Sensium Communication Protocol

Robust and reliable ultra-low power wireless connectivity

Overview

As the clinical and economic benefits of wearable, wireless patient monitoring are becoming more widely recognized, a range of products based on different wireless technologies are beginning to appear on the market. In this White Paper, we discuss the main features of various well-known wireless standards, and outline the main features of the proprietary Sensium radio protocol, which is uniquely optimized for wireless vital signs monitoring. These features make the Sensium system unique in ensuring robust, reliable and secure wireless patient monitoring in a miniature and disposable form factor.

The Sensium Wireless Monitoring System

Figure 1 illustrates the operation of the Sensium system. The Sensium Patch is a lightweight, energy-efficient, single use device for monitoring patients' heart rate (HR), respiratory rate (RR), and temperature (T) in a hospital environment. The Patch is designed as an ambulatory wireless monitoring device for patients throughout their stay in the general hospital ward, with no need to recharge the batteries. This single-lead device is attached to the patient's chest by means of two conventional self-adhesive ECG electrodes. Each patch wirelessly links and transmits the vital signs data to dedicated Bridges installed throughout the hospital, which ultimately convey the information to a central monitoring station/server. Patients can be tracked and monitored unobtrusively when wearing the patch, since as patients move through the hospital the Patch will automatically connect to the nearest available Bridge. At the heart of the Patch is a custom integrated circuit (IC) which combines the sensor processing and wireless communication functions into a single piece of low-cost silicon, which enables production of a lightweight device with low manufacturing cost. Therefore the sales price is economic for 'one per patient per stay' use, with the Patch being discarded when the patient is discharged, removing the need for cleaning and sterilisation to prevent cross-contamination.

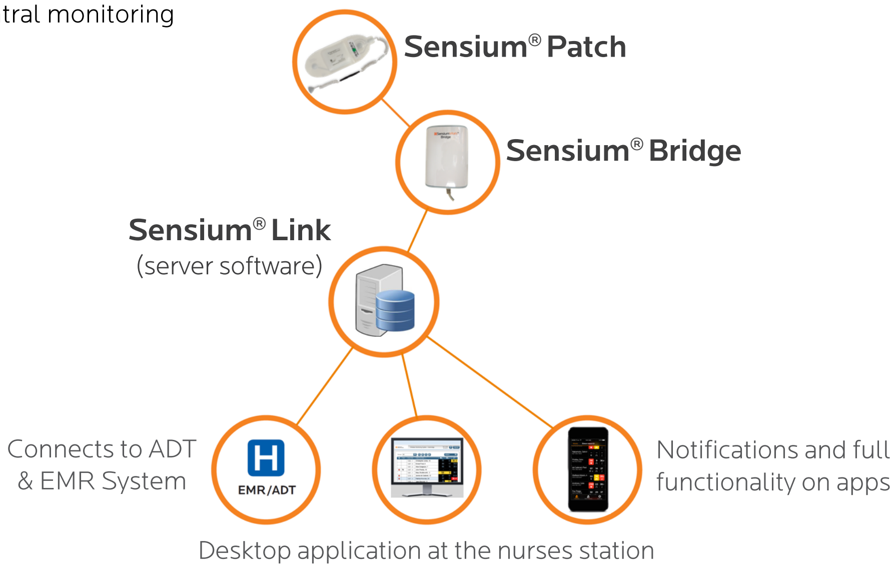

Figure 1: The Sensium system

The wireless link between each Patch and Bridge must satisfy the following requirements:

Low Power: Once activated, the Patch is required to last for five days operating from a CR2032 coin cell. Since the energy storage of a CR2032 coin cell is around 200 milliamp-hours (mAh), the average current consumption of the Patch must be less than 1.7 milliamps (mA). Since the radio operates in a duty-cycled fashion (i.e. it is only on for short periods of time while exchanging data with the Bridge), the peak current consumption can be higher as long as this average target is not exceeded. However the maximum current that can be supplied by a CR2032 is limited to ~10mA; if a larger current than this is drawn, then the battery storage capacity is heavily degraded. So both the peak and the average currents required by the radio must be limited as shown in Figure 2.

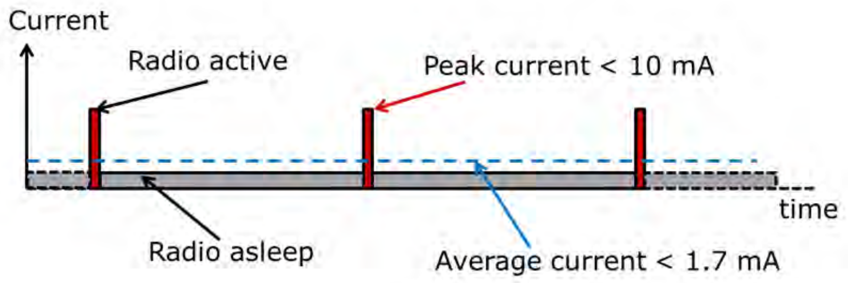

Figure 2: Peak and Average current requirements for five-day operation from a CR2032

Roaming Capability: The Patch is designed for use by ambulatory patients, thus as the patient 'roams' around the hospital, the wireless signal from the patch should transfer seamlessly from one Bridge to the next with no loss of data.

Robust: The wireless connection between the Patch and Bridge must be robust; that is, the data sent by the Patch must be received by the system free of any errors even in the case of interference from other wireless devices nearby.

Secure: The Patch wirelessly transmits personal information (vital signs data) relating to the patient wearing the device. Any unauthorized person 'eavesdropping' as this data is transmitted should not be able to detect and decode the data to discover its meaning.

Safe: Wireless devices such as mobile phones, Wi-Fi enabled laptops and tablets are part of our everyday lives and any health risks relating to the transmission of wireless energy from these devices are generally accepted to be very small. However since the Patch is permanently attached to the patient for up to five days (or longer in some cases), the radio power from the Patch should be minimized ideally below the levels emitted by these other mobile devices, to reassure both patients and clinical staff as to their safety.

Short Range Wireless Technologies

In recent years a number of 'short range' wireless technologies have emerged enabling seamless connectivity between devices (the term 'short range' typically refers to communication distances of 10 - 100m, as opposed to long range cellular links which can be up to several km). The most widely deployed are Wi-Fi, Bluetooth/Bluetooth Low Energy, and Zigbee. These wireless technologies are termed 'standards' because devices are required to conform to a set of rules for communication, to ensure that products (for example from different manufacturers) will be interoperable. The relative merits of each of these technologies for wireless patient monitoring are discussed below.

Wi-Fi

Wi-Fi is a wireless communication technology developed to allow high-speed, low-latency data streaming between devices. The standard has continued to evolve to enable ever higher data rates, so that even large video files can be transferred in just a few seconds. Wi-Fi networks support roaming; a mobile device such as a tablet will transfer seamlessly between fixed access points as it moves through a building. Wi-Fi devices operate in the 2.4GHz and 5GHz frequency bands and a given network will usually be on a fixed channel frequency, so if several different Wi-Fi networks are required in the same vicinity they must be co-ordinated to operate on different channels to avoid interference. Wi-Fi devices typically achieve long range because the transmitted power is high; a typical access point transmit power is 100 milliwatts (mW) which translates to up to 100m range. The penalty for this high speed, long range operation is power consumption; a Wi-Fi device will require many hundreds of milliamps, which is not compatible with small coin cell operation.

Bluetooth (BT)

Bluetooth was developed primarily to allow wireless connectivity between electronic devices and peripherals; for example, between a laptop and a printer, or a mobile phone and a headset. Bluetooth offers robust, reliable and low latency connectivity. While a single BT 'master' device (e.g. a laptop) can support multiple peripherals ('slaves'), the BT protocol does not have inherent support for roaming. This is because master and slave devices need to be paired to set up a connection and thus the peripherals cannot hop from one master to another.

Bluetooth devices operate in the same 2.4GHz frequency band as Wi-Fi, which means that the signal from a BT device can be 'lost' due to interference from Wi-Fi transmissions. To mitigate this, BT uses a technique known as 'frequency hopping' in which the BT devices continually change channel frequency according to a pre-arranged sequence. So if one data packet is lost due to Wi-Fi interference, the next packet transmission will be at a different frequency so is likely to be received successfully.

Bluetooth devices achieve a range of typically 10 to 50 meters depending on the transmit power of the device (which may be up to 100mW but is typically much lower, between 1 and 10 milliwatts depending on the application). Although not as high power as Wi-Fi, the use of frequency hopping, the low latency and the relatively high data rate supported by Bluetooth does incur a power penalty, and typical current consumption is many tens of milliamps.

Bluetooth Low Energy (BTLE)

BTLE (also called BT-Smart) is a recent extension to the BT standard targeted specifically towards low power applications, such as miniature and wearable sensors; an example of a BTLE device could be a heart rate monitor sending data to a sports watch. The communication range is assumed to be relatively short and thus the transmit power is typically just a few milliwatts. The protocol is much simpler than classic Bluetooth because the assumption is that the data rate is low, and the communication is point-to-point, i.e. from any slave device to a single master. Like BT there is no inherent support for roaming, and frequency hopping is employed although the rate at which the devices change frequency is much lower than that of classic BT. As a result, the simplicity of the protocol and the duty-cycled nature of operation mean that current consumption can be as low as 10 mA.

Zigbee

The Zigbee protocol was developed primarily to enable networks of connected objects, for example the creation of intelligent buildings. In such a building, lighting and heating could be automatically controlled by sensors which detect whether the building is occupied, how many occupants are present etc. Zigbee technology thus supports a large number of wireless devices (as there may be many sensors in a large network). One of the main drivers for the Zigbee protocol is achieving good communication range without the very high transmit power required for example by Wi-Fi. This is achieved through the use of more complex modulation techniques as well as by the use of mesh networking, where 'router' devices can store and forward messages from other sensor devices to extend the network range. As a result a Zigbee can achieve a range similar to a Wi-Fi device (100 meters), but at the power consumption of a BT device (10s of milliamps)

Sensium

Sensium was the first wireless protocol developed specifically for ultra-low power wearable wireless patient monitoring. Since new vital sign data is available every two minutes there is no requirement for high data rate and low latency. However, inherent support for roaming is included, as are many other key features including interference detection and avoidance, communication re-try, error detection and encryption. In addition, the power radiated by the Sensium radio when transmitting is very low – around 0.1 milliwatts. This is around 10 times lower than BTLE, 1000 times lower than Wi-Fi, and 10,000 times lower than the power transmitted by a mobile phone. The Sensium radio operates at a frequency between 865MHz and 928MHz depending on geographical region, and thus avoids the crowded 2.4GHz spectrum where Wi-Fi, Bluetooth and other devices such as microwave ovens can generate high levels of interference. Nevertheless there are other devices which operate in the 800/900MHz frequency bands (such as cordless phones, smoke alarms etc.) and these can disrupt the Sensium radio signal because of its very low transmit power. As mitigation, the Sensium radio performs a 'search' across all available frequency channels and selects a channel which is quiet and free from interference. If the Sensium radio detects at a later time that interference is now present, the radio leaves this frequency and repeats the search for another quiet channel. So the radio effectively implements a 'sticky' frequency hopping mechanism, whereby the device will stick on the same channel while that frequency remains clear and will only move channels when significant interference is detected. This allows robust operation without the power overhead required for high speed frequency hopping. As a result the peak current drawn by the Sensium radio is just a few milliamps.

	Wi-Fi	BT	BT-LE	Zigbee	Sensium
Use Case	Real-time streaming (audio/video)	Low latency peripherals	Low data rate peripherals	Connected, smart devices	Wireless patient monitoring
Data Rate	100s Mbps	few Mbps	few 10s kbps	few 10s kbps	few 10s kbps
Range	Up to 100m	few 10s m	~10s m	up to 100 m	~10s m
Roaming	Yes	No	No	Yes	Yes
Frequency	2.4G & 5 GHz	2.4 GHz	2.4 GHz	900M & 2.4 GHz	800/900 MHz
Standard	Yes	Yes	Yes	Yes	No
Power	100s mW++	10s mW+	10-20 mW	10s mW+	Few mW
Peak Current	~100s mA	~50 mA	~10 mA	~50 mA	~ 3 mA

Table 1: Proportions of data available from the wireless digital patch; these data largely reflect the patch algorithm rejecting data that did not pass the internal quality assurance step

Summary

The Sensium radio was the first wireless protocol designed specifically for very low power wireless patient monitoring. As a result, Sensium is the only wireless technology which can implement a robust and secure wireless link which supports seamless roaming at ultra-low power levels. These unique characteristics translate to a small, lightweight wearable Patch which is economic for 'one per patient per stay' use, with the Patch being discarded when the patient is discharged, removing the need for cleaning and sterilization to prevent cross-contamination

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