



Comparisons between Low Power Wireless Technologies

Bluetooth low energy,
ANT, ANT+, RF4CE,
ZigBee, Wi-Fi, Nike+,
IrDA and NFC

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This whitepaper describes the differences between various competing wireless technologies in the ultra low power market place.

Abstract

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 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 that 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 targeted devices needing to operate for extended periods of time from coin cells or energy scavenger technology. Apart from a low chipset cost having obvious advantages, 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 document analyses 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.



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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 [1].

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 may also be known as Bluetooth v4.0 and is part of the public Bluetooth specification [2]. As a result of being a standard, LE benefits from all the advantages of conformance and extensive interoperability testing at unplugged tests. 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 chip sets 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 2.4GHz spectrum. It was established in 2004 [3] by the sensor company Dynastream. Typically, the ANT transceiver device is treated as a black box [4] and shouldn't require much design effort to implement 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 all ANT+ branded devices work seamlessly [5]. 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 [6].



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 controls [7]. Unfortunately, ZigBee's complexity and power requirements don't make it particularly suitable for unmaintained devices that need to operate for extensive periods from a limited power source [8]. ZigBee channels are similar to those for LE, in that they are 2MHz wide, however they are separated by 5MHz thus wasting spectrum somewhat [9]. ZigBee is not a frequency hopping technology [10], it therefore requires careful planning during deployment, to ensure no interferers are 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 [11]. 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 [12].

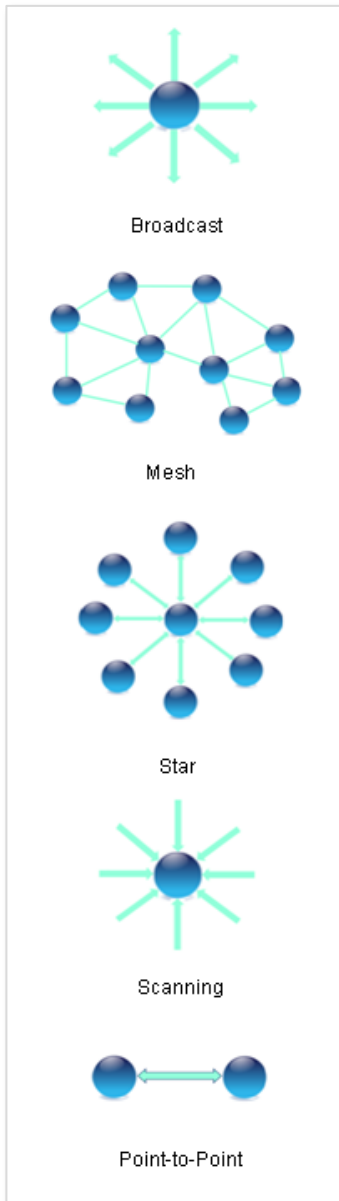
How does Wi-Fi compare?

In recent years, a number of improvements have been made to the wireless-fidelity (Wi-Fi) IEEE 802.11 wireless networking standard, which may be able to reduce its power consumption: 802.11v and proprietary. Although Wi-Fi is a very efficient wireless technology, it is optimized for large data transfer using high speed throughput and not really suitable for coin cell operation. Some companies are attempting to use Wi-Fi for HID devices, however special proprietary driver software is required and only limited functionality can be achieved [10].

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 [13]. 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 document, 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).





Network Topologies

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 1Gbps. However, it only works over a distance of less than 10cm [14]. 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's a two component solution as an absolute minimum, because it needs a processor and transceiver.

Is NFC going to take over?

Unlikely. Near Field Communication (NFC) is significantly different to the other low power wireless technologies discussed in this document. It only works up to a range of approximately 5cm and consumes relatively more power. Passive NFC tags can be completely unpowered, but will only become active when an NFC field is present. That eliminates it 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 document. 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, similar to a television signal.
- **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 device which is constantly in receive mode, waiting to pick up a signal from anything transmitting within range.
- **Point-to-Point:** A one-to-one connection, where only two devices are connected, similar to a basic phone call.

Which technology supports which topology?

The table below shows which wireless technologies, support which network topologies:

Network Topologies supported by Wireless Technologies

	LE	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	✓	✓	✓	✓	✓	✓	✓	✓	✓

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?

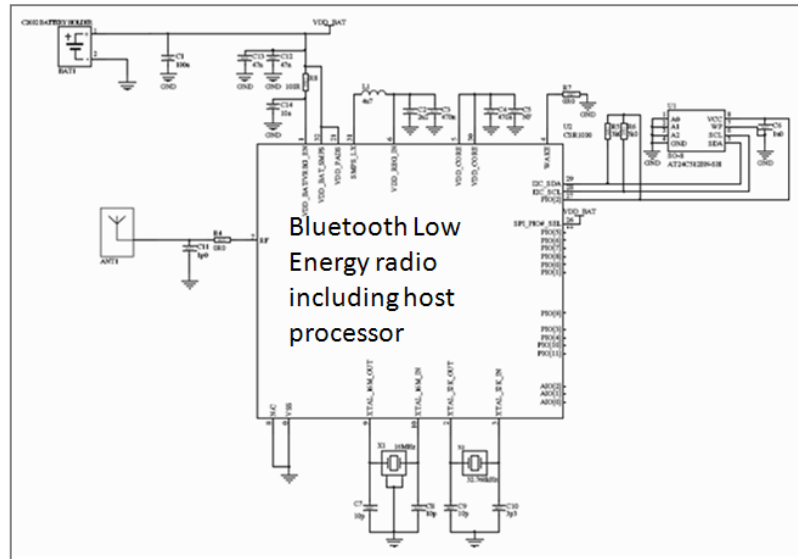
Based on the amount of software that would be required to implement a simple program and hardware requirements, it's possible to estimate how much effort may be required to implement a simple connectivity application.

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 work with. 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 a pre-certified unit. This means Original End Manufacturers (OEM) don't need to spend resources qualifying their new products. If the developer decides to deviate significantly from a given reference design, then it's possible that some features may need retesting.

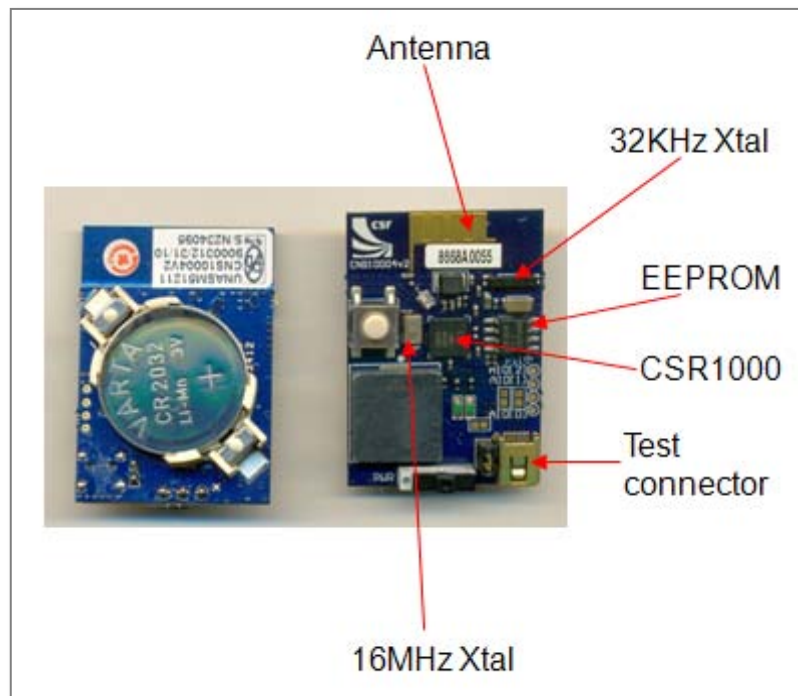
Bluetooth low energy chipsets come in two categories: single mode and Bluetooth + Bluetooth low energy.

The hardware for a single mode LE device is very simple, as shown in the schematic below.



A Complete Bluetooth Low Energy Beacon Schematic

The photo below shows a real device implementing Bluetooth v4.0. This unit consists of the above schematic, a buzzer, a Light-Emitting Diode (LED) and a switch.



A Real Bluetooth Low Energy Device

A Bill of Materials (BOM) for the real LE device, is shown below:

A BOM for a Bluetooth Low Energy Device

Component	Quantity	Cost (\$)
Battery	1	0.325 [15]
Antenna	1	0 (Printed Antenna)
EEPROM¹	1	0.89 [16]
Decoupling Cap	6	0.002 [17]
Signal Cap	5	0.0.02 [17]
Resistor	4	0.0001 [18]
Crystal	2	0.243 [19]
Bluetooth low energy IC	1	Approx \$1
Total		\$2.72

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 64Kbytes [11] 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 are a single chip solution that offer 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 [20]. Certification for ANT+ is compulsory and costs are still being finalized [6]. 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 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 [6].

IrDA has some simple protocols that can be obtained in a simple micro processor IC + LED and receiver [21]. 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 [22].

NFC integration has recently been simplified with the release of an open source protocol stack from Inside Contactless [23]. 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 13.56MHz band. A new certification program has been established which offers manufacturers the opportunity to prove their device is fully interoperable [24].

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 radio specified performance is achieved. Certification is not compulsory, however the Wi-Fi logo can not be obtained unless certified [25]. Certification costs are high relative to the other technologies discussed here. This is because of the amount of testing that's 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 processor, radio, antenna, battery, battery connector, sensor, regulator and the Printed Circuit Board (PCB). The table below 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 listed below:

Least Expensive

- NFC 500ppm (parts per million): NFC provides data clocking, a crystal is only required keep the radio in band.
- LE 250ppm [26]
- Nike+ 60ppm [27]
- ANT 50ppm [28]
- RF4CE 40ppm [29]

Most Expensive

An equivalent frequency crystal at 30ppm and 250ppm gives a cost adder of £0.58 – £0.248 = £0.332

Bluetooth Low Energy Device Manufacturing Costs

	Processor	Radio	Antenna	Regulator	PCB Size
LE	N/A	\$2.95/1k ¹ [30]	Printed 8mm ²	N/A	20mm2 ³
A	\$low	\$3.95/10k [31]	Printed 'F' 15mm	N/A	125mm2 [32]
A+	N/A	\$3.33/1k [33]	Printed 'F' 15mm	N/A	306mm2 [34]
Zi	N/A	\$3.20/1k [35]	Printed 'F' 15mm	N/A	305mm2 [29]
RF	N/A	\$2.75/1k [36]	Printed 'F' 15mm	N/A	305mm2 [29]
Wi	\$high	\$3	Printed 8mm ²	\$1.50 ⁴	60mm2
Ni	\$low	\$1.60/10k [37]	Metal 2cm	N/A	300mm2 [38]
Ir	N/A	\$1.97/10k [39]	8mm	N/A	21 mm2 + CPU [40]
NF	\$high	\$1	50mmx 30mm	\$0.33 ⁵	100mm2 [41]

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% adder.

² Cambridge Silicon Radio (CSR) patented printed antenna design may be used with CSR chips.

³ Bluetooth and LE [42]. LE only is aimed at medium cost PCB technologies, therefore modules are approximately 96mm2 including antenna [43].

⁴ Wi-Fi requires 1v8 @200mA and 3v3 @400mA = £0.86. At an exchange rate of £1.75 to \$1 => \$1.50 [44] [45].

⁵ NFC requires 50mA @ 3v3 = £0.194. At an exchange rate of £1.75 to \$1 => \$0.33 [46].

Efficiency

Protocol

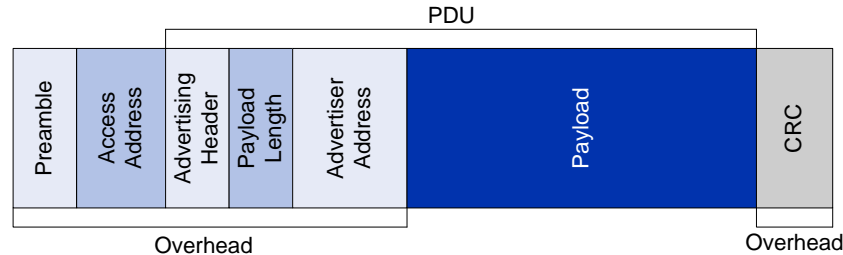
A wireless transmission consists of two main components, payload and overhead. These are used to ensure packets are delivered reliably. The efficiency of the protocol can be measured as the ratio of payload to total packet length. If a protocol is very inefficient and spends most of its time transferring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

ANT

An ANT packet consists of an 8 byte payload wrapped by various other components [8]. Without any evidence, due to its proprietary black box nature, the efficiency of ANT is stated to be 47%.

Bluetooth low energy

LE, being an open standard, has the breakdown of packets published. The following diagram shows a typical packet [47].



Protocol efficiency has a significant bearing on the amount of useful data that can be transferred from a single battery charge. A

Bluetooth low energy device is 66% efficient. When compared with its nearest competitor's 47% efficiency, one can expect a Bluetooth low energy device to last 19% longer or achieve 19% more data throughput from the same battery.

```
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:

$$\text{Payload/Total length} = 31/47 = 0.66 > \mathbf{66\% \text{ efficient}}$$

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 32Bytes/second and consumes 61uA [48].

- A byte consists of 8 bits, therefore $32 \times 8 = 256$ bits/second
- Power = $VI = 3v \times 61uA = 0.183mW$
- Power per bit = $0.183mW / 256bits = \mathbf{0.71uW/bit}$

Bluetooth low energy


Connectable adverts, broadcast every 500ms. Each packet has 20bytes of useful payload and consumes 49uA at 3V [49]. 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 = $49uA \times 3V = 0.147mW$
- Bytes per second = $20 \times (1second / 500ms) \times 3 channels = 120Bytes/second$
- Bits per second = $120 Bytes/second \times 8 = 960 bits/second$
- Power per bit = $0.147mW / 960 = \mathbf{0.153uW/bit}$

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 31bytes 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 0.1uA during sleep, allowing for its negligible power consumption to be ignored for this calculation). The transaction takes 1.5ms @170uA then 114ms @ 55uA [50].

- Power = $0.163mW$
 - Bits = 14
 - Power per bit = $0.163mW / 14bits = \mathbf{11.7uW/bit}$
- 

Ultra high efficiency is achieved by Wi-Fi operating at high speed. However, it's unsuitable for power sensitive coin cells. Bluetooth low energy is the next most efficient technology and also brings various other benefits over Wi-Fi for the intended use cases.

With a demonstrable range of 300m at <10dBm output power, Bluetooth low energy should be capable of virtually any personal area network required.

Nike+

A foot pod lasts 1000 hours and transmits its payload every second. The payload is 34 bytes [51]. A typical CR2032 has 225mAh.

- Current drawn = $225\text{mAh} / 1000\text{hours} = 0.225\text{mA}$
- Power = $3 \times 0.225\text{mA} = 0.675\text{mW}$
- Bits per second = $34 \times 8 = 272 \text{ bits/second}$
- Power per bit = $0.675\text{mW} / 272 = \mathbf{2.48\mu\text{W/bit}}$

Wi-Fi

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

- Power = $116\text{mA} \times 1.8\text{V} = 0.210\text{W}$
- Power per bit = $0.210 / 40,000,000 = \mathbf{0.00525\mu\text{W/bit}}$

Zigbee

A Zigbee device consumes 0.035706W when transferring 24 bytes of data [77].

- Bits per second = $24 \times 8 = 192 \text{ bits}$
- Power per bit = $0.035706 / 192 = \mathbf{185.9\mu\text{W/bit}}$

From the above calculations, it's clear that Wi-Fi is the most power efficient technology and would be ideally suited to large file downloads. However, 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, however, 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 [52]. Similar problems can be observed in the health and fitness space, where users have body mounted gadgets and move continuously. It's worth noting that 2.4GHz 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 ~ 5cm [53]
- IrDA ~ 10cm [54]
- Nike+ ~ 10m [55]
- ANT(+) ~ 30m [32]
- ZigBee ~ 100m [32]
- RF4CE based on ZigBee ~ 100m
- Wi-Fi ~ 150m [56]
- LE ~ 280m

Robustness

Reliable packet transfer has a direct influence on battery life or 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 which can be avoided in future transactions.

ANT is specified to operate over 8 channels. However, it is often the case that sensor node chipsets only operate on a single channel [57]. 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+ recognises this and recommends file transfers are only 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 [9].

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 [9] and 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 a 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 centimetres of each other. LE adverts are spread across 3 channels, therefore requiring 3 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 signalling rate, which is often quoted on packaging (for example Wi-Fi 54Mbps)
- The more useful method is to measure how quickly useful payload data can be transferred

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

- IrDA ~ 1Gbps [54]
- Wi-Fi (lowest power 802.11b mode) ~ 6Mbps [58]
- NFC ~ 424kbps [53]
- LE ~ 305kbps [59]
- ZigBee ~ 100kbps [60] [61]
- RF4CE (same as ZigBee)
- ANT+ 20kbps [62]
- Nike+ ~ 272bps [51]

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's 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 powered wireless network technologies:

- ANT ~ "zero" [63]
- Wi-Fi ~ 1.5ms [64]
- LE ~ 2.5ms [59]
- ZigBee ~ 20ms [61]
- IrDA ~ 25ms [50]
- NFC ~ polled typically every second, this is manufacturer specific
- Nike+ ~ 1second [51]

Low latency is often achieved at the expense of increased power consumption at the receiver. If a negotiated link is established, as with Bluetooth low energy, then the latency can be minimised while still maintaining low power requirements.

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 don't 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 15mA peaks without damage [65]. If the peak current exceeds 15mA then battery life may be degraded. Demanding 30mA peaks would reduce realized capacity by about 10% of manufacturers stated figures. Acceptable continuous standard loads are typically 2mA 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 (3cm²) would yield 1.5v x 8uA = 12uW [66]. With such small amounts of power available, it is critical that a radio is selected that doesn't have high current demands.

The figure below shows typical peak current consumption for wireless technologies, and therefore, which can operate from Manganese Dioxide Lithium coin batteries such as the CR2032:

<ul style="list-style-type: none"> ▪ IrDA peak current draw ~ 10.2mA [67] ▪ Nike+ peak current draw ~ 12.3mA [68] ▪ LE peak current draw ~ 12.5mA [69] ▪ ANT peak current draw ~ 17mA [70] 	CR2032 OK
<ul style="list-style-type: none"> ▪ RF4CE peak current draw ~ 40mA [71] ▪ NFC ~ 50mA [53] ▪ Wi-Fi peak current draw ~ 116mA (@1.8v) 	Too much current demand

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 signalling 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 document, we will refer to coexistence schemes as active and passive, where passive is an interference avoidance system and active is chip-to-chip signalling.

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, AFH 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 2.4GHz 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 neighbouring wireless technology.

IrDA doesn't 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.

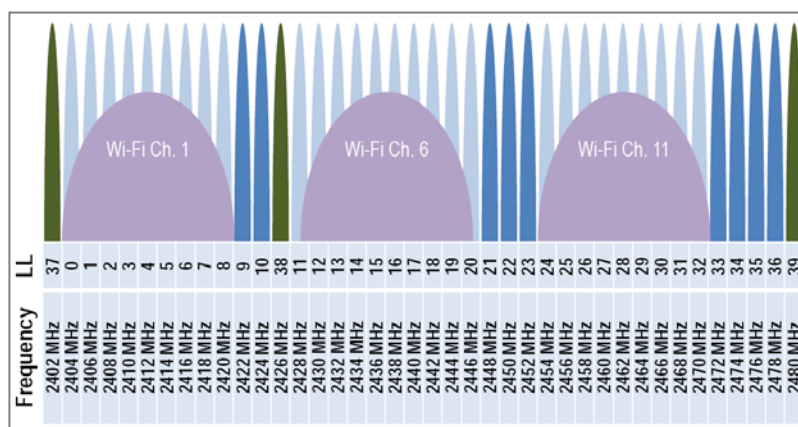
NFC implements a form of coexistence where the reader is able to select a particular tag from a wallet containing many NFC cards. NFC is similar to IR in that its range is very short and unlikely to interfere with other NFC devices. It is worth noting that 13.56MHz, has harmonics in the Frequency Modulation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

ANT devices normally operate over a single channel, 8 channel chipsets are available, but 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 [72]. 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 [73]. If the used channel is fully occupied, an ANT network doesn't have the ability to hop to a clear part of the spectrum. This therefore halts data transfer. ANT burst mode uses the assigned channel in an aggressive manner and can quite easily absorb a channels entire bandwidth. This halts communications between other ANT devices in the vicinity [74]. One would assume other continuous interferers, Wi-Fi or household mobile phones, would also cause similar problems to an ANT network.

ZigBee doesn't implement a coexistence scheme, but does have the ability to continuously listen for clear time on its channel. If the channel is heavily used then 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 [9].

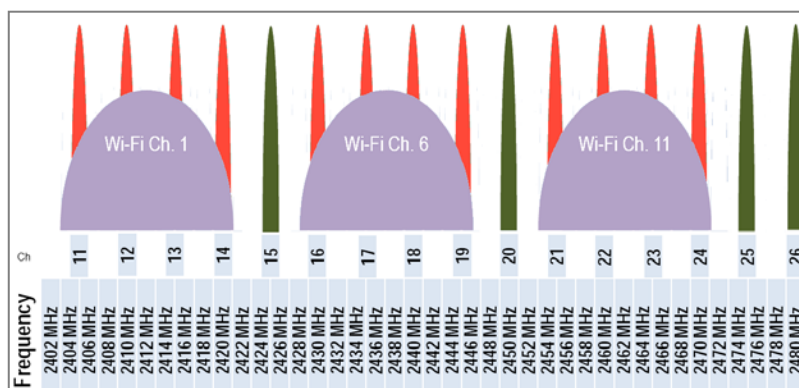
It is unclear whether Nike+ implements any form of coexistence scheme. It can evidently operate in the same vicinity as other Nike+ devices, because it works in crowded gyms. The likelihood of discovering a regular interferer while exercising outdoors, is minimal, therefore reducing the need for 100%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

The following diagrams show spectrum usage for LE and ZigBee.



Bluetooth Low Energy Channel Allocations

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



ZigBee Channel Allocations

Note: Each channel is 2MHz wide with a wasteful 5MHz spacing. In the presence of Wi-Fi, only 4 channels are likely to be available.

Each channel is 2MHz wide, but the spacing and placement of ZigBee channels implies that only 4 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 signalling data rate of only 250kbps 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.

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 to physical size.

Life time figures for this type of battery can be obtained in two ways. From earlier in this document, 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's possible to look at average power consumption while a sensor device is operating.

The ANT website provides a handy calculator for estimating current draw [75]. The scenario modelled, is the most efficient chipset (AT3), which sends 120Bytes/second. Each page in ANT is 8Bytes long [73] and therefore needs to transmit at $120/8 = 15\text{Hz}$ to achieve 120B/s throughput. The unit is switched on continuously throughout the day with a 225mAh battery. Average current is 175.5uA and a battery would last **52.64 days**.

Achieving the same data rate of 120Bytes/second with LE, draws an average current of 49uA as described in earlier calculations. A 225mAh battery should support this current draw for $225\text{mAh}/49\text{uA} = 4592\text{ hours} = \mathbf{191\text{ days}}$.

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 34Bytes/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 document are targeted towards specific market segments, some of which overlap. The table below shows examples of these identified target markets.

Low Power Wireless Technology Target Markets

	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	✓
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	✓

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

Summary

The research in this document 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 [3] 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 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 Windows 7 PCs [76]. 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 [70].

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 (~5cm) 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's 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'.



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