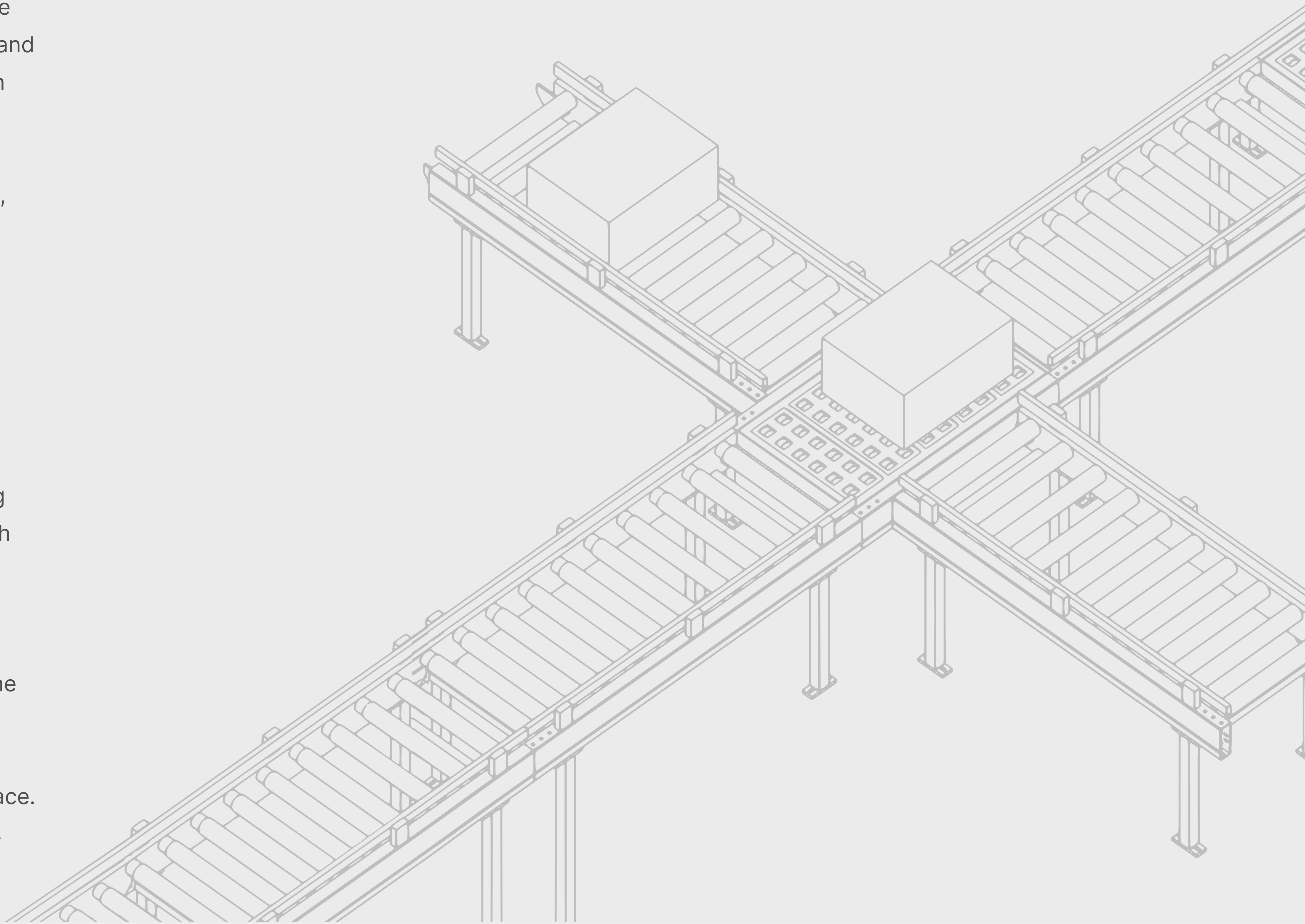
SILICON LABS

Exploring the Capabilities of IO-Link Wireless

Introduction to IO-Link Wireless

IO-Link Wireless (IOLW) [1, 2] is an industrial-grade wireless technology capable of providing reliable and low-latency communication for factory automation applications. In contrast to other short range communication standards such as Bluetooth Low Energy (LE), Zigbee, Wireless HART, and ISA100.11, IOLW guarantees a low W-cycle (wireless cycle) error rate of 10^{-9} with a communication latency of 5 ms, which makes it a wireless solution whose performance is similar to a wired communication. This makes the wireless standard suitable for many closed-loop control applications in factories as a cable replacement technology. For example, wireless solutions are ideal for use cases requiring communication with moving or rotating items, such as robotic control, and with items on a conveyer belt, such as an assembly line. In such scenarios, establishing a communication using legacy wired IO-Link interface (IEC 61131-9) can be cumbersome and expensive. IOLW addresses this issue by maintaining cable-grade latency and reliability performance metrics while using a wireless interface. The following section provides an overview of this wireless standard.



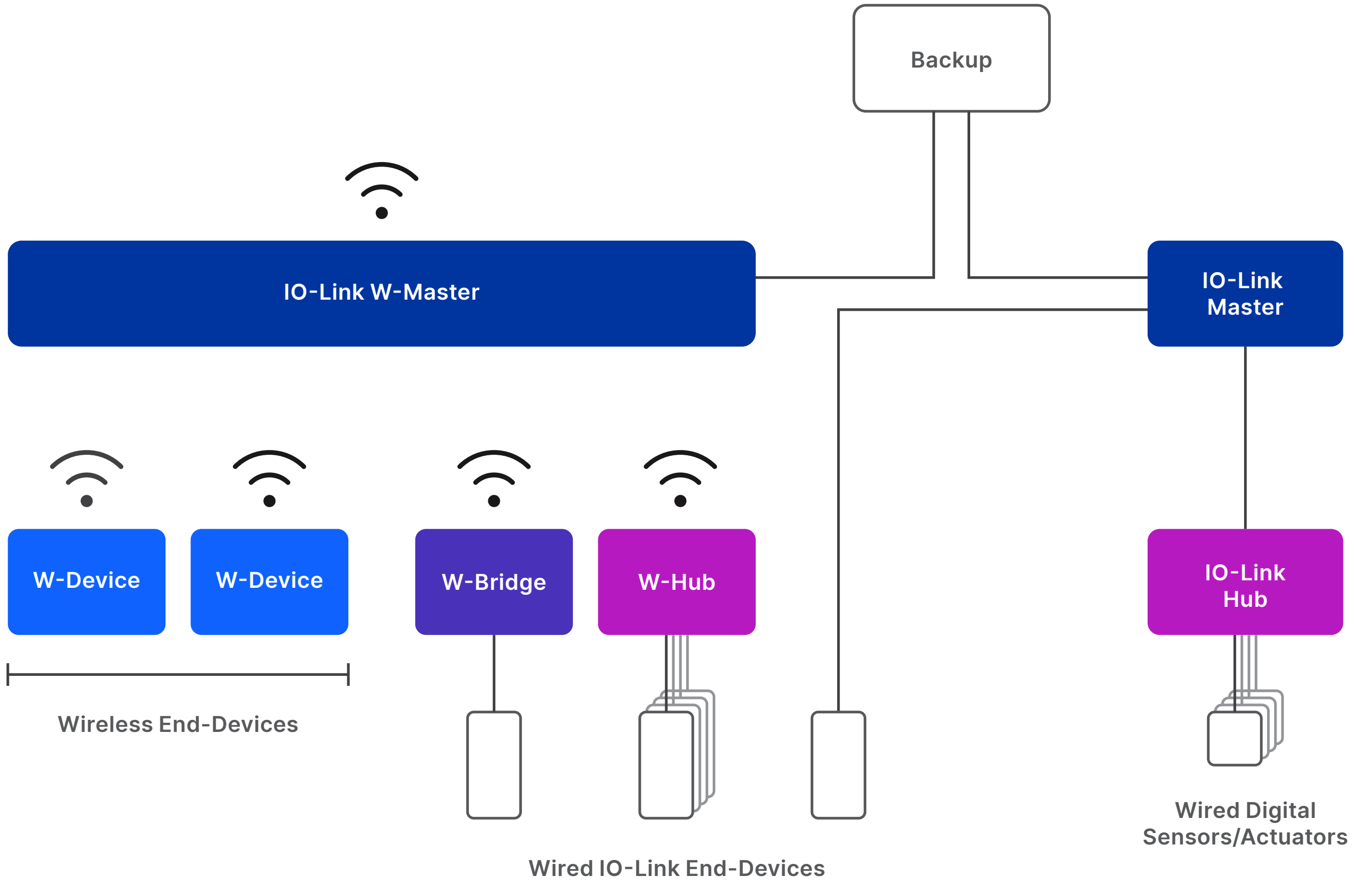


Figure 1
IO-Link Wireless Device Type

IO-Link Wireless Technology Overview

An IO-Link Wireless system, shown in Figure 1, consists of the following devices:

W-Master

A device that interfaces with the backend infrastructure (Fieldbus or Ethernet) via a wired connection and provides radio interfaces – called tracks – to communicate with end-devices.

W-Device

A wireless end-device, usually a line-powered sensor or actuator. Battery-powered operation is also feasible, although IOLW is not optimized to provide long battery life.

W-Bridge

Connects to a single wired IO-Link device to add wireless as a retrofitting option. IOLW is backward compatible with the wired IO-Link standard.

W-Hub

Connects to multiple wired IO-Link devices and enables them all to interact with the IOLW system. While this device is not standards specified, some solution providers offer this to support backward compatibility.

IOLW uses star topology to minimize latency by preventing multi-hop routing. A W-Master can support up to five radio front ends, each supporting eight wireless connections with clients such as W-devices, W-bridges, or W-hubs. To meet the performance guarantees, the standard limits the transmission range to 20 m if a single radio track is used but is reduced to 10 m when multiple radio tracks are to be supported. To improve scalability, the standard allows installing up to 3 W-Masters within a transmission range, resulting in a network density of 120 wireless clients within a transmission cell.

OSI Network Stack

IOLW operates in the 2.4 GHz ISM-band similar to Wi-Fi, Bluetooth, and several other protocols. Figure 3 shows the channel map, including the various protocols operating in the 2.4 GHz spectrum, where IOLW specifies eighty 1 MHz wide RF channels in the 2.401-2.480 GHz frequency range. The wireless standard currently specifies a maximum of 10 dBm transmit power to conform with FCC 15.247 and EN 300328 specifications. IOLW device implementations use an 802.15.1 radio PHY with Gaussian Frequency Shift Keying (GFSK) modulation scheme and a modulation index of 0.5.

To achieve industrial-grade reliability and latency over the wireless medium, IOLW defines a combination of frequency- and time-division multiple access schemes (F/TDMA). The protocol uses frequency hopping to minimize the effects of channel-selective fading and shadowing, as well as interference from other 2.4 GHz RF devices.

The hopping sequence is pre-determined by the W-Master and shared with the peer W-devices during commissioning. The used frequencies can be manually configured to avoid certain RF channels that are known to be congested. In addition, IOLW also offers the option to let the W-Master adaptively adjust the hopping sequence.

Application / Application Support	Compatible with IO-Link base IEC-61131-9
Transport Layer	Cyclic data: Process Data On-Demand data: ISDU, Events, Commands
Network Layer	TDMA W-Cycles TDMA combined with FDMA (F/TDMA); Acks and 3-times retransmission within 5ms frame; Multicast downlink, dedicated slots for uplink
Data Link Layer	
Physical Layer	802.15.1 (2005) PHY; 1MHz spacing, GFSK mi=0.5 10dBm

Figure 2
IO-Link Wireless Communication Stack

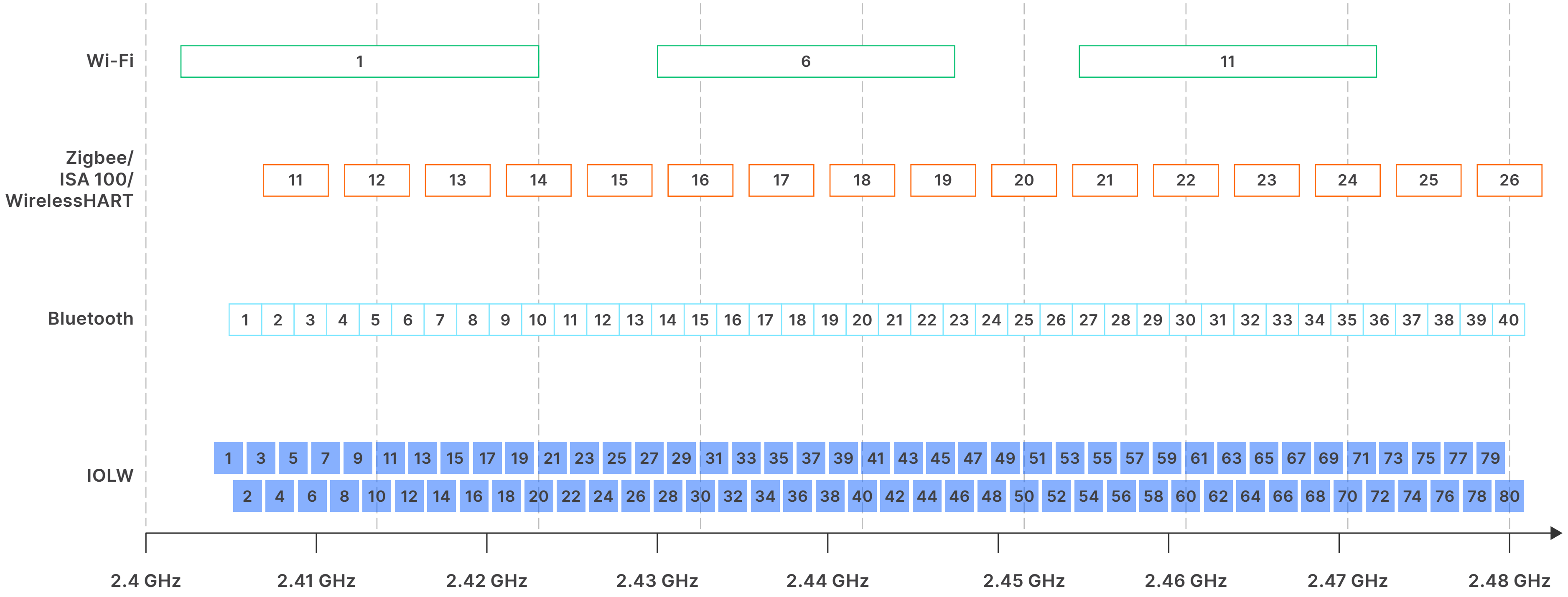


Figure 3
RF Channel Map of the 2.4 GHz ISM Band

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The TDMA scheme guarantees a deterministic communication between the W-devices and W-Masters by allocating dedicated time slots for each device. Communication takes place in 5 ms-long W-Cycles, each equally subdivided into 3 W-Sub-Cycles of 1.664 ms length. Let's consider the W-Cycle shown in Figure 4. Here, each W-Sub-Cycle starts with a frequency hop that is synchronized among the participating devices, followed by a downlink message broadcast by the W-Master.

After the broadcast, the W-Master performs a radio state switch from Transmit to Receive mode and listens for communication from the 8 W-devices during their allocated time slots, which are numbered 0 through 7 in Figure 4. Both downlink and uplink messages are acknowledged by the receiver. If the acknowledgement fails, the remaining W-Sub-Cycles are used to retransmit the message over different frequencies. This improves the success rate of reception while also ensuring the communication latency is within 5 ms.

To implement the F/TDMA scheme of IOLW, the radio needs to support the timing requirements for a fast and deterministic state switching and frequency hopping. As shown in Figure 4, only 208 μs is available for the radio to switch from transmit to receive mode and vice versa. Moreover, in case of the receive to transmit switching event (RX2TX) at the start of the W-Sub-Cycle, this duration also includes the time it takes for the device to perform channel hopping and packetizing the data.

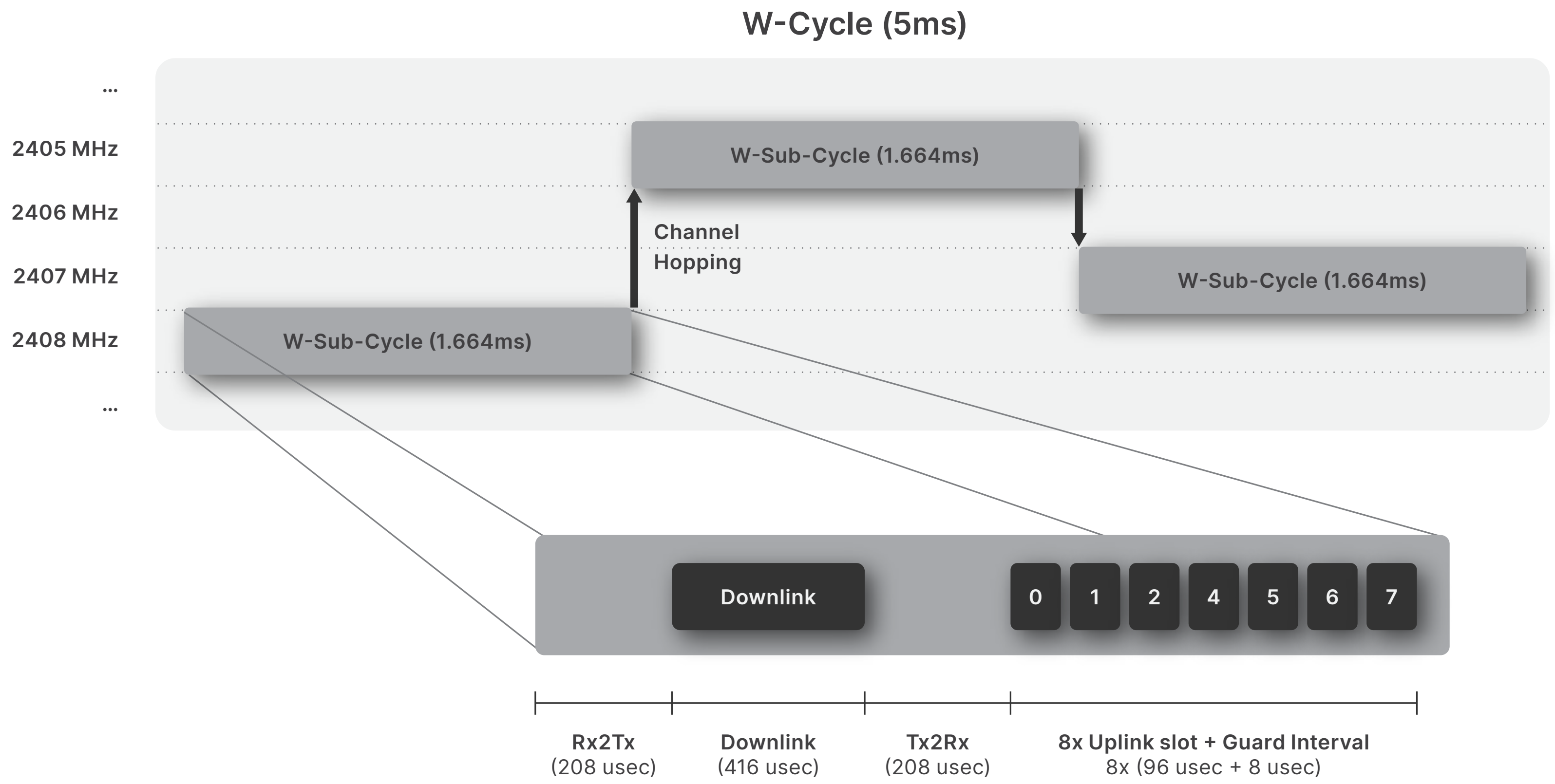


Figure 4
F/TDMA Scheme of IO-Link Wireless

Silicon Labs EFR32 SoCs for IOLW

Silicon Labs products, such as EFR32FG13 [3] and EFR32xG24 [4] devices, achieve RF channel and radio state switching times that fulfill the timing requirements of IOLW. The SoC supports accurately configuring and validating timing parameters within an actual implementation as explained in the referred knowledge article [5]. In addition to featuring a hardware that supports such fast-switching time, Silicon Labs also provides a clean and easy to use programming framework. The RAIL library is the closest interface to the hardware level, available for programming EFR32 radios, while the Flex Software SDK enables simple and structured implementation.

IOLW is demanding on other parameters of the radio receiver as well. The low W-cycle (wireless cycle) error rate target of 10^{-9} has been widely analyzed using both analytical and simulation approaches [6]. These simulations show that IOLW requires the receiver sensitivity to be -94.5 dBm or better to achieve such W-cycle (wireless cycle) error rate performance.

Currently, Silicon Lab radio SoCs, such as the EFR32xG24, offer a sensitivity of -97.6 dBm in 1 Mbps GFSK mode, making it suitable for a robust implementation of the IOLW protocol.

Battery-powered wireless solutions often call for power-optimized implementations. To this end, Silicon Labs SoCs have very low current consumption in the active, sleep, and radio communication states. For example, EFR32xG24 has an active current consumption of 33.3 µA/MHz, sleep current of 1.3 µA with a 16 kB RAM retention, receive current of 7.0 mA, and transmit current of 7.8 mA at 0 dBm output power. With such current profile, the SoC achieves an average current consumption of 2.89 mA.

Application Layer and Value Stack

From a data rate point of view, the IOLW standard supports 32 data bytes in the downlink connection and 2 bytes in the uplink connection, which results in a transmission rate of 51.2 kbps and 3.2 kbps on the downlink and uplink connections, respectively. For applications with higher uplink throughput requirement, IOLW supports merging two consecutive slots to allow payload data of 14 bytes, thereby achieving 22.4 kbps uplink speed.

Since IOLW is backwards compatible with legacy IO-Link devices, different data types are defined in the application layer to support this and are stated below:

Process Data refers to time-critical data. Therefore, transmission is always attempted in the first W-Sub-Cycle. Process data can be sent in both downlink and uplink connections and must be acknowledged by the receiver. If the acknowledgement fails, automatic retransmissions are performed during the subsequent W-Sub-Cycles.

Indexed Service Data Unit (ISDU) refers to the on-demand data accessible by specifying a 16-bit address. This data type includes standard and equipment-specific data elements which can be read or written by the W-Master.

Event Codes are transmitted on-demand without polling and are used for diagnostic purposes.

Master Commands are used for administration purposes, such as transmitting the frequency hopping sequence.

The IOLW standard specifies wireless communication protocol, application data transfer, and basic commissioning process. Further service-level elements of the end-to-end implementation shall be defined and provided by either the device manufacturer or solution integrator.

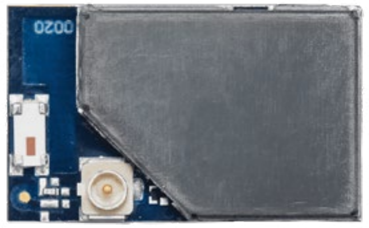


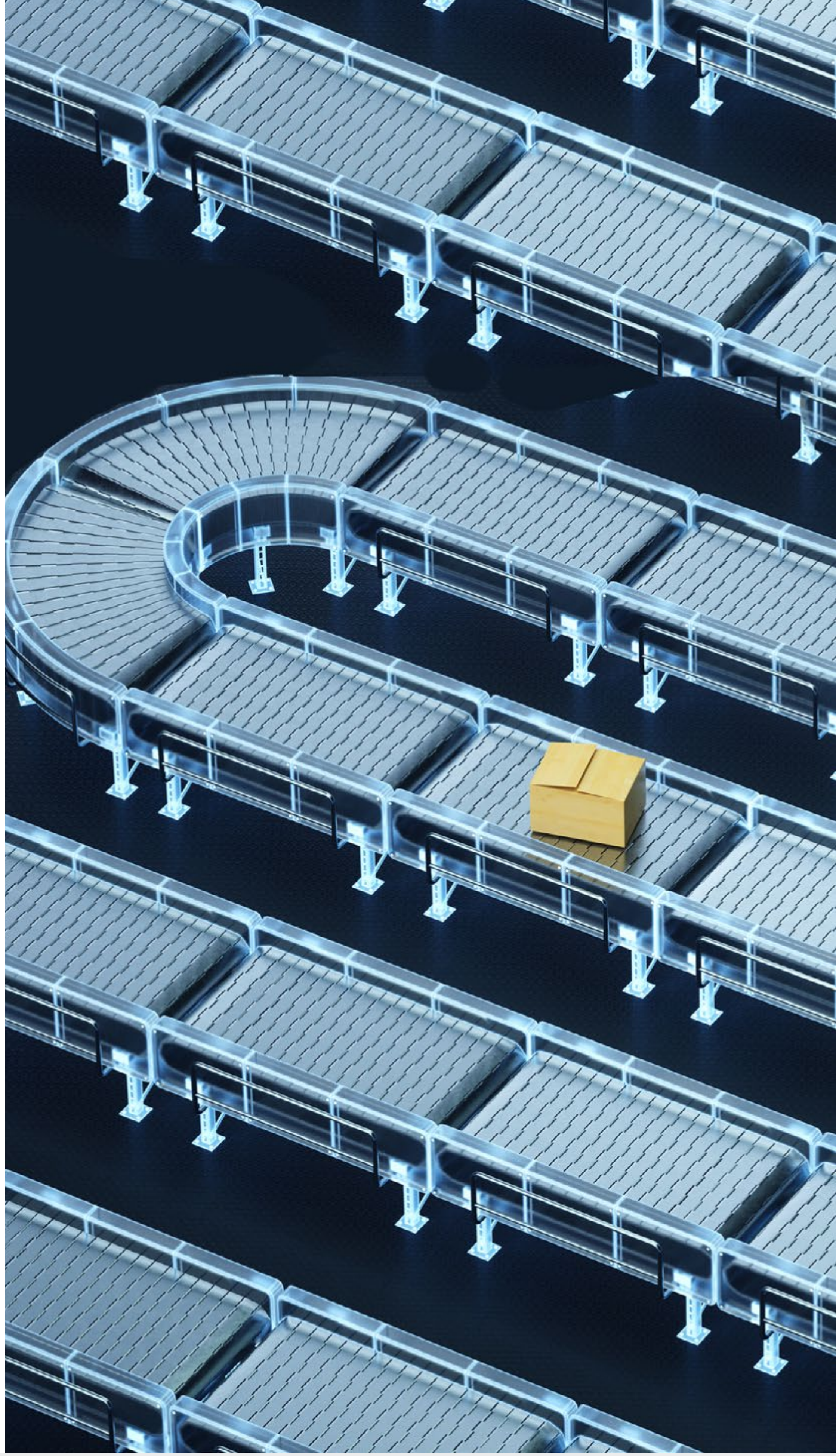
Figure 5
TigoAir 2 System on Module

Existing IOLW Solution in the Market

Silicon Lab's customer, CoreTigo [7], offers all elements of a full IOLW system, such as TigoMaster, TigoAir, TigoHub, TigoBridge, and TigoEngine. TigoAir is a System-on-Module (SoM) solution offered with a pre-implemented IOLW stack. TigoAir 2 [8], shown in Figure 5, is a small form factor W-Device implementation and a fully integrated and certified IOLW module that uses the Silicon Labs EFR32FG13 2.4 GHz SoC. The module enables IOLW integration into industrial end-devices, such as sensors and actuators, and supports using either the integrated antenna or an external antenna using the U.FL connector.

CoreTigo also offers a browser-based TigoEngine software tool that allows users to easily commission and monitor IOLW devices, as well as make network configuration changes, channel blocklisting, performance monitoring, over-the-air firmware updates, etc. Moreover, for seamless cloud connectivity and integration, the tool allows decoding process data and publishing it in a meaningful format over MQTT protocol, which simplifies the implementation for end customers.

Beyond IOLW capabilities, Silicon Labs also offers PSA level 3 certified SoCs that offer protection against a wide range of physical and remote attacks. In addition, the SoCs support a wide range of hardware accelerators for security, DSP, and Machine Learning-based edge computing applications. Finally, multiprotocol solutions can be built with EFR32MG24, supporting combined and flexible solutions with its 2.4 GHz radio.



Summary for IO-Link Wireless Implementation

IO-Link Wireless is a widely accepted industrial grade standard that provides reliable and low latency communication for closed loop factory automation applications, such as robotics. With a 5 ms communication latency and a cable grade 10^{-9} W-cycle (wireless cycle) error rate, the standard addresses the key limitations of other wireless communication protocols in this application space. Moreover, being an operational technology, deployment of IOLW does not fall under IT policies. To this end, Silicon Labs offers 2.4 GHz wireless SoCs such as EFR32FG13 and EFR2xG24, which feature rapid channel and radio state switching times and industry-leading sensitivity figures that make it suitable for IOLW implementation.

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