U.S. Department of Energy's Wireless Energy Efficiency Initiative

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ABSTRACT

The Department of Energy's (DOE) Industrial Technologies Program (ITP) is widely recognized for its contribution to bringing the wireless revolution to the industrial marketplace. As part of the DOE/Energy Efficiency and Renewable Energy (EERE) office, ITP facilitated the creation of a broad vision and a jointly funded program for the development and deployment of the first market-ready products. The ITP wireless initiative has resulted in the creation of a number of startup companies supplying hi-tech components and products for the new market, the inception of the Wireless Industrial Networking Alliance (WINA) that promotes industrial wireless applications, and ongoing efforts with the ISA100 standard for wireless industrial automation. The *Wireless Energy Efficiency Initiative* focuses on achieving the vision identified by the National Academy of Sciences for using wireless technology for saving energy in the nation's infrastructure. Subsequently, in 2007, Executive Order 13423 mandated that Federal laboratory sites would set the standard for energy efficiency by improving their energy use by 30%. This has led to several initiatives including showcasing industrial wireless technology applications. Further, Oak Ridge National Laboratory (ORNL), as part of DOE's Transformational Energy Action Management (TEAM) initiative, is deploying wireless technology to improve efficiency of energy use at their site to demonstrate the energy efficiency potential of their applications in the hope that such achievements will foster awareness and encourage other organizations - both public and private- to adopt these industrial energy conserving practices. This paper highlights recent applications of industrial wireless technologies and ORNL initiatives underway.

Introduction – The Role and Chronology of the Industrial Technologies Program

Since 1999, ITP has supported early-stage R&D confirming the benefits of wireless sensing. However, in 2002, ITP brought together about 30 participants (suppliers, end-users, and researchers) to develop a long-term vision for guiding the development of industrial wireless sensor systems. The resulting workshop report, *Industrial Wireless Technology for the 21st Century,* continues to guide the development of industrial wireless technology today.

Based on the guidance from this report, ITP issued a solicitation to support R&D projects in the industrial wireless area. As with all ITP-supported projects, these were designed to share the R&D costs of development, thereby reducing the development risks and accelerating the progress through project partners and leading to the adoption of wireless systems.

Subsequently, ITP indirectly supported the formation of WINA, an organization that facilitates wireless deployment in industry and the ISA standards development process, which will allow separately produced sensors to communicate with each other thereby accelerating market adoption.

In January 2007, Executive Order 13423, The Energy Independence and Security Act of 2007, mandated goals for sustainability in energy, environment, transportation, and water at Federal installations:

> *The order required that each agency shall: (a) improve energy efficiency and reduce greenhouse gas emissions of the agency, through reduction of energy intensity by (i) 3 percent annually through the end of fiscal year 2015, or (ii) 30 percent by the end of fiscal year 2015, relative to the baseline of the agency's energy use in fiscal year 2003;*

In terms of Federal facilities, the Executive Order mandate of a 30% energy efficiency improvement meant that each site developed a plan that called for more widespread and deeper energy efficiency improvements in Federal facilities and activities. The practical implication allowed facility managers at these sites to consider technologies with longer-term payback than might otherwise have been considered, and the deployment of higher efficiency technologies that contained somewhat more deployment risk. Within the DOE/EERE Division, the new initiative was entitled TEAM.

In August 2008, a wireless workshop was held at ORNL to determine the status, and use of a number of wireless industrial sensors. This paper documents the identified wireless sensor applications and follow-up wireless applications being pilot-tested at ORNL.

Through these efforts, DOE is attempting to facilitate the nation's industrial energy efficiency effort by providing specific tangible guidance for "the person on the street" and charged with the responsibility to improve the facility's energy use and a means to monitor efficiency.

The Benefits of Wireless

The use of industrial wireless technology has been estimated to improve production efficiency by 5%-15%, depending on the application. Operational benefits of wireless technology include:

- **Reduced cost -** Eliminates wiring costs ($50-$2,000 per foot) and reduces maintenance costs for motors and other plant equipment. Exhibit 1 presents a cost-benefit analysis of wired versus wireless systems.
- **Increased productivity** - Enables faster, real-time identification and repair of poorly performing motors, equipment, and manufacturing infrastructure, resulting in energy savings. Minimizes requirement for frequent, manual equipment checks throughout plant. Easy installation by facility staff - can be mounted anywhere in the plant.
- **Improved knowledge management capability** – Helps manage large quantities of information overload and provides greater accuracy of system data.

Exhibit 1. Honeywell Analysis: Wired vs. Wireless

Wired Automation Investment	**Initial $**	**Annual $**
Wired Installation cost	385,000	
Wire inspections	70,000	70,000
Wired total	455,000	70,000
Wireless Automation Investment	**Initial $**	**Annual $**
Sensors and Wireless System	121,000	
Average Annual Maintenance	14,000	14,000
Wireless Total	135,000	14,000
Payback: 6.1 months as compared to 23 months for the wired solution		

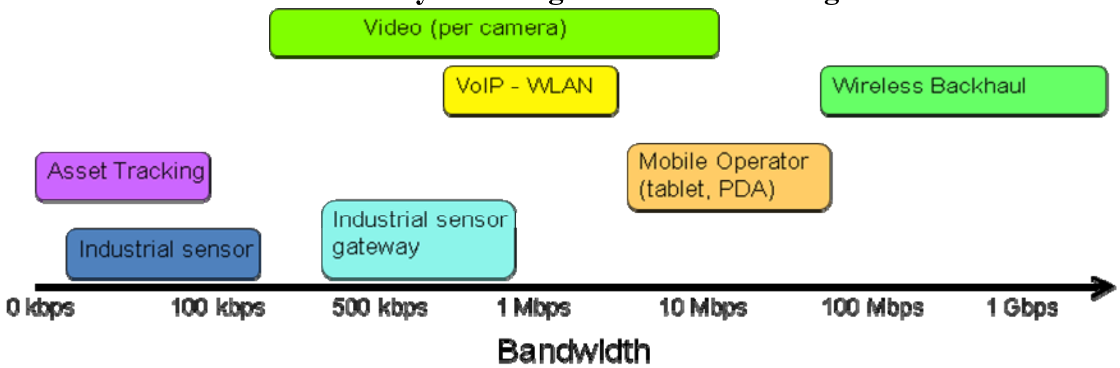
Potential barriers also exist which have impeded the market adoption for these wireless systems. Those most commonly cited as concerns limiting the adoption in an industrial setting include, lack of technical standards, data security concerns, and perceived cost and reliability issues. Many wireless technology developers are pursuing solutions to these concerns.

Evolution of Wireless Technology

There has been a fundamental acceptance of certain types of wireless technology worldwide, most notably cellular and wifi. While various sociological studies have reported on the reasons why individuals are so accepting of wireless - the most common reason is the most obvious - ease of mobile communications, the second being social networking – the user acceptance of having to redial/reconnect on dropped calls and the variability in communication system performance are simply not acceptable in an industrial setting.

That stated, there is the constant push from industry to deploy wireless devices and systems to help in the optimization of a facility's operation. Process optimization in this context means much more than installing wireless sensors to bring more process monitoring "points" into the control system; it also means providing wireless coverage to support applications such as mobile video cameras (security department), voice communications (VoIP replacing aging walkie-talkie products), tracking assets through the facility (via RTLS, RFID, companion techniques), and providing the wireless backbone to support wireless condition monitoring sensors (for the maintenance department). These applications require differing amounts of bandwidth implying that different wireless technologies may be required. A list of applications, bandwidth requirements and associated wireless technology is shown in Figure 1.

Figure 1. Applications Require Different Amounts of Bandwidth, Bandwidth that Is Delivered by Differing Wireless Technologies

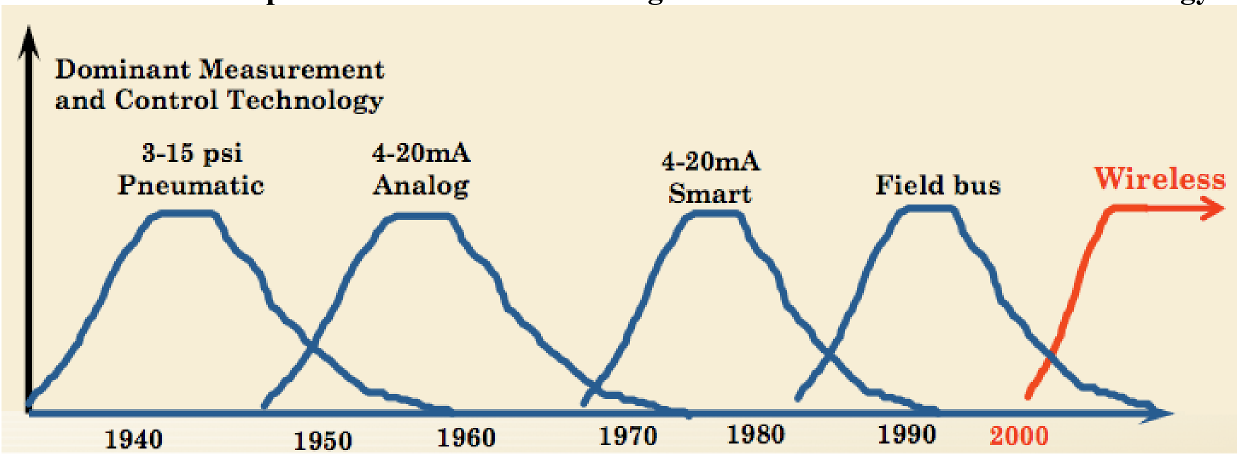


Application	Required Bandwidth	Technology
Video	~500 kbps/camera	802.11, 802.16
Sensor Network	~8 kbps/sensor	802.15.1, 802.15.4
Sensor Network Transport	~400 kbps/gateway	802.11, 802.16
VoIP over WLAN	~2 Mbps (phone dependent)	802.11
Asset Tracking	~1-100 kbps (wide variety)	RFID, 802.11, 802.15.3,etc

As previously stated, there is a considerable "pull" from the industrial user community for wireless devices if for no other reason than that they are much easier (i.e., less expensive) to install. Wireless is less disruptive to occupants and also provides the flexibility of temporary installation of wireless sensors which could be useful for site surveys or short-term energy assessments for interim monitoring of systems and devices. However, the industrial setting is technically challenging as the performance demands placed on wireless devices require that they must sometimes be operable in harsh industrial settings. These environments can be metal intensive, operating in temperature ranges of -40 to +50^{o}C, contain varying levels of electromagnetic interference in corrosive or explosive industrial settings that far exceed the demands of commercial settings. The general comparison of the home or building setting and the industrial setting has been reduced to "the carpet setting" versus "the concrete setting".

Some individuals feel that this situation is the same as has been faced by many other technologies that are deployed in this setting. So what's new in the wireless case? It is the relative ease and reduced cost of wireless sensor deployment into existing systems. WINA (www.wina.org) describes the situation as the logical evolution of the dominant control technology, a timeline of which is presented in Figure 2.

Figure 2. Just as Analog Electrical Systems Replaced Pneumatic Systems, Wireless Devices Are Poised to Replace the Fieldbus Technologies as the Dominant Control Technology



The net result of the efforts of DOE, via ITP, and efforts by numerous companies – large and small – is that as of today wireless devices that meet the rigorous requirements for the industrial setting are available. By meeting the tight requirements of the industrial plant, these wireless devices are also well suited to work in most other environments.

Wireless systems' ease of installation and enhanced ability to allow users to measure many parameters at a multitude of locations throughout the setting allow the ability to, in the words of one facility manager at a West Coast Federal facility to comment, " know information about parts of my facility and the status of devices, I can begin to isolate where the energy loss is occurring".

Applications of Wireless Technology in Industry

The Executive Order mandate serves as a driver to implement these types of technologies, but low-cost, effective, and reliable wireless system applications are what the facility is expecting. Over the past few years there have been significant developments in technologies that, unique to their domain of service, provide high fidelity advantages that can meet the needs of Federal facility managers. For example, connectivity industrial wireless sensor systems provide the type of high fidelity measurements that may allow and justify direct or indirect modification and tuning of facility systems so that the impact on energy losses and inefficiencies at a facility can document the value of improvement. The combination of factors such as new technology with unprecedented functionality and capability, the lowered cost of that technology, a labor force fully competent to invoke technology, the increased cost of inefficiency, the changes underway in the fundamental economic structure of the United States, and many other transformations create the circumstances and environment right for, for example, marrying the needs of facility managers with the possibilities for measurements (and even control!) of onsite systems provided by cost effective and easy to install wireless communications and sensing.

To address that point, DOE held a workshop under the TEAM initiative. Over 50 individuals representing a cross section of government facilities, field experts, and vendors participated in the workshop, which was held at ORNL. The highly interactive meeting provided an excellent arena where facility managers (and others) could ask their fellow attendees for advice on how these wireless systems may help them meet Federal mandates and the Federal objective. It also provided vendors some direct input from potential customers on what functionality is important and/or required for successful deployment of their systems in the facility monitoring setting and the necessary information that these systems must robustly collect and transmit.

Discussions and breakout sessions relating to the present or future applications of industrial wireless systems and how they might apply to facilities were conducted. Providing realistic communication among representatives of the sector early enough and concrete enough to set directions on developing useful and needed technology was successfully accomplished.

Another question was posed by numerous facility managers asking if there were identified projects where wireless sensor systems were already being deployed for the express purpose of the Federal energy efficiency objectives. While a fairly extensive list of such instances was generated and is available from the authors, an extract from that list is presented as Figure 3.

Figure 3. Wireless Systems Are Being Used in Numerous Energy Efficiency Projects: An Abbreviated List of Such Identified Projects Is Provided

TEAM Wireless Energy Efficiency Keys Initiative Workshop Projects Matrix

	Customer/ Supplier	Application	Status	Energy Efficiency Category	Attributes	Benefits
energy management	Tennessee State Building/ Digital AV	50M ft^2 correleates energy usage w/ environment	in-use now, adding lighting…	buildings	enables proactive maintenance and demand awareness	15-20% savings (out of the box) - low cost installation
kiln monitoring	Manufacturing Site/ Honeywell	temperature monitoring for optimizing energy and process	in use, dozens of applications	industrial	4 - 5 wireless sensors on each kiln	rotating kiln, wireless gave $5K/year savings per kiln
data center	Computing/ GE	power monitoring, distributed energy management, temperature	In use	data centers	wireless augments wired sensors for power per ft sq, and power per unit	improved efficiency
steam trap	Manufacturing Site/ Honeywell	monitoring and control plus instant notification of steam release location	In Use	industrial	measure temperature, vibration, acoustic properties	ability to save energy through quicker repairs etc…
motors	Numerous Sites/ GE	temperature, vibration, current sensing for motor health	In Use	industrial, buildings, transportation	control of motor and the process it runs	wireless sensors for matching motors and processes
wireless light control	Numerous Sites/ Eaton	control based on time of day, room occupancy, ambient light	In Use	buildings	Wireless Ballast Control	wireless contributes to up to 40% energy savings

As shown, these applications include energy monitoring on a subsystem basis, temperature measurement of rotating kilns, data center energy and temperature measurements, leaky steam traps, motor efficiency, and condition and building light controls. Other industrial applications of wireless that have been deployed in manufacturing environments include:

- Monitoring of compressed air systems including temperature, line pressure, airflow, and energy-usage of the compressor and data display to readily spot system degradation resulted in up to 50% efficiency gains.

- Successfully monitoring and recording temperature fluctuations within water jackets of giant steel furnaces where harsh environments and strong magnetic and electrical fields would interrupt communication,resulting in improved maintenance and productivity.
- Monitoring and transmitting the temperature of aluminum billets to identify the earliest time the aluminum coil can be moved thereby eliminating the need for manual measurements - increased plant throughput by 6 million pounds with a payback of 3 months

Other wireless applications are being developed and introduced and are being brought to our attention.

Wireless Condition-Based Monitoring

One particular application of wireless is worth highlighting. This is the sensing of equipment's deteriorating condition rather than the sensing of its energy use. Individuals involved in the maintenance of motors – or large rotating machinery – repeatedly state that they wish they could monitor the condition of the machine on a more frequent basis than they are currently able to do. An example of this is the knowledge that as a motor degrades, its operating performance decreases. This degradation of performance in turn leads to a decrease in energy efficiency. The maintenance crew also knows that the leading indicators for an impending motor failure are an increase in machine temperature as well as a change in the motor's vibration signature (e.g., as the bearings wear nonuniformly, their mere rotation will cause changes in the vibration spectrum). Wireless communication is a good vehicle for monitoring the condition of a motor's health, such as by having a temperature+vibration sensor's readings transmitted to the cognizant maintenance operator.

Trials of such sensors have been conducted under the DOE/ITP Industrial Wireless program. The studies are incomplete, but the early returns are very promising.A webcast of these and other wireless industrial opportunities was recently given which is available from the DOE ITP website (www.eere/energy.gov/industry). Considerably more detail is presented in the downloadable material.

A Wireless for Energy Efficiency Case Study: Wireless Steam Trap Monitoring and Visualization

ORNL has identified an immediate need to monitor the key steam line locations within their facility. The ORNL site has 12 miles of steam line with 1,600 steam traps located across the facility. The steam traps work as safety releases to relieve the excess pressure in the steam line but subsequent undetected failures contribute to major energy waste. ORNL loses a great deal of energy through faulty traps, as does any facility with steam lines. A DOE study published in 2005 identified steam traps as a major energy waster in industrial sites. The study of a hospital showed a potential savings of $1,400 per trap attributed solely to reduced energy consumption. Overall, the study showed that 30% of the steam could be saved in the steam system if the faulty valves could be identified and appropriately serviced. A report that was used to develop our steam trap replacement project as part of ORNL's performance contract with Johnson Controls, Inc., has targeted 1,256 traps for replacement. It was determined that these 1,256 traps have an annual steam loss of 69,693 Mlb/year. At $9.74/Mlb, the dollar value of steam lost through failed and malfunctioning steam traps is $678,800/year. On average, each trap has an annual steam loss of 55.5 Mlb/year, worth an estimated $540/year. Any wired attempt to monitor 1,600 traps would be cost prohibitive. Wireless now makes monitoring of distributed or low-probability events economically viable.

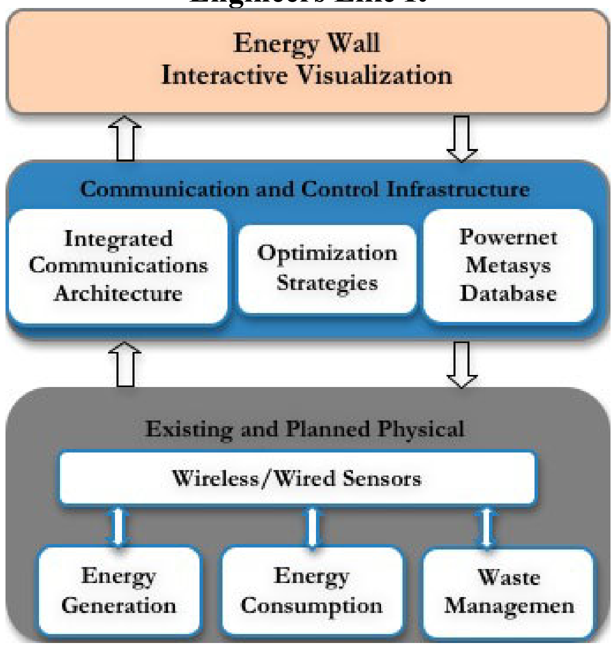
ORNL's Wireless Steam Trap Monitoring is also a pilot project to investigate feasibility of site-wide multi-modal wireless sensor installation for monitoring and eventual integrated visualization of the entire energy supply and usage at the site. The project developed wireless instrumentation for five steam trap locations. A multi-technology, multi-vendor, standards-based wireless solution is being implemented with an extensible framework for integrating additional sensors in the future. The plan is to extend the implementation to include more than just steam traps and to make the approach transplantable to other DOE and non-DOE sites. The plan also includes understanding the feasibility of integrating electric distribution data (Powernet), buildings data (Metasys), and other sensors sources into a unified site-wide visualization of energy generation, consumption, and waste management. The cost of the initial **prototype** installation covering five valves is expected to be about $50,000 or about $10,000 per valve. The next batch will be somewhat lower in cost per valve with a final cost for the full 1,600 valve suite of about $2.4 million, including the cost of an integrated visualization system.

Maximizing the value of sensor information so that quick corrective control actions are possible requires a mechanism for understanding where energy is being used and where the energy usage exceeds the expected level of use or is out of compliance. The present ORNL effort is also focused on understanding specifically which information needs to be collected, the collection frequency (periodicity) followed by presenting the information in a simple and clear fashion, such as by use of a dashboard approach. An example of a dashboard approach is illustrated in Figure 4 where device information for multiple systems are displayed.

Region View showing regions with zones and conditions

More extensive data treatment would also be possible by way of an "Energy Wall" visualization that could show current time interactions among previously uncorrelated data, such as weather, temperature, and fuel use by type of use, or efficiency of facility architecture and time of day profiles of energy use. An example or this more complex schematic is shown in Figure 5.

Figure 5. A Framework for Deploying Technologies Enabling ORNL Site-Wide Energy Efficiency: To an Information Systems Architect, this Chart Offers Little Insight but the Engineers Like It



Current TEAM efforts include the development and demonstration of an easy-to-use dashboard system for visualization of appropriate information to, among others, facility managers.

Summary

Wireless sensing technologies have been shown to have broad and increasing applicability in the industrial and commercial market, and create energy efficiency opportunities that were previously inopportune or not cost effective in a wired environment. As described, these benefits include reduced cost sensing by eliminating wiring costs, reduced maintenance costs for motors and other plant equipment, increased productivity by way of real-time identification of poorly performing motors and other manufacturing equipment, and the elimination of manual equipment checks around the plant. Wireless sensors have broad applicability in improving our real-time knowledge and our ability to readily identify energy system data and take quick corrective action thereby quickly saving the energy that would otherwise be lost until the faulty system was identified and corrected. ITP continues to encourage activities to promote further applications of these wireless systems and the development of standards which will lead to multi-supplier interoperability resulting in their industrial adoption.

Through a recently held ITP-sponsored wireless workshop, facility managers who are responsible for meeting Federal government energy efficiency goals and mandates shared their needs with wireless developers and system integrators to form a better basis for integration and direct action via a two-way flow of information, leading to the increased deployment of wireless sensors and monitoring and control systems, which would result in increased production and energy efficiency at reduced costs.