

# Reliable, Low Power Wireless Sensor Networks for the Internet of Things: Making Wireless Sensors as Accessible as Web Servers

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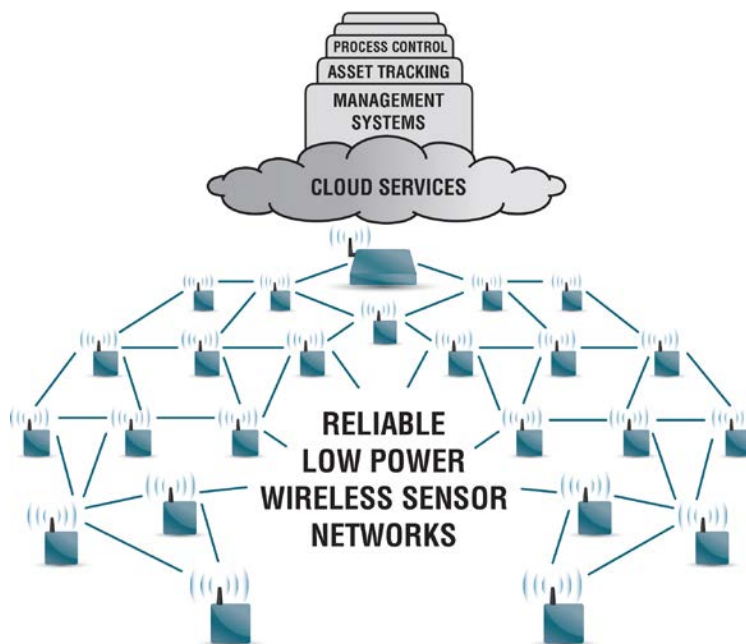
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The Internet of Things revolution is upon us, and by the year 2020, there will be over 50 billion connected things in the world. With the world’s population increasing and resources becoming more precious, this interconnection promises to supply real-world data to drive higher efficiencies and to streamline business practices.

With the wide acceptance of Internet Protocol (IP), it is becoming easier to process data and make meaningful use of information. Fortune 500 companies provide enterprise-level database solutions for data storage and software tools to streamline business processes, such as asset tracking, process control systems, and building management systems (see Figure 1). Smart phones and

tablets provide people with useful and actionable information, such as live parking information or real-time machine health monitoring to inform maintenance schedules. And, while there are wireless sensors in place today, there is a hunger for more sensor data to measure and optimize processes that have not been previously measured.



**Figure 1. Making IP-Enabled Wireless Sensors Reliable and Low Power Will Enable Widespread Usage**

To further enable wide scale deployment of sensors, IP standards efforts are underway, with the goal of making small wireless sensors as easy to access as web servers. These efforts are the confluence of two driving forces: the proven low power, highly reliable performance of time-synchronized mesh networks, and the ongoing IP standards efforts for seamless integration into the Internet. Together these forces will drive relatively small, low power sensors that communicate reliably and are IP-enabled.

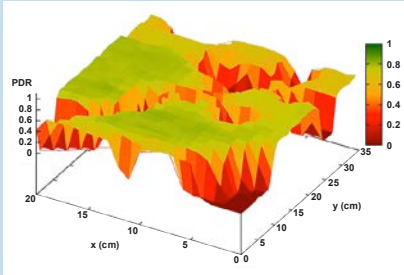
## Wireless Sensor Network Challenges

Since wireless is unreliable by nature, it is important to understand the sources of unreliability to be able to account for them in communication systems. In low power wireless networks, the main sources of unreliability are external interference and multipath fading. Interference occurs when an external signal (e.g., Wi-Fi) temporarily prevents two radios from communicating. This requires them to retransmit, hence, to consume more power. Multipath fading happens when a wireless signal bounces off objects in the vicinity of the transmitter, and the various echoes destructively interfere at the receiver’s antenna. This phenomenon is a function of the position of the devices, the frequency used and the surrounding environment. Because the surrounding environment of any wireless system changes over time, any single RF frequency channel will experience problems over the operational life of a wireless system.<sup>1</sup>

<sup>1</sup> See the accompanying sidebar article, The Effects of Multipath Fading on Wireless Communications

## The Effects of Multipath Fading on Wireless Communications

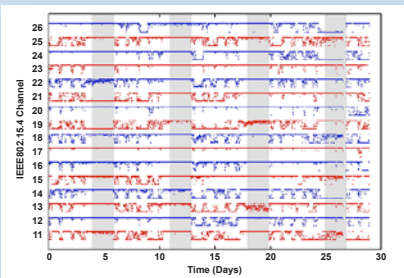
Multipath fading depends on the position and nature of every object in the environment, and is unpredictable in any practical setup. One good property is that the topography depicted in Figure A1 changes with the frequency. That is, if a packet is not received because of multipath fading, retransmitting on a different frequency has a high probability of succeeding.



**Figure A1. Multipath Fading Causes the Quality of a Link to Vary Dramatically, Even When Moving the Receiver by Only a Couple of Centimeters**

Because objects in the environment are not static, i.e., cars drive by and doors are opened and closed, the effect of multipath changes over time. Figure A2 shows the packet delivery ratio on a single wireless path between two industrial sensors over the course of 26 days, and for each of the 16 channels used by the system. There are weekly cycles where workdays and weekends are clearly visible. At any given time, some channels are good (high delivery), others bad, and still others highly varying. Channel 17, while generally good, has at least one period of zero delivery. Each path in the network shows qualitatively similar behavior, but unique channel performance, and there is never any one channel that is viable everywhere in the network.

Because of interference and multipath fading, the key to building a reliable wireless system is to exploit channel and path diversity.



**Figure A2. The Packet Delivery Ratio of a Wireless Link Evolves Over Time**

However, multipath fading is frequency-dependent. Therefore, while one frequency may be experiencing a problem, there will be several other RF frequency channels that work well. Because of interference and multipath fading, the key to building a reliable wireless system is to employ channel and path diversity without sacrificing low power operation. Such a system was pioneered by Dust Networks (now part of Linear Technology) with its time-synchronized, channel-hopping mesh networking.

## Time-Synchronized, Channel-Hopping Mesh Networks

In a time-synchronized, channel-hopping mesh network, all wireless nodes across a multihop network are synchronized to within a few tens of microseconds, and time is sliced into time slots. Communication is orchestrated by a schedule which indicates to each node what to do (transmit, receive, sleep) in each time slot. Because they are synchronized, each node switches on its radio only when communicating, thereby significantly reducing their radio duty cycle (<1% is commonplace) and increasing their battery lifetime. Furthermore, since the schedule is flexible, the network is always available to the application, unlike other “sleepy” network architectures

that completely shut down the network for extended periods of time. Each packet sent between two nodes is done so on a frequency calculated using a pseudo-random hopping pattern. The resulting frequency diversity is an effective way of combating interference and multipath fading. Time-synchronized mesh networks enable a decade of battery lifetime and >99.999% end-to-end reliability.

## Time-Synchronized Mesh Networking Successes

Time-synchronized, channel-hopping mesh networks have already been widely deployed for several years. Dust Networks introduced its first SmartMesh® system in 2004 and the industrial process industry was one of the earliest adopters.

Industrial applications have some of the harshest operating environments, yet have the most stringent demand for data integrity, which, when assured, significantly improves efficiency, productivity and safety of industrial plants. Because traditional wired industrial sensors are expensive to install, only a small fraction of potential measurement points in a plant are traditionally instrumented. While this creates significant demand for wireless in industrial applications, traditional point-to-point wireless systems lack the required



**Figure 2. Streetline Networks Has Deployed Time-Synchronized Channel Hopping Networks to Improve Parking in Such Cities as Hollywood, California.**

reliability and are difficult to install, limiting their use to small, isolated applications.

With the introduction of time-synchronized mesh networks, low power wireless systems that deliver the reliability normally associated with wired systems became a reality. Its standardization into the industrial standard, IEC62591 (also known as WirelessHART) established interoperability within the industrial process market. Most of the major industrial manufacturers, such as Emerson Process, Siemens, ABB, Endress & Hauser, Pepperl & Fuchs, and Phoenix Contact are shipping WirelessHART products. Today, SmartMesh networks have been widely accepted, with 30,000 networks deployed in over 120 countries around the world to improve safety and efficiency in a variety of locations, ranging from steel mills and refineries to remote oil fields and offshore platforms to food and beverage plants.<sup>2</sup>

Beyond the industrial process industry, SmartMesh systems have been successfully deployed in data centers and commercial buildings to optimize air conditioning costs.<sup>3</sup> Streetline Networks<sup>4</sup> is a smart parking provider that monitors the real-time availability of urban parking spaces (see Figure 2). Vehicle detectors are installed beneath parking spaces, inside the pavement and flush with the roadway. This brings challenges, as the antenna for the sensor device is located underground, and then covered by a metal vehicle when the space is occupied. Applications such as these, previously thought impossible or impractical, are being deployed with time-synchronized, channel-hopping mesh networks.

### A Standards-Based World

Standards play an important role in networking technology, with end users advocating the development of standards-based solutions. Knowing that a technology has been developed and approved by a major standards organization inspires confidence. And while WirelessHART/IEC62591 is the standard in industrial process, beyond that market, Internet Protocol (IP) is the communications standard.

All devices connected to the Internet use IP to communicate with each other. Each device

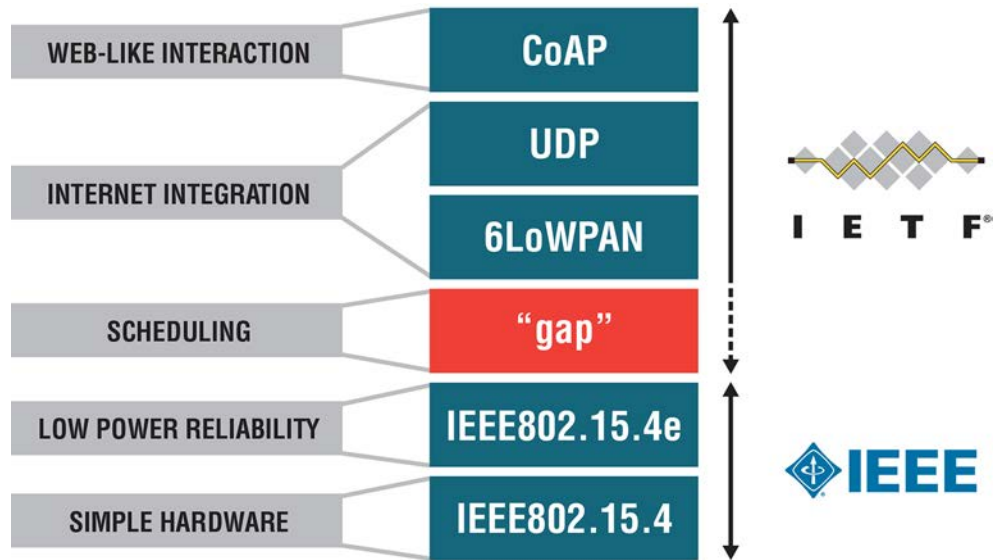


Figure 3. IP Protocol Stack for Low Power, Reliable Wireless Sensor Networks

acquires an IP address which unambiguously identifies it on the Internet. Data packets exchanged contain an IP header, a series of bytes that encode the addresses of the device that created the packet, and the destination device. Many other protocols are needed to form a protocol stack (TCP, HTTP, etc.), but the IP protocol is the common denominator. Allowing low power mesh networking devices to connect to the Internet using the IP protocol represented a major contribution toward development of the Internet of Things.

Several standardization bodies have developed standards for the Internet of Things (see Figure 3). The challenge is to enable full Internet integration, while incorporating the proven principles of time-synchronized, channel-hopping mesh networking. Within the Internet Engineering Task Force (IETF)—the standards body behind most protocols used in today’s Internet—the CoRE working group has defined the Constrained Application Protocol (CoAP) application layer protocol. CoAP runs on top of UDP (User Datagram Protocol) and is easily translated to HTTP for web-like interaction with wireless sensor nodes. The 6LoWPAN working group has defined an IP adaptation layer that compresses an IP packet’s large headers into small wireless frames or data packets, allowing sensor nodes to be individually addressable by IP addresses. While these upper layers enable web-like interaction and Internet integration, it is the protocol layers beneath them that

determine the quality of the wireless sensor network communications.

The standards developed by the IETF typically run on radio chips that comply with the IEEE802.15.4 standard. IEEE802.15.4 provides a healthy trade-off between data rate (250kbps), range (10s to 100s of meters), power consumption (5mA to 20mA when transmitting or receiving) and packet size (up to 127 bytes). This trade-off makes IEEE802.15.4 a good fit for low power mesh technology, and has therefore become the de facto link technology for those networks.

In 2012, the IEEE published a new medium access standard to run on IEEE802.15.4-compliant radios, known as IEEE802.15.4e. Its Time Slotted Channel Hopping (TSCH) mode incorporates principles from Dust Networks’ time-synchronized mesh protocol to enable precise time-slotted synchronization and RF channel hopping.

While IEEE802.15.4e defines the mechanism for two nodes to establish a synchronized data packet transfer, it does not define how each node is assigned a schedule. The communication schedule affords a TSCH network the flexibility to match the communication needs of the nodes in the network (see Figure 4). For example, a network can be configured for small networks with low data rates and extremely low power consumption, as is common in remote environmental monitoring. The same network can be configured

2 [www2.emersonprocess.com/en-US/plantweb/wireless/applications/Pages/Wireless-Applications.aspx](http://www2.emersonprocess.com/en-US/plantweb/wireless/applications/Pages/Wireless-Applications.aspx)

3 Vigilent: [www.linear.com/docs/41384](http://www.linear.com/docs/41384)

4 Streetline Networks: [www.linear.com/docs/41387](http://www.linear.com/docs/41387)



**Figure 4. Small TSCH-Based Wireless Nodes, Such as the LTP5901-IPM from Linear Technology, Deliver 5 to 10 Years of Battery Life With >99.999% Data Reliability**

as a large network, optimized for faster data throughput. In addition, an automatically assigned yet flexible schedule enables a TSCH network to adapt to the surrounding environment. Specifically, network functions such as self-healing, routing optimization and load balancing are enabled by scheduling and are critical to delivering high performance over the life of a network. Solutions for building and assigning the TSCH schedule can be developed, but until standards are established, such solutions will not be interoperable over the air.

This is, however, changing with a new standards activity inside the IETF known as IPv6 over the TSCH mode of IEEE802.15.4e.<sup>5</sup> (6TiSCH). Co-chaired by Linear Technology

and Cisco Systems, this activity will define the missing communication protocols to allow the TSCH schedule to be managed by a scheduling entity.

By closing this remaining gap in the IP protocol stack, 6TiSCH will enable fully standardized, interoperable IP-based wireless sensor networks that deliver the level of reliability typically associated with wires. Web developers will be able to request real-time sensor data by making web requests to the IP address of a sensor, and the underlying wireless sensor network will support such communications with >99.999% data reliability. By making sensors as easily accessed as web servers, wireless sensor networks will feed real-world information to the Internet of Things.

<sup>5</sup> <http://tools.ietf.org/wg/6tisch/>

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