White Paper

Device-level Interoperability in UWB-based Real-Time-Locating-Systems enabled by the omlox Core Zone v2 Specification

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Authors/contact persons for inquiries

Franz Lehmann
CTO
TRUMPF Tracking Technologies GmbH
Dornierstraße 12
71254 Ditzingen
Germany

E-Mail: franz.lehmann@trumpf.com

Erik Mademann
CEO
ZIGPOS GmbH
Räcknitzhöhe 35a
01217 Dresden
Germany

E-Mail: erik.mademann@zigpos.com

Introduction

Digitalizing industrial sites and manufacturing floors can provide significant productivity gains. Although digital use-cases and applications see an increasing adoption, they often lack a proper basis of data and, hence, rely on an ongoing manual effort in feeding digital signals. The ability to locate objects, assets or people in real-time in an industrial space, creates the perfect data foundation for digital twins in a cyber-physical system.

Therefore, **real-time locating systems (RTLS)** see an increasing interest in industrial environments, logistics, health care, retail, transportation, and others. RTLS usually consist of fixed infrastructure devices (called **satellites** or anchors) and mobile devices (called **tags**) to be tracked. Satellites and tags communicate with each other (e.g., via a radio like for GNSS/GPS or Bluetooth Low Energy) enabling either satellites to determine the position of tags (i.e., **tracking**) or enabling tags to locate themselves (i.e., **self-location**).

In recent years, **ultra-wideband (UWB)** radio stood-out to become the leading technology for indoor (but not limited to indoor) RTLS. In contrast to other narrow-band or wide-band radio technologies, UWB is an impulse-radio that uses extremely sharp pulses of a few nanoseconds. This enables UWB-systems to measure distances at cm-level precision and high robustness. Several distances can be combined to determine a position.

Interoperability Challenges in current UWB-based RTLS

Figure 1: Typical industrial setup of an UWB-based RTLS consisting of fixed satellites and mobile tags to track objects

As of today, however, UWB-based RTLS lack interoperability between devices from different vendors. This results in a vendor lock-in where a given satellite infrastructure can only track tags of this specific vendor. Especially for large and versatile installations end-customers wish to avoid such a lock-in, since addressable use-cases are limited by available tags of one specific RTLS vendor. At the same time, equipment vendors cannot enable their assets (pallet, forklift, power tools, AR-devices, AGVs, etc.) to become trackable without developing and offering their own satellites or associating themselves to a specific RTLS vendor.

The lack of common interfaces can currently also be found in higher software layers where locating data structures, API interfaces and basic features (such as geo-fences) are mostly proprietary, not openly accessible or well documented.

This is resulting in todays' siloed systems where an additional location-enabled use-case often requires an additional RTLS associated with unnecessary high total cost of ownership, ultimately limiting the adoption rate of RTLS overall.

omlox – the World's first open locating Standard

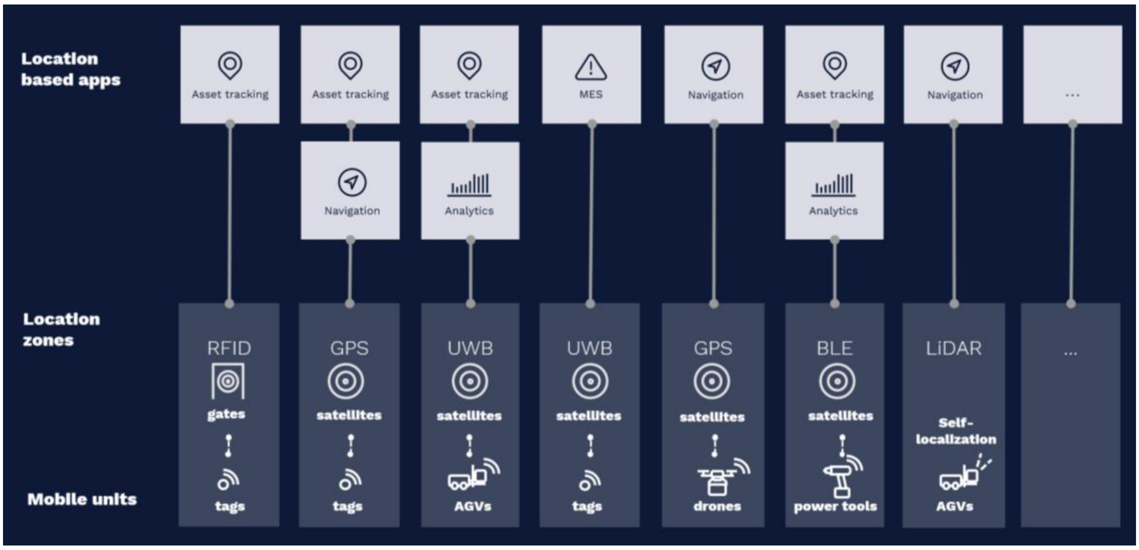

Figure 2: Currently, RTLS are implemented as siloed stand-alone systems due to the lack of interoperability

With the goal to harmonize access to location data and foster interoperability across RTLS and devices from different vendors, the **omlox standard** has been initiated by industrial leaders back in 2018. By now, omlox is hosted by the **PROFIBUS & PROFINET International (PI)** standardization body and shaped by an ever-growing member community including **TRUMPF Tracking Technologies GmbH**, **ZIGPOS GmbH** and many other companies.

The omlox standard defines an open and generic RTLS architecture. To overcome siloed RTLS, omlox standardizes two main interfaces that pave the way towards flexible, extendable and interoperable locating solutions:

- The **omlox hub API** allows running an unlimited variety of location-based applications by deploying just a single unified and technology-agnostic API interface accessing positions, ranges etc. Those can be originating from different kinds of ranging and locating technology, such as UWB, BLE, GPS, 5G, WiFi or others.
- The **omlox air-interface** definition provides interoperability within the **omlox Core Zone** across various UWB-enabled RTLS devices from different vendors, allowing flexible configurations and extensions to address numerous use-cases in industry, logistics and beyond.

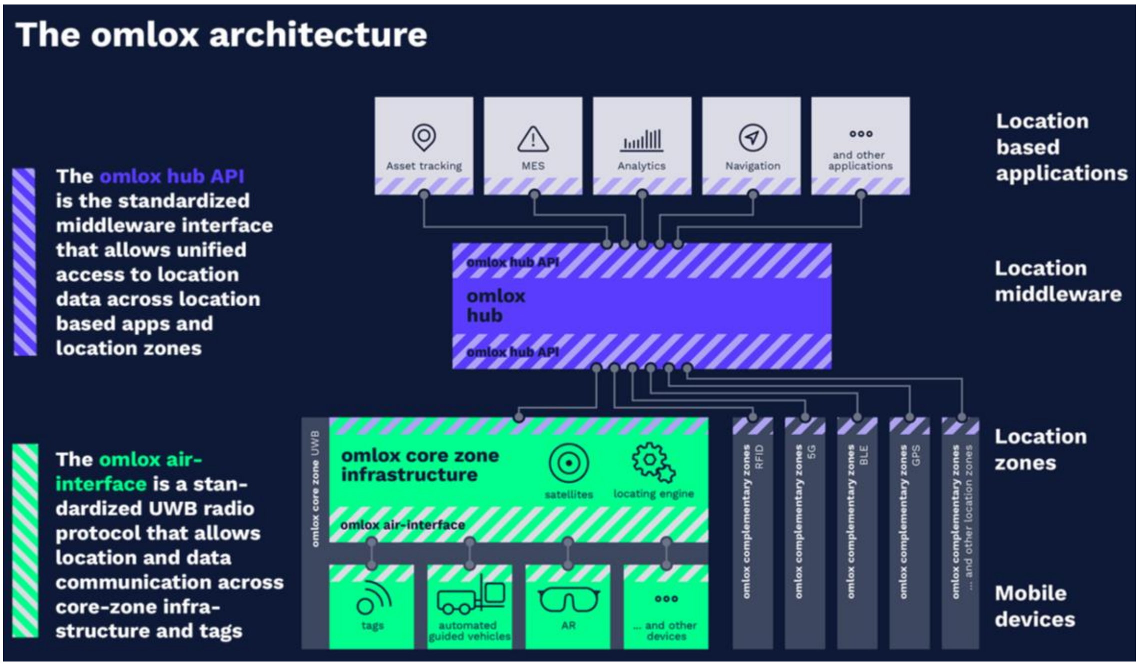

Figure 3: The omlox architecture cuts an RTLS into layers with defined interfaces that allow interoperability and open competition on each layer

The standardized omlox Air-Interface

Figure 4: The omlox Core-Zone v2 Specification defines the air interface between UWB-capable satellites and tags

The omlox air-interface standardizes locating and data communication within the omlox Core Zone across UWB-capable satellites and tags from different vendors. This interface is described in the omlox Core Zone v2 Specification and defines the UWB radio (also called **In-band (IB)**) as well as an **Out-of-Band (OoB)** radio protocol. Whereas the regulatory emission-limited UWB radio is primarily used for time/distance measurements, all other communication is typically off-loaded to a separate and less limited narrow-band OoB radio.

In order to achieve vendor-agnostic interoperability between satellites and tags, configurations and concepts on various layers have been standardized. This covers the physical layer (PHY), media access control layer (MAC) as well as upper layers, as also analyzed by a publication from Coppens et.al. on Multiple Access Schemes and Vendor Interoperability ("*An Overview of Ultra-WideBand (UWB) Standards (IEEE 802.15.4, FiRa, Apple): Interoperability Aspects and Future Research Directions*“).

PHY-layer: UWB Radio Chip Support and Configuration

UWB radio manufacturers like Apple, NXP, Samsung and Qorvo already paved the way towards UWB interoperability by jointly defining and widely adopting the **IEEE 802.15.4z standard (short 4z)**. The 4z standard enhances the pre-existing IEEE 802.15.4 standard and defines a set of PHY as well as MAC features and configuration options, spanning pulse shape, pulse rates, modulation, frame structure, etc.

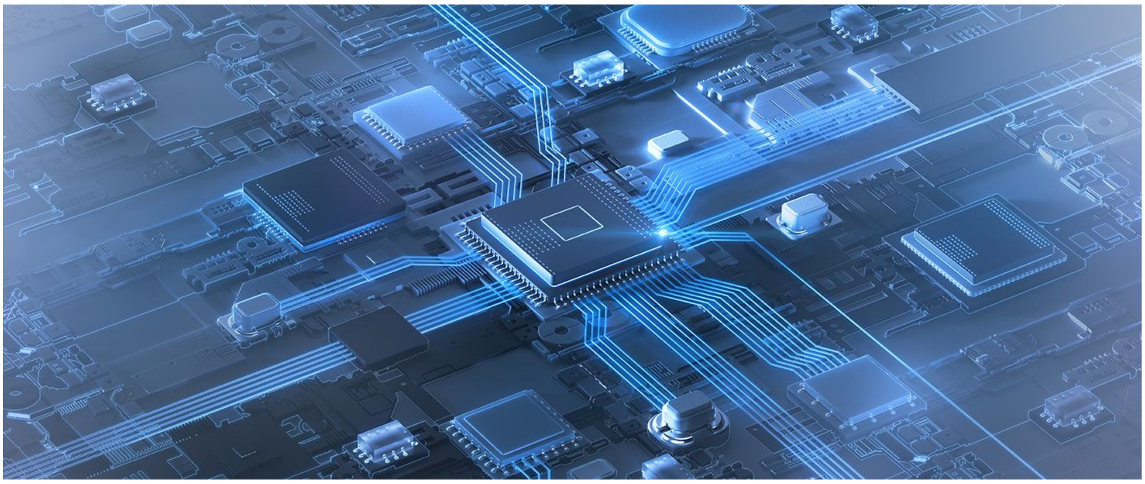

Figure 5: Modern UWB-based RTLS are based on 4z-compliant UWB-transceivers that lay the ground for physical interoperability

Despite the fact that modern RTLS-vendors use 4z-compatible UWB radio chips, they still run them with individual PHY configurations, making communication between satellites from one vendor and tags from another vendor physically impossible.

Therefore, the omlox Core Zone v2 Specification introduces two common PHY configurations:

- **World-wide** configuration which satisfies global regulation: UWB channel 9 (**8 GHz** high-band operation with its center frequency at 7987.2 MHz) in base pulse repetition frequency (BPRF) mode
- **Long-range** configuration which is optimized for performance and range: UWB channel 3 (**4 GHz** low-band operation with its center frequency at 4492.8 MHz) in higher pulse repetition frequency (HPRF) mode

PHY- and MAC layer: OoB Radio and Device Management

Due to the regulated duty cycle and link budget of UWB radio channels, the use of a separate narrow-band OoB radio is recommended to off-load device management, data exchange or energy efficient scheduling for power-limited and lifetime-optimized devices.

Various existing RTLS rely on Bluetooth/BLE as OoB radio, which results in a non-deterministic tag-triggered and therefore uncontrolled behavior that might cause issues in regulated environments such as airplanes. The omlox Core Zone v2 Specification therefore introduces a novel satellite infrastructure-triggered OoB radio (IEEE 802.15.4-2020, O-QPSK, §12) using the ISM band on 2.45 GHz. The specification defines all required device management procedures from device discovery, over ranging, up to over-the-air-updates.

Furthermore, the specification introduces an IB-only mode where all communication is shifted to the UWB-radio. Although this further limits the UWB link budget, it allows operation in environments where 2.45 GHz operation might be unwanted or prohibited.

MAC-layer: TDMA Scheme

The omlox air-interface originally got designed with industrial use-cases in mind that require a solid level of robustness, reliability and a deterministic behavior. Therefore, the omlox Core Zone v2 Specification defines crucial MAC layer features, mainly how satellites and tags share the UWB medium as well as several localization techniques that can be simultaneously deployed.

Figure 6: Typical use-cases in an industrial setting covering asset tracking, automated booking and navigation

The omlox Core Zone v2 Specification introduces a **block-based time-division multiple access (TDMA)** scheme whereas time is divided into **slots** of 0.833 ms. In a slot only one specific device (i.e., satellite or tag) is allowed to transmit, thus avoiding collisions. A **ranging round** consists of 150 such slots. Each ranging round takes 125 ms, hence 8 ranging rounds (making up a so-called **ranging block**) fit in one second, allowing self-location with an update rate of up to 8 Hz and tracking with even higher maximum update rates.

Each omlox ranging round (amending the IEEE 802.15.4z ranging round structure) consists of three consecutive phases:

1. An **extended Ranging Control Phase (xRCP)** of 16 slots assigned to **controller** satellites that sequentially propagate synchronization signals across the network
2. An **Initiation Phase** of 32 slots assigned to satellites that transmit downlink ranging messages to tags
3. A **Response Phase** of 102 slots assigned to tags, to transit uplink ranging messages

Beforementioned xRCP extends the IEEE 802.15.4z Ranging Control Phase from just a single to 16 controller slots, which allows multiple controller satellites to co-exist in a synchronous way. Slots can be reused, hence assigned to multiple devices, if they are sufficiently distant to each-other. This concept delivers the basis for a non-zonal, scalable yet synchronous satellite network.

MAC- and upper Layers: Locating Techniques

Whereas the initial version of the omlox Core Zone Specification only defined two locating techniques, version 2 of the standard now features four locating techniques that can be simultaneously deployed by an omlox satellite infrastructure. For each tag one of the following locating technologies is chosen:

- **Two Way Ranging (TWR):** Subsequent handshakes between a tag and several satellites allows the computation of a position based on a time-of-flight principle. This mode is highly precise, but energy-hungry and has limited scalability in terms of number of simultaneously tracked tags.
- **Uplink Time Difference of Arrival (UL-TDoA)**: A highly energy-efficient tag now and then sends a blink that is received by surrounding satellites. Since satellites are synchronized, they can calculate the tag position based on the time difference of arrival.
- **Reconstructed Time of Flight (RToF)**: This energy optimized Two Way Ranging mode is based on a single handshake between a tag and one satellite that is also received and processed by other surrounding satellites. Since satellites are synchronized, they can calculate (reconstruct) the time of flight between all satellites.
- **Downlink Time Difference of Arrival (DL-TDoA)**: To support an unlimited number of mobile devices, this tag-centric **GPS-like**-mode only uses downlink signals from satellites to tags. Based on signals and known positions of several satellites, the tags can calculate their position themselves.

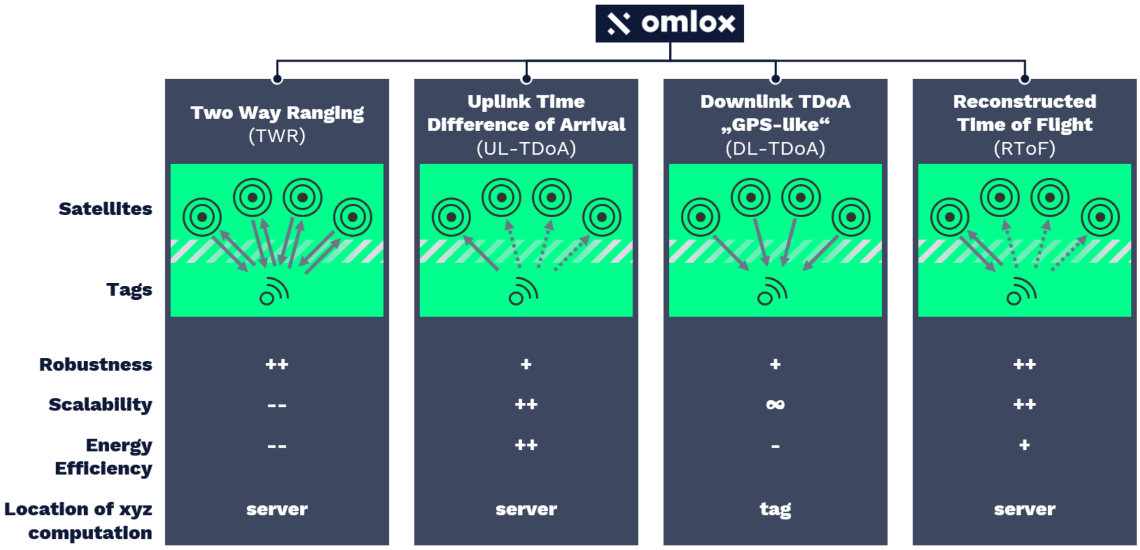

Figure 7: Locating techniques that can be simultaneously deployed by an omlox-compliant satellite infrastructure

Instead of choosing a specific locating technique for an RTLS, the simultaneous nature of omlox locating techniques allows to deploy various use-cases at the same time, e.g., stored assets being tracked for inventory now-and-then via UL-TDoA, a forklift self-locating at high update rate via DL-TDoA and an order in motion being seamlessly tracked via RToF.

Further Features and the Way towards your omlox-Offering

The up mentioned features are only a glimpse into the omlox Core Zone v2 Specification, which further defines features like:

- **Correction mechanism** for a robust and scalable synchronization of the satellite infrastructure
- **Contention access periods** allowing unslotted, hence indeterministic transmission phases for tags that are used by highly energy-efficient long-life tags
- **Battery-powered satellite mode** that allows flexible and lower-cost extension to achieve high satellite density for GPS-like locating mode

The specification got defined and will be further enhanced by a working group within the omlox ecosystem. If you are interested to contribute, feel-free to join the omlox community within PROFIBUS & PROFINET International (PI)! Both, the omlox Core Zone v2 Specification as well as the omlox Hub specification can be accessed, used and implemented by everyone, whereas omlox-compliant Products must pass a certification procedure that ensures conformance and hence interoperability

If you are interested in using, integrating or complementing your offering with omlox-compliant RTLS functionality, **TRUMPF Tracking Technologies GmbH** or **ZIGPOS GmbH** are happy to support you.

About TRUMPF Tracking Technologies GmbH

TRUMPF Tracking Technologies is a global player in the implementation of locating software. As the initiator of the open locating standard omlox, we are an active driver in a large and constantly growing ecosystem. We are the first and leading enabler for system integrators and infrastructure providers, supporting them as they enhance their offering using flexible omlox-based real-time locating solutions. Our ultra-wideband-based RTLS delivers centimeter-level precision and is optimized for scalability, flexible deployment and robust operation in industry and beyond.

Franz Lehmann, CTO, TRUMPF Tracking Technologies GmbH

Before joining TRUMPF Tracking Technologies, Franz initiated and established TRUMPF's corporate venture capital unit, investing in various startups, now resulting in a portfolio of more than 15 companies. Franz has a background as strategy consultant for international projects (in particular digitalization and growth strategies) at McKinsey. In addition to a German computer science degree and a French engineering degree, he holds an MBA from the Collège des Ingénieurs.

About ZIGPOS GmbH

Founded in 2011, ZIGPOS is a leading pioneer in the RTLS market. We started as university spin-off and became an expert in real-time locating solutions based on various short-range communication technologies, such as UWB, BLE, WiFi and RFID. We are a trusted supplier of a diverse international customer base, spanning automotive OEMs, hospitals, semiconductor manufacturers and many others. As a partner of Qorvo since 2017, a member of the UWB Alliance and active driver in the open locating standard omlox, we have become an integral part in the ever-growing ecosystem.

Erik Mademann, CEO, ZIGPOS GmbH

Erik shapes ZIGPOS as a co-founder and CEO since its inception in 2011, when he got inspired from his participation in the largest EU funded R&D project on UWB. Erik, together with his colleague and co-founder Christoph Götze, was involved in technology and product development, production as well as product management and now focusses on business and company development. Erik holds a German engineering degree from the Dresden University of Applied Sciences.

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TRUMPF

TRUMPF Tracking Technologies GmbH
Johann-Dornierstraße 12
71254 Ditzingen
Germany

ZIGPOS

ZIGPOS GmbH
Räcknitzhöhe 35a
01217 Dresden
Germany