Comparing Low-Power Wireless Technologies

By Phil Smith
Contributed By Convergence Promotions LLC
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About this author

Phil Smith

Article authored by Phil Smith of CSR PLC.

This article compares Bluetooth low-energy, ANT, ANT+, ZigBee, ZigBee RF4CE, Wi-Fi, Nike+, IrDA, and the near-field communications (NFC) standard, detailing the features, benefits, and shortcomings of each protocol in various applications.

Many innovative new use cases are now being made possible with the introduction of ultra-low-power wireless chipsets. Until recently, the only way to achieve data transfer between a sensor and a client has been to use wires, or manually collect data from a logging device. Wireless technologies have been available for decades. However, they tend to use significant amounts of power and need specialized equipment to establish communications.

Most target markets are characterized by periodic transfer of small amounts of sensor information between sensor nodes and a central device. Some identified end products which may implement a low-power radio system include cell phones, health and fitness devices, home automation, heating, ventilating, and air conditioning (HVAC), remote controls, gaming, human interface devices (HID), smart meters, payment, and many others.

These applications are all constrained by the following critical key requirements: ultra-low-power, low cost, and physical size.

The ultra-low-power requirement is mainly due to the need of targeted devices to operate for extended periods of time from coin cells or energy scavenger technology. Apart from the obvious advantages of a low chipset cost, overall product expense is largely affected by the power source. For example, if a shopping mall has a wireless beacon in every shop and batteries need replacing regularly, the maintenance cost will soon outweigh the advantages of such a technology being deployed.

This article analyzes the pros and cons of various low-power wireless technologies and leaves it up to the reader to decide which technology is most suitable for their intended product.

Background on Bluetooth low energy

Bluetooth® low energy (LE) started life as a project in the Nokia Research Centre with the name Wibree. In 2007, the technology was adopted by the Bluetooth Special Interest Group (SIG) and renamed Bluetooth Ultra-Low-Power and then Bluetooth low energy.

The aim of this technology is to enable power sensitive devices to be permanently connected to the Internet. LE sensor devices are typically required to operate for many years without needing a new battery. They commonly use a coin cell, for example, the popular CR2032.

LE technology is primarily aimed at mobile telephones, where it is envisaged that a star network topology, similar to Bluetooth, will often be created between the phone and an ecosystem of other devices.

LE is also known as Bluetooth v4.0 and is part of the public Bluetooth specification. As a result of being a standard, LE benefits from all the advantages of conformance and extensive interoperability testing at unplug fests. A device that operates Bluetooth v4.0 may not necessarily implement other versions of Bluetooth; in such cases it is known as a single-mode device. Most new Bluetooth chipsets from leading Bluetooth silicon manufacturers will support Bluetooth and the new LE functionality.

What is ANT?

ANT™ is a low-power proprietary wireless technology which operates in the 2.4 GHz spectrum. It was established in 2004 by the sensor company Dynastream. Typically, the ANT transceiver device is treated as a black box and shouldn't require much design effort to implement into a network. Its primary goal is to allow sports and fitness sensors to communicate with a display unit, for example a watch or cycle computer. It also typically operates from a coin cell. ANT+™ has taken the ANT protocol and made the devices interoperable in a managed network, thereby guaranteeing that all ANT+ branded devices work seamlessly. Similar to LE, ANT devices may operate for years on a coin cell.

ANT devices are not subject to the extensive conformance and interoperability testing applied to other standardized technologies. ANT+ is introducing a new certification process in 2011 which will be chargeable and a prerequisite for using ANT+ branding.

What about ZigBee?

ZigBee® is a low-power wireless specification based on the Institute of Electrical and Electronics Engineers (IEEE) Standard 802.15.4-2003 and was established in 2002 by a group of 16 companies. It introduces mesh networking to the low-power wireless space and is targeted towards applications such as smart meters, home automation, and remote control units. Unfortunately, ZigBee's complexity and power requirements do not make it particularly suitable for unmaintained devices that need to operate for extensive periods from a limited power source. ZigBee channels are similar to those for LE in that they are 2 MHz wide. However, they are separated by 5 MHz, thus wasting spectrum somewhat. ZigBee is not a frequency hopping technology, therefore and requires careful planning during deployment in order to ensure that there are no interfering signals in the vicinity.

Does RF4CE tick all the boxes?

Radio Frequency for Consumer Electronics (RF4CE) is based on ZigBee and was standardized in 2009 by four consumer electronics companies: Sony, Philips, Panasonic, and Samsung. Two silicon vendors support RF4CE: Texas Instruments and Freescale Semiconductor, Inc. RF4CE's intended use is as a device remote control system, for example for television set-top boxes. The intention is that it overcomes the common problems associated with infrared: interoperability, line-of-sight, and limited enhanced features.

How does Wi-Fi compare?

In recent years, a number of improvements have been made to the wireless-fidelity (Wi-Fi®) IEEE Standard 802.11 wireless networking standard, which may be able to reduce its power consumption, including IEEE Standard 802.11v and other proprietary standards. Although Wi-Fi is a very efficient wireless technology, it is optimized for large data transfer using high-speed throughput and is not really suitable for coin cell operation. Some companies are attempting to use Wi-Fi for HUD devices. Special proprietary driver software is required, however, and only limited functionality can be achieved.

What is NIKE+?

Nike+® is a proprietary wireless technology developed by Nike and Apple to allow users to monitor their activity levels while exercising. Its power consumption is relatively high, returning only 41 days of battery life from a coin cell. Being a proprietary radio, it will only work between Nike and Apple devices. Nike+ devices are shipped as a single unit: processor, radio, and sensor. In this article, we therefore evaluate this technology as a single entity. The design is a two-chip solution, consisting of a processor and a Nordic nRF2402 radio transceiver integrated circuit (IC).

Doesn't IrDA solve the problems already?

The Infrared Data Association (IrDA) is a SIG consisting of 36 members. IrDA has recently announced an ultra-high-speed connectivity version, yielding 1 Gbps. However, it only works over a distance of less than 10 cm. One of the main problems with infrared (IR) is its line-of-sight requirement, which RF4CE was established to overcome. IrDA® is also not particularly power efficient (power per bit) when compared against radio technologies. By its very nature, it is a two-component solution as an absolute minimum because it needs a processor and a transceiver.

Is NFC going to take over?

This is unlikely, as near field communication (NFC) is significantly different from the other low-power wireless technologies discussed in this article. It only works up to a range of approximately 5 cm and consumes relatively more power. Passive NFC tags can be completely unpowered, only becoming active when an NFC field is present. That eliminates NFC from many of the use cases discussed here. NFC is a perfect fit for its intended use cases, and is likely to be integrated alongside the other technologies discussed in this article. It has few competing technologies.

Network topologies

Five main network topologies exist when discussing personal low-power radio networks:

- **Broadcast:** A message is sent from a device in the hope that it is received by a receiver within range. The broadcaster doesn't receive signals.
- **Mesh:** A message can be relayed from one point in a network to any other by hopping through multiple nodes.
- **Star:** A central device can communicate with a number of connected devices — Bluetooth is a common example.
- **Scanning:** A scanning device is constantly in receive mode, waiting to pick up a signal from anything transmitting within range.
- **Point-to-Point:** In this mode, a one-to-one connection exits, where only two devices are connected, similar to a basic phone call.

Which technology supports which topology?

Table 1 shows which wireless technologies, support which network topologies.

	LA	A	A+	Zi	RF	Wi	Ni	Ir	NF
Broadcast	√	√[1]	√[1]	x	x	x	x	x	x
Mesh	√[2]	√	√	√	√	x	x	x	x
Star	√	√	√	√	√	√	x	x	x
Scanning	√	√[3]	√	√	√	x	√	x	x
Point-to-Point	√	√	√	√	√	√	√	√	√

Table 1: Network topologies supported by wireless technologies.

Key: **LE** (Bluetooth low energy), **A** (ANT), **A+** (ANT+), **Zi** (ZigBee), **RF** (RF4CE), **Wi** (Wi-Fi), **Ni** (Nike+), **Ir** (IrDA), **NF** (NFC)

Notes:

1. Not just broadcasting, it also needs to listen.
2. An application can be put on LE to enable meshing.
3. All connections stop and power consumption is high.

Is Bluetooth low energy easy to implement?

Based on the amount of software that would be required to implement a simple program and hardware requirements, it is possible to estimate how much effort may be required to implement a simple connectivity application.

LE chipsets come in two categories: single-mode and Bluetooth + LE.

Single-mode configurations are shipped as a single chip that contains the host processor and radio. The protocol stack is integrated in the silicon and exposes some simple application programming interfaces (API) for a developer to use. As a result, there is little effort required by the developer when creating a new product. Single-mode LE devices are often shipped from silicon vendors as pre-certified units. This means original end manufacturers (OEM) do not need to spend resources qualifying their new products. If the developer decides to deviate significantly from a given reference design, then it is possible that some features may need retesting. The hardware for a single-mode LE device is very simple, as shown in Figure 1.

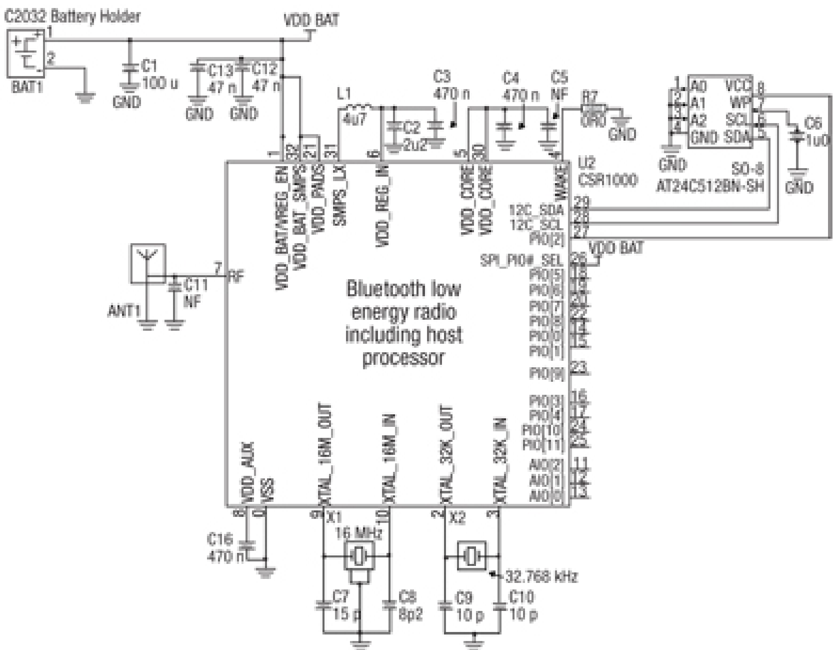

Figure 1: A complete Bluetooth low energy beacon schematic.

Figure 2 shows a real device implementing Bluetooth v4.0. This unit consists of the schematic in Figure 1, a buzzer, a Light-Emitting Diode (LED) and a switch.

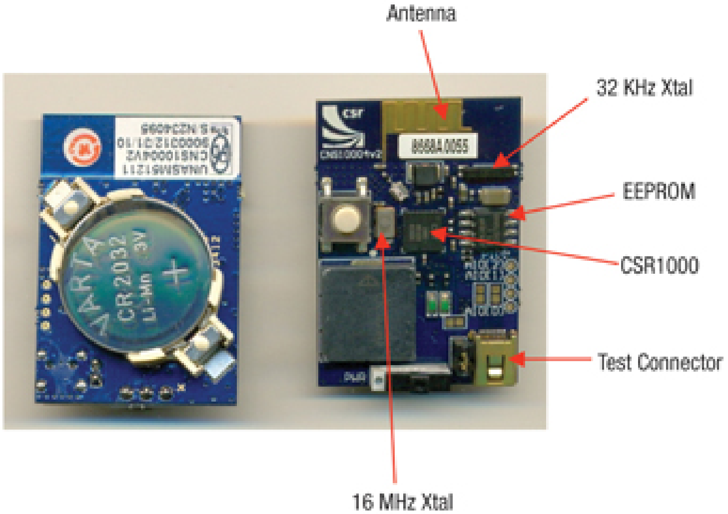

Figure 2: A real Bluetooth low energy device.

A bill of materials (BOM) for the real LE device is shown in Table 2.

Component	Quantity	Cost ($)
Battery	1	0.325
Antenna	1	0 (Printed Antenna)
EEPROM[1]	1	0.89
Decoupling Cap	6	0.002
Signal Cap	5	0.002
Resistor	4	0.0001
Crystal	2	0.243
Bluetooth low energy IC	1	Approx Rs139.01
Total		Rs378.1

Table 2: A BOM for a Bluetooth low energy device.

Notes: 1 Electrically Erasable Programmable Read-Only Memory. Component costs will be lower in mass production.

Dual-mode Bluetooth chipsets, as used in a mobile handset, have a host processor present. Silicon vendors normally ship a protocol stack which executes on the host processor and provides a simple API to access Bluetooth and LE. Dual-mode Bluetooth chips may also contain their own application processor. Such devices have the sensitive protocol stack burnt into Read-Only Memory (ROM) and expose an API as a virtual machine. These types of chips are often found in consumer electronics, like headsets, where more than just sensing applications are necessary.

RF4CE is also an easy technology to implement, but requires approximately 64 Kbytes of protocol stack to be ported to the host processor. Some RF4CE chips contain an application processor, which may simplify the hardware effort required.

ANT is often a two-chip solution, where developers need to choose which radio and host processor to use. SensRcore® chips are a single-chip solution that offers a power saving over regular ANT devices, but they are typically only suitable for the sensor end of a link and require a proprietary scripting language. Certification for ANT+ is compulsory and costs are still being finalized. There are some ANT development kits on the market which ship with various modules and all required software. This makes life easier for the developer. The protocol stack is intended to be treated as a black box, implying that ANT-based products should be easy to develop. It is worth noting that device profiles are a collaborative effort between the ANT+ team and application developers. They are likely to require some effort to write and verify as interoperable with other technologies.

IrDA has some simple protocols that can be obtained in a simple microprocessor IC + LED and receiver. Complexity increases when higher data rates are required, because a full IrDA protocol stack and powerful processor are needed. Plastic IR transmission windows are also a requirement for end products using IR. They must ensure IR intensity is within specification. Certification is compulsory and needs to be carried out at an IrDA authorized test lab.

NFC integration has recently been simplified with the release of an open source protocol stack from Inside Contactless. Some porting effort is required to implement NFC in a system and significant thought needed when designing an optimal antenna. NFC requires at least two chips (a radio and a processor) and a power supply. Certification is not compulsory for NFC, but standard radio emission testing should be performed to ensure it remains in the 13.56 MHz band. A new certification program has been established which offers manufacturers the opportunity to prove their device is fully interoperable.

Wi-Fi is probably the most complicated technology to integrate into a system. It requires various drivers and a full protocol stack. The hardware also needs to be designed with tight tolerances to ensure that radio specified performance is achieved. Certification is not compulsory. However, the Wi-Fi logo cannot be obtained unless the device is certified. Certification costs are high, relative to the other technologies discussed here because of the amount of testing that is required at a specialist test facility. Most new power-saving specifications are still being written, or are not in mass production yet, thereby lengthening the time-to-market of such advancements.

What does it cost to manufacture low-energy devices?

Some of the main costs associated with a low-power sensor are the processor, radio, antenna, battery, battery connector, sensor, regulator, and the printed circuit board (PCB). Table 3 shows typical costs for different technologies.

Note: It is assumed that battery, battery connectors, and sensors are equal across all platforms and therefore not included.

Crystals can also contribute a significant portion of cost to a small sensor device. In wireless technologies, a high quality crystal is often required to meet strict regulatory requirements. Typical crystal tolerances are:

Least Expensive

- NFC 500 ppm (parts per million): NFC provides data clocking, a crystal is only required keep the radio in band.
- LE 250 ppm
- Nike+ 60 ppm
- ANT 50 ppm
- RF4CE 40 ppm

Most Expensive

	Processor	Radio	Antenna	Regulator	PCB Size
LE	N/A	Rs410.08/1 k(1)	Printed 8mm(2)	N/A	20 mm^2(3)
A	$low	Rs549.08/10 k	Printed 'F' 15 mm	N/A	125 mm^2
A+	N/A	Rs462.9/1 k	Printed 'F' 15 mm	N/A	306 mm^2
Zi	N/A	Rs444.83/1 k	Printed 'F' 15 mm	N/A	305 mm^2
RF	N/A	Rs382.27/1 k	Printed 'F' 15 mm	N/A	305 mm^2
Wi	$high	Rs417.03	Printed 8 mm(2)	Rs208.51(4)	60 mm^2
Ni	$low	Rs222.41/10 k	Metal 2 cm	N/A	300 mm^2
Ir	N/A	Rs273.85/10 k	8 mm	N/A	21 mm^2 +CPU
NF	$high	Rs139.01	50 mm x 30 mm	Rs45.87(5)	100 mm^2

Table 3: Bluetooth low energy device manufacturing costs.

Key: **LE** (Bluetooth low energy), **A** (ANT), **A+** (ANT+), **Zi** (ZigBee), **RF** (RF4CE), **Wi** (Wi-Fi), **Ni** (Nike+), **Ir** (IrDA), **NF** (NFC)

Notes:

1. If used as part of a Bluetooth design, the cost would be less than a 20 percent addition.
2. Cambridge Silicon Radio (CSR) patented printed antenna design may be used with CSR chips.
3. Bluetooth and LE. LE only is aimed at medium cost PCB technologies, therefore modules are approximately 96mm2 including antenna.
4. Wi-Fi requires 1.8 V @200 mA and 3.3 V @400 mA = Rs187.05. At an exchange rate of Rs380.63 to Rs139.01 => Rs208.51.
5. 5NFC requires 50 mA @ 3.3 V = Rs42.2. At an exchange rate of Rs380.63 to Rs139.01 => Rs45.87.

Efficiency

Protocol

A wireless transmission consists of two main components: payload and overhead. These are used to ensure that packets are delivered reliably. The efficiency of the protocol can be measured as the ratio of payload to total packet length. If a protocol is very inefficient and spends most of its time transferring non-payload information, it will soon discharge the battery and transfer very little data. Alternatively, a protocol close to 100 percent efficiency will transfer significantly more data on a single charge. There is a tradeoff between reliability and efficiency when looking at extremes. Consider an ultra-efficient protocol that does not incorporate a reasonable checksum or error corrections. Each packet could easily be corrupted by interference in the 2.4 GHz band, resulting in virtually no payload being realized. By analyzing on-the-air packets, it is possible to determine the efficiency of a protocol.

ANT
An ANT packet consists of an 8-byte payload wrapped by various other components. Without any public evidence, due to its proprietary blackbox nature, the efficiency of ANT is stated to be 47 percent.

Bluetooth low energy
LE, being an open standard, has the breakdown of packets published. Figure 3 shows a typical packet.

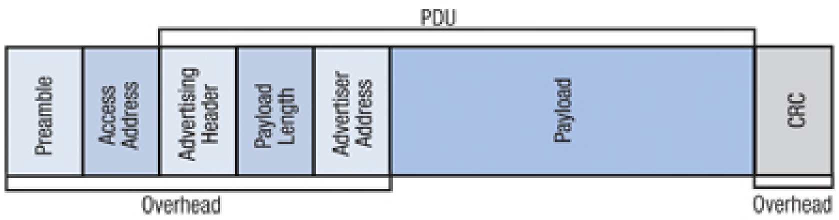

Figure 3: Bluetooth low-energy packet.

```
Preamble = 1 octet
Access Address = 4 octets
PDU (Protocol Data Unit (packet or message)) =
39 octets
       Advertising Header = 1 octet
       Payload length = 1 octet
       Advertiser Address = 6 octets
       Payload = 31 octets
CRC (Cyclic Redundancy Check) = 3 octets
```

From these figures, it is possible to show the following LE protocol efficiency: Payload/Total length = 31/47 = 0.66 > 66 percent efficient.

Power efficiency

Power efficiency is often queried by customers who are interested in prolonging the battery life of their devices while still achieving good user experience.

For example, when a mobile handset needs to synchronize email, the handset's battery (with a fixed mAh) must last long enough to allow all emails (a fixed quantity) to be downloaded and read by the user.

Which wireless technology on the handset would be most efficient — Wi-Fi or cellular?

Similar questions need to be answered for remote sensor devices. The quantity derived is the power per bit measurement.

ANT

An ANT device is configured to transmit 32 bytes/second and consumes 61 μA.

- A byte consists of 8 bits, therefore 32 x 8 = 256 bits/second
- Power = VI = 3 V x 61 μA = 0.183 mW
- Power per bit = 0.183 mW / 256 bits = 0.71 μW/bit

Bluetooth low energy

Connectable advertising packets (adverts) are broadcast every 500 ms. Each packet has 20 bytes of useful payload and consumes 49 μA at 3 V. For this particular setup, adverts are spread across all three channels, with the positive side effect of increasing robustness over a single-channel technology.

- Power consumption = 49 μA x 3 V = 0.147 mW
- Bytes per second = 20 x (1 second/500 ms) x 3 channels = 120 bytes/second
- Bits per second = 120 bytes/second x 8 = 960 bits/second
- Power per bit = 0.147 mW/960 = 0.153 μW/bit

It should be noted that this configuration uses connectable packets. Therefore, the advertising device is also scanning after each advert. This consumes significant power, but is still lower than its nearest competitor. By increasing the payload to 31 bytes per packet and configuring for broadcast only, power per bit efficiency would be improved further. This would occur due to the increase in protocol efficiency from 20 payload bytes to 31 for the same overhead.

IrDA

A television remote control sends a 14-bit payload. This is implemented with an ultra-low-power processor (consuming 0.1 μA during sleep, allowing for its negligible power consumption to be ignored for this calculation). The transaction takes 1.5 ms at 170 μA, then 114 ms at 55 μA.

- Power = 0.163 mW
- Bits = 14
- Power per bit = 0.163 mW/14 bits = 11.7 μW/bit

Nike+

A foot pod lasts 1000 hours and transmits its payload every second. The payload is 34 bytes. A typical CR2032 has 225 mAh.

- Current drawn = 225 mAh/1000 hours = 0.225 mA
- Power = 3 x 0.225 mA = 0.675 mW
- Bits per second = 34 x 8 = 272 bits/second
- Power per bit = 0.675 mW / 272 = 2.48 μW/bit

Wi-Fi

Wi-Fi consumes approximately 116 mA at 1.8 V when transmitting a 40 Mbps User Datagram Protocol (UDP) payload. Unfortunately, current consumption does not reduce when throughput is reduced in a Wi-Fi chipset.

- Power = 116 mA x 1.8 V = 0.210 W
- Power per bit = 0.210/40,000,000 = 0.00525 μW/bit

Zigbee
A Zigbee device consumes 0.035706 W when transferring 24 bytes of data.

- Bits per second = 24 x 8 = 192 bits
- Power per bit = 0.035706/192 = 185.9 μW/bit

From the above calculations it is clear that Wi-Fi is the most power efficient technology and would be ideally suited to large file downloads. Unfortunately, its peak current consumption is far beyond the capabilities of a coin cell and would need to be provided with a large battery. Work is being conducted in Wi-Fi groups to lower power consumption, enabling use with HID devices. Currently, proprietary drivers are needed, with the technology only applicable to the personal computer market where receiver power budgets are higher. LE is second, requiring approximately a quarter of the power of its closest competitor, ANT. It is surprising to see how much energy is wasted by infrared remote controls currently in wide global use.

Performance

Range
The range of a wireless technology is often thought of as being proportional to the radio frequency (RF) sensitivity of a receiver and the power of a transmitter. This is true to some extent. However, there are many other factors that affect the real range of wireless devices. For example, the environment, frequency of carrier, design layout, mechanics, and coding schemes. For sensor applications, range can be an important factor. Range is usually stated for an ideal environment, but devices are often used in a congested spectrum and shielded environments. For example, Bluetooth is quoted as a 10 meter technology, but can struggle to provide a reliable Advanced Audio Distribution Profile (A2DP) stream from a pocket to headset due to cross-body shielding. Similar problems can be observed in the health and fitness space, where users have body-mounted gadgets and move continuously. It is worth noting that 2.4 GHz is easily attenuated by human bodies.

The following list shows typical ranges that can be expected from ultra-low powered technologies in an open environment:

- NFC – 5 cm
- IrDA – 10 cm
- Nike+ – 10 m
- ANT(+) – 30 m
- ZigBee – 100 m
- RF4CE based on ZigBee – 100 m
- Wi-Fi – 150 m
- LE – 280 m

Robustness

Reliable packet transfer has a direct influence on battery life and the user experience. Generally speaking, if a data packet is undeliverable due to suboptimal transmission environments, accidental interference from nearby radios, or deliberate frequency jamming, a transmitter will keep trying until the packet is successfully delivered. This comes at the expense of battery life. If a wireless system is restricted to a single channel, its reliability may deteriorate in congested environments.

A proven method to assist in overcoming interference is to use channel hopping, as implemented in Bluetooth. Channel hopping has been carried forward to LE. Bluetooth devices use Adaptive Frequency Hopping (AFH), which allows each node to map out frequently congested areas of the spectrum to be avoided in future transactions.

ANT is specified to operate over eight channels. However, it is often the case that sensor-node chipsets only operate on a single channel. ANT employs a Time Division Multiplexing (TDM) system, which increases reliability. A technique is used in an ANT network known as bursting. Bursting uses the available spectrum aggressively and is known to block other ANT devices in the vicinity. ANT+ recognizes this and recommends that file transfers only be conducted on a clear channel.

ZigBee PRO™ implements a technique known as frequency agility (not hopping). A network node is able to scan for clear spectrum and communicate its findings back to the ZigBee coordinator so that a new channel can be used across the network. While this method will work most of the time, it will not always be possible for the scan reports to migrate across the mesh under severe congestion/interference.

Can these technologies be jammed?
As already mentioned, ANT is susceptible to bursting and continuous interference on its assigned channel. ZigBee is easy to block with a Wi-Fi access point, so networks must be planned to avoid placing the two technologies together. As Wi-Fi output power increases with advances in technology, it will be increasingly difficult for a ZigBee network to coexist.

Jamming an LE network is particularly difficult. Advertising channels can be blocked with a strong continuous carrier. However, tests in the lab, using high-power signal generators, have shown such jamming to only be effective if the node and signal generator are within a few centimeters of each other. LE adverts are spread across three channels, therefore requiring three signal generators to be used at high power. When data channels hop (adaptively) across 37 different frequencies, it becomes much more difficult to inhibit data transfer during a connection.

Throughput

Throughput of a wireless network can be measured in two ways:

- On air signaling rate, which is often quoted on packaging (for example, Wi-Fi at 54 Mbps).
- Measuring how quickly useful payload data can be transferred, which is the more useful method.

For the intended monitoring use cases, it is unlikely that ultra-high data rates will be needed regularly. The following figures show how different technologies' payload throughputs compare:

- IrDA ~1 Gbps
- Wi-Fi (lowest power 802.11b mode) ~6 Mbps
- NFC ~424 kbps
- LE ~305 kbps
- ZigBee ~100 Vkbps
- RF4CE (same as ZigBee)
- ANT+ ~20 kbps
- Nike+ ~272 bps

Latency

The latency of a wireless system can be defined by a user action sent to a receiving device. A common scenario is gaming, where a user hits a button on the controller and the effect is perceived to be instant at the console. It is not acceptable that a user presses the trigger and must wait for a bullet to appear. Latency is also critical in applications such as HID (mice and keyboards), sports and fitness (instantaneous body readings), and security devices.

The list below describes some of the typical latencies of low-power wireless network technologies:

- ANT ~zero
- Wi-Fi ~1.5 ms
- LE ~2.5 ms
- ZigBee ~20 ms
- IrDA ~25 ms
- NFC ~polled typically every second, this is manufacturer specific
- Nike+ ~1 second

Although ANT and Wi-Fi have possible low latencies, they require the receiving device to listen continuously and therefore use considerable power. The previous references show that this low latency is often only achieved on devices that do not have strict power budgets.

Peak power consumption

Peak power consumption is a critical figure when designing long-life, low-power sensor devices. The main reason for this is that certain types of battery technology are not able to source high currents instantaneously. The common CR2032 coin cell is a popular choice for long life sensor gadgets. However, it can only source about 15 mA peaks without damage. If the peak current exceeds 15 mA, battery life may be degraded. Demanding 30 mA peaks would reduce realized capacity by about 10 percent of manufacturers' stated figures. Acceptable continuous standard loads are typically 2 mA or less, in order to achieve published capacity figures.

Other alternative forms of energy source are available from energy harvesting technologies. Energy harvesters are likely to be used in conjunction with mass deployment, ultra-low energy radios, to reduce ongoing maintenance costs of battery replacement. Solar cells are a well known example of an energy harvester, but they are notorious for low efficiency when converting ambient light into useful electrical energy. An amorphous solar cell of similar dimensions to a CR2032 ($3 cm^2$) would yield 1.5 V x 8 μA = 12 μW. With such small amounts of power available, it is critical that a radio is selected that does not have high current demands.

Table 4 shows typical peak current consumption for wireless technologies which can operate from Manganese Dioxide Lithium coin batteries such as the CR2032.

- IrDA peak current draw ~ 10.2 mA
- Nike+ peak current draw ~ 12.3 mA
- LE peak current draw ~ 12.5 mA

• ANT peak current draw ~ 17 mA	CR2032 OK
• RF4CE peak current draw ~ 40 mA • NFC ~ 50 mA • Wi-Fi peak current draw ~ 116 mA (@1.8 V)	Too much current demand

Table 4: Peak power consumption for wireless technologies.

Coexistence

Coexistence means different things to different people. Coexistence is sometimes thought of as the ability of technologies to operate in the presence of other radios in the same room or building. However, others would define coexistence as the collocating of radios on the same PCB with little radio separation. A standard approach between Bluetooth and Wi-Fi is to use a signaling scheme between two ICs. This often consists of a number of wires to inform each IC when its radio is clear to transmit/receive. For the purpose of this article, we will refer to coexistence schemes as active and passive, where passive is an interference avoidance system and active is chip-to-chip signaling.

When added to Bluetooth chips, LE will be able to use existing coexistence features available in Bluetooth Wi-Fi coexistence schemes. LE also implements passive interference avoidance schemes. For example, adaptive frequency hopping can be used to keep clear of channels where interference is detected. LE advertising channels are also specifically chosen to be in the least congested regions of the 2.4 GHz ISM band.

Wi-Fi has active coexistence technology implemented, when integrated with a device containing Bluetooth, and a mechanism to reduce its data rates, when interferers are detected from neighboring wireless technology.

IrDA does not implement any form of coexistence technology. However, it is only likely to be affected by bright background light. A positive side effect of IR being short range and line-of-sight is that it is unlikely that IR devices will interfere with each other.

NFC implements a form of coexistence where the reader is able to select a particular tag from a wallet containing many NFC cards. NFC is similar to IR in that its range is very short and unlikely to interfere with other NFC devices. It is worth noting that 13.56 MHz has harmonics in the frequency modulation (FM) band that are particularly strong at 81.3 MHz and 94.9 MHz. This can potentially cause clicking noises in a colocated FM receiver. However, FM interference effects may be reduced in a handset by implementing anti-collision techniques — for example, by skewing or clean up.

ANT devices normally operate over a single channel; 8-channel chipsets are available but are often only implemented in the hub device. Because the sensor device only operates on a single channel, it limits any form of frequency agility. ANT+ is defined as a single-frequency system, where each sensor transmits at one particular RF frequency. ANT implements a Time Division Multiple Access (TDMA) system where it attempts to detect and avoid regular interferers by informing a remote device to offset its timing. If the used channel is fully occupied, an ANT network doe not have the ability to hop to a clear part of the spectrum. This halts data transfer. ANT burst mode uses the assigned channel in an aggressive manner and can quite easily absorb a channel's entire bandwidth. This halts communications between other ANT devices in the vicinity. One would assume other continuous interferers, Wi-Fi or household mobile phones, would also cause similar problems to an ANT network.

ZigBee does not implement a coexistence scheme, but it does have the ability to continuously listen for clear time on its channel. If the channel is heavily used, ZigBee throughput and latency are adversely affected, eventually halting. ZigBee PRO has a feature known as frequency agility (not the same as hopping) where it may be possible to search for a clear channel (of the 16 channels defined) and then re-establish the network. Placing a ZigBee node in close proximity to a wide band (Wi-Fi) device causes severe problems to the ZigBee network.

It is unclear whether Nike+ implements any form of coexistence scheme. It can evidently operate in the same vicinity as other Nike+ devices, because it works in crowded gyms. The likelihood of discovering a regular interferer while exercising outdoors is minimal, therefore reducing the need for 100 percent reliable packet transfer.

Figure 4 and Figure 5 show spectrum usage for LE and ZigBee.

Each channel is 2 MHz wide, but the spacing and placement of ZigBee channels implies that only four are likely to be free in the presence of average Wi-Fi network settings. Typically, channels 1, 6, and 11 are defaults. With an on-air signaling data rate of only 250 kbps and the inability to implement hopping, ZigBee is at high risk of non-delivery of its packets. LE makes much more efficient use of the spectrum and employs adaptive frequency hopping as proven by Bluetooth.

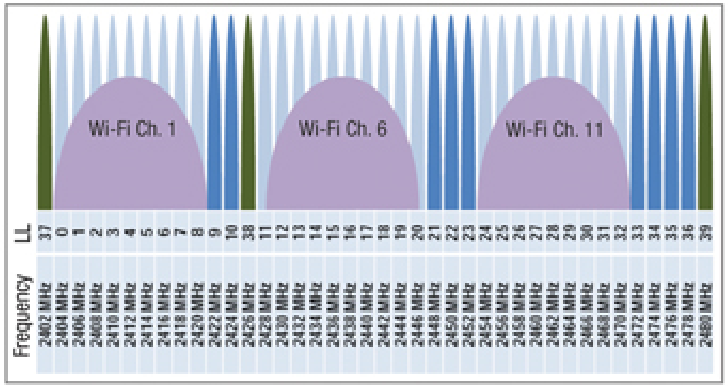

Figure 4: Bluetooth low energy channel allocations.

Note: Each channel is 2 MHz wide with no wasted spectrum.

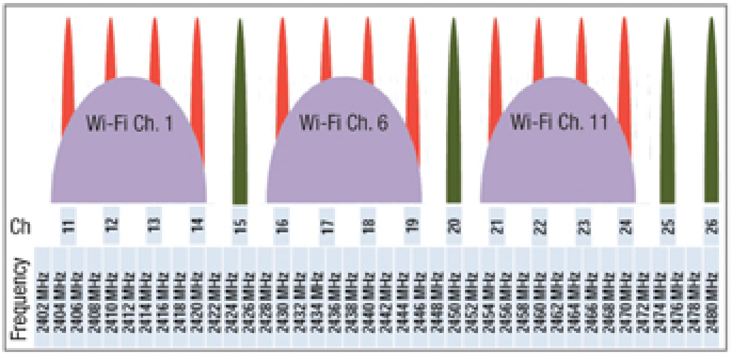

Figure 5: ZigBee channel allocations.

Note: Each channel is 2 MHz wide with a wasteful 5 MHz spacing. In the presence of Wi-Fi, only four channels are likely to be available.

How long will my battery last?

As mentioned previously, the most common preference for remote sensor devices is the Lithium coin cell. These cells are typically found in wrist watches and sports accessories because of their low cost, size, and weight. Lithium coin cells are very sensitive to the amount of current that is demanded from them. If treated correctly, they have a relatively high capacity relative to physical size.

Lifetime figures for this type of battery can be obtained in two ways. From earlier in this article, we know how much power is required to transmit a wanted payload bit using each technology.

This would enable us to determine how much data the sensor can offload in a single charge. Alternatively, it is possible to look at average power consumption while a sensor device is operating.

The ANT website provides a handy calculator for estimating current draw. The scenario modeled is the most efficient chipset (AT3), which sends 120 bytes/second. Each page in ANT is 8 bytes long and therefore needs to transmit at 120/8 = 15 Hz to achieve 120 bytes/second throughput. The unit is switched on continuously throughout the day with a 225 mAh battery. Average current is 175.5 µA and a battery would last 52.64 days.

Achieving the same data rate of 120 bytes/second with LE, draws an average current of 49 µA as described in earlier calculations. A 225 mAh battery should support this current draw for 225 mAh/49 µA = 4592 hours = 191 days.

Nike+ devices are specified to operate for 1000 hours, which equates to 42 days. It should be noted that the data rate is fixed, and is only 34 bytes/second.

In reality, desired throughputs would be much lower, resulting in years of battery life with a similar ratio of lifetime.

Target markets

The low-power wireless technologies described in this article are targeted towards specific market segments, some of which overlap. Table 5 shows examples of these identified target markets.

Summary

The research in this article has shown a number of technologies competing for the same market space.

ANT is a good example of a technology that is already in mass production and has begun to establish itself as the "sports and fitness" technology. However, it has only managed to sell approximately 15 million chips to date, beginning in 2004 and has only been integrated into three mobile handsets. ANT makes a good attempt at operating from limited power sources and has built a niche ecosystem.

	LE	A	A+	RF	Zi	Wi	Ni	Ir	NF
Remote Control	√	x	x	√	x	√	x	√	x
Security	√	x	x	x	√	√	x	x	√
Health and Fitness	√	√	√	x	x	x	√	x	x
Smart Meters	√	x	x	x	√	√	x	x	x
Cell Phones	√	x	√	x	x	√	x	√	√
Automotive	√	x	x	x	x	√	x	x	√
Heart Rate	√	x	√	x	x	x	x	x	x
Blood Glucose	√	x	√	x	x	x	x	x	x
Positioning	√	x	x	x	√	√	x	x	x
Tracking	√	x	x	x	√	x	x	x	√
Payment	x	x	x	x	x	x	x	x	√
Gaming	√	x	x	x	x	x	x	√	x
Key Fobs	√	x	x	√	x	x	x	√	√
3D TV	√	x	x	x	x	x	x	√	x
Smart Applications	√	x	x	x	√	x	x	x	x
Intelligent Transport Systems	√	√	√	x	√	x	x	x	x
PCs	√	x	x	x	x	√	x	√	√
TVs	√	x	x	√	x	√	x	√	x
Animal Tagging	√	x	x	x	√	x	x	x	√
Assisted Living	√	√	√	x	x	x	x	x	√

Table 5: Low-power wireless technology target markets.

Key: **LE** (Bluetooth low energy), **A** (ANT), **A+** (ANT+), **RF** (RF4CE), **Zi** (ZigBee), **Wi** (Wi-Fi), **Ni** (Nike+), **Ir** (IrDA), **NF** (NFC)

LE is the closest competitor and will be competing in the same markets and many others, offering mobile handset manufacturers a route to a larger ecosystem. LE also provides the best power per bit requirements of the personal space technologies, beaten only by Wi-Fi.

Wi-Fi is normally intended for bulk traffic transfer at high speed. Work is in progress to enable special Wi-Fi chips to operate in HID equipment. However, currently available chipsets for HID over Wi-Fi are proprietary and require a special driver to be installed on Microsoft Windows® 7 PCs. In addition, such systems are likely to consume significant power at the PC end of the link to minimize latency.

ZigBee and RF4CE are virtually the same technology and appear positively power hungry compared with the other radio technologies.

NFC is not seen as a competitor to most low-power wireless technologies, because it brings new use cases to the mobile scene. It is a short range (~5 cm) radio which is ideally suited to "Touch to <action>" applications.

The cost of implementing IR transmit-only is very cheap and may still remain a viable option in low-end televisions for the near future. IR has been around for a long time and is being replaced in most areas by non-line-of-sight radio technology. It is also relatively power hungry. By switching to radio, running costs for traditional IR products will be reduced considerably. In an increasingly environmentally conscious world, this reduction in power consumption is a good thing — it's 'Green.'