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Machine-to-Machine Communication

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Although wireless communication is integral to our daily lives, there are numerous crucial questions related to coverage, energy consumption, reliability, and security when it comes to industrial deployment. Michael Weyrich, Jan-Philipp Schmidt, and I provide an overview of wireless machine-to-machine (M2M) technologies. I look forward to hearing from both readers and prospective column authors about this column and the technologies you want to know more about. —*Christof Ebert*

IMAGINE A WIDESPREAD manufacturing plant equipped with smart machinery and RFID-enabled technology. All machines are interconnected and communicate through their sensors and actuators as they work their way through the manufacturing process. Operators use wireless pads and connect to production systems for diagnostics and manufacturing oversight. Machine load, status, and diagnosis data are further aggregated in enterprise systems for resource planning and production optimization. The machines receive usage feedback to adjust production schemes and therefore optimize cost and quality. The machines also communicate with their own manufacturers to request repairs or order new parts to avoid costly outages. Agent-based systems allocate load to machines in a distributed, often global, production setup to optimize supply-chain cost.

Future fantasy? No, this is a growing reality in what we call the smart factory. The smart factory of the future is far more agile than the approaches in today's flexible manufacturing. The smart factory connects the machines, devices, logistics, and humans to perform the necessary coordination ubiquitously and ad hoc.

The same concepts that seamlessly connect various devices in the field with management and enterprise IT apply not only to automation and production industries. For instance, we've already introduced the machine-to-machine (M2M) approach in transport, such as for vehicle diagnosis or for connecting vehicles with information systems. The same is true for healthcare with implanted devices or aerospace for global parts tracking. For consistency, we'll stick with M2M communication in the smart factory in this article, but we invite you to apply it in your own industry.

Machine to Machine

The future smart factory and supply chains need ubiquitous communication among a plethora of production units, services, diagnoses, handheld devices, and enterprise systems in the push to

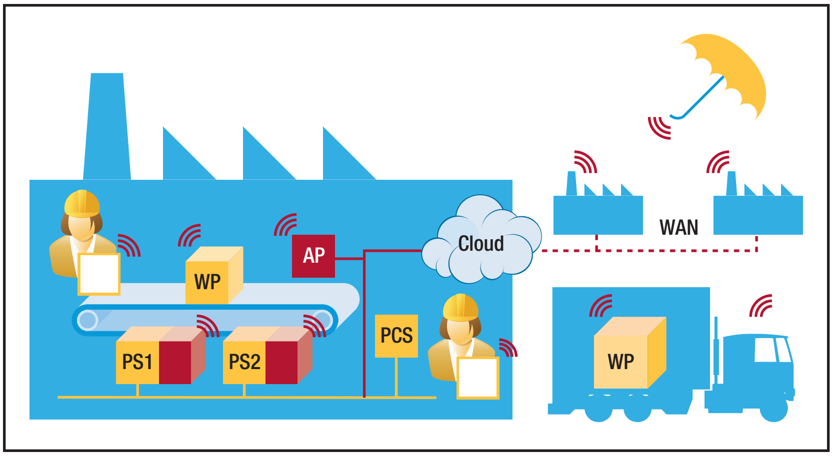

FIGURE 1. Communication in a smart factory. The work pieces and processing stations are equipped with advanced wireless communication to allow the tracking of material at any time. In this way, the materials navigate intelligently. (PS: processing station; WP: work piece; PCS: process control system; AP: access point; and WAN: wide area network.)

design, manufacture, and service goods. This is fairly obvious to most forward-looking engineers, but reality shows that the exploding number of often ad hoc connected sensors, controllers, and actuators is creating swarms of devices that are difficult to organize in an industrial network.

For a smart factory to prevail, communication technologies will need to efficiently connect machinery over varying distances in a flexible manner with high security, robustness, and availability at a low cost. One option is self-organizing logistics, but logistics becomes difficult once the number of product variants increases and production volumes fluctuate. The risk of supplier shortages or errors in the supply chain intensifies with complexity. M2M communication provides a solution by registering and tracking material, pallets, trucks, and so on.

M2M connects production and automation with enterprise IT. The Organization for Economic Cooperation and Development (OECD) estimates that there were roughly 2 billion M2M devices globally in 2013. Communication suppliers such as Cisco and Ericsson estimate that by 2020, 100 billion devices will communicate M2M. Assuming low-cost communicating technology embedded in components, this number could skyrocket even higher. Forrester Research and others see the current global sales volume of M2M as close to US$10 billion with an expected $50 billion by 2020. Again, that's a rather conservative estimate that's amazing to see.

Wired technologies have matured over the years and are widely used in M2M communication. However, they're rather static in their setup, depending on a wiring scheme that's costly to change. They also feature demanding infrastructures and topologies that are well designed without knowing future demand. Cables play a key role in today's communication, but their continued use is questionable for future needs.

Wireless M2M communication is slowly entering the production process. RFID and WLAN technologies are cost-effective and seamless to install and operate on a global basis, but clearly don't yet fully address the industry production needs of all possible applications. Engineers from domains such automation, automotive, transport, and medical all face the same questions when engineering a new automation project: Which wireless technologies are available to fulfill what type of demands from which applications? What are the criteria for choosing among the different wireless technologies on the market today? Which technologies are easy and cost-effective to engineer, build, and operate?

As a case in point, smart factories can use new organizational approaches due to advanced communication technology. Consider Figure 1, in which each device relevant to manufacturing is equipped with individual communication facilities. In the future, each product and its components and parts will carry communication tags, and those elements of production and logistics will remain traceable and manageable even in the event of unforeseen circumstances, such as rerouting. Shortages and supply mistakes will be quickly rectified, and machine diagnostics easily performed and resolved. Without wireless M2M communication, such an evolution isn't feasible.

Wired or Wireless?

Networks can be both wired and wireless, but wireless M2M protocols are increasingly used because they're convenient to install, use, maintain, and enhance. Today, there's no single M2M interface serving as a global standard. Interfaces between machines depend on the industry segment—for instance, the automotive industry has area controller networks (CANs) inside cars, and the energy industry has its M-Bus to remotely read meters. Standards definition is increasingly dominated by alliances of IT suppliers due to the high economic relevance of seamlessly connected devices. Google's acquisition of Nest Labs shows the relevance of connecting consumer products and classic IT.

Wired M2M technology is widely applied today due to its robustness and availability, which are demanded in critical environments where security or explosive hazards must be considered. When such constraints don't apply, wireless technology can reduce deployment cost, provide access to remote or difficult locations, and has the advantage of not involving cabling. The biggest advantage is ubiquity: with wireless M2M, the position and status of anything processed in the factory is known at every stage and can be seamlessly connected to ERP and other enterprise-level IT environments.

To ascertain a wireless technology's suitability, you need to know the characteristics of the different offerings. Today, the physical transport layer is based on ISM bands: 2.4 GHz, 5 GHz, and 868 MHz. Various standards are available, such as IEEE 802.11 for wireless LAN, IEEE 802.15.1 for WPAN/Bluetooth, or IEEE 802.15.4 for low-rate wireless private area networks (PANs). Unfortunately, there's still the very real problem of similar-frequency bands overlapping with each other, partially blocking frequencies or causing disturbances.

Obviously, M2M communication needs more than a discussion about standards for the physical and data link layers. New protocol stacks support wireless network technologies and protocols for communication with low bandwidth or limited memory consumption (http://postscapes.com/internet-of-things-protocols). The Internet of Things also has strong requirements for the address space in devices and the way messages are communicated.

Seamless M2M communication will boost innovation such as smart factories and networked cars.

IPv6 has facilitated M2M communication by resolving the address space problem but with only a small percent of data used for the M2M application and the rest dedicated to message overheads, IPv6 isn't efficient for energy-constrained applications.

To counteract this, several energy-efficient wireless M2M protocols are available. Message Queue Telemetry Transport (MQTT; www.mqtt.org) is a simple and lightweight messaging protocol designed for constrained devices and low-bandwidth, high-latency networks with low reliability needs. Invented in 1999, it is currently undergoing standardization at the Organization for the Advancement of Structured Information Standards (OASIS). The Constrained Application Protocol (CoAP), another energy-efficient protocol used to communicate interactively over the Internet, translates HTTP for sensors and switches, thereby facilitating machine connectivity to the Internet of Things with low overheads. The Data Distribution Service (DDS) protocol is a specific M2M middleware that provides real-time, dependable, high-performance communication between machines.

The Path Forward

Moving beyond mere protocols, we can find several industry-ready wireless technologies that vary in coverage, data rate, and usage. Wireless product solutions are usually based on IEEE standards but are increasingly defining additional specifications and providing product qualification programs, certification, and promotion.

Table 1 gives an overview of today's most relevant wireless technologies. It highlights nine current technologies for wireless M2M, along with a typical use case (including commercial availability of devices), encoding features for providing secure communication (range, throughput, and infrastructure), efficiency, chip size, integration effort to add devices into networks, cost, and scaling potential.

Key decision drivers for the choice of products include investments for hardware, costs, and speed to adjust and extend a network and integrate new devices. However, additional requirements also affect the final choice: energy efficiency, chip size, and security.

For instance, if a wide area wireless connection is required to interconnect vehicles for diagnosis,

TABLE 1

Table 1. Overview of wireless technologies.

	Use cases	Sector	Range	Through-put	Infrastructure needs	Efficiency	Chip size
LTE	Wireless communication for mobiles and data terminals	IT and communication	10 km	150 Mbit/s	Complex infrastructure from provider	High	Small
WLAN	Wider Internet access	Multiple sectors	100 m	600 Mbit/s	Router, access points	High	Medium
Bluetooth	Product interface	Consumer	100 m	706.25 kbits/s	No special infrastructure, point to point (p2p)	Low	Small
ZigBee	Device control	Consumer and industrial equipment	100 m	250 kbit/s	Access points	Low	Large
Wireless HART	Sensors and actuators	Process, industry	250 m	2 measurement	HART gateway to the fieldbus	High	Large
Industrial WLAN	Sensors and actuators	Process, industry	100 m	450 Mbits/s	Access points, gateways to the fieldbus	High	Large
EnOcean	Energy harvesting, smart homes	Building, automation	30 m	125 kB/s	Transceiver modules	Very low	Large
RFID	Non-contact identification and tracing	Many industries	6 m	100 kbit/s	Tags, scanner	Very low	Very small
NFC	Radio communication	Smartphones	10 cm	424 kbits/s	Smartphones, tags	Very low	Very small

	Integration effort	Cost	Scaling potential	Encoding	Market Readiness	URL
LTE	High	Low	Low	AES128	Mature for wide usage	www.3gpp.org/technologies/keywords-acronyms/98-lte
WLAN	Very high	Low	High	WPA2	Mature for wide usage	www.radio-electronics.com/info/wireless/wi-fi/ieee-802-11n.php
Bluetooth	Low	Low	High	AES128	Mature for wide usage	www.bluetooth.com/Pages/what-is-bluetooth-technology.aspx
ZigBee	High	High	High	AES128	Mature for wide usage	www.zigbee.org/About/AboutTechnology/Standards.aspx
Wireless HART	Low	High	Low	AES128	Niche markets	www.hartcomm.org/protocol/training/training_resources_wihart.html
Industrial WLAN	Very high	High	High	WPA2	Niche markets	https://a248.e.akamai.net/cache.automation.siemens.com/dnl/TM/TM0MTMzAAAA_90880063_HB/22681042_Aufbau_IWLAN_DOKU_V30_en.pdf
EnOcean	High	Low	Medium	ARC4 or AES	Certain sectors	www.enocean.com/fileadmin/redaktion/pdf/articles/perpetuum_radio_standards_en.pdf
RFID	Low	Low	Low	Not required	Mature for wide usage	www.rfid-journal.de/rfid-technik.html
NFC	Low	Low	Low	Not required	Upcoming	www.nfc24.info

vehicle ad hoc network, and fleet management, LTE is the technology of choice. It offers reasonable coverage in many regions.

However, WLAN and ZigBee would be the choice for service technicians in industry using mobile access devices. Both networks provide a high data rate, don't need centralized communication infrastructures and overhead, are secure, and can be provided with reasonable coverage in manufacturing sites. NanoLOC, a technology for tracking objects based on the ZigBee standard, is suitable to detect work pieces in widespread industrial production sites.

Some other use cases require low-range object identification or near-field communication (NFC). RFID is an established technology for identifying objects such as work pieces; NFC can help exchange data between objects in close proximity.

Many special interest groups have emerged around wireless M2M technology and the attempts to use it to evolve and promote product solutions. Bluetooth has an interest group of more than 20,000 companies, and the ZigBee Alliance hosts a thriving global ecosystem of businesses, universities, and government agencies to grow that particular standard and a solution space with products around it.

The HART Communication Foundation and products such as Industrial-WLAN are more focused on the industrial automation application fields. Once a wired HART or Profinet infrastructure is available, Wireless-HART or Industrial-WLAN make sense in terms of compatibility: existing industrial wired infrastructures can be connected easily, especially remote sensors or diagnostics that are difficult to access. The EnOcean Alliance provides applications with low power and energy harvesting needs, and EnOcean-enabled switches can be powered by batteries or harvested energy because the transmitters have very low power consumption.

A critical success factor of M2M protocols is their energy-efficiency. Batteries are certainly not a first choice as they need service and are ecologically damaging. For example, Bluetooth and ZigBee provide several energy-safe modes when no communication between master and slave is necessary. Moreover, RFID tags can be activated with transducers, before data can be written and read, thus boosting energy efficiency.

With the rapid progress toward applications with ad-hoc connected devices, seamless M2M communication will boost innovation such as smart factories and networked cars. Our entire engineering environment will change based on these new ways to interconnect devices, machines, and products, starting with production and covering the entire product life cycle. Smart factories and big data have ignited some sparks, but the fire of seamless ubiquitous communication will grow faster and bigger than what we can imagine with today's manually installed communication systems.

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