Wireless Survivor's Guide: Surviving 2.4GHz at Low Power

By: Jim Davis, Product Marketing Engineer, Cypress Semiconductor Corp.

Executive Summary

What do wireless sensor networks, industrial wireless sense and control and the growing demand for personal area networks have in common? Two-things: Wireless and ultra low-power. Historically these two have always been contradictory to each other due to the physics and energy required to transmit signals as well as recently in response to the growing number of wireless solutions—spectrum congestion. This article details the challenges of operating in the 2.4GHz spectrum while maintaining a very low power consumption budget. It introduces active power management and reliability as two factors of maintaining a low power budget while still surviving the interference challenges of the 2.4GHz spectrum.

If you thought the 2.4-GHz wireless spectrum is overcrowded now, let's review some of the emerging wireless technologies that will soon join the party. A quick review of the 2009 International CES list of innovations honorees as well as exhibitors includes: Several Wireless-N Gigabit Network Routers, Wireless HD Video/Audio, Wireless Blu-ray Players, Wireless Earphones/Speakers, Wireless Sensor Networks, and the list goes on; and this is just from the annual consumer electronics show. The list exponentially grows when you include lighting control, home automation, automated meter reading, commercial building control and automation as well as industrial process control and automation applications. We are witnesses to an exciting wireless evolution! This evolution has taken foot thanks to the many innovations in the wireless technologies themselves as well as the radios that are used to transmit and receive their signals—it's obvious that we would not be where we are today if every wireless application required large and cumbersome power sources or if they had to be recharged every hour or two.

How have the 2.4-GHz wireless technologies adapted to meet these requirements? For embedded wireless solutions, the answer has historically been to reduce the power consumption of the components that make up the solution—the microcontroller and the radio transceiver. This Moore's law-like response continues to improve, however, now at a rate of diminishing returns. What was 100s to 10s of milliamp improvements in power savings is now nearing 5 and 1 milliamp differences in efficiency. So, what's next? How do we continue improving power efficiency in our embedded wireless systems? As with most innovations, we need to think outside the box and look at these solutions within the context of the systems they serve. In particular, instead of a focus on just the power efficiencies of the components within the system we must look at their interactions in the system. I propose the most important factors that play a role in further increasing these efficiencies is a combination of protocol or algorithm that adapts to changes within the environment as well as system functions and capabilities that increase reliable communications between system devices and reduce the number of wireless transmissions. In this article I'll highlight how these two changes in how we view embedded wireless solutions can help developers and designers survive the 2.4-GHz spectrum at low power.

Adapting to the Environment

Adapting to the environment is an evolutionary efficiency that runs within our DNA. If the world had no land masses or even fewer land masses then it does, we might all have webbed feet and possibly even gills as our DNA would naturally evolve and with natural selection, only the strong and best adapted for the environment would survive. In a similar context, wireless technologies that have the ability to adapt to the increasingly overcrowded RF environments will survive—and, through the law of transitivity, so will the systems they serve.

Adaptation, in the context of wireless technologies, is the ability of a system to measure and respond to the hostilities that face them—mainly, RF interference. A system that can detect RF interference, or the impacts of that interference, can then appropriately apply countermeasures to respond. For example, let's assume we have a wireless technology that can measure the receive signal strength of a communication transaction. Based on this signal strength and known baselines for ideal and harsh environments, a technology can then *know* what the environment looks like and how ideal or harsh the environment is. A less elegant means of *knowing* the environment could include detecting failed communication attempts as well. The latter method, however, becomes a more reactive approach to triggering adaptation and thus would be less efficient but just as effective in the end. Regardless the method for evaluating and understanding the environment, the next step is to be able to respond—the physical action of adapting to the environment.

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The act of adapting to the environment for embedded wireless technologies is fairly broad but can include actions such as changing power output levels—talking softer or louder, activating a more robust means of communicating—talking clearer, boosting the speed of communicating—talking faster, or moving to a quieter environment to communicate. The first response of changing the output power in response to the environment makes clear logical sense in terms of reducing power outputs in a quiet RF environment, can be counter-intuitive in terms of the reverse. In a noisy environment and in an embedded wireless application where power is like gold, the act of using more power to get the same communications across sounds costly. But let's review what happens if you don't. Assuming all other factors the same and constant, a radio that is transmitting at lower-than-needed power levels to complete a communications transaction will repeatedly try to transmit the data over a short period of time and more-than-likely, burn more power than a solution that immediately transmits the same data in fewer attempts at a higher power output. Let's throw some math into this example to help explain this counter-intuitive approach. First, the configuration: one radio is configured to transmit at +4dBm, or 34.1mA, per transaction and a second radio is configured to transmit at -5dBm, or 20.8mA, per transaction. Power required to transmit the data is defined as the number of attempts multiplied by the power per transaction for each of the radios. In this case, it's very clear that if the +4dBm radio can transmit the data in one pass while the other, -5dBm radio, takes more than one attempt; the +4dBm radio burned less power to get the same data across. What's important here though, is a system's capability to dynamically increase or decrease the power required in response to the environment—use more power when needed and conserve when not needed.

Another means of responding to the RF environment is the ability to speak slower & clearer or, its inverse, faster. In a harsh environment, if a system can dynamically activate a slower but more robust means of communicating, it may be able to improve its ability to deal with the impacts of the interference without impacting its communication. Here are two examples of doing just this: 1) using modulation schemes such as Direct Sequence Spread Spectrum; and 2) advanced forward error correction to the date in-transit. Direct Sequence Spread Spectrum (DSSS) is a modulation scheme that essentially spreads its signal over a relatively wider signal that allows more of the original signal to be received even if there is a higher-power signal in the same area of the spectrum. Another use of DSSS is to take the underlying principles and apply it to the data portion of a packet being transmitted and in the end have a more robust means of forward error correction. In the latter, for example, one can then encode a smaller chunk of data across a larger data packet and then transmit that data packet. In doing this, the system can then deal with interference and still get the message across (see figure 1). The inverse of this method of adaptation is to know when interference is less of a concern and to take advantage of the quieter environment by transmitting at a faster yet less robust means. Again, the important aspect of these methods to adapt to the environment is the dynamic means of switching between these two approaches.

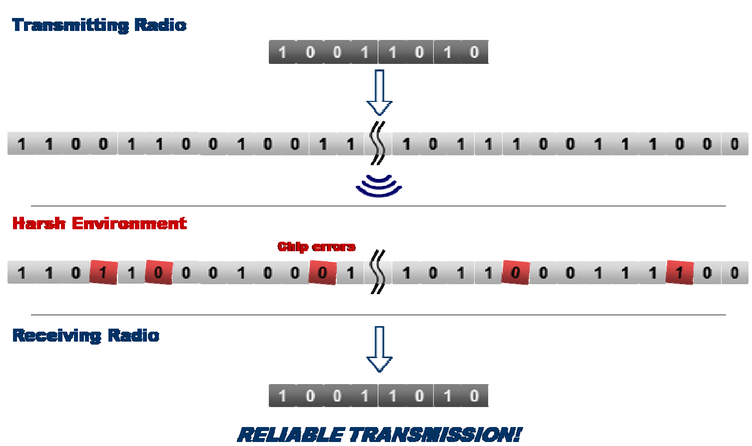

Figure 1 - Example of DSSS principles in use to encode bits of data

Finally, the next available method, but certainly not the last, is to respond by physically moving to a quieter environment in the presence of noise. Two methods employed today by some technologies include a constant and predictable means of moving around the spectrum as well as another approach that only moves when required. While both are relatively effective, the latter is more efficient because 1) the system moves less often; and 2) the system locates and moves to quiet environments rather than a constant hop that can result in moving to less than ideal areas of the spectrum at times.

As with most responses to challenges, the best approach to adaptation is for a system to be able to dynamically adapt across all three of these dimensions. A system that can detect and respond with a multitude of countermeasures will be better able to adapt to a wider variety of environments while minimizing its power consumption.

Reliability = Efficiency

Because of its importance, let's further discuss how reliability leads to better power-efficiencies in a system. Reliability in this context is the ability of a wireless solution to communicate with minimal retransmissions. Retransmission, as we previously saw, is an expensive means of communicating and by no means is a method of adapting to a RF environment. How many times have we heard the cliché, *Work Smarter not Harder*? This is true in RF systems as well. A response to increase a system's reliability to overcome a harsh environment is clearly working smarter while the act of constant retransmissions to get the same data across is the act of working harder and is less efficient.

When does reliability come at the cost of efficiency? When the application of the technology does not need the added redundancy or robustness that may be applied to boost reliability. So, as previously stated, the ultimate enabler for efficiency and thus the ability to survive in the 2.4-GHz spectrum at low-power is the ability to adapt to your environment, or more importantly, your customer's diverse environments.

Conclusion

So, how does one compare wireless technologies to determine whether one is more efficient than the other? To quantitatively evaluate both is to put each to the test in an environment consistent with that of the end application. While costly and time consuming, this method results in the best analysis and provides the truest indicator as to which solution will result in the best efficiencies. A qualitative analysis, on the other hand, can provide a less expensive and timely means to evaluate these solutions—or to reduce the number of solutions you wish to take to the quantitative analysis. This can easily be done by means of simply answering the following questions for each of the proposed solutions—the more yes's then the more that system will be able to adapt to its environment and the more efficient that solution will be in the end.

- Does the solution adapt to its environment?
    - Does the solution have a means of measuring and evaluating its environment?
    - Does the solution have the capability to dynamically change its output power level?
    - Does the solution have the capability to dynamically change its method of communicating (robust to less robust and vice-versa)?
    - Does the solution have the capability to dynamically and smartly move to a quiet environment in the spectrum (static vs. hopping vs. agility)?
    - Does the solution have the capability to do one, two or all three of these means of adapting to the environment?
- BONUS: Does the solution have a protocol that takes advantage of these environmental adaptations that can be reused for my application?

Cypress Semiconductor
198 Champion Court
San Jose, CA 95134-1709
Phone: 408-943-2600
Fax: 408-943-4730
http://www.cypress.com