

On Wireless Sensor Networks

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Abstract

This paper investigates the research issues in Wireless Sensor Networks (WSNs), which is a new computing paradigm that emerged from the fusion of the SCADA (Supervisory Control and Data Acquisition) systems and Ad hoc networks technologies. WSNs provide network connectivity without the aid of any preexisting networking infrastructure. Very small sensor nodes, capable of sensing, data processing, and wireless communication, brought the idea of WSNs based on joint effort of a large number of nodes. WSNs are becoming an increasingly vital technology that will be used in a variety of applications such as inventory tracking, home automation, physiological monitoring, habitat monitoring, home automation, precision agriculture, and forest fire detection. Dynamic network topology, limited battery power, and constrained wireless bandwidth are the special characteristics of WSNs which make management of it significantly more challenging than conventional wired networks. This paper presents an overview of research trends and challenges in the design and implementation of WSNs. It summarizes the potential challenges that influence the WSNs design. Prospective applications of WSNs are described to show the importance of WSN. It also investigates the research issues of communications protocol at different layers.

Keywords

Wireless Sensor Networks (WSNs), Ad Hoc Networks, Protocol layers

1. Introduction

Wireless Sensor Network (WSN) is a new computing paradigm that emerged from the fusion of the SCADA systems and Ad hoc networks technologies. WSN derives the networking characteristics of ad-hoc network and combines it with the hardware facilities of tiny wireless sensors. Once a sufficient number of nodes have been deployed, the sensor network can be used to fulfill its task, such as measuring the physical variables. This task can be issued and supervised by an external entity connected to the WSN, such as manager or supervisor.

WSNs are increasingly attractive tools to detect, monitor and control environmental conditions. WSNs can be used to bridge the gap between the physical and the virtual world. WSNs have a variety of applications of distributed wireless sensing including medical, home security, machine diagnosis, military

applications, environmental monitoring, chemical/biological detection, precision agriculture, etc. Microsensors of WSN must be designed in a highly integrated way with the goal of optimizing energy dissipation, limited computation and self-configuration. WSNs must be self-directed and require a high degree of cooperation and adaptation to perform the desired coordinated tasks, so that the WSN as a whole can provide functionality that an individual node can't. Microsensors will be able to coordinate among themselves on a higher-level sensing task (e.g., reporting the speed, direction, size, and other characteristics of a moving vehicle). Figure 1 shows the concept of WSN.

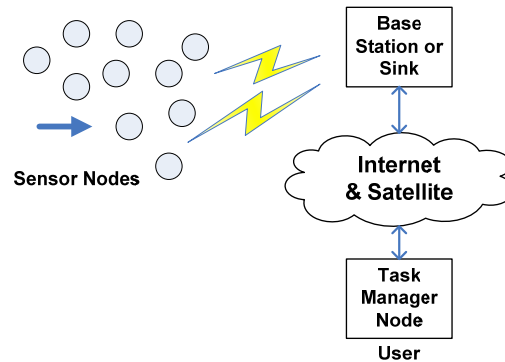


Figure 1: Wireless Sensor Network (WSN)

Within few years, sensor integration and electronic miniaturization will make possible to produce extremely cheap sensing devices. These devices will be able to monitor and control wide variety of ambient conditions: temperature, pressure, relative humidity, viscosity, soil makeup, vehicular movement, noise levels, moisture, lighting conditions, mechanical stress levels, and so on. Smart sensor alone can be used to measure the many physical parameters such as temperature, pressure, speed, etc.

2. Sensor Network Challenges

Support for very large numbers of unattended autonomous nodes, adaptability to environment and task dynamics in are the fundamental challenges of WSNs as they have limitations of dynamic network topology, limited battery power, and constrained wireless bandwidth. The configuration of sensor nodes would frequently change in terms of position, reachability, power availability, and even task details. Because these sensor nodes interact with the physical environment, they would experience a significant range of task dynamics. Node mobility, node failures, and environmental obstructions cause a high degree of dynamics in WSN. This includes frequent network topology changes and network partitions. The partitioned subnetworks need to continue running independently, and the management protocol must be robust enough to adapt this condition.

Sensors are energy constrained and subject to unfriendly environments; they can store or reproduce very limited energy from the environment. That is why they fail due to depleted batteries or due to environmental influences. Restricted size and energy typically means restricted resources (CPU performance, memory, wireless communication bandwidth and range). Thus, we need to ensure that network protocol overhead is kept to a minimum so that energy is conserved. The number of packets transmitted/received/processed at each node should be reduced since energy is consumed in these operations.

Other issue is that the transmission distance of microsensor nodes can be very short in compare to the conventional macrosensors and handheld devices. So, the transmitted power is low, and hence requires significantly different architectures for intelligent resource efficiency. While some applications such as image sensors demand a high transmission data rate, most sensing applications will require very low data

rates compared to conventional multimedia traffic. Existing radio architectures are not suitable for these very low data rates since they have significant energy overhead in powering on and off.

WSNs will exist with the plenty of nodes per user (or more). At such heavy quantity, it is impossible to pay attention to any individual node. Furthermore, even if it is possible to consider each node, sensors may be inaccessible, since they are incorporated in physical structures, or thrown into hostile terrain. Thus, for such a system to be effective, it must provide unattended operation and self-configuration functionality. There are many large scale unattended systems exist now a days. For example, automated process and pharmaceutical companies may contain hundreds of largely unsupervised computers as part of SCADA. It can still monitor the different process variables according to the system design. In our case, here, WSN is even bigger and wireless, so we require more consideration.

WSN middleware should support the implementation and basic operation of WSN as outlined above. However, this is a not a trivial task, as WSNs have some unique properties different from ad hoc networks. To outline this point, the differences between sensor networks and ad hoc networks are illustrated below:

1. Sensor nodes are densely deployed in compare to the ad hoc network nodes.
2. The WSN has larger number of sensor nodes than a hoc network.
3. WSN network topology changes more frequently than ad hoc network.
4. WSN nodes are inclined to fail more than ad hoc network nodes.
5. WSN nodes are scarce in resources such as limited in power, and memory.

3. WSN Applications

The features described above provide a wide range of applications for WSNs. WSNs may consist of numerous diverse kinds of sensor nodes to sense different types of parameters such as acoustic, thermal, visual, magnetic, infrared, seismic, radar, etc. These sensor nodes are able to monitor a wide variety of ambient conditions that include the following: flow, temperature, pressure, humidity, moisture, noise levels, mechanical stress, speed, etc. Smart sensors that can monitor many physical variables can be used with WSN. Many new applications are being developed because of this new concept of microsensing and wireless networking of these smart sensors. Some of the potential diverse applications of WSNs are as follows: temperature control, inventory management, physiological monitoring, habitat monitoring, precision agriculture, forest fire detection, nuclear, chemical, and biological attack detection, military, transportation, disaster relief, and environmental monitoring (air, water, and soil chemistry). WSNs can reform information gathering in a variety of situations. Some of the applications are discussed below in detail.

Temperature control: One central controller controls the air conditioning or heating systems of the majority buildings centrally. One central control is not enough to control the airflow evenly in huge room; coldness or heat is not evenly distributed. The airflow and temperature can be controlled by incorporating the WSN in the huge room, so proper turning on and off air conditioning or heating unit can save energy.

Inventory management: Sensor node can be attached to every item of inventory, walls, gates or ceiling in a warehouse. These sensor nodes can track the location of the item of inventory all the time. The supervisor or warehouse engineer can find out the location of the item whenever he/she wishes to do so, therefore items can be located by the WSNs automatically and can be reported to the end users. Any unpredicted large-scale movements of items or significant changes in inventory levels are alarmed to the manager or supervisor of the warehouse. In this way, WSNs based systems will remove manual scanning and offer more efficient way of locating the items without spending much money on manpower. Inventory can be updated automatically by binding the sensors to the new arrived items in the warehouse.

Physiological monitoring: WSNs can be used to collect and store the physiological variable such as blood pressure, heart rate, etc. of the patients for a long period of time. Doctors can monitor these data remotely

for medical examination through the use of WSNs. This is actually more convenient for the patient as they facilitate a higher quality of life compared to the medical hospitals. It also lets the medical examiner to better predict and understand the patient's situation by identifying pre-defined symptoms earlier. Even in the hospital, WSN can be used very efficiently. Tiny sensor nodes of WSN can be attached to each patient to do their assigned tasks such as measuring heart rate, blood pressure and brain activities and so on. Smart sensor can be used to measure these parameters at different times. Doctors can track other doctors by wearing the smart badge on their shoulders, so they can be easily found when they need to find.

Habitat monitoring: Habitat monitoring provides a wide collection of sensing modalities and environmental conditions (Cerpa et al., 2001). Think the aim of supporting data collection and model development of composite ecosystems. Scientists and environmental authorities would like to supervise soil and air chemistry, as well as plant and animal species populations and activities. The primary modalities are video (imaging) and audio (acoustics) to track species or phenomena based on sound, or video information. The sensor nodes for this purpose must be deployable in remote locations that lack the power and the communication facilities, motivating the need for low-energy wireless communication. Along with these advances, the sensor nodes also have the ability to connect with the internet, which allows remote users to monitor and control the environment.

Precision agriculture: WSNs can also be used to sense the pesticides level in the water, the level of soil erosion, and the air pollution. Smart sensors can help to identify the type, concentration, and location of pollutants. Basically, WSNs will offer the end users such as farmers and agriculture department a better understanding of the agriculture environment.

Forest fire detection: WSNs may be deployed randomly, and densely in a forest, sensor nodes can transmit the source of the fire to the fire rescue team or fire fighting department before the fire is expand over other region. Plenty of sensor nodes can be deployed and networked using today's transmission technologies. They might have power recharge capability, such as solar cells, or vibrating method (Chandrakasan et al., 1999) to recharge the battery to cope with limited battery and unattended operation for very long time.

Nuclear, chemical, and biological attack detection: In chemical and biological warfare, WSNs can also be used to detect the foreign chemical agents or biohazard agents in the air and the water. WSN containing thousands of sensor nodes can be deployed in the targeted area and used as a chemical warning system that can be very useful to the end users, which help in investigating this type of casualties easily. Defending team can investigate the detail without exposing to nuclear rays with the help of WSN.

Military applications: Military command, control, intelligence, surveillance, and targeting systems can be benefited from WSNs. Because of rapid deployment, self-configuration, self-healing and fault-tolerance characteristics, WSNs are very useful monitor and control for military systems. If some nodes are destroyed by the enemy, it doesn't affect the over all military operation since WSN are consist of many rapidly deployed low cost sensor nodes. Military commanders and leaders can utilize the facility of WSNs to monitor the situation of their troops, the status and the availability of the equipment in battlefield. Sensor attached to every troop, vehicle, and equipment can report the status by their own. This information can be aggregated into the sink nodes or base stations and sent to the command leaders.

Vehicle tracking: WSNs can be deployed to track the vehicles within a geographic region. Every vehicle in a large metropolitan area can have one or more attached sensors. The sensors are able to detect their location, vehicle sizes, speeds and densities, road conditions and so on. When vehicles come near to each other, they exchange information summaries. These summaries eventually reach across sections of the cities by the internet or satellite to determine the traffic condition and related information to remote end users for analysis. Drivers can also be warned of dangerous driving conditions for alternate routes, and

estimate trip times. Car thieves can be identified and caught with the use of the WSN coupled with internet or satellite within a targeted area and report these threats to police stations.

Disaster relief: WSNs can be used to map the disaster area. They can be efficiently used to direct the nearest emergency rescue teams to affected sites if sensors are densely scattered over a targeted area. Even if some of these sensors are destroyed due to their location in the disaster area itself, the remaining sensors coordinate their duties and help rescue team to find safe evacuation paths.

In future, we foresee that WSNs would be an integrated everywhere in our lives and intensity of use would be more than the present-day personal computers or mobile phones. Realization of these and other 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 for the unique features and application requirements of WSNs.

4. Communication protocols

4.1 Physical Layer

The physical layer is responsible for frequency selection, carrier frequency generation, signal detection, and modulation and data encryption. Thinking the same way as in conventional radio transmission, the main issue is how to transmit as energy efficiently as possible, taking into account all related costs (overhead, possible retransmissions etc.) considering scattering, shadowing, reflection, diffraction, multipath and fading effects. Very little work has been done regarding protocols well suited to the needs of WSNs at physical layer. (Chien et al., 2001) & (Schurgers et al., 2001) discusses the some energy efficient modulation work with low-power direct-sequence spread-spectrum modem architecture. This low-power architecture can be mapped to an ASIC technology to further improve efficiency. Modulation schemes and strategies to overcome signal propagation effects, and hardware design are main open issues for WSNs design and are unexplored.

4.2 Data Link Layer

The data link layer is responsible for the multiplexing of data streams, data frame detection, and error control. It ensures reliable point-to-point and point-to-multipoint connections in a communication network. (Sankarasubramaniam et al., 2003) looks at the question of choosing packet size with energy efficiency into consideration. Many researchers have targeted at taking into account the degree of redundancy that an aggregated message carries on the link layer.

4.2.1 MAC Layer

Since thousands of sensor nodes are densely scattered in a sensor field, the MAC (Medium Access Control) scheme must establish communication links for data transfer. It forms the basic infrastructure needed for wireless communication hop by hop and gives the WSNs self-configuration ability. Fairly and efficiently share communication resources between sensor nodes must be the other criteria. In most of the research work, the question is how to ensure that the sensor nodes can sleep as long as possible, not being able to communicate. Most of the proposals show at least some aspects of TDMA. Some of the more relevant papers are the PicoRadio MAC (Zhong et al., 2001), the S-MAC (Ye et al., 2002), and the STEM work (Schurgers et al., 2002).

4.3 Network Layer

Network layer is responsible for routing the packet properly and efficiently. Many active researchers are interested in the research of the network layer beyond the MAC and topology control. Ad hoc network

routing can be used but the more strict criteria regarding energy efficiency and scalability require new solutions. The traditional routing problems of unicast, multicast, and anycast routing exist in WSN. The geographic routing and data-centric routing can be considered in WSNs (Shen et al., 2001).

4.4 Transport Layer

Transport layer is responsible for overall end to end reliable data delivery of the transmission. Very little consideration has been given so far to find suitable transport layer solution for WSN. Acknowledgement (TCP) is very expensive since sensor node doesn't have enough memory and power. UDP type scheme is need to communicate between sensors and sink. TCP can be used between sink and end user through internet or satellite.

5. Conclusions

Wireless sensor networks (WSNs) are more than ad hoc networks. The rigorous miniaturization, hardware, cost requirements, frequent topology changes and optimize use of power are vital issues and are different from normal ad hoc networks. The flexibility, scalability, fault tolerance, high sensing ability, low-cost and rapid deployment characteristics of WSNs create many new and exciting applications. These WSN applications require a rethinking of the basic paradigms with which communication softwares are designed. As WSNs are still a very new research field, much activity is still on going to solve many open research issues. Many scientists and engineers are currently engaged in developing the technologies needed for different layers of the WSN protocol stack. As some of the underlying hardware problems, especially with respect to the energy constraint and miniaturization, are not yet completely solved. These problems could be resolved in the future, but will take very long time to solve them.

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