Wireless Sensor Network Architecture

Pradhnya Kamble[1] R.V. Kshirsagar[2] and K. Mankar[3]

***Abstract*-- Recent advancement in wireless communications and electronics has enabled the development of low-cost sensor networks. The sensor networks can be used for various application areas (e.g., health, military, home). For different application areas, there are different technical issues that researchers are currently resolving.The current state of the art of sensor networks is captured in this article, where solutions are discussed under their related protocol stack layer sections. This article also points out the open research issues and intends to spark new interests and developments in this field.**

***Index Terms*—Design factor, environment, fault toleracne, fibre optic micro cable, power consumption, protocol stack, scalability, sensor network topology, transmission media, wireless communication.**

I. Introduction

RECENT advances in wireless communications and electronics have enabled the development of low cost, low-power, multifunctional sensor nodes that are small in size and communicate untethered in short distances. These tiny sensor nodes, which consist of sensing, data processing, and communicating components, leverage the idea of sensor networks. Sensor networks represent a significant improvement over traditional sensors. A sensor network is composed of a large number of sensor nodes that are densely deployed either inside the phenomenon or very close to it. The position of sensor nodes need not be engineered or predetermined. This allows random deployment in inaccessible terrains or disaster relief operations. On the other hand, this also means that sensor network protocols and algorithms must possess self-organizing capabilities. Another unique feature of sensor networks is the cooperative effort of sensor nodes. Sensor nodes are fitted with an onboard processor. Instead of sending the raw data to the nodes responsible for the fusion, they use their processing abilities to locally carry out simple computations and transmit only the required and partially processed data.[1]

The above described features ensure a wide range of applications for sensor networks. Some of the application areas are health, military, and home. In military, for example, the rapid deployment, self-organization, and fault tolerance characteristics of sensor networks make them a very promising sensing technique for military *command*, *control*, *communications*, *computing*, *intelligence*,*surveillance*, *reconnaissance*, and *targeting systems*.

In health, sensor nodes can also be deployed to monitor patients and assist disabled patients. Some other commercial applications include *managing inventory*, *monitoring product quality*, and *monitoring disaster areas*. Realization of these and other sensor network applications require wireless ad hoc networking techniques. Although many protocols and algorithms have been proposed for traditional wireless ad hoc networks, they are not well suited to the unique features and application requirements of sensor networks. To illustrate this point, the differences between sensor networks and ad hoc networks are:

- The number of sensor nodes in a sensor network can be several orders of magnitude higher than the nodes in an ad hoc network.
- Sensor nodes are densely deployed.
- Sensor nodes are prone to failures.
- The topology of a sensor network changes very frequently.
- Sensor nodes mainly use a broadcast communication paradigm, whereas most ad hoc networks are based on point-to-point communications.
- Sensor nodes are limited in power, computational capacities, and memory.
- Sensor nodes may not have global *identification* (ID) because of the large amount of overhead and large number of sensors.

Many researchers are currently engaged in developing schemes that fulfill these requirements. In this article we present a survey of protocols and algorithms proposed thus far for sensor networks. Our aim is to provide a better understanding of the current research issues in this emerging field. We also attempt an investigation into pertaining design constraints and outline the use of certain tools to meet the design objectives. The remainder of the article is organized as follows. We discuss the communication architecture of the sensor networks as well as the factors that influence sensor network design. We provide a detailed investigation of current proposals in the physical, data link, network, transport, and application layers, respectively.

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II. Sensor Networks Communication Architecture

The sensor nodes are usually scattered in a *sensor field* as shown in Fig. 1. Each of these scattered sensor nodes has the capabilities to collect data and route data back to the *sink*. Data are routed back to the sink by a multihop infrastructureless architecture through the sink as shown in Fig. 1. The sink may communicate with the *task manager node* via Internet or satellite. The design of the sensor network as described by Fig. 1 is influenced by many factors, including *fault tolerance*, *scalability*, *production costs*, *operating environment*, *sensor network topology*, *hardware constraints*, *transmission media*, and *power consumption*.

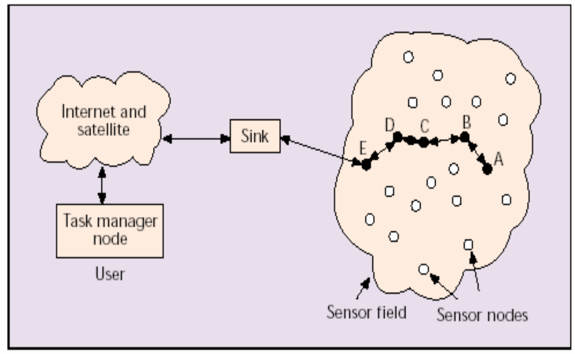
III. Design Factors

The design factors are addressed by many researchers as surveyed in this article. However, none of these studies has a fully integrated view of all the factors driving the design of sensor networks and sensor nodes. These factors are important because they serve as a guideline to design a protocol or an . algorithm for sensor networks. In addition, these influencing factors can be used to compare different schemes.

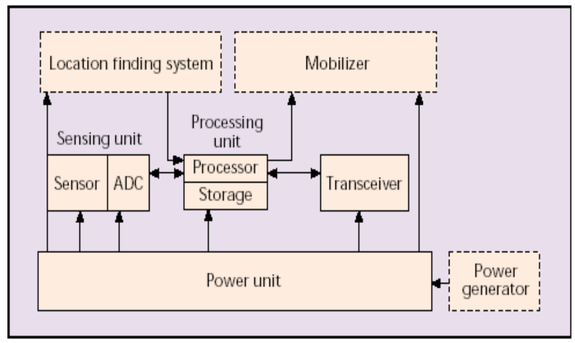
Production Costs — Since sensor networks consist of a large number of sensor nodes, the cost of a single node is very important to justify the overall cost of the network. If the cost of the network is more expensive than deploying traditional sensors, he sensor network is not cost-justified. As a result, the cost of each sensor node has to be kept low. The state-of-the-art technology allows a Bluetooth radio system to be less than US$10 [4]. Also, the price of a piconode is targeted to be less than US$1. The cost of a sensor node should be much less than US$1 in order for the sensor network to be feasible. The cost of a Bluetooth radio, which is known to be a low-cost device, is even 10 times more expensive than the targeted price for a sensor node.

Scalability — The number of sensor nodes deployed in studying a phenomenon may be on the order of hundreds or thousands. Depending on the application, the number may reach an extreme value of millions. New schemes must be able to work with this number of nodes. They must also utilize the high density of the sensor networks. The density can range from few sensor nodes to few hundred sensor nodes in a region, which can be less than 10 m in diameter. The density μ can be calculated according to [3] as $\mu(R) = (N \pi R2)/A$, (2) where N is the number of scattered sensor nodes in region A, and R is the radio transmission range. Basically, $\mu(R)$ gives the number of nodes within the transmission radius of each node in region A.

Fault Tolerance — Some sensor nodes may fail or be blocked due to lack of power, or have physical damage or environmental interference. The failure of sensor nodes should not affect the overall task of the sensor network. This is the reliability or fault tolerance issue. Fault tolerance is the ability to sustain sensor network functionalities without any interruption due to sensor node failures [1, 2]. The reliability $Rk(t)$ or fault tolerance of a sensor node is modeled in [2]



■ **Figure 1.** *Sensor nodes scattered in a sensor field.*



■ **Figure 2.** *The components of a sensor node.*

Figure 1. Sensor nodes scattered in a sensor field.

using the Poisson distribution to capture the probability of not having a failure within the time interval $(0,t)$: $Rk(t) = e^{-\lambda k\, t}$, (1) where λk is the failure rate of sensor node k and t is the time period.

Hardware Constraints — A sensor node is made up of four basic components, as shown in Fig. 2: a *sensing unit*, a *processing unit*, a *transceiver unit*, and a *power unit*. They may also have additional application-dependent components such as a *location finding system*, *power generator*, and *mobilizer*. Sensing units are usually composed of two subunits: sensors and analog-to-digital converters (ADCs). The analog signals produced by the sensors based on the observed phenomenon are converted to digital signals by the ADC, and then fed into the processing unit. The processing unit, which is generally associated with a small storage unit, manages the procedures that make the sensor node collaborate with the other nodes to carry out the assigned sensing tasks. A transceiver unit connects the node to the network. One of the most important components of a sensor node is the power unit. Power units may be supported by power scavenging units such as solar cells. There are also other subunits that are application-dependent. Most of the sensor network routing techniques and sensing tasks require knowledge of location with high accuracy. Thus, it is common that a sensor node has a location finding system.

Sensor Network Topology — Hundreds to several thousands of nodes are deployed throughout the sensor field. They are deployed densities may be as high as 20 nodes/m3 [8]. Deploying a high number of nodes densely requires careful handling of topology maintenance. We examine issues related to topology maintenance and change in three phases: • *Predeployment and deployment phase*: Sensor nodes can be either thrown in as a mass or placed one by one in the sensor field. They can be deployed by dropping from a plane, deliveried in an artillery shell, rocket, or missile, and placed one by one by either a human or a robot.

• *Post-deployment phase*: After deployment, topology changes are due to change in sensor nodes' [5] position, reachability (due to jamming, noise, moving obstacles, etc.), available energy, malfunctioning, and task details.

• *Redeployment of additional nodes phase*: Additional sensor nodes can be redeployed at any time to replace malfunctioning nodes or due to changes in task dynamics.

Environment — Sensor nodes are densely deployed either very close or directly inside the can hence be divided into three domains: *sensing*, *communication*, and *data processing* phenomenon to be observed. Therefore, they usually work unattended in remote geographic areas. They may be working in the interior of large machinery, at the bottom of an ocean, in a biologically or chemically contaminated field, in a battlefield beyond the enemy lines, and in a home or large building.

Transmission Media — In a multihop sensor network, communicating nodes are linked by a wireless medium. These links can be formed by radio, infrared, or optical media. To enable global operation of these networks, the chosen transmission medium must be available worldwide. Much of the current hardware for sensor nodes is based on RF circuit design. The AMPS wirelesssensor node described in [8] uses a Bluetooth-compatible2.4 GHz transceiver with an integrated frequency synthesizer. The low-power sensor device described in [9] uses a single-channel RF transceiver operating at 916 MHz. The *Wireless Integrated Network Sensors* (WINS). detect events, perform quick local data processing, and then transmit the data. Power consumption can hence be divided into three domains:*sensing*,*communication*,and *data processing.*

IV. Protocol Stack

The protocol stack used by the sink and sensor nodes shown in Fig. 1 is given in Fig. 3. This protocolstack combines power and routing awareness, integrates data with networking protocols, communicates power efficiently through the wireless medium, and promotes cooperative efforts of sensor nodes. The protocol stack consists of the *physical layer*, *data link layer*, *network layer*, *transport layer*, *application layer*, *power management plane*, *mobility management plane*, and *task management plane*. The physical layer addresses the needs of simple but robust modulation, transmission, and receiving techniques. Since the environment is noisy and sensor nodes can be mobile, the medium access control (MAC) protocol must be power-aware and able to minimize collision with neighbors' broadcasts. The network layer takes care of routing the data supplied by the transport layer. The transport layer helps to maintain the flow of data if the sensor networks application requires it. Depending on the sensing tasks, different types of application software can be built and used on the application layer. In addition, the power, mobility, and task management planes monitor the power, movement, and task distribution among the sensor nodes. These planes help the sensor nodes coordinate the sensing task and lower overall power consumption. The power management plane manages how a sensor node uses its power. For example, the sensor node may turn off its receiver after receiving a message from one of its neighbors. This is to avoid getting duplicated messages. Also, when the power level of the sensor node is low, the sensor node broadcasts to its neighbors that it is low in power and cannot participate in routing messages. The remaining power is reserved for sensing. The mobility management plane detects and registers the movement of sensor nodes, so a route back to the user is always maintained, and the sensor nodes can keep track of who their neighbor sensor nodes are. By knowing who the neighbor sensor nodes are, the sensor nodes can balance their power and task usage. The task management plane balances and schedules the sensing tasks given to a specific region. Not all sensor nodes in that region are required to perform the sensing task at the same time. As a result, some sensor nodes perform the task more than others depending on their power level. These management planes are needed so that sensor nodes can work together in a power efficient way, route data in a mobile sensor network,and share resources between sensor nodes.

V. Distributed Surveillance Sensor Network

The purpose of the Distributed Surveillance Sensor Network (DSSN) program is to investigate the applicability of small, inexpensive undersea vehicles to surveillance applications and submarine connectivity. It is based on the concept of a fleet of autonomous undersea vehicles which gather surveillance data and communicate acoustically. Each occasionally docks at an underwater station to dump its data, recharge its batteries, receive any new mission instructions and perhaps remain dormant until its next deployment. The docking station is self powered and is not connected to shore or ship by communications cable. The massive quantity of accumulated data is retrieved at a later time by means of a Flying Plug, a remotely controlled vehicle guided to the docking station by means of a fiber optic microcable (FOMC).

The FOMC is the high-bandwidth channel by which the data is recovered and instructions are downloaded to be disseminated to the surveillance fleet. The DSSN program combines the Flying Plug and FOMC, which were developed at SSC San Diego, with other concepts and technology funded by the Office of Naval Research (ONR).

VI. Autonomous Ocean Sampling Network

The conceptual basis for a distributed array of autonomous sensors is provided by the Massachusetts Institute of Technology's Autonomous Ocean Sampling Network (AOSN). AOSN is a distributed, highly mobile, adaptive sensor network composed of a mix of autonomous underwater vehicles (AUV's) which exhibit complementary capabilities. It is being developed for oceanographic characterization. The architecture is very general, hence the mix of AUV's and their payloads can be optimized for specific mission scenarios, making the concept both highly flexible and very powerful.

The AOSN concept is predicated upon the assumption that the geometric growth in signal processing power we are experiencing at the present continues into the future. Besides increasing capabilities and driving costs down, this trend ultimately permits a single hardware device to support multiple applications. For example, digital signal processing (DSP) chips are used to compensate for multipath propagation in the current generation of acoustic modems developed for AOSN. As DSP's become more capable they will be able to support higher reliable data transfer rates. More importantly, as increased processor speed becomes commercially available enough signal processing capability will eventually exist to permit the extraction of information from the multipath signals themselves (which are currently only discriminated against).

This capability configures the AUV communications network into a huge multi-static active sonar capable of detecting and localizing anomalies within the volume of seawater supporting the acoustic propagation paths. In time the same basic hardware which was originally employed for data communications can simultaneously detect mines and submarines in the water volume --- with only an upgrade in the silicon! This is a striking, but realistic, example of the efficacy of selecting a system's architecture to take maximum advantage of expected technological evolution.

The Odyssey Vehicle

Odyssey is a low-cost AUV specifically developed by the Massachusetts Institute of Technology, SeaGrant Office for the AOSN Program. Constructed to operate at full ocean depth, Odyssey was designed from the beginning to be both highly capable and inexpensive to mass-produce. At less than two meters in length and not requiring any special handling equipment for launch and recovery, Odyssey can transit at several knots for up to 20 hours due to its ultra-low hydrodynamic drag profile and efficient propulsion system, yielding a very respectable range and oceanographic mission profile. An integral part of the Odyssey is its powerful onboard computer, which is based upon a commercial 68030 processor board. This computer executes a control program based upon a flexible high-level behavioral language developed at MIT, and supports vehicle control in a wide range of conditions and mission profiles. New mission profiles are quickly configured, tested (via a simulator developed by the Charles Stark Draper Laboratory) and entered into the computer's library. A sophisticated acoustic modem (developed by the Woods Hole Oceanographic Institute) is an integral part of the system and is used to support reliable two-way digital communications. A large fraction of Odyssey's internal volume is available for mission sensors. Odyssey is a mature technology which has been successfully deployed and operated in many types of ocean environments, including the arctic.

VII. Self-Organizing Sensor Networks

Self-organizing sensor networks may be built from sensor nodes that may spontaneously create impromptu network, assemble the network themselves, dynamically adapt to device failure and degradation, manage movement of sensor nodes, and react to changes in task and network requirements.

Reconfigurable smart sensor nodes enable sensor devices to be self-aware, self-reconfigurable and autonomous. The main benefits of these features are:

Support tactical and surveillance applications using reconfigurable sensor network nodes that are capable of forming impromptu network, being deployed incrementally, and assembling themselves without central administration provide capabilities for sensor networks to adapt dynamically to device failure and degradation and changes in task and network requirements Integrate various application-specific network and system services provided by mixed types of sensor nodes and embedded defense applications.

VIII. Conclusion

The flexibility, fault tolerance, high sensing fidelity, low cost, and rapid deployment characteristics of sensor networks create many new and exciting application areas for remote sensing. In the future, this wide range of application areas will make sensor networks an integral part of our lives. However, realization of sensor networks needs to satisfy the constraints introduced by factors such as fault tolerance, scalability, cost, hardware, topology change, environment, and power consumption. Since these constraints are highly stringent and specific for sensor networks, new wireless ad hoc networking techniques are required. Many researchers are currently engaged in developing the technologies needed for different layers of the sensor networks protocol stack.

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