

Zigbee

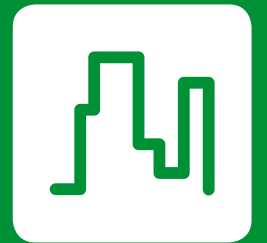
Setting Standards for Energy-Efficient
Control Networks



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The art of simplicity



Introduction

In 2005 Schneider Electric's Innovation Department began running tests to assess the performance of ZigBee, a ready-to-use wireless technology with ultra-low power consumption. The department's aim was to gauge Zigbee's performance in ensuring the continuous operation of machines and processes, while contributing to a greener environment – even in harsh industrial environments.

The cost-related and environmental gains became immediately apparent. Because it is wireless, it does away with accessory equipment, and makes no or low use of batteries. It saves energy and raw materials, while dramatically cutting installation and maintenance costs.

Schneider Electric believes that innovative, Zigbee-based solutions can bring about major advances in wireless networks in the home and industrial facilities. It is coming into its own in consumer electronic device control, energy management and efficiency, healthcare, telecom services, consumer, home and commercial building automation, and in industrial plant management.



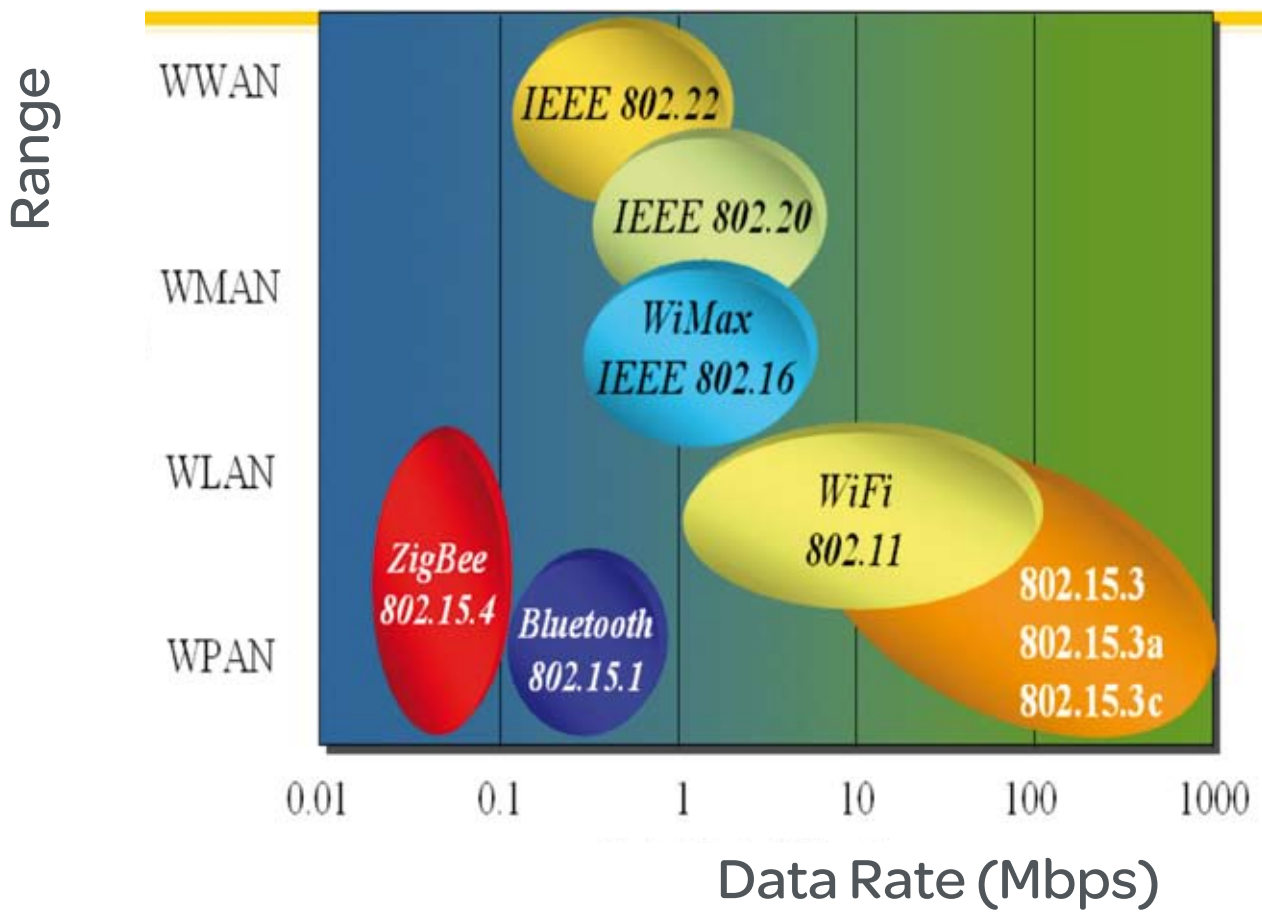
1 What is ZigBee?

ZigBee is a set of specifications created specifically for control and sensor networks. Built on IEEE 802.15.4, the standard for low data rate wireless personal area networks (WPANs), it was developed by the ZigBee Alliance. Formed in 2002, the Zigbee Alliance brings together public and private industry leaders who sought to address the need for a single standard that would ensure the interoperability of proprietary wireless sensors and control systems both with each other and newer technologies. Such systems require low latency, low data rates, low cost, and low energy consumption. IEEE standard 802.15.4, which defines the physical layer (PHY) and media access control (MAC) for low-rate WPANs, restricts the data rate to 250 kbps in the global 2.4-GHz Industrial, Scientific, Medical (ISM) band, while also specifying low power consumption and cost. Taking the low-level PHY and MAC layers as their base, the Zigbee Alliance developed Zigbee – the network protocol, security, and application layers for low-rate WPANs.

Since the ZigBee specification was released in 2006, it has developed to the point where it is now poised to become the global control/sensor network standard for a wide and varied range of residential, industrial, and commercial applications. It enables wireless two-way communications between commands and controls (e.g. boiler and thermostat), travels as far as 75-100 meters, and controls sensors that perform many different tasks. Residential and commercial applications include lighting controls, smoke and CO2 detectors, HVAC controls, home security, automatic utility meter readings, and communication between a remote control and a digital set-top box. And, with mobile telephone operators integrating ZigBee into phones and PDAs, consumers can use their cell phones as their single remote control device. In industry, examples are monitoring medical equipment, building and industrial automation, and environmental controls.

The secret of ZigBee's success is that it is fit to purpose. At 250 kbps, ZigBee's data rate is hundreds of times lower than WiFi's. But it does not need to be higher. An intrusion sensor, for example, does not need to transmit and receive much data. In fact, low data rates mean low power requirements. ZigBee's very low energy consumption (door opening sensors, for instance, can run for five years on an ordinary AAA battery) is an economic and ecological advantage. It is related to the way ZigBee networks work.

The 802 wireless space



2 How ZigBee Works

Function Devices

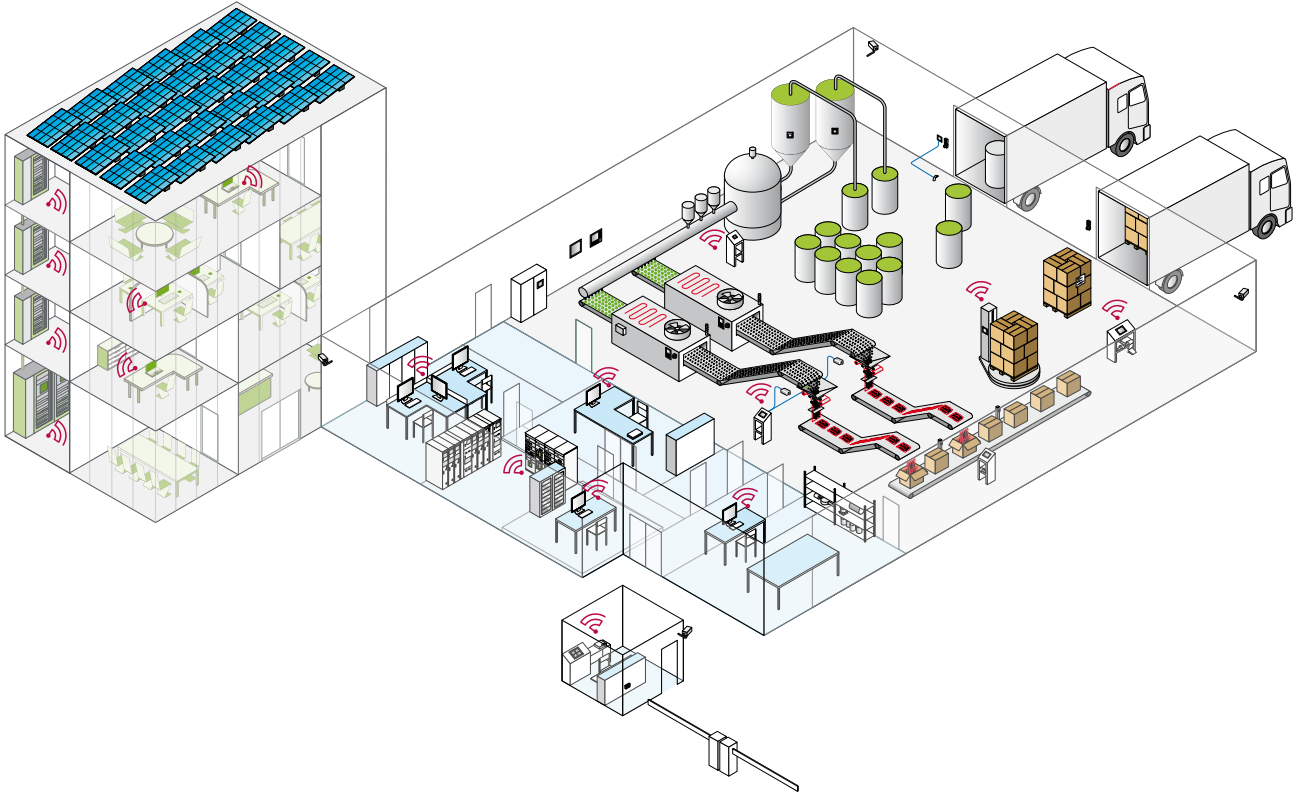
ZigBee and its underlying 802.15.4 standard provide networks with two kinds of devices – full function devices (FFDs) and reduced function devices (RFDs). All must have 64-bit IEEE addresses, although short 16-bit addresses can be allocated to reduce packet size. FFDs may be network coordinators or routers, while the endpoint devices that interact with the physical world are the RFDs. All ZigBee networks must have a coordinator. The coordinator sets up the network, is aware of all its constituent nodes, handles and stores information, acts as a repository for security keys, and manages the information transmitted and received within the network. Routers act as intermediaries, channelling information between devices. The endpoint devices have limited functionality in order to reduce system cost and complexity. They are also the cheapest devices to manufacture. They require limited memory and usually only interact with the physical world. They have just enough capability to talk to their parent nodes, be they the coordinator or routers.

Network Topologies

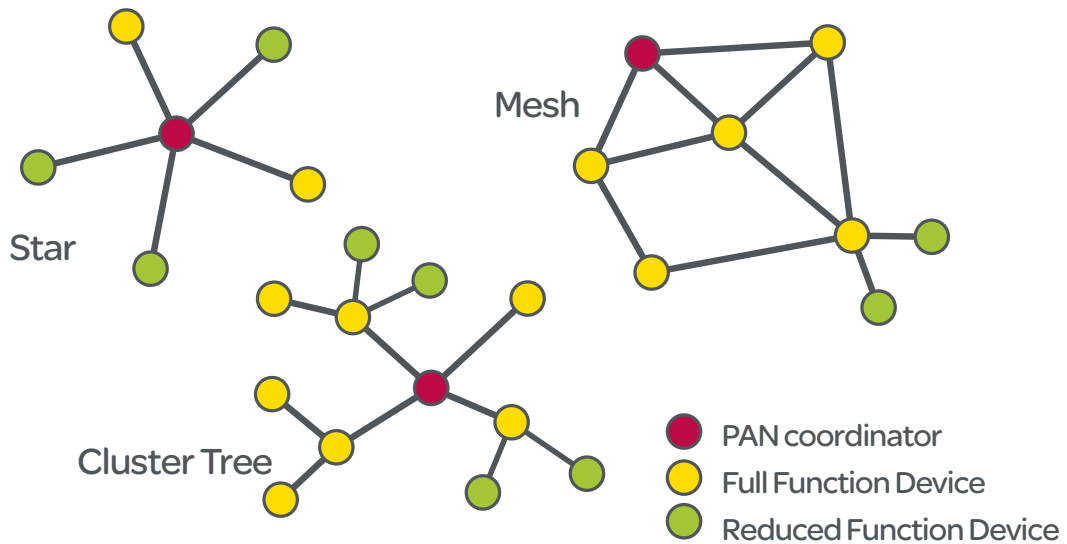
Although ZigBee supports several network topologies, the Zigbee Alliance states that the “core specification defines ZigBee’s smart, cost-effective and energy-efficient mesh network. It’s an innovative, self-configuring, self-healing system of redundant, low-cost, very low-power nodes.” In mesh networks each wireless node communicates with the one adjacent to it. Should one node fail, information is automatically rerouted to allow devices to go on communicating. This dynamic node link redundancy contributes to ZigBee’s low maintenance needs, reliability, and seeming “unstoppability”. Because of their rerouting capability, nodes on a ZigBee can “walk through” walls and even communicate with each other through a building’s floors. Furthermore, even when they cannot see each other, nodes are still able to set up networks.

The most common network configuration, however, is probably the star topology. It is particularly useful when endpoint nodes are closely clustered and communicate with a single router node. This arrangement enables individual client nodes to save battery power. Zigbee specifications also refer to the tree topology, where a single large network brings together several star networks.

Example of application



3 topologies defined in the IEE 802.15.4 standard Star, Cluster Tree, and Mesh.



3 Operating Modes and Low Power Consumption

To enable different kinds of two-way data traffic ZigBee operates in two main modes: non-beacon mode and beacon mode. The beacon mode is for battery-powered coordinators and so saves maximum energy, whereas the non-beacon mode serves mains-powered coordinators. In beacon-enabled networks, the coordinator periodically wakes up and sends beacons to the routers in its network. The beacons wake up other nodes to check whether there is any incoming message. If there is none, both the nodes and the coordinators go back to sleep. Beacon-oriented networks use guaranteed time slots – in other words, devices are active only when a beacon is being transmitted. The result? Shorter duty cycles and longer battery lives.

In non-beacon mode, some devices are always active and others sleep. The coordinator and routers' receivers do not sleep because any node can wake up and talk to it. Although the non-beacon mode requires a robust power supply (mains) and uses more energy, its overall power consumption is low because most of the network devices can remain inactive over long periods. In short, ZigBee devices are either awake or asleep. Its two modes may be set against Bluetooth's multiple modes, dictated by latency and power requirements – e.g. sniff, park, hold, active.

Listed below are three power consumption scenarios for a future home with 100 wireless control/sensor devices. They illustrate the savings ZigBee brings even when devices are mains powered.

- **Case 1 – WiFi:** 802.11 Rx power is 667mW (always on) @ 100 devices/home & 50,000 homes/city = 3.33 megawatts
- **Case 2 – Non-beacon:** 802.15.4 Rx power is 30mW (always on) @ 100 devices/home & 50,000 homes/city = 150 kilowatts
- **Case 3 – Beacon mode:** 802.15.4 power cycled at 1% (typical duty cycle) = 150 watts.

Even at full deployment ZigBee devices are incomparably more energy-efficient than earlier RF devices, WiFi and – as we shall see – Bluetooth. They save megawatts thanks to their ability to switch automatically to sleep mode. ZigBee-based radios sleep, waking up only to transmit and receive. As a result, battery-powered devices show very low duty cycles and power consumption. The same is true of RF-power-hungry devices in demanding industrial applications.

A Cirronet white paper points out that the power rating of an RF radio is “irrelevant” as energy is consumed only when it transmits. “In the case of Cirronet's ZigBee solutions, a radio with 100mW RF power will typically consume 150mA at 3.3V when transmitting, compared to 75mA at 3.3V for a radio with 1mW RF power. The 100mW radio consumes twice as much power – but only when actively transmitting ...

[P]ower consumption while sleeping is roughly equivalent to that of a low power radio.” Furthermore, the authors of the white paper go on to argue that ZigBee’s use of sleep mode delivers long battery life even for radios with high RF output ratings, making them “excellent candidates for use with battery-powered devices”.

ZigBee’s beacon and non-beacon operating modes can seamlessly manage different data types, whether periodic, intermittent, or repetitive low latency. Although “[e]ach of these traffic types mandates different attributes from ... IEEE802.15.4 MAC, the MAC is flexible enough to handle each of these types”. The beaconing system can manage periodic data like sensor data, whereas intermittent data (e.g. light switches) is handled in the beaconless mode. Intermittent data traffic can, however, also be managed in a disconnected way whereby a device joins the network only when it needs to communicate – an operating mode that, once again, saves significant amounts of energy. Low latency usage – typically, computer mice – make use of guaranteed time slots (GTS), whereby devices are active only when beacons are being transmitted.

Low Cost

Low cost for users is not only about lower power consumption. Other factors are low retail cost and low maintenance and installation costs.

The 802.15.4 PHY layer was designed precisely to ensure low cost and high levels of integration. Although ZigBee’s radio design principally uses digital circuitry it does include analog stages. However, the use of direct sequence CDMA results in very simple analog circuitry that lends itself to low-cost implementation.

As observed above, 802.15.4’s MAC enables multiple topologies that are not complex and have only two basic modes of operations. The result is low or no maintenance (particularly in residential fit-and-forget applications), while networks’ self-healing capability and node redundancy further dispenses with maintenance. The extensive use of RFDs – cheap to manufacture and maintain thanks to their inherent low functionality, low ROM and RAM – helps keeps cost down.

Further controlling cost is the ZigBee application layer. It was designed to let networks grow physically without the need for more powerful power transmitters, even when networks have very large numbers of nodes with low latency requirements.

In addition to low power consumption, the key factor in ZigBee’s low cost is, perhaps, its simplicity. By way of comparison, the number of layers in ZigBee’s protocol stack is four times less than in Bluetooth’s. Indeed, further comparison with Bluetooth can be a convenient way of highlighting some other ZigBee strong points.

Comparisons with Bluetooth

Because of its reliance on beacon-beaconless/active-sleep modes latency can be critical in ZigBee. When a ZigBee device is off, nothing runs except its clock – at 32kHz. Low latency – the time it takes the network to wake up and respond – is therefore imperative. ZigBee’s latency is 15 milliseconds, while Bluetooth’s is three seconds. ZigBee networks can consist of over 250 devices, while Bluetooth can support only eight. With ZigBee batteries can run for years, while Bluetooth has to be recharged as often as every day. Admittedly, ZigBee boasts less bandwidth than Bluetooth, but then it doesn’t need it.

Ultimately, comparison between ZigBee and Bluetooth is not itself a valuable exercise. Although they share the 2.4GHz frequency band and both are wireless technologies, they have little else in common. The difference in ranges – 75-100 metres for ZigBee, 10 for Bluetooth – is attributable to the very purposes for which they were designed. The same is true of ZigBee’s low data rate and transmission of small packet devices as against Bluetooth’s higher data rate (1Mbit) and transmission of large packet devices. Designed to replace cables in the home and office, connecting and synchronising computers, PDAs, etc., Bluetooth is a useful mobile technology. ZigBee focuses on large-scale automation and remote control.

In fact, it makes more practical sense to address ways in which the two technologies complement each other – possibly within the same LAM to meet an even wider range of applications.

Another, more legitimate, point of interest concerns another kind of wireless technology – WiFi – and whether ZigBee can coexist comfortably with it in the 2.4GHz frequency band.

ZigBee and other wireless technologies				
Market Name Standard	ZigBee™ 802.15.4	GSM/GPRS CDMA/1xRTT	Wi-Fi™ 802.11b	Bluetooth™ 802.15.1
Application Focus	Monitoring & Control	White Area Voice & Data	Web, Email, Video	Cable Replacement
System Resources	4KB - 32KB	16MB	1MB	16KB
Battery Life (days)	100 - 1,000	1 - 7	.5 - 5	1 - 7
Network Size	Unlimited	1	32	7
Bandwidth (KB/s)	20 - 250	124 - 68	11,000	720
Transmission Range (meters)	1 - 100	1,000	1 - 100	1 - 10
Success Metrics	Reliability, Power, Cost	Reach, Quality	Speed, Flexibility	Cost, Convenience

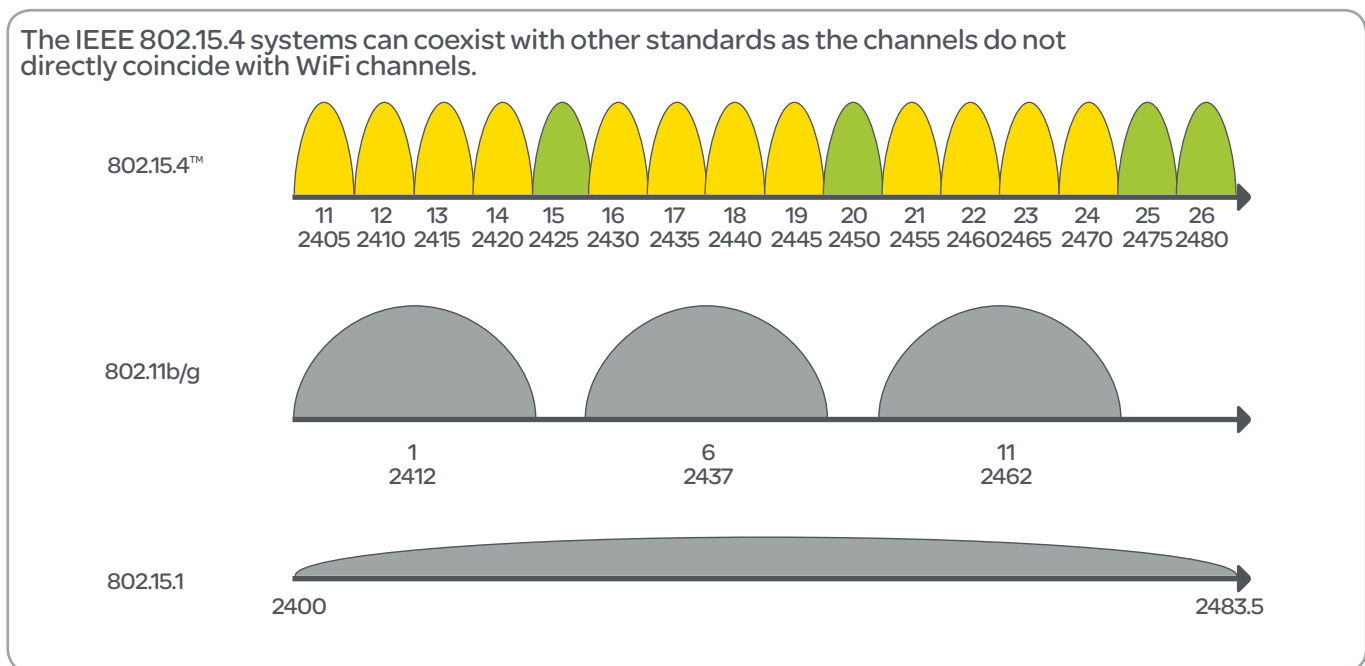
Coexistence with WiFi

The 2.4 GHz band, which ranges from 2400 MHz to 2483.5 MHz, is a worldwide band allocated to wireless LAN devices governed by IEEE 802 standards:

- **IEEE 802.11 – WiFi standard**
- **802.15.1 – Bluetooth**
- **802.15.4 – ZigBee.**

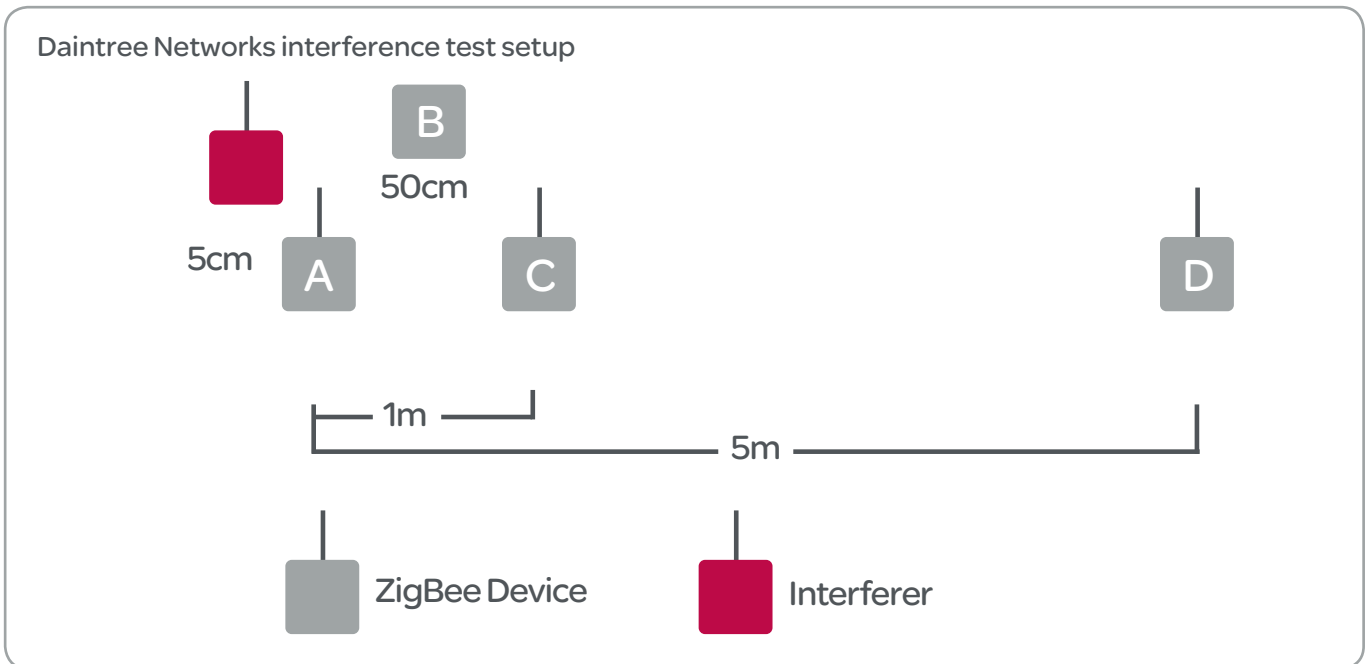
The three standards cover local area networks and metropolitan area networks carrying variably sized packets. They determine the number of channels that devices can use within the 2.4GHz band and at first sight they appear to coexist happily. ZigBee devices can access up to 16 different 5MHz channels (nos. 11-26) within the 2.4 GHz band, almost all of which do not overlap with channels used by 802.11 and WiFi. What's more, as considered above, ZigBee automatically retransmits data end-to-end in the event of interference. And even then, very little data is retransmitted. With its exclusive focus on sensors and controls, ZigBee should not be affected by similar wireless technologies with different purposes.

Yet concerns have been voiced that despite efforts made by standardisation bodies to ensure smooth coexistence, communication technologies transmitting at very different power levels could interfere with each other. Questions have in particular been raised over how WiFi might affect ZigBee when both are transmitting in the same channel with WiFi transmissions taking place at a much higher power rating.



Schneider Electric's Innovation Department addressed the issue of interference in a series of measurements in real-world and laboratory test environments in 2005 and 2006. The first set of measurements used first-generation ZigBee chipsets, which obviously presented inferior RF performance characteristics to today's.

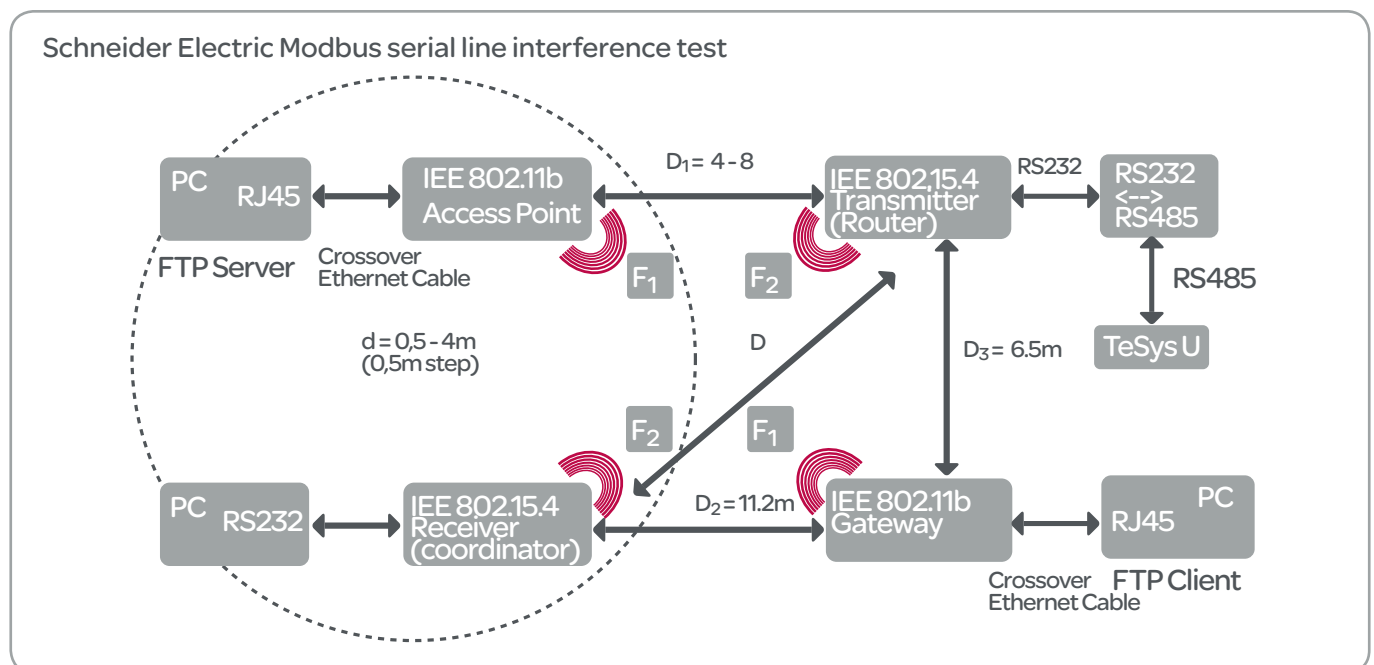
The first test was a physical characterisation test to evaluate how much interference IEEE 802.15.4's PHY layer could tolerate from IEEE 802.11b transceiver interference. The second test was conducted on a real-world Modbus serial line application. Its aim was to assess how the full IEEE 802.15.4 transceiver (including MAC layer) was affected by IEEE 802.11b. The third test addressed a real-world ZigBee lighting application in a very functional way in which an IEEE 802.15.4 transceiver acted as a switch, an IEEE 802.15.4 as a lamp and an 802.11 WiFi interferer. Initial results prompted two installation recommendations from Schneider Electric, formulated as safe values in the knowledge that less stringent requirements would often suffice in the real world. The recommendations were:



- The distance from WiFi interferers to ZigBee nodes should be at least 2 meters.
- The frequency offset between both networks should be at least 30 MHz.

ZigBee chipsets evolved from 2006 and the protocol could mitigate interference at application level more effectively. Consequently, there was a need to revisit these results in the light of up-to-date hardware and protocol stacks. In 2007 ZigBee Alliance member, Daintree Networks, analysed traffic at the Hanover Fair where several WiFi networks were operating on several channels and a ZigBee network on channel 17 overlapped adjacent WiFi activity.

At network layer level, Daintree Networks found first a 2% packet loss rate, then a 0% loss, which underlined the importance of mitigated interference in the later-generation protocol stack. A subsequent Daintree laboratory test to assess ZigBee behaviour in the presence of heavy WiFi traffic showed that although no data packets were lost, there was an impact on latency. In the light of the above, and other, tests, ZigBee can safely be said to operate satisfactorily in the presence of WiFi interference attributable to the real-world applications for which it is currently used, e.g. web browsing, file transfer, and audio and video streaming. ZigBee packets can, however, experience higher (i.e. slower) latency due to the higher number of retransmissions. Thus, although ZigBee/WiFi coexistence has theoretical limits highlighted in laboratory experiments, real-world traffic today does not reach those limits. In a word, WiFi interference is not an issue for ZigBee applications which benefit homes, buildings, and industrial facilities.



4 Zigbee's Practical Applications

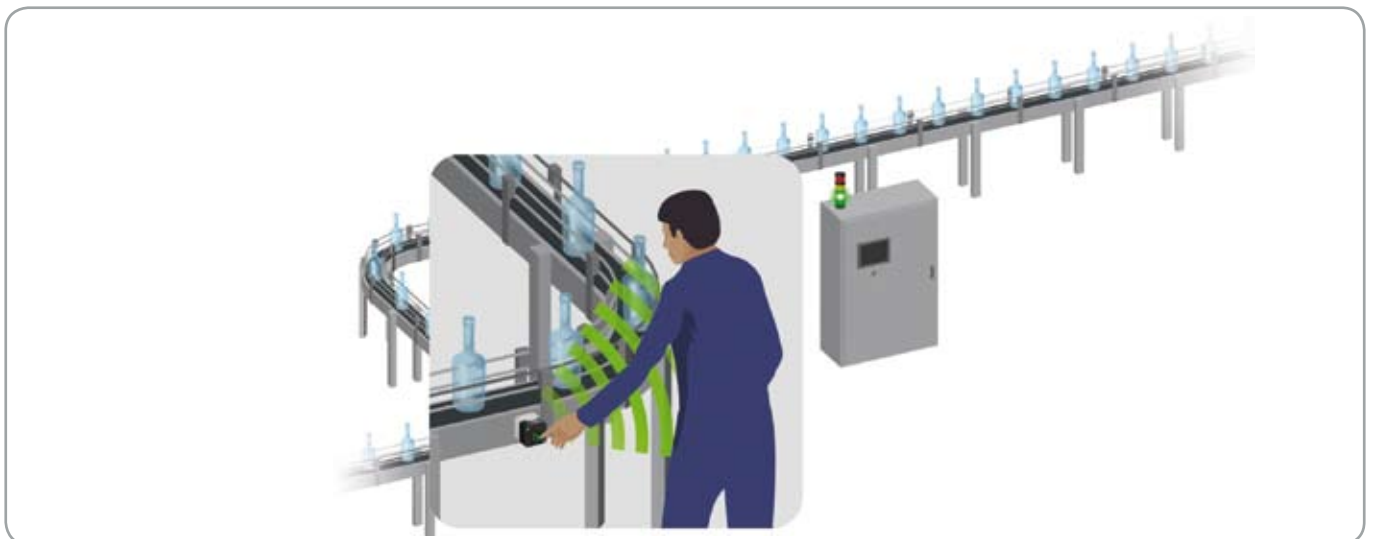
In industrial automation, ZigBee strengthens the reliability of manufacturing and process systems. Its continuous monitoring of critical equipment is a valuable aid in asset management. It reduces energy costs by helping to optimise processes and identifying inefficiencies and underperformance.

In the home, lighting, heating and cooling systems can be managed, with automated control of different systems improving conservation, convenience and safety. Households benefit from comprehensive electric, water and gas utility data and optimise their consumption of natural resources.

In automated buildings ZigBee helps optimise HVAC management and allocate utility costs equitably based on actual consumption. Data can be networked and integrated from different access control points, while wireless monitoring networks strengthen the surveillance of premises.

Since work first began on ZigBee in the late 1990s, it has evolved into a mainstream technology. It is now the chosen low-power wireless standard for advanced metering and home area networks. But it does not appear to be stopping there: chipsets using ZigBee specifications accounted for 75% of the 802.15.4 units shipped in 2009. It was in that same year that the ZigBee Alliance announced it was developing the ZigBee Green Power feature set to establish a global, standard technology for self-powered devices operating through energy harvesting techniques.

ZigBee's wireless open standard technology is asserting itself globally as the energy management and efficiency technology of choice. ZigBee is playing a major role in how energy is priced and used, giving consumers and companies the chance to play a role in energy conservation. And with billions being invested in smart grid programmes as part of efforts to control global warming, ZigBee has a promising future. .



Conclusion

Schneider Electric is one of the leading companies that is further exploiting ZigBee's potential for remote-controlled industrial applications. Remote control device commands are nothing new – indeed, they are an established component of modern production facilities. Yet users still have to contend with device failures, some 50% of which are reported to be due to batteries running low or out. The question does not even arise with Schneider Electric's newly developed Harmony XB5R, the first industrial pushbutton switch of its kind which the company unveiled in May 2011.

XB5R operates without wires or batteries and delivers unprecedented flexibility and mobility, enabling operators to remotely control machines at ranges of up to 25 meters. It improves the control of machines and processes anytime and – literally– anywhere, because the devices on the ZigBee mesh network can communicate through walls, floors and doors. What's more a single receiver can be paired to up to 32 transmitters. XB5R is particularly effective in the control of conveyance machines in automotive, mining, and logistics applications and palletizers and bottling machines in the food and beverage industry, as it is possible to pair up to 32 transmitters to a single receiver!

XB5R cuts installation costs by 20% and gives manufacturers fresh scope for control system design that incorporates ultra-low energy usage and no wires. The environmental gains are clear, too: it saves energy and reduces pollutions as there are no batteries to be disposed of. And saves raw materials by helping to reduce copper use in manufacturing and possibly phasing it out altogether in sensor-based industrial control systems.

The ZigBee-based Harmony XB5R is helping Schneider Electric to act on its commitment to innovative sustainable solutions that contribute to safeguarding the environment and shaping a new future for the generations to come.



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