Sub-GHz Wireless Design Choices for Smart Metering

Introduction

The worldwide focus on energy conservation in the last decade has led to tremendous growth in smart meter deployments, which help manage energy distribution and consumption more efficiently than traditional utility meters. The smart meter is a central device that bridges home energy management systems to long-range back haul communication to utility companies. Utility providers are adding more intelligence to smart meters to differentiate their offerings and allow their customers to make energy choices that best meet their needs. Bidirectional wireless communication enables accurate, real-time utility pricing information to be sent to consumers based on their energy consumption. While "time-of-day" pricing is common today, consumers can now make informed decisions on when to use major appliances in their homes to reduce their energy bill.

The choice of wireless communications technology for a smart meter is a major decision that requires careful consideration of various design choices. The main factors in choosing the optimal communications technology include cost of deployment, security, regulatory compliance, range and power consumption. Several communications technologies are available for wireless connectivity such as Wi-Fi, Bluetooth, ZigBee and sub-GHz wireless. For long-range applications such as the backhaul communication from the meter to a data concentrator and to other meters, sub-GHz technology is a popular choice because of its superior propagation characteristics, long-range performance, low-power operation and the broad access to unlicensed sub-GHz spectrum throughout the globe.

Worldwide Opportunity

Over the next few years, significant numbers of smart meters are expected to be deployed worldwide. The United Kingdom is one of the most-watched markets for smart meter rollouts with the goal of installing smart gas and electric meters in every home and small business by 2020. These deployments in the UK will use ZigBee as well as sub-GHz wireless communications to connect 30 million properties to the smart grid. Italy has the second largest number of gas meters in Europe at 21 million and plans to replace 80 percent of these with smart meters over the next five years. GrDF, a natural gas distributor in France, plans to install 11 million smart gas meters over six years starting in 2015. The 169 MHz and 868 MHz frequency bands are widely expected to be used in all EU smart meter implementations.

According to a report by Pike Research, the installed base of smart meters in China will grow to 377 million units by 2020. The deployment will be split between various wired and wireless technologies, and a large portion of these meters is expected to use sub-GHz wireless devices in the 470-510 MHz band.

TEPCO in Japan has announced plans to install 27 million smart meters over the next decade.

Sub-GHz Wireless in Smart Meters

Sub-GHz wireless technology is present in almost all smart meters today. It is also easy to retrofit traditional meters with sub-GHz wireless communications modules and upgrade services or software over the air.

The most common use of the sub-GHz link is for communication between meters and from the meter to a data collector or concentrator. The sub-GHz network is typically a proprietary network in an unlicensed ISM band such as 902-928 MHz in the US. An emerging trend has been the use of sub-GHz to communicate with in-home appliances. Industry alliances such as ZigBee and Wi-SUN are in the process of standardizing the sub-GHz communication protocol from the physical to the application layer for home energy monitoring systems. These alliances aim to realize interoperability between home appliances and smart meters from any manufacturer with the goal of accelerating the pace of adoption.

Figure 1 shows a typical wireless smart meter system connecting the consumer to the utility.

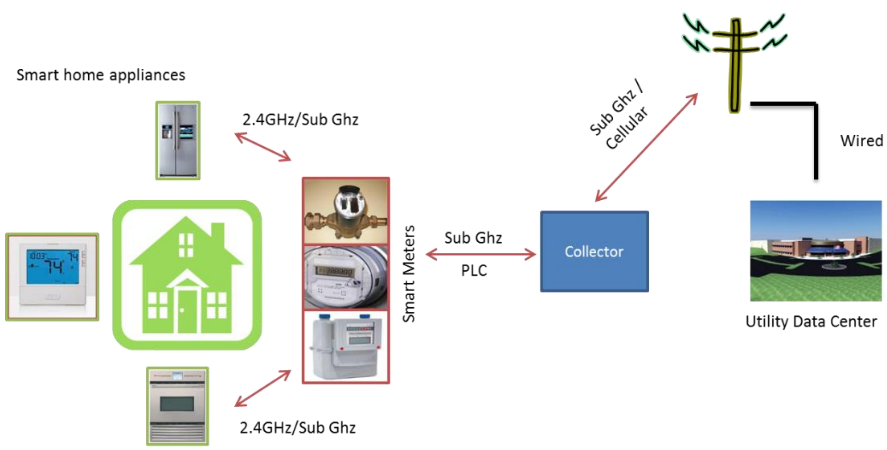

Figure 1. Typical Wireless Metering System Architecture

Let’s take a closer look at some of the key considerations in designing a sub-GHz wireless solution for smart metering.

Wireless Range

One of the primary advantages of using sub-GHz wireless in any application is the long-range capability of this frequency band. Long-range systems reduce the cost of deployments as fewer concentrators and/or repeaters are required to serve the same number of smart meters. RF waves at lower frequencies can travel longer distances for a given output power and receiver sensitivity. This phenomenon can be seen by using the Friis formula for path loss and is governed by the laws of physics.

$P_r = P_t G_t G_r (\lambda/4\pi R)^2$ where Pr is the received power, Pt is the transmitted power, Gt and Gr are the antenna gains at the transmitter, and receiver, R is the distance between antennas and λ is the wavelength.

As a general rule of thumb, a 6 dB increase in link budget will double the range in an outdoor, line-of-sight environment. Thus, the achievable range in the 169 MHz band is better than the 868/915 MHz bands assuming all else is equal.

As wireless system manufacturers try to squeeze every last dB of performance to get the best link budget, it is important to take into consideration other parameters to make an informed decision on trade-offs. In the commonly used GFSK modulation, lower data rates offer better sensitivity and hence longer range. However, the time to transmit a packet at lower rates means that the transmitter and receiver will have to stay in active modes for a longer period of time, which can increase the overall power consumption. Increasing the transmit power of the radio is an easy way to increase range (“whoever shouts the loudest wins”), but this approach comes at the cost of higher power consumption. While several wireless ICs provide solutions with an integrated power amplifier (PA), the efficiency of the PA is a key differentiator. For example, Silicon Labs’ Si446x EZRadioPRO transceivers require only 18 mA to output +10 dBm or 85 mA to output +20 dBm in the 915 MHz frequency band.

As range tests are highly sensitive to the environment and device parameters, it is often tricky to achieve an accurate, apples-to-apples comparison between RF transceiver solutions from different vendors. Care should be taken to ensure that the radio parameters such as frequency, transmit power, bandwidth, packet structure, antenna, and the method of calculating Bit Error Rate (BER) or Packet Error Rate (PER) are all comparable.

Table 1 shows ideal link budgets for different data rates based on currently available transceiver solutions.

Table 1. Wireless Link Budget

Data Rate	Link Budget with +20 dBm Tx
500 kbps	117 dB
100 kbps	126 dB
9.6 kbps	136 dB
500 bps	146 dB

Ultra-Low Power Consumption

Another key design consideration for a wireless smart meter is power consumption. Low-power operation is a critical concern for battery-powered water and gas meters and slightly less so for electric meters. Battery-powered meters typically use Lithium-Thionyl-Chloride ($LiSoCl_2$) batteries, which need to last for 15-20 years with low duty cycle operation. These $LiSoCl_2$ batteries are significantly more expensive than the cost of the other components in the smart meter (roughly 7X-10X the cost of the transceiver IC). Material and labor costs involved in replacing spent batteries frequently are also much higher than the cost of adding expensive batteries upfront.

In gas and water meter systems, embedded components tend to spend a majority of time in low-power sleep or standby states so the current consumed in this state needs to be extremely low in the range of tens of nA. The active transmit and receive currents also need to be low especially at low data rates as they lead to longer transmission and reception times. For example, it will take 1.25 seconds (s) to transmit 1500 bytes at 9.6 kbps and only 0.024s at 500 kbps. PA efficiency is a key parameter that affects link and power budgets. A higher transmit power will increase the communication range at the expense of battery life. Some other parameters that should be considered are fast signal detection within a few bits of preamble, fast state transition times to wake up and go back to sleep, and the ability of the radio to autonomously duty-cycle the device without interrupting the host microcontroller (MCU) for every wakeup and sleep event.

Another factor affecting system power consumption is the ability of the radio transceiver to offload the host MCU from typical packet handling functions such as preamble and sync word detection, Manchester coding and CRC calculations. Performing a majority of these functions in the radio allows the host MCU to spend less time processing the packet and frees up memory and MIPS to perform other functions or remain in a low-power state.

As communication from the meter is periodic and typically on a very low duty-cycle, the low standby and receive current is a key benefit. Silicon Labs' EZRadioPRO transceivers, for example (as shown in the Figure 2 architecture diagram), consume only 50 nA in standby mode. In addition, the device supports a fully configurable autonomous low duty cycle mode, enabling extremely low system power consumption.

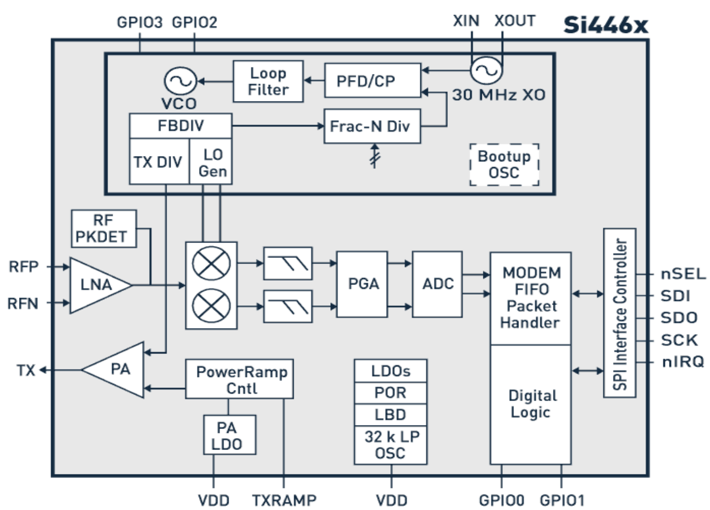

Figure 2. Architecture of Sub-GHz Wireless Transceiver Optimized for Smart Metering

Regulatory Compliance

One of the more challenging aspects of using sub-GHz wireless technology is regulatory and standards compliance. For a designer trying to create a worldwide smart meter product, the 2.4 GHz band is available globally, and only the transmission power needs to be adjusted based on the region's regulatory requirements. However, sub-GHz frequencies vary depending on the region, making it more challenging for hardware and software designers. The ISM band, which is typically where sub-GHz radios operate, is license free. Each country allocates spectrum independently, and some of the common smart meter frequencies are shown in Table 2 and Figure 3.

Table 2. ISM Frequency Bands by World Region

Region	Main Frequency	Regulatory Body and Standard
USA	902-928 MHz	FCC part 15.247
Europe	169 MHz and 868MHz	ETSI EN 300-220 / Wireless M-Bus
Japan	920 MHz	ARIB T-108
China	470-510 MHz	SRRC

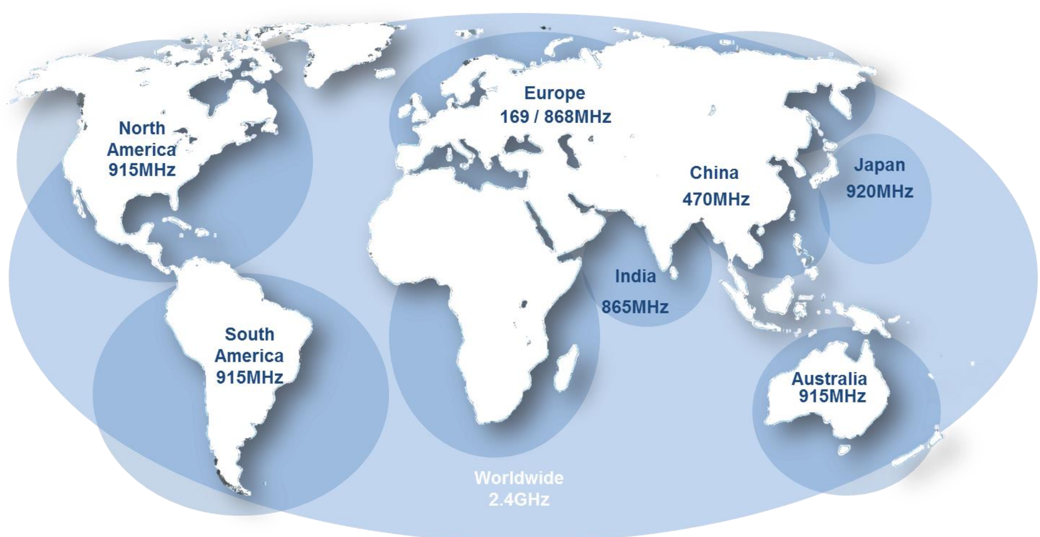

Figure 3. Sub-GHz Frequencies for Smart Meter Deployments Vary Widely by Region

Licensed sub-GHz bands are available in several countries for utilities that may be concerned with interference from other wireless devices. Typically these licensed bands have more stringent regulatory compliance requirements.

For example, in the United States, FCC part 90 applies to a licensed frequency band around 460 MHz. Compliance with certain spectrum mask requirements such as mask D requires extremely good phase noise and narrowband performance at low data rates. More recent integrated sub-GHz transceivers, such as Silicon Labs' Si446x EZRadioPRO devices, meet the regulatory requirements in this frequency band as well.

Most smart meter designs have dedicated hardware for each region or frequency band rather than a common design to meet all worldwide requirements. It is possible to limit the changes to just component values by selecting a common front end matching topology such that the same layout can be used for various regions. Typically the low-level PHY parameters must be optimized for each region to meet regulatory standards requirements.

Significant care must be taken to design a fully compliant solution with the lowest possible BOM cost. Harmonics and spurious emissions have caused many a sleepless night for designers. To ensure success at the compliance testing lab, it is critical to have accurate power control and filtering on the board to minimize emissions.

Packet lengths, data rates and protocol choices such as frequency hopping and number of channels are largely constrained by regulatory requirements.

Standards Compliance

In addition to regulatory compliance, designers must be aware of several wireless standards and industry alliances such as IEEE 802.15.4g/e, Wireless M-Bus, ZigBee and Wi-SUN. All indications are that the industry is moving towards a standard solution based on IEEE 802.15.4 (g/e), which will eventually lead to more choices for consumers as it will enable interoperability among end products. This interoperability ultimately will give consumers the freedom to choose their preferred smart energy products, regardless of the utility that provides their energy. In Europe, Wireless M-Bus is the popular choice for smart meters but there is no official certification process. In the rest of the world, proprietary implementations dominate the deployments today. A worldwide standard acceptable to major players in the smart grid space will help increase the pace of deployments.

IEEE 802.15.4g specifies the physical layer, which is typically supported by the wireless transceiver itself. A majority of MAC layer functions are implemented in a software stack that runs on the host processor. For some applications that do not require interoperability, a standards-based software stack may not be optimal especially in terms of memory requirements and architectural choices such as a star or mesh network. Network latency and power consumption are key factors in determining the final implementation. In these cases, it is common to see proprietary software stacks or a hybrid solution that uses parts of 802.15.4g with a proprietary implementation of the upper layers. Silicon providers today offer standards-based and proprietary stacks that are optimized to run on their MCUs and wireless transceivers and allow for some customization as well. The key is to provide a clean and simple user interface that hides the complexity of the PHY and MAC within the stack.

Conclusion

Range, power consumption and standards compliance are some of the factors that define a sub-GHz wireless design. Fast signal detection, ultra-low power standby currents in the tens of nanoamps and faster state transition times combined with a robust software solution are a few building blocks that enable new ways to improve smart meter efficiency at the system level. While Europe and the US are leading the way in deploying smart metering systems, the high-volume growth in this market is yet to come from emerging economies such as the BRIC nations. China and India, the world's most populous countries with a huge need for secure, energy-efficient metering solutions, are experiencing a growing trend toward the adoption of "smart" sub-GHz wireless communications for smart meters.

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