The Bluetooth Special Interest Group (SIG) has recently formally adopted the latest variant of the popular short-range wireless technology, known as Bluetooth Core Specification Version 4.0 ("Bluetooth v4.0"). The much-anticipated ultra-low power (ULP) form of the popular wireless technology, Bluetooth low energy, is a hallmark feature of this version.

Bluetooth Version 2.1 + EDR and Version 3.0 + HS (commonly referred to as "Classic Bluetooth technology") and Bluetooth v4.0 have much in common: they are all low cost, short range, interoperable, robust wireless technologies operating in the licence-free 2.4 GHz industrial, scientific and medical (ISM) RF band.

But there is one critical difference: The Bluetooth low energy technology part of Bluetooth v4.0 was designed from the outset to be an "ultra-low power" (ULP) wireless technology whereas Classic Bluetooth technology forms a "low power" wireless connection.

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. In contrast, 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.

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).

A tale of two chips

There are two types of chips that together form Bluetooth low energy architecture: Bluetooth low energy devices and Bluetooth v4.0 devices. The Bluetooth low energy chip is brand new to the Bluetooth specification – it’s the part of the technology optimised for ULP operation. These devices can communicate with other Bluetooth low energy chips and Bluetooth v4.0 chips when the latter are using the Bluetooth low energy technology part of their architecture to transmit and receive. (See Fig. 1.) Bluetooth v4.0 devices are capable of both Classic Bluetooth and Bluetooth low energy communication.

Bluetooth v4.0 chips will be used anywhere a Classic Bluetooth chip is used today. The consequence is that cell phones, PCs, personal navigation devices or other applications fitted with the new Bluetooth chips 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, Bluetooth v4.0 chips are not optimised for ULP operation to the same degree as Bluetooth low energy devices.

Bluetooth low energy chips can operate for long periods (months or even years) from a coin cell battery such as a 3 V, 220 mAh CR2032. In contrast, Classic Bluetooth technology (and Bluetooth v4.0)
The technology of ultra low power wireless

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

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 minimise 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 1,2 ms to scan for other devices, while Classic Bluetooth technology requires 22,5 ms 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 Fig. 2.)

Once connected, Bluetooth low energy technology switches to a single data channel. 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 1 Mbps – greater bandwidth allows more information to be sent in less time. An alternative technology that features a bandwidth of 250 kbps, 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” terminates) in just 3 ms. 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 keeps 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. 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 intention to follow up the adoption of Bluetooth v4.0 with the release of a family of “profiles”: these profiles optimise a generic Bluetooth low energy chip for a specific application such as personal user interface devices (PUID) (such as watches), remote control, proximity alarm, battery status and heart rate monitor. Other health and fitness monitoring profiles such as blood-glucose and -pressure, cycle cadence, and cycle crank power will follow. (See Fig 3.)

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”).

Bluetooth v4.0 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. (See Fig. 4.)

Final step

Several silicon vendors are well advanced in the design of their families of Bluetooth low energy chips, and have released samples and development kits. Some, including Nordic, have qualified their chips to the Bluetooth v4.0 specification.

The first device in Nordic’s µBlue Bluetooth low energy chip family, the nRF8001 (plus a µBlue prototype kit and software development kit) was released in January 2011.

By delivering sub 12.5 mA peak currents and connected mode average currents as low as sub 12 µA (for 1s connection intervals), Nordic claims the nRF8001 represents the industry’s lowest power Bluetooth low energy solution.

The chip is a fully qualified Bluetooth v4.0 low energy combining radio, link layer, and host into one end product listing, enabling designers to easily create new Bluetooth end products without any additional listing fees. (See Fig. 5.)

With the silicon now available from several suppliers, the final piece of the Bluetooth low energy puzzle, the profiles, are imminent. The Bluetooth SIG says the first profiles – such as proximity alarm – will start appearing within weeks. That means electronics designers can finally get their hands on fully qualified chips to begin their product development of proximity applications.

It’s taken a while for Bluetooth low energy to reach commercialisation. But now that the fully qualified silicon is reaching the market, expect a tsunami of Bluetooth low energy products to follow. For example, 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.

Contact Andrew Hutton,RF Design, Tel 021 555-8400, andrew@rfdesign.co.za