One Small Step for Bluetooth Low Energy Technology

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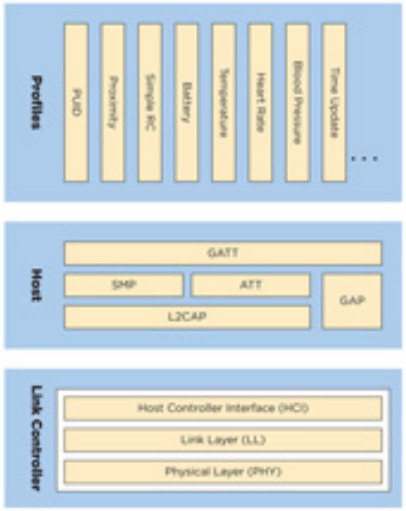
Last December, the Bluetooth Special Interest Group (SIG) announced in a statement that it had adopted Bluetooth low energy wireless technology and that the much anticipated ultra-low power (ULP) form of the popular wireless technology, would be the hallmark feature of the Bluetooth Core Specification Version 4.0. Although the adopted portions of the new specification are available on Bluetooth.com and samples of sensors utilizing this specification are available from some silicon manufacturers today, semiconductor vendors won't be shipping Bluetooth low energy chips for a while yet because the full integration of the technology is not yet complete.



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What this means is that there are still several parts of the technology's layered architecture that are being tested by the SIG. (Behind the scenes, engineers from member companies, including the firm I work for, ULP wireless technology expert Nordic Semiconductor, are working tirelessly to iron out the last few glitches of the full specification.) The SIG currently estimates that the full specification will be published this summer. But what the adopted portion of the specification does do is define the layers of Bluetooth low energy architecture, the Physical Layer (PHY) (which transmits bits), Link Layer (LL) (which defines packet structure and control) and Host Controller Interface (HCI). Collectively, these three layers are known as the Bluetooth low energy Link Controller (or "Controller"). (See Figure 1.)

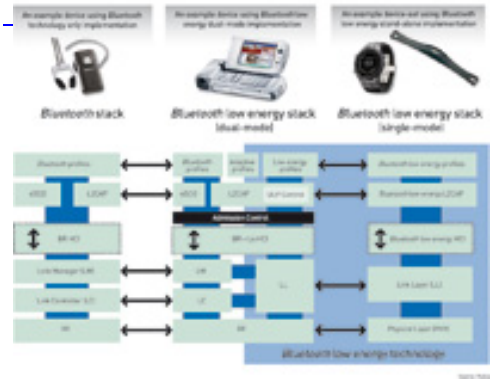
While it's short of a full product definition, publishing the Controller specification is a significant development because it lifts the veil from Bluetooth low energy

technology foundation and reveals how it is able to operate with such low power demands that it can operate from low capacity and limited peak current coin cell batteries. Let’s take a closer look.

Single and Dual Mode

Bluetooth Version 2.1 + EDR and Version 3.0 + HS (commonly referred to as “Classic Bluetooth technology”) and Bluetooth low energy technology have much in common: they are all low cost, short range, interoperable, robust wireless technologies operating in the license-free 2.4GHz Industrial, Scientific and Medical (ISM) RF band.

But there is one critical difference: Bluetooth low energy technology was designed from the outset to be ULP technology whereas Classic Bluetooth technology is a “low power” wireless technology.



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This difference dictates that the operational characteristics of Classic Bluetooth technology and Bluetooth low energy technology are opposites. Classic Bluetooth technology is a “connection oriented” radio with a fixed connection interval ideal for high activity connections like mobile phones linking with wireless headsets. Among several measures to reduce the power consumption, Bluetooth low energy technology employs a variable connection interval that can be set from a few milliseconds to several seconds depending on the application. In addition, because it features a very rapid connection, Bluetooth low energy technology can normally be in a “not connected” state (saving power) where the two ends of a link are aware of each other, but only link up when absolutely necessary and then for as short a time as possible.

Frequency (MHz)	Bluetooth low energy Advertising channel	Bluetooth low energy Data channel	Wi-Fi Channel
2480	39		
2478		36	
2476		35	
2474		34	
2472		33	11
2470		32	11
2468		31	11
2466		30	11
2464		29	11
2462		28	11
2460		27	11
2458		26	11
2456		25	11
2454		24	11
2452		23	11
2450		22	
2448		21	6
2446		20	6
2444		19	6
2442		18	6
2440		17	6
2438		16	6
2436		15	6
2434		14	6
2432		13	6
2430		12	6
2428		11	6
2426	38		
2424		10	
2422		9	1
2420		8	1
2418		7	1
2416		6	1
2414		5	1
2412		4	1
2410		3	1
2408		2	1
2406		1	1
2404		0	1
2402	37		1

[3]

The operational mode of Bluetooth low energy technology ideally suits transmission of data from compact wireless sensors (exchanging data every half second) or other peripherals like remote controls where fully asynchronous communication can be used. These devices send low volumes of data (i.e. a few bytes) infrequently (for example, a few times per second to once every minute or more seldom).

Before we look in more detail at what this means for a design engineer, we need to consider the two types of chips that together form Bluetooth low energy architecture: single mode and dual mode.

A single mode device is a Bluetooth low energy-only chip that’s brand new to the Bluetooth specification – it’s the part of the technology optimized for ULP operation. Single mode chips can communicate with other single mode chips and dual mode chips when the latter are using the Bluetooth low energy technology part of their architecture to transmit and receive. (See Figure 2.)

Dual mode chips will also have the capability of communication with Classic Bluetooth technology and other dual mode chips using their conventional Bluetooth architecture.

Dual mode chips will be used anywhere a Classic Bluetooth chip is used today. The consequence is that cell phones, PCs, Personal Navigation Devices (PNDs) or other applications fitted with a dual mode chip will be capable of communicating with all the legacy Classic Bluetooth devices already on the market as well as all future Bluetooth low energy devices. However, because they are required to perform Classic Bluetooth and Bluetooth low energy duties, dual mode chips are not optimized for ULP operation to the same degree as single mode devices.

Coin Cell Wireless Technology

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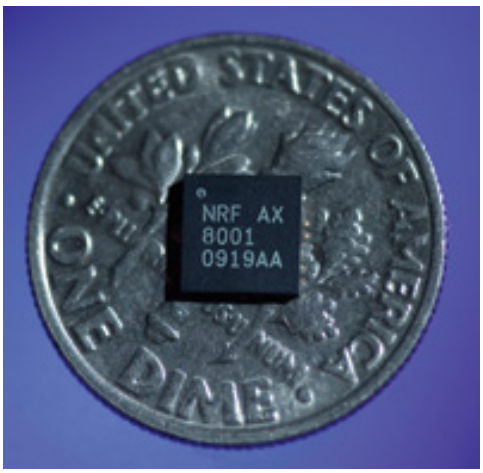
How will the ULP characteristics of Bluetooth low energy influence wireless design? Well, these characteristics mean that a Bluetooth low energy single mode chip can operate for long periods (months or even years) from a coin cell battery such as a 3V, 220mAh CR2032 or 3V, 160mAh CR2025. In contrast, Classic Bluetooth technology (and Bluetooth low energy dual mode devices) typically require the capacity of at least two AAA cells (which have 10 to 12 times the capacity of a coin cell and much higher peak current tolerance), and often more, to power them for days or weeks at most (depending on the application). (Note: There are some highly specialized Classic Bluetooth applications that can run on batteries with a lower capacity than AAA cells.

) Coin cell operation placed severe restrictions on the engineers drawing up the specification. For example, drawing even a transient peak current of more than 20mA from a CR2032 coin cell risks damage.

The maximum nominal constant current is around 200µA (depending on the battery manufacturer). But with this usage the battery won’t last as long as mathematically determined by the nominal capacity, because lifetime is related to discharge rate as well as current. The lower the discharge rate, the closer to the nominal capacity the battery will supply. For example, to last for a year, a CR2032 coin cell can sustain a maximum nominal current of just 25µA (220mAh/(24hr x 365days)).



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Several silicon vendors are designing single mode Bluetooth low energy transceivers with peak currents below the maximum tolerance of a coin cell battery when transmitting or receiving packets. (Multiple vendors of “standard” parts are one of the key benefits of an open standard – although note that some “standard” parts are better than others. For example, Nordic Semiconductor has designed a single mode Bluetooth low energy silicon radio that features peak currents below 15mA.

A simple calculation shows that with peak currents of 20mA the silicon radio can transmit for no more than 0.25 percent of the time - the rest of the time has to be spent sleeping, drawing just nanoamps - if the average current is to be kept to just a few tens of microamps and coin cell battery life extended to one year or more.

Much depends on the application of course, but for a typical Bluetooth low energy sensor application such as a sports watch linking to heart rate belt (used for, say, 1.2 hours per day), the average current drawn from a Nordic single mode chip would be about 12µA, giving up to two years of life from the CR2032 battery.

The Technology of Ultra Low Power Wireless

There are three characteristics of Bluetooth low energy technology that underlie its ULP performance: maximized standby time, fast connection, and low peak transmit/receive power.

As we’ve seen above, switching the radio “on” for anything other than very brief periods dramatically reduces battery life, so any transmitting or receiving that has to be done needs to be done quickly. The first trick Bluetooth low energy technology uses to minimize time on air is to employ only three “advertising” channels to search for other devices or promote its own presence to devices that might be looking to make a connection. In comparison, Classic Bluetooth technology uses 32 channels.

This means Bluetooth low energy technology has to switch “on” for just 0.6 to

1.2ms to scan for other devices, while Classic Bluetooth technology requires 22.5ms to scan its 32 channels. Consequently, Bluetooth low energy technology uses 10 to 20 times less power than Classic Bluetooth technology to locate other radios.

Note that the use of three advertising channels is a slight compromise: it's a trade between "on" time (and hence power) and robustness in what is a very crowded part of the spectrum (with fewer advertising channels, there is a greater chance of another radio broadcasting on one of the chosen frequencies and corrupting the signal). The specification's designers are confident they have balanced this compromise – they have, for example, chosen the advertising channels such that they don't clash with Wi-Fi's default channels. (See Figure 3.)

Once connected, Bluetooth low energy technology switches to one of its 37 data channels. During the short data transmission period the radio switches between channels in a pseudo-random pattern using the Adaptive Frequency Hopping (AFH) technology pioneered by Classic Bluetooth technology (although Classic Bluetooth technology uses 79 data channels).

Another reason why Bluetooth low energy technology spends minimal time on air is because it features a raw data bandwidth of 1Mbps – greater bandwidth allows more information to be sent in less time. A competing technology that features a bandwidth of 250kbps, for example, has to be "on" for eight times as long (using more battery energy) to send the same amount of information.

Bluetooth low energy technology can "complete" a connection (i.e. scan for other devices, link, send data, authenticate, and "gracefully" terminate) in just 3ms. With Classic Bluetooth technology, a similar connection cycle is measured in hundreds of milliseconds. Remember, more time on air requires more energy from the battery.

Bluetooth low energy technology also keeps a lid on peak power in two other ways: by employing more "relaxed" RF parameters than its big brother, and by sending very short packets. Both technologies use a Gaussian Frequency Shift Keying (GFSK) modulation, however, Bluetooth low energy technology uses a modulation index of 0.5 compared to Classic Bluetooth technology 0.35. An index of 0.5 is close to a Gaussian Minimum Shift Keying (GMSK) scheme and lowers the radio's power requirements (the reasons for this are complex and beyond the scope of this article). Two beneficial side effects of the lower modulation index are increased range and enhanced robustness.

Classic Bluetooth technology uses a long packet length. When these longer packets are transmitted the radio has to remain in a relatively high power state for a longer duration, heating the silicon. This changes the material's physical characteristics and would alter the transmission frequency (breaking the link) unless the radio was constantly recalibrated. Recalibration costs power (and requires a closed-loop architecture, making the radio more complex and pushing up the device's price).

In contrast, Bluetooth low energy technology uses very short packets - which keep the silicon cool. Consequently, a Bluetooth low energy transceiver doesn't require

power consuming recalibration and a closed-loop architecture.

Extending the Bluetooth Ecosystem

Bluetooth low energy technology was designed for applications where Classic Bluetooth technology is not viable because of severe power restraints. All of these applications will have one thing in common: they incorporate sensors (or other peripheral devices) powered by coin cell batteries sending small amounts of data infrequently. This is the first time a ULP wireless technology with guaranteed interoperability has been available to electronics designers and promises to kick start hundreds of new applications.

A clue to some of the likely early applications is provided by the Bluetooth SIG's stated intention to follow up the publication of Bluetooth Version 4.0 with the release of profiles for Bluetooth low energy technology including Personal User Interface Devices (PUID) (such as watches), Remote Control, Proximity Alarm, Battery Status, and Heart Rate Monitor coincident with the release of the full specification (or soon after). Other health and fitness monitoring profiles such as blood-glucose and -pressure, cycle cadence, and cycle crank power will follow.

It is beyond the scope of this article to list dozens of potential applications suffice to say this new technology will extend the reach of the Bluetooth ecosystem dramatically. Let's take a look at how Bluetooth low energy technology will be used in just two potential applications: Proximity Alarm and Indoor Location (sometimes referred to as "Indoor GPS").

Dual mode chips are being adopted by cell phone and portable PC makers because they'll cost only very slightly more than Classic Bluetooth technology yet offer so much more functionality. This will allow cell phone makers to offer a security device comprising a Bluetooth low energy powered watch that periodically communicates with the cell phone. If the cell phone moves out of range - and hence can't contact the watch worn by the user – it would automatically lock and the watch would emit an alarm. This would prevent the cell phone being accidentally left behind and prove a major deterrent for any would-be thief.

The proximity alarm application could be extended to a portable PC that locks when the user moves out of range (and perhaps unlocks to be ready for use when the approaching user presses a button on their watch). The application could also be used as a child safety device where the child's watch communicates with a parent's while they remain in range with an alarm sounding if the child wanders away.

The low cost and low maintenance (because batteries require only infrequent changes) of Bluetooth low energy sensors will encourage widespread use in public places. One key application could be indoor location (where there is no GPS signal) whereby sensors around a large public building (such as an airport or rail station) constantly broadcast information about their location. A Bluetooth low energy equipped cell phone passing within range could then display that information to its owner. (See Figure 4.)

Sensors could transmit other information such as flight times and gates, location of amenities, or special offers from nearby shops.

Final Step

The current specification for Bluetooth Version 4.0 doesn't allow silicon vendors to start shipping chips to excited customers. However, it does mean that those companies can qualify their silicon to the Bluetooth low energy Controller specification – and this is a significant step. The Controller forms the bottom three layers of the architecture and is fundamental to the silicon radio's functionality.

Some silicon vendors are well advanced in the design of chips, and have released samples and development kits to selected customers. Nordic, for example, recently announced sample availability of its µBlue ("MicroBlue") Bluetooth low energy chips (and a µBlue Prototype Kit for key customers). The first product in the µBlue family is the nRF8001 – a single mode peripheral solution in a 32-pin 5 by 5mm QFN package incorporating a fully embedded radio, link controller, and host subsystem - suitable for watches, sensors, and remote controls among other applications. (See Figure 5.)

With Controller qualification now possible, these selected customers will receive sample chips that will function exactly as the eventual product in terms of electrical performance and form factor allowing them to embark on some early development work. (These samples will be unable to perform specific applications, such as proximity sensing, because application profiles have not been released in this version of the specification.)

Because the final step to a full specification is not due to happen until this (northern) summer, electronics designers will only get their hands on fully qualified chips to begin their actual product development towards the end of the year. Nonetheless, for a technology that started as a Nokia-led initiative in 2005, to be adopted as a full Bluetooth standard – available to all 13,000 members of the Bluetooth SIG - just five years later is a remarkable achievement.

And once the fully qualified silicon reaches the market, expect a tsunami of Bluetooth low energy products to follow. Analyst IMS estimates that by 2013, a billion Bluetooth low energy devices will be sold every year. That represents the fastest adoption of any wireless technology by far.

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