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Design Criteria and Challenges of Industrial Wireless Sensor Network

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***Abstract*--Wireless Sensor Network (WSN) for industrial automation and applications are becoming more prevalent. Mature industries such as oil and gas refineries, Waste water treatment and delivery, Electrical generation, Natural gas distribution have migrated from wired to wireless sensor networks over the past decades. This is because of the advantage of the cost benefit and infrastructure advancements. There are number of challenges in migrating from a wired to a WSN. The main aim of this paper is to discuss the challenges in implementing Industrial WSN (IWSN) and the basic design criteria to be considered when implementing IWSN.**

Keywords- Industrial WSN, Technical challenges.

I. INTRODUCTION

Unlike the office networks, the industrial environment for wireless sensor networks are harsher due to the unpredictable variations in temperature, pressure, humidity, present of heavy equipments etc. So, before moving to the real implementation, it is necessary to test some of the communication pattern in simulation environment.

The aim of this paper is to discuss about challenges of wireless sensor network for industrial applications. Mostly the classification of WSNs are based on their application objectives, traffic characteristics and data delivery requirements [1]. Although WSNs have different characteristics in terms of their applications and requirements, there are certain design problems that are common to most of the sensor networks. When communicating information over the wireless channel, the design considerations in view of WSNs in industries, the problems like interference and other issues that could be encountered in WSNs are discussed. Some challenges are discussed based on the result from the simulator Castalia based on OMnet++.

II. TECHNICAL CHALLENGES IN IWSN

Implementation of WSNs requires a fundamental understanding of

i) Designing sensor hardware in terms of Low-Power and Low-Cost Sensor-Node Development, Radio Technologies and Energy-Harvesting Techniques

ii) System architectures and protocols

iii) Software Development namely Application Programming Interface (API) and Operating System and Middleware Design [2].

A. Localization and Synchronization

The objective of the sensor nodes is to report their measurements to the sink. Hence it is important for the sink to know the locations at which these measurements were taken so that future actions can be taken accordingly. Time synchronization is also required so that the measurement can be time stamped [3].

The Node locations and other Simulation setup is,

Sink Node[0] – (0,0) Sources are Node[1] – (0,25), Node[2] – (0,50), Node[3] – (20,0), Node[4] – (20,25), Node[5] – (20,50), Node[6] – (40,0), Node[7] – (40,25), Node[8] – (40,50). other specific parameter included are include../Parameter_Include_Files/Radio/TelosB_CC2420/radio_CC2420.ini

SN.Physicalprocess[0].directnodevalueassignment – All values are 40 .

The output of one cycle is shown in Table I.

TABLE 1 PACKET STRUCTURE

Received time (s)	Source node	Value	Sensed/ Received	Sensed Time (s)
7.43117	Node [1]	38.55	R	6.7841
7.85099	Node [8]	43.16	R	6.21022
----------	Node [5]	39.79	S	8.11145
9.17646	Node [3]	40.41	R	8.76819
11.1834	Node [6]	43.95	R	10.3638
36.692	Node [4]	41.36	R	35.2474
43.2129	Node [2]	41.96	R	42.3932
56.033	Node [7]	36.2	R	54.8027

The table shows the received time, sensed time, source node identification, sensed value and status of value, that is whether the sensed value is received or not. Packet structure is one of the design criteria. The consideration of Packet Reception Rate (PRR) due to the environment and the mechanism to improve PRR is major important.

One essentially needs to carefully consider the sensing frequency at which sensing data is provided, Range that gets covered in form of angle/ distance with resolution, size depending on the device on which sensor will be mounted and operating environment / conditions under which such a sensor will function. Sample rate requirements are also a main factor to be considered.

B. Energy consumption

Mostly WSNs are characterized by Many-to-one communication paradigm where all the sensor nodes wish to send their data to a single sink node. The Many-to-one data flow results in a non-uniform energy drainage pattern in the network causing the nodes in certain region of the network may exhaust their battery energy earlier than other nodes due to excessive relaying burden. [4, 5]

One of the major design challenges of WSNs is limited energy resources. So it is necessary to test the lifetime of a battery based on the size of the data packet to be transmitted and network size. Energy consumption (joule or J) is based on the time the radio is on (listening, transmitting or receiving). To calculate the energy consumption, the properties of the resource manager 2AA battery is included.

include./Parameter_Include_Files/resourceMgr_2AAbatteries.ini

The output is

Time: 276011Sec --- Radio Disabled --- Out of energy.

This is equivalent to 3 days, 4.7 hours; the channel may withstand to pass the information shown in Table I. The related studies are Power consuming factors, Power saving algorithms for the Radio. Table II shows Typical Battery Lifetime, Throughput, and Range for IEEE 802.11 and IEEE 802.15.4 Devices [6]. Comparison of various industrial WSNs standards are reported in [7].

TABLE II
PARAMETERS OF IEEE 802.11 AND IEEE 802.15.4 DEVICES

Parameter	Typical IEEE 802.11(n) Devices	Typical IEEE 802.15.4 Devices
Typical Battery lifetime	1-2 days	2-3 years
Bit rate (maximum)	300 Mbits/s	250 Kbits/s
Range (without repeaters)	100m	300m

Likewise it is also necessary to compute the memory capacity needed in sink to store data from all sources, memory capacity needed in source to store data before transmission, memory management and resource management techniques in a constrained environment.

C. Physical process and interference

The implementation of WSNs is prone to multiple factors and is not guaranteed as easily as the cable. The provision of environmental space, the distance between nodes, electromagnetic interference and too many other factors determine the quality of the connection and achieving a wireless communication network [8]. Before installing a network, it is necessary to ensure a degree that it will be successful and functional.

The physical process is the stimulus to be monitored. The sensor may some extent be sensitive to properties other than the property being measured. Usually, the most sensors are influenced by the temperature of their environment and especially air pollution monitoring at point source stack may be affected by the metrological data such as wind direction, wind speed, temperature, and atmospheric stability.

All these deviations can be classified as systematic errors or random errors. Systematic errors can sometimes be compensated for by means of some kind of calibration strategy. Noise is a random error that can be reduced by signal processing, such as filtering, usually at the expense of the dynamic behavior of the sensor. In some scenario it is better to include the monitoring stimulus as more than one physical process.

Attainable capacity and delay at each link depends on location, interference level perceived at the receiver, varying characteristics of the link over space and time due to obstructions and noisy environment, high bit error rates.

Before applying WSNs in industrial applications it should be aware that the coverage areas and reliability of data in the industrial environment may suffer due to noises, co-channel interferences, multipath and other interferences.

The interference signal can be classified as narrowband and broadband. Broadband interferences are signals with a constant energy spectrum over all frequencies and have high energy. They are usually unintentional radiating sources whereas narrowband interferences are intentional noise sources with lower energy [9].

TABLE III INTERFERENCE SOURCES

Broadband interferences	Narrowband interferences
Motors	Cellular telephone
Inverter, SCR circuits	Radio & TV transmitters
Electric switch contacts	Power line hum
Computers, ESD	Signal generators
Ignition systems	Local oscillator, UPS system
Voltage regulators	Test equipment
Lightning electromagnetic pulses	Microwave and ultrasonic equipment
Arc/vapor lamps	Electronic ballasts
Pulse generators	Medical equipment
Thermostats	Microprocessor systems
Welding apparatus	Pager transmitters
Frequency converters	High frequency generators

Table III shows the narrowband and broadband interferences sources that are generally found in the industries. Both interferences have varying degradation affects on wireless link reliability.

To reduce the interferences, spread spectrum radio modulation techniques are desirable as it can offer multiple access capability, anti multipath fading capability and anti-jamming capability. There are two main spread spectrum techniques namely the DSSS (Direct sequence spread spectrum) and FHSS (Frequency hopping spread spectrum). Due to different physical mechanisms DSSS and FHSS react differently in industrial settings. Both have their advantages depending on the applications and environments [10].

D. MAC and Routing

The MAC (Medium Access Control) protocol is an important part of the nodes behavior. MAC protocols attempt to provide reliable communication and achieve high throughput with bounded latency, while at the same time minimizing collisions and energy dissipation. One of the design considerations of WSNs is to have each node transmit at the lowest possible power while preserving network connectivity [11]

Efficient transmission power management can be done by using appropriate MAC protocol. The MIMO-LEACH (Multiple Input Multiple Output - Low-Energy Adaptive

Clustering Hierarchy) and CMAC (Cognitive MAC) protocols provide measures to increase link reliability and at the same time reduce transmission power by exploiting spatial diversity gain.

The Synchronous and Asynchronous low duty cycle MAC protocols found in the literature [12] are listed below.

Synchronous protocols:

Power Aware Clustered TDMA (PACT)
LEACH protocol
Self-Organizing Slot Allocation (SRSA)
Sensor-MAC (S-MAC)
Timeout MAC (T-MAC)
Traffic-Adaptive Medium Access (TRAMA)
DMAC (Directional MAC)
IEEE 802.15.4 MAC,
Zebra MAC (Z-MAC)

Asynchronous protocols:

RF Wake-up protocol,
ALOHA with preamble sampling
Wireless Sensor MAC (Wise MAC)
Asynchronous IEEE 802.15.4 MAC
Berkeley MAC (B-MAC)
Speck MAC, X-MAC.

Network Lifetime (NL) is a critical metric in the design of energy-constrained WSNs. Investigation of a joint optimal design of the physical, medium access control and routing layers is needed to maximize NL [13].

E. *Tunable MAC Parameters*

The application sample interval, listening interval, sleeping interval, duty cycle are the parameters that can be tuned for better packet reception rate and energy efficient communication. Fig. 1 shows how the percentage of data received vary with listen interval and fixed sample interval of 2s. . There is a peak of 100% of reception rate at the Listen interval 220ms. Fig. 2 shows the trend line of variation of application sample interval and percentage of data received. The downward trend line shows that the increase of disturbances. This disturbance may be due to node startup delay, circuits prepare delay and other environmental interference. Further, the graph shows in application sample interval 6s, there is a 100% of reception rate due to tolerable interferences.

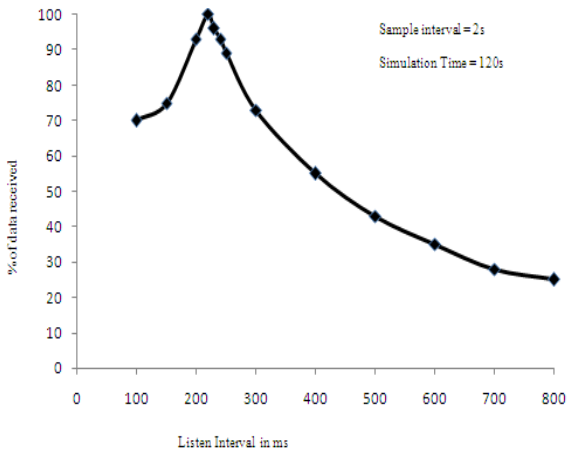

Fig.1 Variation of Listen interval with % of data received

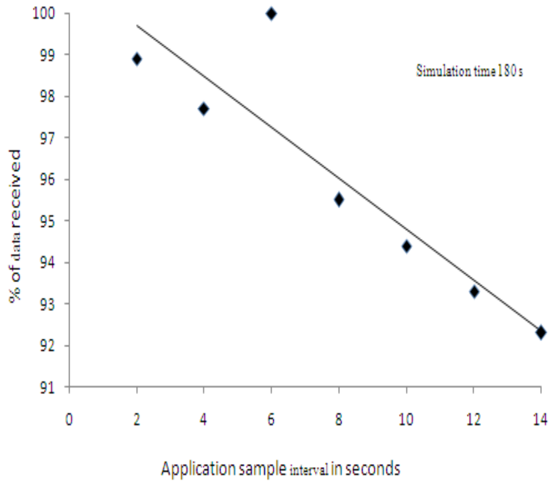

Fig.2 Variation of application sample interval with % of data received

III. CONCLUSION

The application of the IWSN need much experiment and test, to resolve number of critical issues that need to be overcome before those applications become reality. Systematic approach to creating IWSN leads to powerful wireless monitoring and control system. This paper outlines the basic criteria to be considered when IWSN implementation. The technical challenges include some of the performance metrics like power supply, design of energy efficient protocol, throughput, routing, channel access and scheduling. These are all related to application level performance analysis. Other challenges are due to industrial environment interferences.

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