Industrial IT Revolution through Wireless Sensor Network Technologies

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Abstract— **Recent advances in wireless technology have enabled the deployment of low-cost wireless solutions that are capable of robust and reliable communication in the resources and manufacturing industries. Wireless application areas such as networking, sensors, and asset tracking offer great opportunities for production optimization where the use of wired counterparts prove to be prohibitive, expensive or difficult to implement and maintain. Data that is gathered from such wireless devices and networks is quite valuable and leads to new and innovative solutions that may aid the resources and manufacturing industries in preventing problems, reducing operating costs and generally improving operations. Using wireless sensor networks, we propose new intelligent solutions that aid factory monitoring, maintenance, error tolerance and security and safety. In this paper, related wireless technologies are discussed.**

Keywords- Wireless sensor networks and devices

I. Introduction

Recent advances in wireless technology have enabled the development of low-cost wireless solutions capable of robust and reliable communication. International standards such as the IEEE 802.11a/b/g [1][2][3][4] for wireless local area networks and the IEEE 802.15.4 [5] for low-rate wireless personal area networks, as well as numerous RFID (radio-frequency identification) specifications, have enabled applications such as wireless networking, sensing, monitoring, control, and asset tracking solutions.

A. Operational Environment

Wireless technology has the potential to be beneficial to the resources and manufacturing industries in a number of ways [6]. Eliminating the need for cables can contribute to;

- Reduced installation costs
- Reduced operating costs
- Reduced maintenance costs
- Speedy installation and removal in remote and hostile areas
- Mobile and temporary installations
- Research and development of sensor data applications

Technical requirements for the deployment of such wireless technology have been identified in [7]. This work states that wireless solutions have to be based on open, international standards, and operate in the unlicensed portions of the frequency spectrum. When two or more systems operate in the same frequency band, it is imperative that they are able to coexist. Wireless technologies are more susceptible to environmental changes than their wired counterparts. Therefore, it is imperative that we can clearly define operational reliability and availability of the wireless network within the operational environment. With the use of such networks and devices, new privacy and security threats are more prevalent. Such systems must implement strict encryption, transmitter authentication and data consistency validation. Totally wireless, battery operated devices, require extended battery lifetimes in order to reduce maintenance costs. Remote resources and manufacturing industries look for battery life greater than five years when such devices implement minute by minute updates.

B. Wireless Device and Network Challenges

Therefore, there are several challenges related to the introduction of such wireless devices in the resources and manufacturing industry. Wireless devices must have the following properties;

- Operate reliably within a restrictive environment both in terms of radio noise and obstructions but also where certain restrictions on such radio devices are present (such as flammable areas).
- Implement complex network algorithms with real-time requirements.
- Embedded platforms.
- Limited processing power, memory, storage, battery consumption and screen real-estate resources.
- Restricted size, shape, construction and certification.
- Seamlessly integration with existing IT solutions.
- Simplified ad-hoc and multi-hop network
- Self configurable, dynamic and adaptive network routing protocols.
- Application reconfiguration as required.

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- Provide services within a dynamically changing system environment.
- Fault tolerance and recovery (self-healing, robust and reliable).

Of particular interest to these industries are the use of wireless sensor networks with new business intelligence and data analysis applications that aid;

- Factory and resource monitoring
- Data mining and AI processing
- Information visualization and operation transparency
- Maintenance forecasting and scheduling
- Plant automation remote operation
- Error tolerance and recovery
- Plant security and safety
- Integrated operations

In this paper, the application areas for wireless technology in the resources and manufacturing industries defined and described along with relevant business intelligence applications. The main contribution of this paper is the investigation of the configuration, monitoring and control of the wireless systems, and the integration of intelligent solutions with existing IT infrastructure and user applications.

II. WIRELESS SENSORS

A sensor is a device that reacts to changes in conditions. It returns a value of a physical quantity or parameter and converts the value into a signal for visualization, processing, recording or automation. Such information can be used to monitor factory performance and optimize production. A typical wireless sensor consists of three main parts; a sensing unit, a processing unit and a communication unit (see Figure 2).

- **Sensing Unit -** The sensing unit measures information about a physical phenomenon and converts the measurements to a digital representation via an A/D-converter
- **Processing Unit -** As a part of its processing unit, it has processor, mainboard, memory (RAM) and storage (flash) components. This unit usually analyzes and processes phenomenon data, as well as handles the network protocol, controls the local RF transceiver and application software. Wireless sensors usually have very limited resources in terms of processing capacity, available memory and storage space due to strict low-power requirements. Yet, they are still required to execute software implementations of complex networking algorithms with real-time requirements.
- **Communication Unit -** The communication unit provides the wireless interface, and consists of an RF transceiver and an antenna.

A. *Wireless Sensor Networks*

For wireless sensing, monitoring and control applications, a growing number of industrial standards using the IEEE 802.15.4 [5] physical (PHY) and medium access control (MAC) layers are emerging. The ZigBee specification [8], released in 2004 and updated in 2006, defines both a network and an application layer based on the IEEE 802.15.4 PHY and MAC. In October 2007, the ZigBee Alliance released the ZigBee PRO specification [9] which is aimed at the industrial market. It offers enhanced security features, a stochastic addressing scheme which allows for larger networks, and frequency agility which enables networks to change channels when faced with noise and interference. WirelessHART, released in September 2007 as a part of the HART 7 specification [10], is the first open wireless communication standard specifically designed for industrial process and control applications. The WirelessHART specification uses the IEEE 802.15.4 PHY with a modified MAC-layer and implements frequency hopping in a multi-hop mesh network topology. Time Division Multiple Access (TDMA) is used for communication between network devices, specifying both which timeslot and frequency to use for each link. The first standard to emerge from the forthcoming ISA100 family of wireless systems for industrial automation will be the ISA100.11a Release 1 [11], which will provide wireless connectivity for fixed, portable and moving devices for non-critical monitoring and control applications. Much like WirelessHART, the ISA100.11a will use the IEEE 802.15.4 PHY with a modified MAC-layer to provide a frequency hopping, multi-hop mesh network capable of inter-network routing. The ISA100.11a is expected to be ratified by Q3 2008.

B. *Wireless Sensor Network Standards*

Specifications for international standards for wireless sensor networks, such as ZigBee PRO, WirelessHART and ISA100.11a, use stacks to provide a layered and abstract description of the network protocol design. Each layer in the stack is a collection of related functions, and a layer is responsible for providing services to the layer above it, while it receives services from the layer below it. In a

C. *Wireless Sensor Network Stack*

- **The Physical Layer (PHY) –** The PHY layer controls the RF transceiver, performs frequency and channel selection, handles energy and signal management functions, and provides means for transmitting raw bits (not packets).
- **The Medium Access Control Layer (MAC) –** The MAC layer handles access to the physical radio channel, is responsible for radio synchronization, and provides a reliable link between two peer MAC entities.
- **The Network Layer –** The Network layer is responsible for joining and leaving a network, it provides end-to-end packet delivery from source to destination, and it discovers and maintains routing tables.

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- **The Application Layer** – The application layer provides services to userdefined application processes (not necessarily to the end-user), it handles fragmentation and reassembly of data packets, and it defines the role of the device within the network (coordinator, router or end-device).

Even though a stack, through all its layers, defines and describes the functionality and operation of a wireless device for a given standard, it does not provide any guidelines on how to develop and implement the embedded software needed in order to realize the application functionality. As a result, creating software stacks for international standards has become a major challenge.

D. *WSN Physical and MAC Layers*

For industrial WSNs to be a viable option for sensing, monitoring and control is important to keep the power consumption as low as possible. The major source of power consumption in a wireless sensor is mainly the communication layer RF transceiver when transmitting and receiving data. To conserve power, it is therefore imperative to be able to shut down the transceiver when it is not in use. The ability to shut down the transceiver can also be beneficial for the power consumption of the processing unit, as in many cases, the microprocessor can enter low-power sleep modes when there is no need for communication. However, power consumption when starting the transceiver is much higher than when it is in use, the average power consumption might actually be larger by turning the unit on and off, instead of leaving it on all the time [12]. In industrial WSNs a common method to achieve this is to synchronize the network with a time-division multiple access (TDMA) algorithm. All network communication is divided into distinct timeslots of equal length. A timeslot is usually so long as to allow enough time for a device to transmit one packet and wait for the reception of an acknowledgement from the recipient. Each communication link between two devices in the network is given their own unique timeslot, thus enabling contention-free communication throughout the network, and enabling each device to enter a lowpower sleep mode with its transceiver turned off in all the timeslots not reserved for its own links. A weakness with this form of division of network traffic is its inability to scale in an efficient manner. To combat this, hybrid TDMA algorithms can be used, where a certain number of timeslots in the frame is not dedicated to a given communication link, but open to free contention between the devices in the network.

E. *WSN Network Layer*

Industrial WSNs have strict requirements regarding availability, stability and reliability requirements. This can be achieved by using self-organizing, self-healing and self-configuring multi-hop, ad-hoc networks. Networks routing challenges are exacerbated by a time-varying network topology, power constraints, and the characteristics of the wireless channel. In order to achieve approximately 100% data reliability in a WSN, the network has to be capable of dealing with the temporary or permanent loss of any communication link in the network. For wireless communication, the performance can be affected by changes in the RF environment due to noise, interference, jamming, temperature variations or the introduction of personnel or equipment in the physical area. To combat these threats, redundant paths are created and maintained in routing tables on each device in the network, such that alternate routes are available should one or more of the communication links fail.

F. *Embedded Software*

A typical wireless sensor consists of three main parts; a sensing unit, a processing unit, a communication unit and web service system. In addition, it has components such as a power supply (battery), memory (RAM) and storage (flash).

- The sensing unit measures information about a physical phenomenon and converts the measurements to a digital representation via an A/D-converter.
- The processing unit usually analyzes and processes the received digital data, as well as handles the network protocol and controls the local RF transceiver. The communication unit provides the wireless interface, and consists of an RF transceiver and an antenna.
- The web service system provides an interface between other sensors and software applications as required. It is defined by a set of technologies that provide platform-independent interoperable interaction protocols and standards used for exchanging data between applications.

Wireless sensors usually have very limited resources due to strict low-power requirements. However, they are still required to execute software implementations of complex networking algorithms with real-time requirements. They have to be capable of selfhealing and self-configuration in order to provide a robust and reliable multi-hop network for rough RF environments. This can be achieved by the use of dynamic routing protocols, where each wireless sensor has to store and constantly update neighbor information, as well as handling network connection requests from other wireless sensors. Importantly, they must provide be self configurable, dynamic and adaptive application services.

III. SOFTWARE SOLUTIONS

The software challenges regarding the user applications for wireless technology falls into the following categories;

- User interfaces for using, configuring, monitoring and controlling wireless sensor networks
- Middleware to bridge devices, operating systems, and applications
- Rapid software tailoring architectures as a response to production reporting requirements
- Intelligent applications that utilize the wireless sensor networks to optimize production

A. *User Interfaces*

All wireless systems need to be configured, monitored and controlled throughout their entire lifetime. It is desirable that

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these tasks can be performed by personnel who often posses neither understanding nor knowledge of the underlying wireless technology. If this is not the case, one would have to rely on technical experts to be brought on-site whenever parameters of the wireless systems have to be altered, or technical problems arise. This is both expensive and time consuming, and in situations where a problem with a wireless system theoretically can lead to a production stop or a facility shut down, the delay of having to transport a technical expert onsite is simply not an option. This is especially important for remote, rural or hazardous facilities. As a consequence, the user interfaces for wireless systems must be able to provide a simple and intuitive interface for advanced configuration, control and management. Creating such applications is a challenge and it requires the software developers have extensive expertise of the wireless systems and good user interface design skills. Introducing wireless sensors in a facility should be transparent process. The operator should not be aware if the system sensors are wired or wireless. Studies performed in [7] shows that the required changes in factory and plant work processes might be the largest hindrance for the introduction of wireless technology in the resources and manufacturing industries.

B. *Middleware*

Middleware is traditionally used as a bridge between the operating system (and similar low-level constructs) and the application, easing the development of distributed applications [13]. As WSNs exert many of the same properties as conventional distributed systems, distributed computing middleware is naturally considered for use in sensor networks. However, common middleware systems for traditional distributed systems, such as CORBA [14], and the IndustrialIT [15] framework developed by ABB for distributed industrial systems, are not capable of supporting the dynamic and adaptive environment found in WSN systems. New WSN systems are required to seamlessly integrate into the existing systems or be used to create completely new ones while considering the strict requirements of this environment. It is essential that both these processes are fast and easy to perform as a response to production requirements. This has lead to the research and development of middleware specifically designed to meet the challenges of resource-constrained WSNs. These challenges are dictated by the WSN characteristics on the one hand, and by the application on the other. We have identified the following challenging areas for WSN middleware:

- Managing limited power and resources
- Scalability, mobility and dynamic network topology
- Heterogeneity
- Dynamic network organization
- Real-world integration
- Data aggregation
- Quality of Service
- Security

Early WSN specific middleware, such as Autosec [16] and Impala [17], are designed for efficient use of the wireless sensor network. Recent research, such as the development of the MiLAN middleware for WSNs [20], concludes that while conventional middleware operates above the network layer, for WSN applications it is not a viable approach to handle the network management independent of the needs of the application. By integrating these two aspects into a single unified middleware system, the middleware can trade application performance for network cost, while still maintaining the separation between the policy specifying the reaction to a dynamic environment and the mechanisms to implement such as policy.

C. *Tailorable Service Architectures*

In order to perform sensor service composition and application reconfiguration within a dynamically changing operation environment, sensor software and middleware systems need to be simple and malleable. Research [18] has outlined the requirement for software service based approach in order to facilitate dynamic software self configuration, adaptation and adhoc network routing protocols. Service-based approaches achieve loose coupling among interacting sensors where disparate components interact using a common interaction protocol and specific architectural and protocol constraints. By abstracting a service's internals through an interface, they become well isolated and standardized. A number of interfaces may either provide and / or require services. Such architectures define service location, integration, management, monitoring and security in a straightforward way. Tailorable architectures allow generic components to be rapidly adapted to satisfy the specialized, rapidly changing, unclear and / or evolving system requirements through hierarchical and iterative service composition. They provides a means for the straightforward creation and modification of application solutions from provided sensor services. Using a reconfigurable approach as a basis for the creation and modification of sensor applications, it possible to construct, customize, integrate and evolve software solutions as a response to production requirements. The following are key requirements for such an architecture;

Composition

- **Context-independence -** Identifying the clear decompositions in such a system is a key to developing a hierarchical system architecture where applications are built from building blocks.
- **Service Model –** A service model ensures that disparate components which reside on different platforms, can interoperate.

Interaction

- **Accessibility -** Services must be accessible by clients that are implemented using different technologies, and are distributed over a network.

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- **Data Exchange** – A data exchange model is a communication protocol that enables components to interact and transfer data in a standardized way.
- **Location Transparency** - To achieve location transparency and seamless interoperability, a piece of wrapping middleware code lies between components that make interactions transparent.
- **Contracts** – An interaction contract guarantees that an interface exists, and will provide its advertised services.

Collaboration

- **Plug and Play** - The use of stable, published interfaces enables assembly or integration of applications from disparate sources. In this way, components can be reconfigured, added, removed, or replaced after system deployment.
- **Automation** – The use of macros and scripts that are implemented to facilitate dynamic discovery, interaction and integration of reusable components at runtime [19][20].

Such a service framework and platform are directed at increasing software quality and performance, reducing software development and maintenance costs and easing runtime software modification.

D. *Intelligent Applications*

Existing sensor output handling has outlined many deficiencies in information processing and presentation. System operators are often presented with large amounts of data that must be processed quickly and decisively. However, the amount of information required to be digested is quite large when crucial decision needs to be made within a constrained timeframe. This can leave the system operator suffering from information overload when decisions have the greatest impact. This problem requires sources of sensor data, methods of obtaining that sensor data, and methods of interpreting the sensor data and producing a relevant and powerful message to be investigated in detail. We have outlined the following areas of research;

- Gathering sensor data
- Interpreting sensor messages
- Classification of output messages through the relationship between sensor outputs
- Separation of output categories
- Suppression of situation irrelevant output messages
- Combination of common messages
- Production of sensor output advice
- Definition of system impact following sensor output
- Notification of effects to relevant staff
- Production of timely, informed, detailed and powerful output message

Sensor output processing is a problem which has been investigated for quite some time. Various problems associated with such processing techniques such as system complexity, output relationships, response time, reasoning, incomplete and incorrect data have been investigated. Expert system approaches have been useful in the areas of sensor output processing. However, several issues have not been addressed. The integration of Expert Systems and Artificial Neural Networks to solve many sensor output processing problems have proved to be quite successful as long as various perspectives such as neurobiological, physical, real-time, cognitive and user systems are considered carefully. The use of Business Intelligence, Artificial Intelligence and Data Mining techniques to process Wireless Sensor Data and optimize production through the following intelligent applications is essential;

- Plant Monitoring
- Information Visualization
- Maintenance Forecasting and Scheduling
- Alarm Processing
- Error Tolerance and Recovery

IV. CONCLUSION

In this paper, a survey of the related wireless technologies and research areas in the resources and manufacturing industries has been presented. Most of these challenges are related to wireless sensor networks and the implementation and execution of software stacks for complex network protocols with real-time requirements on embedded limited resource platforms and reconfigurable service architectures. In addition, there are challenges related to the user applications, both for the user interfaces of the wireless systems themselves, and for the integration of wireless systems with existing IT infrastructure and applications. We suggest that further work should conducted into the challenges related to the many layers of software for wireless technology in the resources and manufacturing industries. Specifically, this could be the development of energy-aware software stacks for the new industrial WSN standards, the design and implementation of a middleware specifically for the needs of industrial WSNs, simple and intuitive user interfaces and intelligent applications for the monitoring and control of wireless services.

Wireless technologies as such are fit for deployment, and can provide benefits such as reduced costs or increased production, but without a proper study on how they can be incorporated into existing work processes; these benefits will not be fully realized. It is expected that WSN technologies will enable cost effective applications of a temporary nature in remote or hostile areas in the resources and manufacturing industries for production optimization purposes.

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