

CAPITALIZING ON 802.11 FOR SENSOR NETWORKS

Low-Power Wireless Sensor Networks

WHITE PAPER BY

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ABSTRACT – Sensors that monitor a variety of physical world conditions such as thermal, mechanical, chemical, optical, acoustical, and other measurable parameters, have long been employed in a variety of industrial, commercial, public, and consumer applications. Utilizing wireless technologies for sensor network solutions affords the potential for new capabilities and increased efficiencies. Today various proprietary wireless solutions exist for sensor network applications such as 802.15.4 based implementations; however, there is yet to be a widely deployed standards-based solution, or even a *de facto* standard per market penetration. At the same time IEEE® 802.11 networks are widely deployed for commercial, public, and consumer applications, having met criteria for such requirements as security, manageability, and cost, but their use in sensor networks has been limited because many applications require years-long battery life for sensors node devices. New 802.11 designs that meet battery life requirements for sensor nodes enable organizations to capitalize on their existing 802.11 infrastructure investment with the benefits that generally come with standards-based solutions, such as lower costs due to economies of scale, interoperability, ease of use, and availability of mature management tools, as well as the ability to support other 802.11 client devices.

I. INTRODUCTION

802.11 DEPLOYMENTS are becoming more pervasive and are the prevailing wireless LAN protocol in business, public use and consumer market applications. 50% of US enterprises have deployed 802.11 networks as of 2006,^[1] and this is projected to reach 80% by 2008.^[1] There are almost 400 metro 802.11 projects underway or in planning in the U.S. alone with many more expected over the next few years.^[1] Businesses and consumers are also connecting through the rapidly growing population of public 802.11 networks, the number of 802.11 hotspots having increased worldwide from 53,000 in January 2005 to 153,000 as of July 2007, of which 57,000 are located in the U.S.^[1]

Given that the 802.11b standard was first adopted less than a decade ago in October 1999, consumer adoption of 802.11 at home has also been remarkable. In 2005, consumers installed 802.11 three to one over wired Ethernet for their homes network needs and by 2010, 802.11 is expected to represent 96% of new home networks. Market penetration of networking is also expected to rise from 19% of US homes in 2005 to 44% by 2010, representing 49 million 802.11 connected homes compared to 14 million in 2005.^[1]

The ongoing business and social mega-trends toward mobility, portable connectivity, and convergence observed over the last decade will continue to drive 802.11 adoption. Just as the PC market and Internet became ubiquitous due to the simple fact that everyone agreed to connect using the same standard set of protocols, as well as developed solutions for security, manageability, and ease of use, it is reasonable to expect that the wireless extension of these networks, including a multitude of new business and consumer devices accessing these networks, will also use a standard set of protocols.

II. IMPORTANCE OF SENSOR NETWORKS

Sensors monitor a host of physical world conditions, such as thermal, mechanical, chemical, optical, acoustical and other measurable parameters, and are readily available for all manner of industrial, commercial, public, and consumer applications, and represent a \$65 billion market for commercial building and industrial automation alone.^[1] Deployment of sensors enable users to do more with less, while providing increased convenience, safety, and comfort through improved or automated processes. Organizations realize positive return on investment with sensor networks by:

- Reducing energy usage
- Reducing labor expenses
- Improving security
- Providing convenience

The US Department of Energy states that commercial buildings alone account for 32% of total national electricity consumption, and that energy consumption overall has doubled in the last eighteen years and will increase another 25% by 2030 unless the growth rate can be curtailed.^[1] Building automation systems can reduce energy consumption, on average, by between 5% and 15%, more for older or poorly maintained buildings.^[1] Building automation systems, however, rely on a sensor network with sufficient number of sensors to provide good data resolution across the environment, embedded intelligence in field level devices, better device integration, and use of decision making

control strategies beyond what most wired building sensor networks can provide.

Sensor networks can integrate with existing enterprise management systems (e.g. accounting, human resources, and databases) and improve or automate processes such as lighting and security systems, inventory tracking, regulatory compliance, and enable remote access for better productivity. Traffic management and home security are other applications of sensor networks used to improve everyday convenience and security.

III. UTILIZING 802.11 FOR SENSOR NETWORKS

In a typical large commercial operation, hundreds of sensors are wired to a centralized process, such as a heating, ventilation and air conditioning (HVAC) or other system, with twisted pair RS-485 wiring. The cost of wiring can range from tens of dollars per foot for simple installations to a few hundred dollars per foot for certain retrofit or difficult access conditions. Thus, the cost and physical constraints associated with wired sensors limits the complexity of wired sensor networks and their reconfigurability. In many installations the cost of the wire, conduit, and labor necessitates adding sensors in only the most critical locations. Replacing hard-wired sensors with low cost wireless sensor nodes can improve the quality and coverage of sensor networks while facilitating easy reconfiguration and customization. Additionally, sensor nodes with multiple modalities (i.e. equipped with several different types of sensors beyond a single parameter) can significantly enhance system capability.^[1]

A wireless sensor network (WSN) must perform the same basic functions of:

- Processing
- Storage
- Communication
- Sensing and actuation (I/O)

The sensor node performs data sensing or acquisition which may be stored in a network database. The information is processed either in a distributed or centralized fashion, and communicated to other parts of the network to actuate a command. The communication of that data among the various network components is the function of the distribution network. It is the combination of having many points for data acquisition and control, and timely access for processing the data that leads to network intelligence and hence a “smart environment.”

While wired network solutions account for the bulk of the installed base of sensor networks, the increasing need for network flexibility, reduced installation costs, and user mobility demand that a wireless solution be made available for sensor networks. WSN can significantly reduce the installed cost per sensor point thus greatly increasing the number of sensors that meet an ROI threshold. Compounding this effect is that as the volume increases, manufacturing and operating efficiencies improve to further lower costs and allow more sensor deployments. Use of 802.11 for WSN offers several advantages.

A. INFRASTRUCTURE

Since 802.11 networks are widely deployed and deployments continue at a rapid rate for multiple reasons, the infrastructure cost attached to sensor data distribution can be essentially eliminated, thus greatly improving the wireless sensor network total cost of ownership (TCO). Adding an overlay network infrastructure such as 802.15.4 for WSN applications is significant for enterprise and metro-scale deployments, and also requires new management tools and IT knowledge be obtained for secure and proper operation.

B. NETWORK EFFICIENCY

Because sensors can transmit their data in discreet micro-bursts, information can easily be prioritized and transmitted within the available capacity of the 802.11 network, as 802.11e specifies multiple levels of Quality of Service. Using standard 802.11 network tools, network capacity can be monitored and additional access points and infrastructure can be installed as network load grows. Overlaying an additional wireless infrastructure such as 802.15.4 with comparable coverage footprint and IT support for implementing WSN capabilities, would represent a significant cost burden. Additionally, the overlaid network infrastructure would have low utilization between periods of intermittent sensor data transmission.

C. FASTER DEPLOYMENTS

Since 802.11 networks are often pre-existing, 802.11 sensors could be deployed in large or small numbers without modifying the data distribution infrastructure. This could enable use of sensors in remote locations, including outdoor environments. SeaWorld in Orlando, FL, for example, utilizes 802.11 to connect a small number of previously isolated buildings located on “islands” to its centralized energy management system. Sensors could also be easily relocated to meet changing operating conditions or set up in remote or temporary locations. Conversely, a centrally managed 802.15.4 sensor network must be deployed in sections with sufficient grid density and application need to justify a new build.

D. KNOWLEDGE BASE

Enterprise IT departments and many small-medium business and consumer network operators are familiar with managing 802.11 networks. Overlaying an additional network for WSN applications may not only be unnecessary, but the other issues of learning new skills and managements tools, along with general ease-of-use and other cost issues are prohibitive. Additionally, users are familiar with most common 802.11 management tools, and introducing an additional network which requires additional tools also incurs additional learning and expense.

E. SCALABILITY

Scalability is directly related to the maximum data rate of a particular network architecture. Consequently, the ability to add new sensors and utilize higher data rate sensors is directly proportional to the maximum data rate supported by the physical channel. As an example, 802.15.4 maximum data rate per channel is 250 Kbps, while 802.11g is 54 Mbps and in the future 802.11n, which will be backwards compatible with 802.11b/g, can theoretically support 540 Mbps. Therefore, 802.11 can scale to a greater number of nodes and faster data rates.

IV. INTEROPERABILITY AND NETWORK CONVERGENCE

Historically, sensor network equipment vendors each developed their own proprietary protocols such that one vendor’s systems could not communicate with other vendors’ systems. This made switching costs significant, limited customer choice, and often resulted in organizations running multiple building control systems over time.

Demand for a more standardized approach increased as customers began to realize the financial impact this was having on their infrastructure costs. In the building automation industry, two standards began to dominate starting around 1995, BACnet

and LonWorks, and most major industry players aligned themselves with one or the other of these protocols.^[1] More recently the BACnet consortium’s open source approach has gained broad appeal, aided by a key enhancement to the earlier BACnet protocol with the introduction of BACnet/IP that enabled TCP/IP networking.

Use of Internet Protocol (IP) instead of proprietary protocols offers several advantages, in that IP is well defined and universally accepted, continually improved, and benefits from the development efforts of thousands of companies across hundreds of industries to address such issues as security, authentication and manageability. Further, as proprietary networks move to TCP/IP, this allows separate systems to share data across enterprise systems as well as utilize the same network infrastructure, tools and management resources.

Broad adoption and volume production of inexpensive processor and networking chips and software has made TCP/IP a cost-effective solution. Industrial and building automation control systems therefore need not be limited to a few centralized interfaces to the Internet as early systems were. The use of TCP/IP provides both reliable point-to-point connections as well as a seamless method for network-to-network communications.

V. SENSOR NETWORK REQUIREMENTS

The need for a scalable, low-cost wireless sensor network (WSN) solution is being driven by customer desire to:

- Increase productivity and efficiencies
- Reduce cost and energy consumption
- Meet or exceed compliance standards
- Realize a competitive advantage

Significant effort has been devoted to developing a standards-based, low-cost, years-long-battery-life wireless solution. Because sensor data rates are typically low, much of this effort has centered around the IEEE 802.15.4 standard. However, given the wide adoption of 802.11, there is a natural desire to leverage 802.11 networks for WSN applications. A major drawback to this has been the power consumption of 802.11 solutions. Innovative new power management technology allows WSN to leverage established 802.11 advantages to meet common network requirements.

A. INTEROPERABILITY

802.11 provides a worldwide interoperability standard that is largely unmatched by other communication protocols. 802.11 devices operating in the 2.4 GHz spectrum are interoperable and backwards compatible with other 802.11 devices operating in the same spectrum regardless of vendor, allowing for greater deployment flexibility, hardware portability, and customer choice. Alternatively, 802.15.4 based WSN implementations are commonly vendor specific solutions utilizing different protocol stacks that are not interoperable, and there is potential for interference with existing wireless infrastructure and protocols.

B. ARCHITECTURAL SUPPORT

The establishment of 802.11 as a dominant worldwide standard guarantees technical advancement and on-going support for a complete range of critical enhancements necessary for reliable, robust network operation. In addition to continued improvements to such related features as security (802.11i), QoS (quality of service with traffic prioritization, 802.11e), higher throughput (802.11n), fast roaming (802.11r), vehicle environments (802.11p), and *ad hoc* mesh networking (802.11s) are also in various stages of completion with established IEEE working groups. Further, with devices available and

continued development supported by multiple vendors, the risks associated with single sourcing are eliminated.

C. BATTERY LIFE

To meet many sensor application requirements and be truly wireless, it is desirable that sensor deployment solutions be free of both communication wiring and electrical wiring. A threshold question is how can an 802.11 WSN compare to other WSN solutions? The simplest answer is in implementing silicon orders of magnitude more efficient at conserving power for sensor nodes, along with adding more intelligence in the network to accommodate a new class of 802.11 clients that are often in low-power standby mode to conserve power. By utilizing such technologies, 802.11 WSN solutions are on par with other WSN solutions, achieving 5-10 years of battery life using one AA battery. Such performance is achieved by designing silicon from the ground up specifically for low power consumption applications, utilizing methodologies such as extremely low sleep currents and fast transitions to active and back to standby states. GainSpan has recently implemented technology resulting in years of battery life for 802.11 sensor devices through its integrated silicon and software solutions.

Feature	900 MHz	802.15.4	802.11	Power efficient 802.11
5-10 years battery life*	✓	✓	x	✓
Installed infrastructure	x	x	✓	✓
Low TCO	x	x	✓	✓
Security	x	x	✓	✓
Manageability	x	x	✓	✓
Reliability	x	x	✓	✓
Data rate scalability	x	x	✓	✓
IT knowledge	x	x	✓	✓

*Based on 1 3.6V, 2000mAh (ex: AA) battery in reference applications.

TABLE 1. WSN Comparisons

VI. APPLICATIONS AND OPPORTUNITIES

Wireless sensor networks help to enable smart environments that reduce energy usage, improve security and safety, enable location awareness and support a host of other operating efficiency, product quality and user convenience gains, in a diverse set of applications such as the examples below.

A. COMMERCIAL

Wireless sensors with multi-sensing capability, flexible placement, and portability can improve building systems such as heating, ventilation and air conditioning (HVAC), fire-life, air quality, and security systems with better monitoring resolution, faster response time, inventory control and support for mobile applications. Further, uses are applicable in specific verticals such as: retail and distribution, for cold chain tracking of refrigerated foods for better food safety and spoilage mitigation; or other production and supply chain related processes.

B. INDUSTRIAL

Industrial processes can be improved with smart use of sensors for such applications as predictive equipment maintenance using vibration, temperature, pressure, corrosion detection, flow rate, or other monitored parameter to reduce downtime, decrease energy usage, and improve efficiencies and safety.

C. RESIDENTIAL

Home security, comfort, and entertainment systems using 802.11 may be installed faster and cheaper using a home 802.11 network rather than a dedicated network, and can be made remotely accessible over the Internet without special gateway interfaces to proprietary systems.

D. METRO

Wireless sensor networks can be used to enhance traffic management systems, improve maintenance monitoring of widely dispersed assets such as street lights, and support first responders such as fire, police and hazmat professionals with better and more timely information.

VII. SUMMARY

Utilizing newly-available, low-power consumption 802.11 silicon for sensor node devices, such as solutions available from GainSpan, enables organizations to:

- Leverage the benefits of existing 802.11 infrastructure and standards.
- Implement new capabilities.
- Realize enhanced return on investment and total cost of ownership.

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