WIRELESS SENSOR NETWORKS FOR INDUSTRIAL AUTOMATION

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ABSTRACT

In today's competitive industry marketplace, the companies face growing demands to improve process efficiencies, comply with environmental regulations, and meet corporate financial objectives. Given the increasing age of many industrial systems and the dynamic industrial manufacturing market, intelligent and low-cost industrial automation systems are required to improve the productivity and efficiency of such systems. The collaborative nature of industrial wireless sensor networks (IWSNs) brings several advantages over traditional wired industrial monitoring and control systems, including self-organization, rapid deployment, flexibility, and inherent intelligent-processing capability.

In this regard, IWSN plays a vital role in creating a highly reliable and self-healing industrial system that rapidly responds to real-time events with appropriate actions.

Wireless Sensor Networks (WSN) provides information for data acquisition and data distribution. It is a network that consists of spatially distributed and automated wireless sensor nodes which are capable of monitoring several physical environmental fields such as air pressure, luminosity, vibration and temperature.

Keywords: IWSN, Industrial Automation, Quality of Service (QoS), Selfhealing

I. INTRODUCTION

In today's competitive industry marketplace, the companiesface growing demands to improve process efficiencies,comply with environmental regulations, and meet corporatefinancial objectives. Given the increasing age of many industrialsystems and the dynamic industrial manufacturing market,intelligent and low-cost industrial automation systems are requiredto improve the productivity and efficiency of such systems[2],[3]. Traditionally, industrial automation systems arerealized through wired communications. However, the wiredautomation systems require expensive communication cablesto be installed and regularly maintained, and thus, they are notwidely implemented in industrial plants because of their highcost [4]. Therefore, there is an urgent need for cost-effectivewireless automation systems that enable significant savings andreduce air-pollutant emissions by optimizing the managementof industrial systems.

WSNs, the realization of low-cost embedded industrial automationsystems have become feasible [5]. In these systems, wireless tiny sensor nodes are installed on industrial equipmentand monitor the parameters critical to each equipment'sefficiency based on a combination of measurements such asvibration, temperature, pressure, and power quality. These dataare then wirelessly transmitted to a sink node that analyzesthe data from each sensor. Any potential problems are notifiedto the plant personnel as an advanced warning system.This enables plant personnel to repair or replace equipment,before their efficiency drops or they fail entirely. In this way, catastrophic equipment failures and the associated repair andreplacement costs can be prevented, while complying with strictenvironmental regulations.

The collaborative nature of IWSNs brings several advantagesover traditional wired industrial monitoring and control systems, including self-organization, rapid deployment, flexibility,and inherent intelligent-processing capability. In this regard,WSN plays a vital role in creating a highly reliable and selfhealingindustrial system that rapidly responds to real-timeevents with appropriate actions. However, to realize the envisionedindustrial applications and, hence, take the advantagesof the potential gains of WSN, effective communication protocols, which can address the unique challenges posed by suchsystems, are required.

The technological advancement in the world has over time taken a new turn and measures to monitor activities inindustries are being developed to provide free access to information and support for end users [6]. This is as a result of thehigh demand for resources capable in assisting industrialists to accomplish set goals and develop programs for theestablishment of time delivery of materials and create opportunity for increased knowledge [7].The importance of providing a well detailed prototype Wireless Sensor Network (WSN) in an industrial application cannotbe over-emphasized; hence this project focuses on bridging the gap between the availability of adequate monitoring datareporting to improve on the existing systems and the conventional method of operations.

WSN are technologies in which characteristically constrained nodes assists each other in transmitting packets of datathrough the network from source to destination. The WSN consists of nodes that can send and receive messages in a meshpattern and a node that can function as a router and can also relay messages for its neighbour. Through this process, [8]wireless packet data will find its way to the predetermined destination, passing through intermediate nodes with reliablecommunication channels.

WSN application varies from one location to another. Various fields such as fire, military installations, pollution, machinehealth and environment monitoring have experienced expanding revolution in the implementation of this technology inmanning activities encompass them. In most network design, basic routing is used as the network architecture, while newflooding-based technology provides the opportunity and advantages especially in large networks [9].

II. WIRELESS SENSOR NETWORKS

A WSN can be defined as a network of devices, denoted as *nodes*, which can sense the environment and communicate the information gathered from the monitored field (e.g., an area or volume) through wireless links [13]. The data is forwarded, possibly via multiple hops, to a *sink* (sometimes denoted as *controller* or *monitor*) that can use it locally or is connected to other networks (e.g., the Internet) through a *gateway*. The nodes can be stationary or moving. They can be aware of their location or not. They can be homogeneous or not. This is a traditional single-sink WSN (see Figure 1, left part). Almost all scientific papers in the literature deal with such a definition. This single-sink scenario suffers from the lack of scalability: by increasing the number of nodes, the amount of data gathered by the sink increases and once its capacity is reached, the network size cannot be augmented. Moreover, for reasons related to MAC and routing aspects, network performance cannot be considered independent from the network size. A more general scenario includes multiple sinks in the network (see Figure 1, right part) [14]. Given a level of node density, a larger number of sinks will decrease the probability of isolated clusters of nodes that cannot deliver their data owing to unfortunate signal propagation conditions.

In principle, a multiple-sink WSN can be scalable (i.e., the same performance can be achieved even by increasing the number of nodes), while this is clearly not true for a single-sink network. However, a multi-sink WSN does not represent a trivial extension of a single-sink case for the network engineer. In many cases nodes send the data collected to one of the sinks, selected among many, which forward the data to the gateway, toward the final user (see Figure 1, right part). From the protocol viewpoint, this means that a selection can be done, based on a suitable criterion that could be, for example, minimum delay, maximum throughput, minimum number of hops, etc. Therefore, the presence of multiple sinks ensures better network performance with respect to the single-sink case (assuming the same number of nodes is deployed over the same area), but the communication protocols must be more complex and should be designed according to suitable criteria.

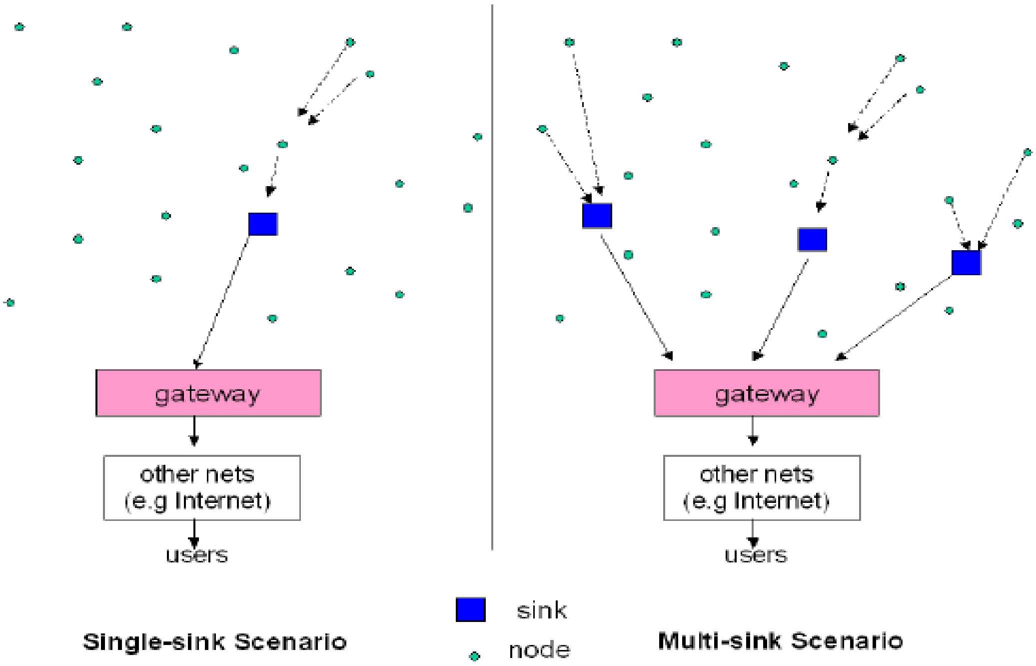


Fig. No. 01 Single and Multi-Sink Scenario

III. MAIN FEATURES OF WSN

The main features of WSNs, as could be deduced by the general description given in the previous sections, are: scalability with respect to the number of nodes in the network, self-organization, self-healing, energy efficiency, a sufficient degree of connectivity among nodes, low-complexity, low cost and size of nodes. Those protocol architectures and technical solutions providing such features can be considered as a potential framework for the creation of these networks, but, unfortunately, the definition of such a protocol architecture and technical solution is not simple, and the research still needs to work on it [5].

The massive research on WSNs started after the year 2000. However, it took advantage of the outcome of the research on wireless networks performed since the second half of the previous century. In particular, the study of ad hoc networks attracted a lot of attention for several decades, and some researchers tried to report their skills acquired in the field of ad hoc networks, to the study of WSNs.

According to some general definitions, wireless ad hoc networks are formed dynamically by an autonomous system of nodes connected via wireless links without using an existing network infrastructure or centralized administration. Nodes are connected through "ad hoc" topologies, set up and cleared according to user needs and temporary conditions [15]. Apparently, this definition can include WSNs. However, this is not true. This is the list of main features for wireless ad hoc networks: unplanned and highly dynamical; nodes are "smart" terminals (laptops, etc.); typical applications include realtime or non-realtime data, multimedia, voice; every node can be either source or destination of information; every node can be a router toward other nodes; energy is not the most relevant matter; capacity is the most relevant matter [15].

Apart from the very first item, which is common to WSNs, in all other cases there is a clear distinctionbetween WSNs and wireless ad hoc networks. In WSNs, nodes are simple and low-complexity devices;the typical applications require few bytes sent periodically or upon request or according to some external event; every node can be either source or destination of information, not both; some nodes do not play the role of routers; energy efficiency is a very relevant matter, while capacity is not for most applications.Therefore, WSNs are not a special case of wireless ad hoc networks. Thus, a lot of care must be used when considering protocols and algorithms which are good for ad hoc networks, and using them in the context of WSNs.

3.1 Sensor Technologies

Sensor Technologies functions in highly powered high-speed and low-cost electronic circuits. In a developing world, the need for sensor technologies with a view to support systems automation, security and information dissemination is on the increase. The application of sensor technology in diverse ways has eventually enforced the increase of the requirement for the implementation. The design of smart homes and environment is made possible by the use of sensor devices.

Sensor technologies in this respect are expected to provide novel approaches and solutions as required. Sensor can be considered as complex devices that can be used to detectand respond to signals being produced. A sensor primarily converts physical parameters into signal. These parameters can be; temperature, humidity, and speed. The signal produced can be measured electronically.

When deciding on a particular sensor to use in a given task, the following consideration will be employed; Cost, Range, Accuracy, Environmental consideration, and Resolution.

IV. APPLYING WSN IN INDUSTRIAL PLANT ENERGY EVALUATION AND PLANNING SYSTEMS

Traditionally, energy evaluation in industrial plants is realized in wired systems formed by communication cables and various types of sensors [16]. The installation and maintenance of these cables and sensors are usually much more expensive than the cost of the sensors themselves. Clearly, the elimination of communication cables and theassociated installation cost can greatly reduce the overall cost. This naturally brings the opportunity to investigate the use of wireless systems. However, because of the high cost of commissioning legacy wireless systems, this was infeasible until the appearance of the wireless sensor network (WSN) during the past few years.

Recent advances in wireless communications, micro electro-mechanical systems, and highly integrated electronics have enabled the implementation of very low cost, ultra-low power consumption, multifunctional sensors and actuators. The deployment of large numbers of these sensors and actuators has resulted in the development of wireless sensor networks [16]. Unique characteristics such as a sensor-richenvironment, flexibility, high fidelity, self-organization,rapid deployment, and inherent intelligent capability makeWSNs the ideal structure for low cost energy usageevaluation, which is important to industrial plant managers inmaking planning decisions.

4.1IEEE 802.15.4 Standard

The IEEE 802.15.4 standard is intended to address applications where existing wireless solutions are too expensive and the performance of a technology such as Bluetooth is not required. While other wireless network standards aim to achieve long distance, large throughput, and high quality of service (QoS) level; the 802.15.4 standard is designed to provide simple wireless communications with short-range distances, limited power, relaxed data throughput, low production cost, and small size. These are exactly the properties of the industrial plant energy evaluation and planning system.

As shown in Fig. 2, the 802.15.4 LR-WPANs standard allows the formation of two possible network topologies: the star topology and the peer-to-peer topology [16]. In the startopology, any active node is a full or reduced function device. That only communicates with the central coordinator node.The coordinator node is a full function device acting as ahub. The star topology is easy to implement but is verylimited in short-range networks such as 802.15.4, because ofthe need for many central hubs to gather the node data. Thepeer-to-peer topology enables multiple direct links between asingle node and other nodes in the WSN, and allows morecomplex network formations to be implemented, e.g., ad hocand self-configuring mesh networks. However, the networkcomplexity is increased.

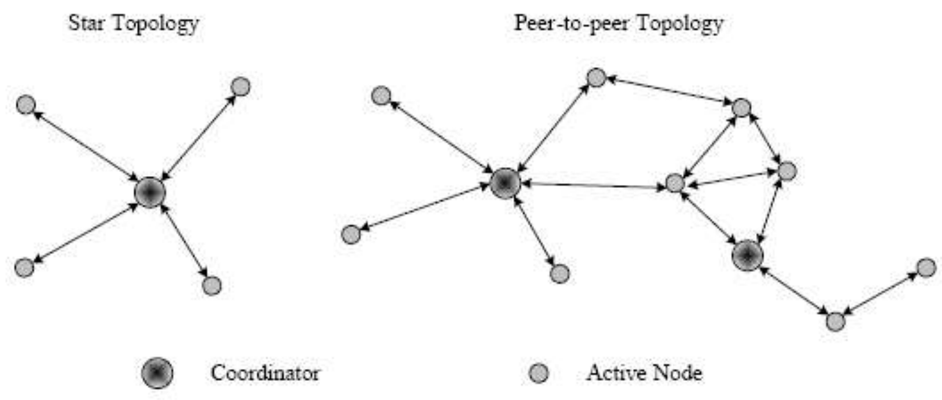


Fig. no. 02 Star and Peer-to-Peer Network Topologies

4.2 Energy Evaluation and Planning

As the cost of energy increases, energy savings in industry are drawing more attention in recent years. In industry, motors below 200 hp make up 98% of the motors in service and consume 85% of the energy used. On average, the motors in industry operate at no more than 60% of their rated load because of oversized installations or underloaded conditions, and thus at reduced efficiency which results in wasted energy.

To improve energy savings, an evaluation of the motor efficiency in the industrial plant is required. Over the years, many motor efficiency estimation methods have been proposed. Generally, most of these methods are too intrusive and even not achievable for in-service motor testing, because either expensive speed and/or torque transducers are needed or a highly accurate motor equivalent circuit needs to be developed; some methods are more practical but are focused in specific applications. To overcome these problems, presents a complete survey of motor efficiency estimation methods, specifically considering the advances in sensorless speed estimation and in-service stator resistance estimation techniques during the last decade. In addition shows an assessment of non-intrusive methods for efficiency estimation. Three candidate methods for non-intrusive efficiency estimation were selected and modified for this model of in-service motor testing. The non-intrusive characteristic of these methods enables efficiency evaluation with a WSN, using only motor terminal voltages and currents.

Motor condition monitoring gives the health condition ofrunning electric motors and avoids production lossesresulting from unexpected motor shutdowns and failures.Sharing many common requirements with energy usageevaluation in terms of data collection, motor conditionmonitoring could be naturally added into an energymanagement system without additional cost for datacollection considering that the necessary data are readilyavailable.

Based on the estimated efficiencies of the motors in theplant, the overall energy usage condition and the operatingcost of the plant can be evaluated. These energy evaluationand health condition monitoring resultscan be very valuablefor plant managers in making planning decisions forscheduled maintenance.

4.3 A Closed-Loop Industrial Plant Energy Evaluation and Planning system

A closed-loop energy evaluation and planning scheme forindustrial plants is proposed with a WSN as the back-bonestructure. The wide deployment of a WSN results in asensor-rich environment which allows for a high levelintelligent energy management system for industrial plants.The importance of the proposed scheme lies in its wireless,non-intrusive, intelligent, and low cost nature.

There are three different types of sensor nodes in atypical WSN: transmitter node, receiver node, an relay node.The transmitter node has both sensing and communicationcapabilities. It could be attached on the motor frame, but inmost cases, it is installed in the Motor Control Centers MCC to collect motorterminal voltages and currents, because the motors in plantare usually not easily accessible. The receiver node andrelay node have only communication capabilities and cannotgather data themselves. Their main function is to pass thetransmitted data to the Central Supervisory Station CSS.

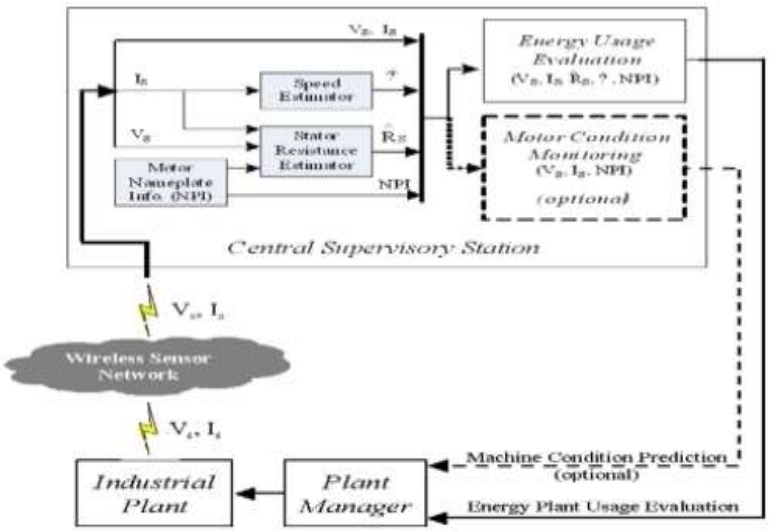
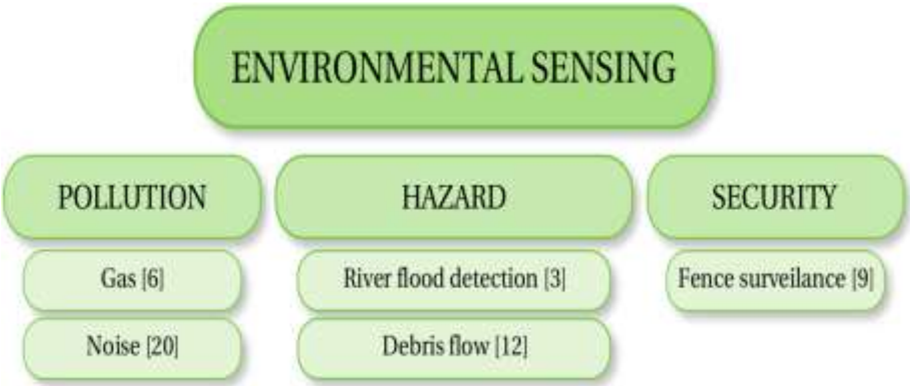


Fig. No. 03 WSN Architecture

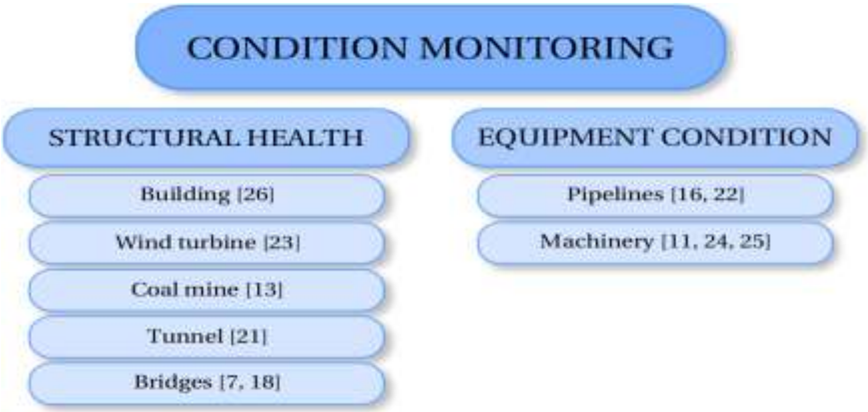
As shown in Fig. 3, the motor terminal quantities aremeasured at the MCC and transmitted to the CSS through theWSN. Using these data, non-intrusive methods are used toestimate the energy usage condition of each motor in theplant, and finally the operating cost of the whole plant. Asan optional block, the motor condition monitoring functionscould also be applied using the same received data. To closethe loop, a plant manager can make planning decisions suchas replacing oversized or malfunctioned motors based on theenergy usage evaluation and diagnosis results.

V. APPLICATIONS OF WSN

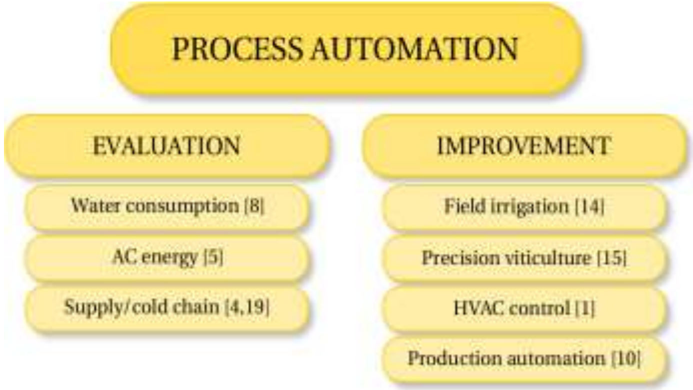
5.1 Environmental Sensing Applications



5.2 Condition Monitoring Applications



5.3 Process and Service Monitoring Applications



VI. CASE STUDY

Fig. No. 04 Power Engineering Lab Setup

In this case study, the laboratory setup of Power Engineering is to be automated by Wireless Sensor Networks. The setup-wise parameters to be considered are as follows-

Setup Details-

i) Setup 1 – 4stroke ,3 cylinder petrol engine

Induction motor=440v, 1Hp,1440rpm

ii) Setup 2 – two stage single cylinder air compressor test rig

Compressor- working pressure=10kg/cm^2 , rpm=650,

Motor=2hp,1440 rpm

iii) Setup 3 – Vapour compression test rig

Thermocouple= type PT100

Heater= 1000W

Electric supply= 230V AC, 50Hz

iv) Setup 4 – single cylinder 4stroke petrol engine test rig

Engine- 4stroke, power 5.5kW @ 7500 rpm

The nodes

VII. CONCLUSION

The IWSNs have the potential to improve productivity of industrial systems by providing greater awareness, control, and integration of business processes. Despite of the great progress on development of IWSNs, quite a few issues still need to be explored in the future. For example, an efficient deployment of IWSNs in the real world is highly dependent on the ability to devise analytical models to evaluate and predict IWSNs performance characteristics, such as communication latency and reliability and energy efficiency. However, because of the diverse industrial-application requirements and large scale of the network, several technical problems still remain to be solved in analytical IWSN models. Other open issues include optimal sensor-node deployment, localization, security, and interoperability between different IWSN manufacturers. Finally, to cope with RF interference and dynamic/varying wireless-channel conditions in industrial environments, porting a cognitive radio paradigm to a low-power industrial sensor node and developing controlling mechanisms for channel handoff is another challenging area yet to be explored.

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