Enabling wireless communications for factory automation in Industry 4.0

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Industry 4.0 is all about communication and data exchange. With all levels of factory automation already being well connected, from the field level up to the enterprise level, the focus now shifts to solutions that can enable additional applications and surpass the restrictions that exist when using wires.

Mobile sensors are essential to enable smart factories; for example if a footwear company offers customized products, its manufacturing line must adjust dynamically to accommodate the parameters of a custom order received through the internet. With a wireless connection, sensors and actuators will not restrict any movement necessary for these adjustments, nor create any hazards with surplus cables.

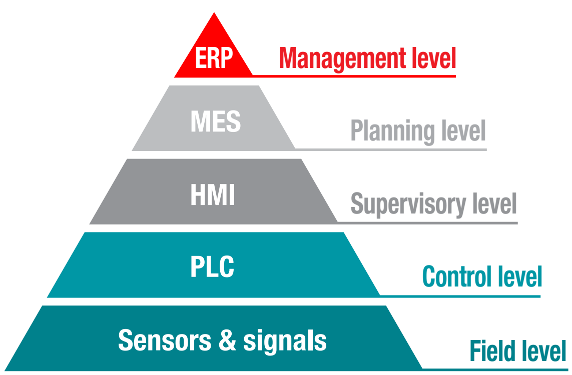

Figure 1. *Factory automation pyramid.*

Or imagine an automotive assembly line where wirelessly connected sensors follow the chassis through different manufacturing stages for hundreds of meters in order to guarantee precise and efficient assembly.

Now picture a technician exchanging a pressure sensor that is nearing the end of its life. Wireless communication makes this simply a job of physically removing the old one and attaching the new sensor without re-cabling entire machines. Imagine how much longer the exchange would take if cables were involved, keeping in mind that a minute of downtime in the automotive industry costs $22,000 per minute on average [1].

In this white paper, I will show the natural evolution of industrial communications toward wireless technologies, address how these technologies solve challenges created by the use of cables and explain how the IO-Link wireless protocol addresses lingering reservations.

Wireless communications: a natural evolution in industrial applications

The traditional method of communication with industrial nodes, in factory as well as in process automation, is a 4 to 20 mA current loop transmitting a single signal. As the number of sensors used to monitor and control production in these environments increases, the technologies interacting with these sensors had to transport more information through a limited amount of wires. Especially the need to remotely configure nodes and continuously monitor machines made the restrictions of current loops more obvious.

The Highway Addressable Remote Transducer (HART) protocol, developed in the 1980s, was the first technology designed to retrofit existing current loop transducers with digital communication.

	IO-Link Wireless	IO-Link	Bluetooth® Low Energy	Wireless HART
Topology	Star	Star	Star/mesh	Mesh
Maximum number of devices	120	N/A	—	250
Roaming	Yes	No	No	No
Communication distance	10 m	20 m	100 m	225 m
Data rate	1000 kbps	230 kbps	1000 kbps	250 kbps
Latency	5 ms	Depending on communication path	5 ms	60 ms
Reliability (packet error rate)	10^{-9}	10^{-9}	10^{-3}	10^{-9}
Security	Pairing	N/A	Pairing and encryption	Authentication, authorization attack detection
Infrastructure re-use	Re-using existing IO-Link infrastructure	N/A	N/A	Re-using existing HART infra-structure

***Table 1.** Communication technology comparison.*

Because HART uses the same cabling, it can achieve theoretical communication distances beyond 1,000 m [2]; however, HART communication is limited to 16 devices on the bus. In 2007, 37 HART Communications Foundation companies published the **Wireless HART** communication standard, covering distances up to 225 m [3]. Because each node can act as repeater, even farther distances are possible. While in theory a single Wireless HART network can contain as many as 250 devices [4], the standard's use of time division multiple access (TDMA) means that throughput scales with the number of active devices.

Unlike mesh-based approaches, wired **IO-Link** provides low-speed point-to-point serial communication for ranges up to 20 m. Its standardized interface [5] enables interoperability between devices of different manufacturers.

IO-Link Wireless extends wired IO-Link technology with a cable-less communication path that is able to fulfill the requirements of industrial applications, including robustness, determinism and latency. To provide an overview over IO-Link wireless' capabilities, **Table 1** compares the protocol with the wired IO-link variant, with the process automation focused wireless HART and the widely known Bluetooth® Low Energy.

Wireless technologies solve challenges inherent to cables

The highest impact on the productivity of a manufacturing line is arguably **downtime** [6]. Cables attached to the moving parts of any equipment, like robotic arms, experience a lot of stress, not only on the wires but also on the connectors, causing the devices to fail rather frequently. On new installations the first set of cables typically needs to be replaced after only three months, causing downtime and additional maintenance and material costs. Because wireless technologies have no cables, there is no issue associated with cable replacement.

In many scenarios, more than one node is attached to a machine. I/O hubs provided for wired technologies support up to 16 devices. In such installations, beyond the effort to set up the machines, the planning effort as well as the actual wiring cost is significant.

Depending on the application, engineers also struggle with the **available space**. Sometimes it is not possible to add another sensor because there is no room for more cabling. This restriction limits the achievable designs on complex setups. Using wireless connections to communicate with nodes helps to reduce the number of cables - or eliminates them completely - in cases where battery use or energy harvesting is an option.

As factories become more dynamic, modular and smart, the **range limitations** imposed by cables become a more pressing topic. Wires prevent the ability to manually move equipment, have machinery follow the manufacturing line, or employ completely autonomous units to roam the factory floor and return to a home location for charging. These tasks are also a challenge for radius-restricted wireless technologies. IO-Link wireless takes inspiration from mobile phone networks – roaming capability - and integrates it seamlessly in its own infrastructure. A device roaming the manufacturing plant is able to connect to different masters (**Figure 2**) and with that provides the impression of a consistent connection to the higher automation layers.

The same approach IO-Link wireless uses for discovering new nodes and pairing is used for roaming as well. Every master monitors the link quality (functionality and reliability) for all devices connected to it. Based on the number of not acknowledged down- or uplink transmissions within the last 3000 packets the link quality is calculated. If it drops under a threshold as the node is moving out of its range, the master initiates a sequence to disconnect that device and communicates this action to the higher layer, the programmable logic controller (PLC). Once the PLC receives a notification from another master about the same device showing up in its range, the handover is complete. Having the PLC as a common point for both masters participating in the roaming handshake eliminates the need for complex implementations within the IO-Link wireless stack.

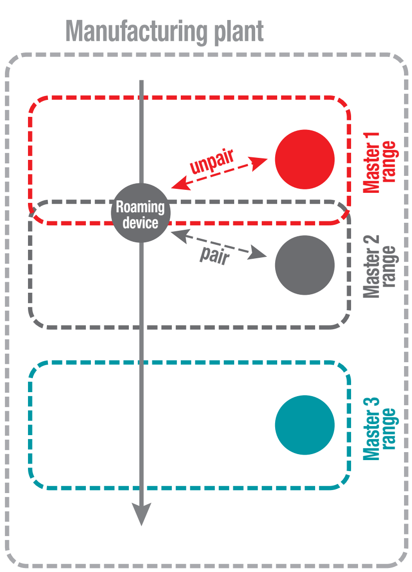

Figure 2. *IO-Link wireless roaming.*

Removing the cables not only helps to prevent downtime; it also enables a cleaner and sturdier production setup. Cables and their connectors can become contaminated easily, and in industries like medical or food processing require regular sanitation. The same issue exists in **harsh environments**, where strong chemicals can affect cable performance or integrity. The typical solution for scenarios like wash-down areas or soldering stations is to use specialized cabling at an increased cost. Plus, because the original issues related to stress caused by movement still persists, replacing specialized cables is more expensive and requires increased maintenance, leading to longer downtimes.

IO-Link wireless addresses reservations about using wireless technologies

Despite all of the benefits that wireless connections have on the field level, there are some reservations; radio links feel less reliable. What about interference from other machines or other wireless communications? How are wireless nodes powered without a cable?

IO-Link wireless is capable of resolving concerns about wireless communication path **robustness**. The goal when designing the technology was to achieve similar characteristics on key parameters compared to a wired connection (such as packet error rate $< 10^{-9}$). Gaussian frequency shifted keying (GFSK) is used to work around challenges such as crosstalk or fading channels that arise when the industrial-scientific-medical band (ISM) is split into 1 MHz channels (**Figure 3**).

This modulation, also implemented with Bluetooth, ensures a data rate of 1 Mbps. Despite the use of

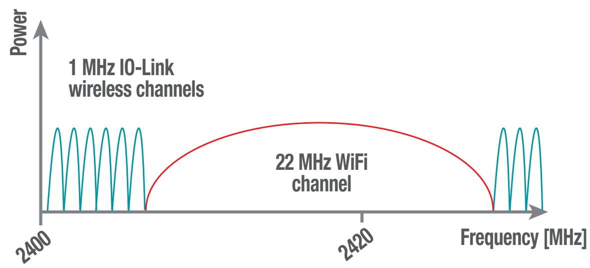

Figure 3. *Co-existence IO-Link wireless & WiFi on the ISM band.*

the heavily deployed, license-free ISM band (2.4 GHz), using a combination of TDMA and frequency division multiple access (FDMA) along with a retransmission mechanism (**Figure 4**) does provide a reliable wireless connection.

A maximum 5 ms cycle time to communicate with any device (regardless of the number of nodes) provides the determinism required for reliable planning and setup. An IO-Link wireless node needs to be able to fit three sub-cycles into those 5 ms cycle. Re-sending the data twice enables the IO-Link wireless protocol to guarantee a packet error rate smaller than 10^{-9}. By splitting the ISM frequency band into five different tracks, each supporting as many as eight devices, one master can reliably support up tp 40 devices with a cycle time of 5 ms.

Without further restrictions IO-Link wireless will use all available channels across the ISM band.

To enable other wireless technologies (such as Bluetooth or Wi-Fi) to **co-exist** on the same frequencies, IO-Link wireless offers a blacklist mechanism that prevents masters from communicating on those channels. The blacklist is transmitted to the nodes by the master during pairing and contains 1-MHz-wide sub-bands not to be used. By the IO-Link wireless standard, the first and the last pair of sub-bands are dedicated to configuration and thus not available for any other communication. While the blacklist mechanism is intended to coordinate different overlapping masters, the same method also ensures co-existence.

Cutting the last cord - the power line – requires operational **energy efficiency** in order to maintain battery life for an acceptable amount of time. IO-Link wireless considers this aspect in the protocol [7], starting with the GFSK modulation which allows the use of energy-efficient power amplifiers. Because communication features enable devices to identify themselves as low power, the master will allow the device's radio to go into a full power-down state while the device is processing received data, saving additional energy.

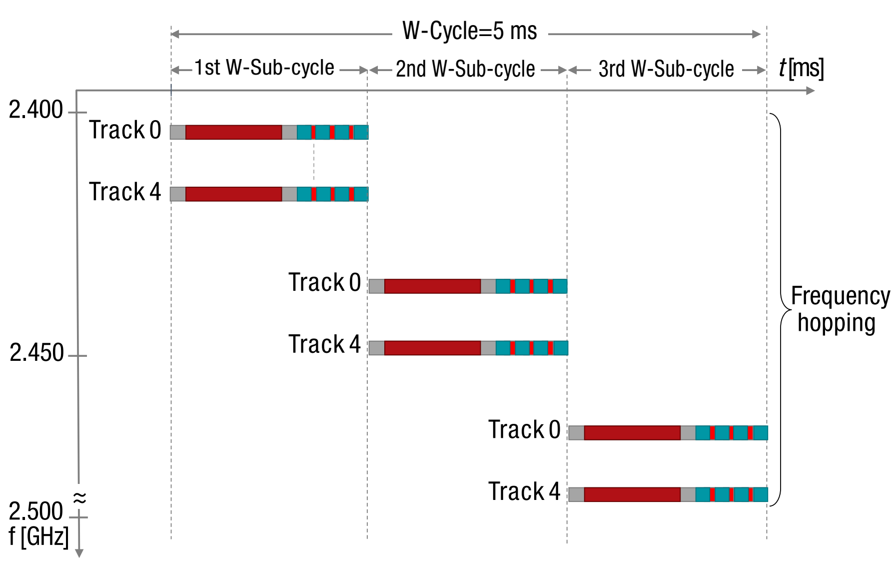

Figure 4. *Retransmission mechanism utilizing several tracks.*

Conclusion

The majority of installations in the industrial world today are still connected with wires. Smarter and more dynamic applications in the factory environment are limited by this and need to look for other solutions enabling for example dynamically adjusting manufacturing lines or automated guided carts (AGCs). IO-Link wireless fulfills the requirements factory automation demands from a wireless communication standard in terms of robustness and performance. With **TI's pre-certified module CC2650MODA and Kunbus' development toolkits** reliable, industrial equipment based on IO-Link wireless can already be created.

Resources:

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3. Abbott, Craig. "**Broadcast Range of WirelessHART Transmitters,**" Emerson Automation Experts blog, Jan. 16, 2014.

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5. IO-Link Consortium, "**IO-Link Interface and System Specification,**" July 2013.

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