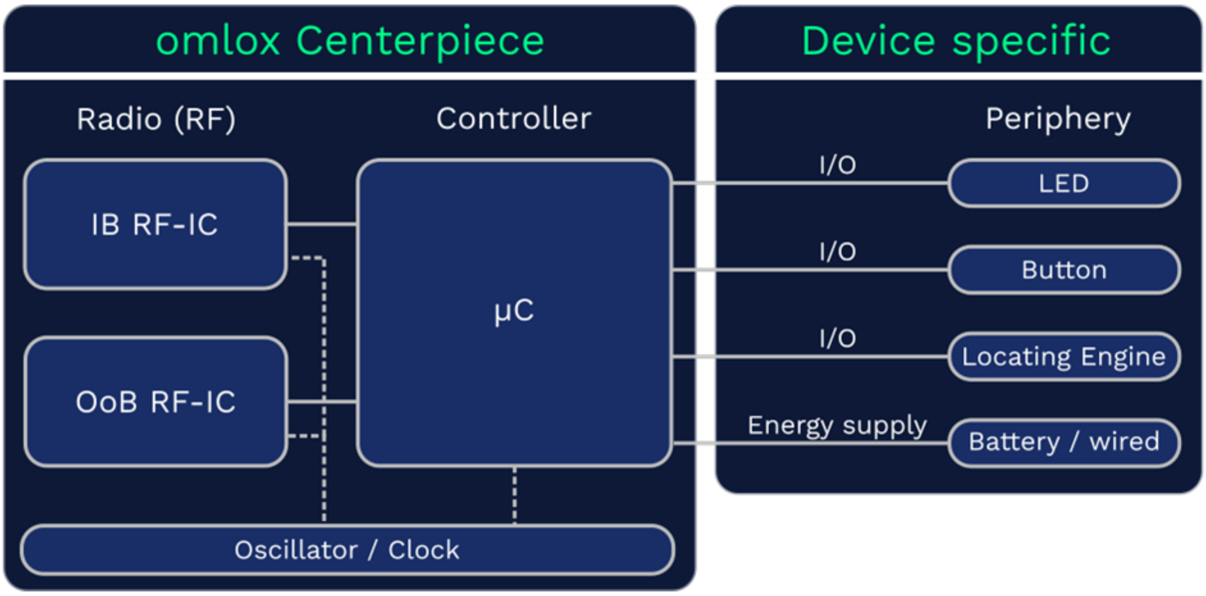

Figure 7: Block diagram with exemplary structure of OAD hardware

Selection of suitable ICs for communication

The ICs are responsible for managing IB and OoB communication. Selecting the right ICs is crucial for ensuring that the device meets performance and regulatory requirements. For UWB communication (IB), factors such as power consumption, range, and sensitivity are paramount. Low power consumption is essential for extending battery life, especially in portable devices, while high sensitivity ensures better performance in various environments, including those with obstacles and interference. The ICs must support the frequency bands and channels required for omlox air 4 or air 8 configurations (both possible):

- omlox air 4: Channel number 3,
  Central frequency 4492.8 MHz.
- omlox air 8: Channel number 9,
  Central frequency 7987.2 MHz.

For OoB communication, the chosen ICs should be compatible with the IEEE 802.15.4 standard. It is important to note that two different radio channels must be operated (e.g. by two separate ICs): one for IEEE 802.15.4 (OoB communication) and one for IEEE 802.15.4z (UWB communication). Ensuring that the ICs operate in the required frequency bands and meet regulatory requirements is also critical; furthermore, it is crucial to operate them simultaneously with sufficient synchronization. Information on detailed specifications and compliance features, can guide the selection process of ICs. Vendors of omlox-compatible chips are listed on the omlox website. under the corresponding tab. This ensures that the devices not only perform optimally but also adhere to the necessary standards and regulations.

IC integration

Integrating ICs at the board level requires careful planning and execution. The process begins with designing the schematic and layout, ensuring that the ICs are correctly placed to minimize signal interference and maximize performance. Power supply considerations are also critical, as fluctuations can affect the ICs' performance. Proper thermal management is necessary to prevent overheating, which can degrade the ICs' functionality and lifespan. Reference designs from IC manufacturers can provide a blueprint for successful integration, offering insights into best practices and common pitfalls. These designs often include suggestions for suitable antennas, power supplies, and other components. Working with certified suppliers ensures that the components used meet the required standards and quality levels. By following these guidelines, developers can achieve a reliable and efficient integration of UWB and OoB ICs into their OADs.

Antenna options and restrictions on integration

Selecting the right antenna is crucial for the optimal performance of OADs. Various types of antennas such as patch, chip, and wire or PCB (Printed Circuit Board) antennas can be used, each with its own set of advantages and limitations. Patch antennas are often chosen for their directional capabilities and ease of integration into compact designs. Chip antennas offer a smaller form factor but may require careful tuning to achieve the desired performance. Wire antennas, while often larger, can provide excellent range and reliability. Placement of the antenna within the device is another critical factor. It should be positioned to minimize interference from other components and maximize signal strength. Additionally, regulatory restrictions must be considered to ensure compliance with local laws and standards, particularly regarding the maximum allowable power levels and frequencies (see also chapter Regulatory topics). Proper antenna design and integration can significantly impact the overall performance and range of the device.

Module and reference designs

The use of modules and reference designs can significantly streamline the integration process for OADs. The reference designs from IC manufacturers provide a step-by-step guide for integrating UWB (IB) and OoB ICs, covering aspects such as power management, signal routing, and antenna placement. These designs often include schematics, layout files, and bill of materials, offering a comprehensive resource for developers. Additionally, these reference designs may offer suggestions for suitable antennas, power supplies, and other components. Further resources, including design files and technical support, can often be accessed via the manufacturer's website. This approach ensures that developers have all the necessary tools and information to achieve a successful integration.

Software development

This chapter covers various aspects of software development, including firmware development, data flow management, and the implementation of self-locating devices. Additionally, it delves into advanced techniques for combining positioning methods with sensor data to enhance accuracy and reliability.

Firmware

Firmware plays a crucial role in the operation of OADs, acting as the bridge between hardware components and higher-level software applications. It must handle tasks such as initialization, data processing, and communication protocols while integrating additional sensors like Inertial Measurement Units (IMUs).

Depending on the type and variant of the device, various functions must be implemented into the respective firmware. A common requirement for all devices is the correct initialization and control of UWB and OoB chip modules, as well as proper handling of IEs. The OCZS dictates which IEs must be routed through which channels. Handling exceptions such as the IB-only mode must also be considered.

Depending on the device type, additional extensive functions and tasks may be required during software development. While the implementation of a tag is primarily concerned with proper behavior (synchronization and timing) in sending and receiving data (except for DL-TDoA tags; explanation follows), multiple firmwares for different devices at different levels may be needed when building an infrastructure based on certain design approaches. For instance, if the approach involves operating multiple satellites with a single locating engine, both satellite software and engine software are required. The tasks could be distributed as follows:

Satellite tasks:

- Time synchronization and communication with other satellites
- Time synchronization and communication with tags
- Measurement of packet travel times to determine tag distance

Engine tasks:

- Managing the satellite network
- Calculating tag positions from distances measured by satellites (methods described below)
- Providing tag positions to the hub via the hub API

Additionally, the firmware must support real-time data processing and low-latency communication to ensure seamless operation within the omlox architecture. Robust error-handling mechanisms and firmware security features, such as secure boot and encrypted communication, are essential to prevent unauthorized access and ensure data integrity.

For more detailed information on the specific IEs and their roles, as well as the exact protocols and standards used, refer to the OCZS [3].

Development of self-locating devices

The omlox core zone supports self-locating devices, which is particularly relevant for the case of DL-TDoA tags mentioned earlier. These devices use the DL-TDoA method to calculate their own position, employing methods and algorithms similar to those used in GPS.

When available, the combination of positioning methods with additional sensor data, e.g. from an IMU, can be a useful practice to enhance accuracy and reliability. This combination, often referred to as sensor fusion, leverages data from multiple sensors to provide a more robust positioning solution.

By integrating sensor fusion techniques, developers can enhance the accuracy, robustness, and reliability of self-locating devices and other positioning methods within the omlox architecture. This approach helps to mitigate the limitations of individual sensors and positioning methods, providing a more comprehensive and reliable tracking solution. Further improved methods can be found in respective literature.

Over the air update

Mechanisms for firmware updates, including over-the-air (OTA) updates, should be implemented to facilitate easy maintenance and feature enhancements. Details on managing OTA updates can be found in the OCZS [3].

Data tunnel towards app

The omlox standard also allows manufacturers to use omlox communication to transfer product-specific data. These are tunneled through all layers (via vendor-specific IEs) and allow data transfer from the manufacturer's software applications to its own omlox-compatible devices [3] [4]. For example, device-specific sensor values (e.g. torque of a drill) can be provided to be used in customer-specific apps. In addition, commands can be transmitted to the tag, e.g. to trigger optical or acoustic signals. This approach enables flexible handling of data and implementation with various applications, so that customer-specific solutions can be developed using the omlox infrastructure.

Test and development tools

Continuous testing during the development of an OAD is crucial for successful and specification-compliant development. The following tests and development tools can be particularly helpful in this process. However, this list is not exhaustive and can be supplemented with additional tools as needed. This section will briefly focus on tools that are useful for developing OADs based on UWB technology. Standard tools for programming (e.g., code editors) and CAD design tools (for, e.g., circuit layout and PCB design) will not be discussed.

In general, a distinction can be made between tools for developing UWB-enabled devices and omlox-specific test tools.

General tools

Signal analyzers can be used, with corresponding antennas and frequency spectrums, to measure and analyze the signals transmitted and received by devices. This includes verifying the signal integrity, measuring signal strength, and identifying any distortions or anomalies.

omlox specific tools

Through PI, so-called Laboratory test equipment can be acquired, which records the entire IB (UWB) and OOB traffic of the omlox core zone device. The integrated protocol analyzers log the communication protocols between devices. They help in verifying compliance with standards, debugging communication issues, and ensuring interoperability between different devices.

Using an omlox-certified satellite infrastructure or a certified tag, it is possible to perform laboratory tests to verify that the device to be developed (tag or infrastructure) communicates correctly with other already certified devices. In addition, measurement analysis can be used to verify that the required accuracies are met by comparing expected and actual positioning.

Regulatory topics

When integrating OADs, it is vital to understand and comply with various regulatory requirements to ensure lawful and efficient operation. This chapter addresses key regulatory topics including power levels, allowed frequency bands, and regional differences in radio-related regulations.

Power levels and regional differences

The maximum allowable power levels for OADs can vary between different geographic regions. In Europe, the European Telecommunications Standards Institute (ETSI) regulates power levels to ensure devices do not cause interference with other spectrum users. Typically, devices must adhere to strict power output limits for indoor use and lower for outdoor applications [5] [6]. In the United States, the Federal Communications Commission (FCC) sets similar regulations, but permissible power levels can be different, often allowing higher power outputs for certain applications. For instance, in the context of omlox, the specific power levels must be adapted to local regulatory limits while ensuring compliance with the IEEE 802.15.4 and IEEE 802.15.4z standards. In Asia, countries like Japan and South Korea have their own specific regulations which may differ from those in Europe and America. It is crucial to consult the relevant regulatory bodies in each region to ensure compliance with local power level restrictions.

Allowed omlox bands and geo regions

Different regions have allocated specific frequency bands for omlox devices, which are based on the IEEE 802.15.4 and IEEE 802.15.4z standards. For OADs, the following frequency bands are used for IB communication [3]:

- Channel number 3: Central frequency 4492.8 MHz, bandwidth 500 MHz, using the High Pulse Repetition Frequency (HPRF) mode (referred to as "omlox air 4" configuration).
- Channel number 9: Central frequency 7987.2 MHz, bandwidth 500 MHz, using the Base Pulse Repetition Frequency (BPRF) mode (referred to as "omlox air 8" configuration).

In addition to IB communication, omlox devices also utilize OoB communication for functions such as discovery, synchronization, device management, and data transmission. The OoB communication for OADs uses the 2450 MHz band as defined in IEEE Std 802.15.4-2020, utilizing O-QPSK PHY at 250kbit/s. OoB communication channels include [3]:

- Discovery Channels: IEEE 802.15.4 channels 11 and 26.
- Management and Data Channel: A configurable channel that is neither channel 11 nor 26, used for efficient data transfer and management tasks.

These OoB channels are intended to offload the higher energy-consuming UWB channel resources for management purposes, allowing for energy-efficient discovery and synchronization.

Spectrum management practices also vary by region. In Europe, spectrum is often managed through licensing and coordination to prevent interference between different services. Devices may need to operate on a duty cycle basis, where transmission time is limited to a certain percentage of each hour to minimize interference. Similar practices are implemented in the U.S., where the FCC requires devices to adhere to specific duty cycle limits and maximum transmission times. These measures are designed to ensure fair and efficient use of the radio spectrum. For OADs, the maximum frame duration for satellites is set to 333.33 µs but must be adapted to local regulatory limits. Additionally, the target data payload is limited to 64 bytes to minimize frame length [3].

Regulatory bodies such as ETSI in Europe, the FCC in the United States, and equivalent authorities in Asia, including Japan and South Korea, enforce these regulations. It is essential to consult the relevant regulatory bodies in each region to ensure compliance with local frequency bands, power levels, and spectrum management practices.

Regulatory compliance and additional considerations

OADs may also be required to comply with environmental and safety regulations, such as the Restriction of Hazardous Substances (RoHS) Directive in Europe. Moreover, regulatory bodies such as ETSI in Europe, the FCC in the United States, and equivalent authorities in Asia, including Japan and South Korea, enforce these regulations. Therefore, it is essential to consult the relevant regulatory bodies in each region to ensure compliance with local frequency bands, power levels, and spectrum management practices. Additionally, other markets or regions may require different certifications. Detailed information on these certifications is provided in the following chapter Certification.

Certification

As an open and collaborative locating standard, omlox is managed by the non-profit organization PROFIBUS & PROFINET International (PI). To ensure the interoperability of devices and software from different manufacturers, PI and its respective committees define and develop standards and monitor their compliance through certification. This requires testing by a test laboratory authorized by PI. A list of authorized omlox test laboratories (OTL) and their respective testing scopes can be found on the PI website under its "Institutions & Support" section.

Types of omlox certificates

The following certificates are issued to confirm omlox conformity. Hard- and software labelled with the respective certificate/logo (shown in Figure 8) were able to demonstrate the required conformity:

The omlox air interface certifications

The omlox air interface certifications (see Figure 8A, logo variation with air 8 only is also possible) guarantee that devices (tags or infrastructure) labelled with this certificate/logo behave as described in the omlox core zone specification and have passed the certification process for the omlox core zone. This means that an omlox infrastructure device marked in this way can locate omlox-certified devices from other manufacturers and devices marked in this way can be located by an omlox-certified infrastructure from other manufacturers (when using the same UWB frequency). In addition, the standardized hub API ensures that location data can be transmitted from the core zone to an omlox hub [1] [7].[2]

Other omlox certifications

While the focus of this guideline is on the omlox air interface, it is also important to acknowledge other certifications that ensure overall system interoperability and compliance:

- The omlox hub API certificate (see Figure 8B) confirms that a hub implements all the specified API in accordance with the hub specification. It also ensures that all specified functions (e.g. fencing, collision events) have been implemented correctly. Therefore, the hub offers the possibility to connect different locating technologies (core zone or complementary zones) according to the specified API and to pass on the position information consolidated to other apps [1] [7].
- The omlox connectable app certificate (see Figure 8C) indicates that a software application uses the omlox hub API and can therefore access the position data and other functions provided by an omlox hub [1] [7].
- The omlox connectable provider certificate (see Figure 8D) ensures that location providers using other locating technologies than the omlox air interface (e.g. BLE, RFID, proprietary UWB) can function as complementary zones. Products with that logo can provide location data to an omlox hub in compliance to its standardized API [1] [7].

By incorporating these certifications, omlox ensures interoperability and compliance across

[2] Since only a limited test setup was available in the initial phase of omlox certifications, certification was based on a reduced test scope. In this case, certified devices are marked with a corresponding omlox ready certificate: omlox ready air 8.

(A) (B) (C) (D)

Figure 8: Logos of omlox certifications

different devices and software, promoting a unified and efficient architecture for location-based solutions. If a certificate expires, the product can no longer be marketed with the corresponding omlox logo, ensuring continued compliance and reliability within the architecture.

The omlox certification process

The certification process for omlox products is designed to ensure that devices meet strict standards for interoperability and functionality within the omlox architecture. A comprehensive guide can be found in the document "How to get a Certificate for an omlox core zone device" [8], the following section summarizes the process.

Path to certification

The certification process begins with the applicant, typically a device vendor or manufacturer (see Figure 9 (1)), selecting an authorized OTL. Once an OTL is selected, the applicant places an order to begin the certification process. The OTL will provide all necessary information and support, including delivery requirements and documentation needed for the certification test set. A prerequisite for the certification process is that the company also has a Vendor ID from the PROFIBUS & PROFINET International Certification Office (PICO). If this is not the case, this can be requested from PICO.

During the conformity testing phase, the OTL performs a series of tests to ensure that the device meets the required standards. This phase includes the following two test setups:

- The **Laboratory Test Setup (LTS)** involves executing test cases for a System Under Test (SUT) in a controlled, simulated environment. Key tests performed in the LTS include OoB communication tests, IB communication tests, and timing tests. The OoB and IB communication tests ensure that the SUT can handle mandatory device management functionalities and operate in the specified

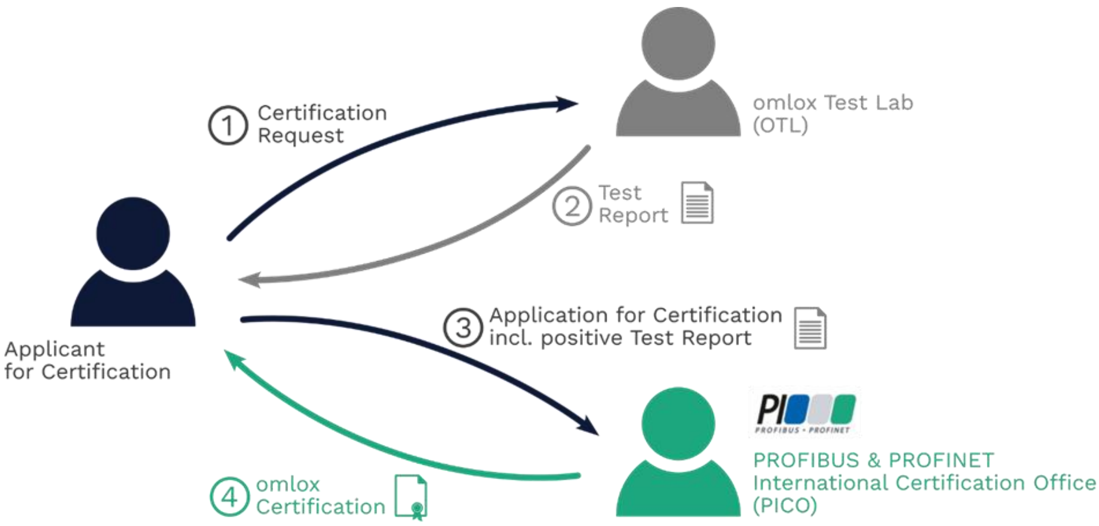

Figure 9: Path for certification of omlox devices

UWB channels, in compliance with the IEEE 802.15.4 and IEEE 802.15.4z standards. Timing tests verify the synchronization and timestamp accuracy of the communications.

- The **Real-World Test Setup (RWTS)** validates the device's performance under real-world conditions using omlox core zone certified reference hardware. Tests performed in the RWTS include positioning performance tests, communication tests and proper communication via the Hub API. The real-world positioning performance tests validate if the SUT can satisfy the minimum positioning performance requirements for 2D and 3D positioning using an omlox certified reference satellite infrastructure. The communication tests ensure that the SUT can perform mandatory device management functionalities with the reference infrastructure. Additionally, proper communication via the Hub API is validated to ensure seamless integration with omlox satellite infrastructure devices.

For further details on the testing procedures, please refer to the "omlox Core Zone Compliance Test Specification" [9]. The required accuracies for passing positioning tests can be found in the chapter Basics and relevant standards of this guideline as well as in the OCZS [3].

Upon completion of testing, the OTL issues a comprehensive test report to the applicant manufacturer (see Figure 9(2)). This report includes the name and version of the test specification, detailed results of the test cases, information about the test equipment used, the date of the report, and device identification details (Vendor ID, Device ID).

With a positive test report, the applicant submits an application for certification to the PICO. This submission must include the original test report(s), and the appropriate application form (see Figure 9 (3)). The PICO will review the application to ensure that all certification requirements are met. This must be completed within three years of the date of the test report to remain valid.

If the PICO approves the application, an omlox core zone certificate will be issued to the applicant manufacturer (see Figure 9 (4)). The certificate includes essential details such as the applicant's name, device name and model number, firmware and software versions, omlox device type, version of omlox specifications implemented, test details, issued omlox core zone logo(s), and the validity period of the certificate. The certificate is valid for three years from the date of the test report.

Recertification and prolongation

Recertification is required when significant changes are made to a previously certified omlox device. Essential omlox features that ensure interoperability and overall functionality must be maintained. Depending on the nature of the changes, different actions are required such as **full certification testing** or a **brand labeler** or a **manufacturer's declaration**. The latter is also required if an expiring certification of an unchanged product is to be prolonged.

For complete details on the recertification and prolongation processes and actions required, please refer to "How to get a Certificate for an omlox core zone device" [8].

This structured certification process ensures that all omlox-certified products meet the required standards, fostering a reliable and efficient architecture for location-based solutions.

Other relevant certifications

In addition to the omlox certification, developers and integrators of omlox air equipment may need to obtain several other certifications to ensure that their products meet regional and international standards. These certifications not only ensure compliance with regulatory requirements, but also assure customers of the product's safety, reliability, and environmental responsibility.

CE (Conformité Européenne) **certification** is mandatory for products sold within the European Economic Area (EEA). It indicates that a product complies with EU safety, health and environmental requirements. For omlox air equipment, CE certification may cover aspects such as electromagnetic compatibility (EMC) and radio frequency (RF) performance. Testing typically includes verification that the product meets the essential requirements for safety and performance as outlined in the relevant EU directives. For more information, visit the European Commission website.

FCC certification is required for electronic equipment marketed in the United States. This certification ensures that the OAD will not cause harmful interference, and that it complies with FCC regulations for radio frequency emissions. The test evaluates the device's radio frequency emissions and ensures that they are within specified limits. More details can be found on the FCC's official website.

The **IP rating** (Ingress Protection) specifies the environmental protection of enclosures around electronic equipment, such as dust and water resistance. This is particularly important for OADs used in industrial environments where exposure to harsh conditions is common. Testing involves subjecting the device to controlled environmental conditions to determine its resistance to dust and water ingress. Testing is typically performed by independent laboratories according to ISO (International Organization for Standardization) /IEC (International Electrotechnical Commission) standards. For more information, visit the IEC (International Electrotechnical Commission) website.

RoHS certification, mandatory in Europe, ensures that devices are free from hazardous materials like lead and mercury, promoting safety and environmental responsibility. Additionally, Underwriters Laboratories (UL) certification is often required to ensure compliance with safety standards in the United States and other regions. For detailed information on these certifications, please refer to the official RoHS website and the UL website.

In addition to certification testing in a laboratory environment, sometimes testing in a more demanding environment, such as production facilities or warehouses, can be useful to verify the robustness of a product. Some OTLs offer additional testing in such environments outside the scope of certification. While these tests don't result in formal certification, they can provide valuable insight into how the device will perform under real-world conditions.

It is also important to note that other markets, specific regions or countries may require additional or different certifications. Developers and integrators should ensure that they are aware of and comply with all relevant local regulations and certification requirements.

By obtaining these additional certifications and conducting real-world testing, developers and integrators can ensure that their OADs are not only compliant with regulatory standards, but also reliable and robust in real-world applications.

Conclusions

This guideline serves as a comprehensive resource for manufacturers aiming to integrate their devices with the omlox standard via the air interface, either as tags or omlox satellite infrastructure. It provides a detailed overview of the standard's features and the foundational standards involved.

Several key aspects have been highlighted as essential for successfully integrating devices with the omlox standard. The guideline begins by detailing the specific requirements for hardware and firmware, focusing on radio ICs and firmware needs. It then addresses the design-related questions that must be considered prior to development, taking into account the various device types defined by the standard. In addition, it provides a list of available tools for the development process, offering a comprehensive overview of the resources manufacturers can utilize. The guideline also discusses the additional regulatory requirements that must be met beyond the omlox standard to ensure compliance. Lastly, it defines the certification process necessary for achieving an omlox-compliant device, providing a clear pathway for manufacturers seeking certification.

Therefore, this guide enables companies to evaluate how the omlox standard can be integrated into their products and what efforts such integration entails. This information forms the basis for making qualified decisions.

While this guideline provides an initial overview and facilitates the integration of omlox technology, it is not a substitute for a thorough study of the relevant specifications. It is important to note that the omlox standard is continually evolving, and the latest specifications are always applicable.

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