# Wireless Sensor Networks: Application, Architecture, Design issues and Research Challenges

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**ABSTRACT**

Wireless Sensor Network (WSN) stands forefront in the scientific research community recently. WSNs are highly scattered self-organizing system which offer a powerful combination of sensing, processing and communication capabilities and are deployed in various fields. However, Routing protocols have been designed depend on both the network architecture and applications. Both routing schemes and algorithms have the common objective of trying to get better throughput with minimum delay and to extend the lifetime of the sensor network. The purpose of this paper is to provide a brief technical introduction to WSN architecture, few potential applications, various essential issues and research challenges. For the performance and efficiency of the WSN to reveals the important issues that to be taken into consideration while designing the WSN routing protocol.

Keywords **-** Design issues, Routing Protocol, Self-organizing, Sensor, Wireless Sensor Networks

## 1. Introduction

Wireless networking technology has seen a thriving development in recent years. Networks of wireless Sensors are being integrated into the environment, machinery and human, coupled with the efficient delivery of sensed information, could deliver tremendous benefits to society. Some of the potential benefits are preservation of natural resources, reinforced emergency response, enhanced manufacturing productivity and improved homeland security. The significance of sensor networks have low energy consumption, low cost, sufficient intelligence for signal processing, self organizing capability, data gathering and querying ability[1, 2].

Research in the area of WSN has been active at many levels such as the component level, the system level, and the application level. The *component level* research focuses on improving the sensing, computation and communication capabilities of a single sensor. Research at the *system level* is focused with the routing mechanism of networking and coordinating sensors in a scalable and energy-efficient fashion. The *application level* research is focused with the processing of the data produced by sensors, depending on the objective of applications. In this paper, our aim is to establish a framework for designing a routing protocol for any applications, involving the infrastructure-less deployment of huge sensors have a limited amount of energy. Hence, there is a need to design the sensor network in generic, interoperable and modular fashion. This approach yields a platform that can support any new application on top of the existing network [3].

## 2. Potential Applications of WSN

Wireless sensor networks are currently being deployed in a variety of applications ranging from medical to military and from home to industry. It aims to provide a reference tool for the increasing number of scientists who depend upon reliable sensor networks. It provides potentially endless opportunities in a number of different applications, a few of which will shortly be described here to illustrate how broad this application field is [4].

**2.1. Military Applications** – WSNs are becoming an integral part of military command, control, communication and intelligence systems. Due to ease of deployment, self-configuration, fault tolerance and unattended operation, sensor network play more important roles in military system and make future wars more intelligent with less human involvement [5].

**2.2. Structural Health Monitoring** – Sensors embedded into machines enable condition based maintenance of these assets and to be inspected at regular time intervals when the sensors indicate that there may be a problem, reducing the cost of maintenance and preventing failure in the event that damage is detected [7].

**2.3. Environment Monitoring** – It is one of the earliest applications of sensor networks. It is used to monitor the conditions of wild animals or precision agriculture in wild habitats. It is also deployed in an intended region to detect natural or non-natural disasters. For example, sensors can be distributed in forest to detect fire or flood [8].

**2.4. Health Care Monitoring** – WSNs can be used to monitor and track patients and elders for health care purpose. To provide interfaces for diagnosing, drag administration and monitoring of human physiological data such as oxygen measurement, blood pressure, heart rate and etc.

**2.5. Home Applications** – WSNs can be used to provide more convenient intelligent living environment for human beings. Sensors can be embedded inside the domestic devices (washing machine, refrigerator, VCR ) can interact with each other and with an autonomous home network connected to internet to control the appliances.

**2.6. Other Commercial Applications** – Some important commercial applications are construct smart office space, monitoring material fatigue, building virtual keyboards, detecting and monitoring car thefts, traffic control, robot control and guidance in automatic manufacturing environment [8].

However, a number of technical issues must be solved before these exciting applications become a reality.

## 3. Communication Architecture of WSN

Wireless Sensor networks have emerged as a promising and intelligent tool for monitoring the larger geographical regions with greater accuracy. Sensor networks have been widely used in the military, civilian, industry, environmental and commercial areas. It gathers application specific parameters like pressure, humidity, chemical activity, battle field, vital body functions and etc., [1, 9].

The sensors are heart of the network which periodically sense the data, process it and transmit to the sink in hop by hop transmission to form a communication network. Sink is also known as *data aggregation point*. The specific task of a sink is receiving, processing and storing data and then routed to the task manager or user via satellite or internet where users can have access to the data. The task manager acts as a centralized point of sensor network which also serves as a gateway to other networks, a powerful data processing and storage centre and an access point for a human interface [4, 10] shown in Fig. 1.

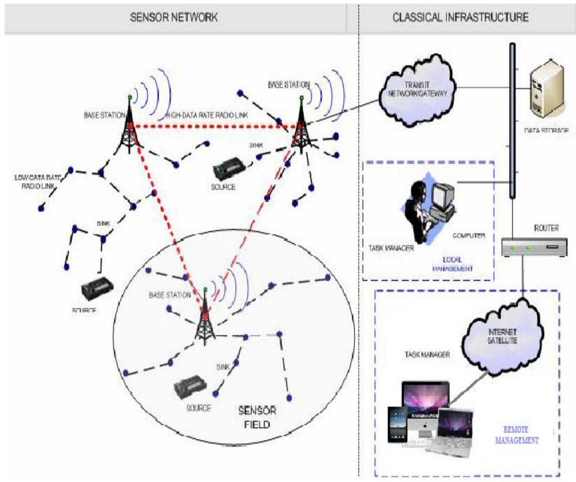


**Fig.1 Illustration of Communication Architecture of Sensor Network**

### 4. Communication Architecture of Sensor

Sensor is a smart tiny device that has a micro-sensor technology, low power signal processing, capable of fast data acquisition, having significant energy constraints, no real time maintenance, reliable and accurate. The main task of a sensor in a sensor field is to detect events, perform quick local data processing and transmit the data. It will initiate transmission according to measures and a query originated from the task manager [5].

Fig. 2 shows sensors are conventionally made up of four basic units such as sensor, processor, power generator and communication unit. Each sensor may also consist of optional components namely Location finding system and Mobilizer. If the user requires the knowledge of location with high accuracy then it uses Location finding system. Mobilizer may be needed to move sensors when it is required to carry out the assigned tasks. They are assigned with different tasks based on its decisions on its mission depending on the routing algorithms used [8, 11].

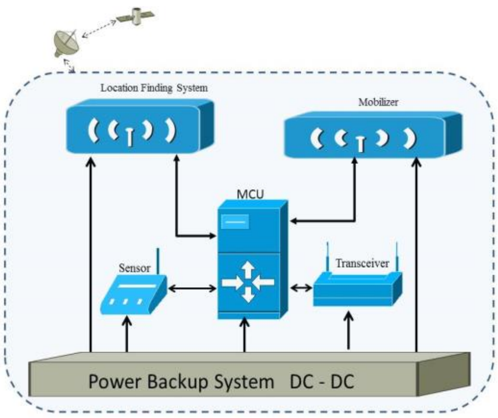


**Fig. 2 Wireless Sensor Architecture**

**4.1. Sensing unit -** It consist sensor and ADC (Analog to Digital Converter). The sensors are interlinked together and each sensor is able to communicate and collaborate for fulfill their tasks by using wireless links. These are able to interact with the environment by sensing physical parameters and transfer it to the MCU (Microcontroller Unit).

**4.2. Processing unit -** It is the most complex unit.

**4.2.1. Microcontroller unit (MCU**) - It is a general purpose processor which performs computations on the received data, computes the next hop to the sink, controls and monitor battery power, etc.

**4.2.2. Memory** - Flash EEPROM is used for storing program code and computes the procedure by non-volatile RAM.

**4.2.3. Operating Systems** - Sensor uses less complex OS such as Contiki, TinyOS, RIOT, LiteOS and etc. [8]

**4.3. Communication unit -** It is responsible for message exchange between the sensors through radio transceiver. Main task of this unit is to receive command or query from and transmit the data from MCU to the outside world.

**4.3.1. Transceiver -** It receives instruction from processing unit and passes it to another sensor via antenna. These sensors communicate over short distance via a wireless media like Radio frequency (RF) (3 KHz to 300GHz) which is based on electromagnetic waves and is best communication media of WSN.

**4.4. Power Generator unit -** It provides energy for sensor and has two essential aspects: i) storing energy and providing in the required form ii) consumed energy by scavenging [12].

**4.4.1. Battery** - It is the power source of a sensor and it implicitly determines the lifetime of the entire network. It may either rechargeable or non-rechargeable. The sensor will expend approximately 4.8mA receiving a packet, 12mA transmits a packet and 5μA sleeping [7]. Hence, the MCU uses on average 5.5mA when in active mode.

**4.4.2. DC-DC converter** - It is used to regulate the voltage of sensor.

## 5. Design issues and Research Challenges

The routing protocols designed for WSN should consider design constraints, application area, and architecture of the network. Some of essential issues are reviewed below. These issues must be overcome before efficient performance can be achieved in WSNs

**5.1. Fault Tolerance and Adaptability -** Some sensors may fail or blocked due to lack of power generation, transmission problem or other environmental interference make the sensors become inactivity. In case of any fault, sensor network can able to adapt by changing its connectivity using well-efficient routing protocols to change the overall configuration of network. Reliability is modeled in [7] using the Poisson distribution to capture the probability of not having a failure within the time interval (0,t): $R_k(t) = e^{-\lambda}k^t$, Where λk : is the failure rate of sensor k and t is the period of time.

**5.2. Scalable and Flexible Architecture** – The routing protocols must be able to work with huge sensors and should be able to accept new sensor and co-ordinate them with existing sensors. The density of these sensors affects the degree of coverage area of interest so it affects data processing, reliability and accuracy. The density can range from a fewer sensors to huge in a region that can be less than 10m in diameter. The density μ is calculated as in [7]: $\mu(R) = (N\pi R^2)/A$, Where N is the number of sensors in sensor field A, and R is the radio transmission range. Basically, μ(R) gives the number of sensors within the transmission radius of sensor in region A.

**5.3. Network Topology Control -** To cover the entire environment of sensor network and careful forming of network topology. It affects many of its characteristics like latency, capacity, data routing and processing. There are three phases related to topology control and maintenance are [13] i) Pre-deployment and development phase ii) Post-deployment phase and iii) Redeployment of additional sensors phase.

**5.4. Energy Consumption without losing accuracy -** Wireless sensor is a microelectronic device which require a limited power source (<0.5 Ah 1.2V) [10]. Sensor network lifetime is strongly dependent on its battery. Hence power conservation and power management is an important issue in WSN especially where no power regeneration is possible in some applications scenarios [12]. Therefore various efficient routing protocols should be used at each layer in order to manage energy consumption.

**5.5. Coverage, Connectivity and Scheduling -** *Coverage* problem reflects how well an area of interest is tracked by sensors. These sensors sense the data using coverage algorithm and send them to base station using routing algorithm. *Connectivity* tells how by using radio transmission senses data by the sensor and delivers to sink. Since it influences routing protocols design and data dissemination techniques [13]. *Scheduling* also plays major role for coverage and connectivity. By using appropriate scheduling algorithm, to improve the lifetime of sensor network and avoid data replication.

**5.6. Data Aggregation -** Data aggregation is described as routing techniques that combine the data that comes from many sensors into meaningful information and eliminate the replication. This technique has been used to improve energy efficient, traffic optimization and bandwidth utilization [13].

**5.7. Data Delivery Models -** Depending on the application of the sensor network, data delivery to the sink can be categorized as time-driven, event-driven, query-driven and hybrid. The routing algorithm is highly influenced by the data delivery model in terms of energy consumption, reliability and route stability [14].

**5.8. Data Latency and Overhead -** These are considered as the important issues that guidance routing protocol design. Data Latency means total amount of time a network spends to deliver data from source to destination. Data aggregation and multi-hop relays cause data latency [13]. In addition, some routing protocols create excessive overheads to implement their algorithms.

**5.9. Self-Configuration -** Sensors work unattended in a dynamic environment; so they need to be self-configuration to establish a topology that supports transmission under severe energy constraints, minimizing delay and maximum throughput. So it is an essential issue to maintain a WSN functions properly and serve its purpose [15].

**5.10. Quality of Service (QoS) -** It provides better service to selected network traffic over various technologies. The sensor network has to trade off between quality of data and energy consumption. In particular, the senor network has to satisfy certain QoS metrics like data latency, energy, packet loss, bandwidth, error rate etc., [13]. Thus, protocol design should consider the QoS metrics of specific applications.

**5.11. Production Costs -** Sensor networks consist of a huge sensors, the cost of a single sensor is very significant to justify the overall cost of the networks [14]. If the cost is high, the adoption and spread of sensor technology will be prohibitive and hence the cost of each sensor has to be kept low.

**5.12. Safety and Security -** It is not possible to introduce a new technology without considering security aspects. Security is very important parameter since hackers can easily attack the network because there is no particular ID associated with sensors [13]. So, there is need to develop distributed security approaches for sensor network which are confidentiality, authentication, authorization, integrity and non-repudiation.

**5.13. Hardware Constraints –** WSN consist of sensors, processing unit, communication unit and power unit. Hardware should be in such way that it should be capable of operating with high densities.

## 6. Conclusion

Unlike other networks, WSN are designed for specific applications which differ in features and requirements. To support this diversity of applications, the development of new routing protocols, designs and services are needed. Moreover, we have highlighted possible improvements and research in each area. By solving these issues, we can close the gap between technology and application.

There are several optimization goals and design principles that should be taken into account for developing and implementing a WSN. For the efficiency and reliability of the sensor network we have to consider different issues based on the design, architecture and applications.

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