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A General Purpose Framework for Wireless Sensor Network Applications

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Abstract

Wireless sensor networks are becoming a basis for a rapidly increasing range of applications. Habitat, flood, and wildfire monitoring are interesting examples of such applications. Each application has different requirements in terms of node functionalities, network size, complexity and cost; therefore, it is worthwhile time investment to design and implement a general purpose framework for wireless sensor networks that would be adaptable to any monitoring application of interest with a minimum amount of effort. In this manuscript, we propose a basic structure for such a framework and highlight a number of challenges anticipated during the course of this doctoral research.

1. Introduction and Problem Description

Numerous applications can benefit from the application of wireless sensor networks. However, each application has its own specifications and requirements, and what applies to a certain application may not necessarily apply to another. While some infrastructures like bridges can be completely monitored by just a few tens of nodes; typically 10-100, other applications of sensor networks may require hundreds or even thousands of nodes to fully satisfy the monitoring requirements. Therefore, in order to allow for these variations in applications, and to avoid reinventing the wheel every time we are presented with a new problem, we suggest that it would be a valuable time investment to design and develop a general wireless sensor network framework that can be adapted to any application of interest with minimal effort.

2. Background and Current Work

Wireless sensor networks are currently used as a replacement for previous monitoring and investigation systems that heavily relied on satellite and microwave images. They are also a suitable alternative to manual on-site human monitoring of the desired phenomena. For example, established flood monitoring systems are primarily based on satellite and microwave images [3], [6]. Both methods are very expensive; moreover, satellite coverage of the desired study area may not be readily available, which leads to additional costs for the data gathering process.

For wildfire detection and monitoring, current techniques can be categorized as either manual or automated. Manual detection techniques include lookout towers [1], cabins on mountain peaks, aerial detection, and public detection [5]. All of these methods have the advantage of allowing the observation of fires from a distance, but suffer from limitations in coverage, dependability, and response time. Automated wildfire detection techniques are more advanced, and provide near-continuous coverage without relying on trained personnel. A simple automated method is lightning detection [1], which can only detect wildfires caused by lightning.

Our alternative to the aforementioned monitoring methods is based upon wireless networks composed of inexpensive sensor nodes. The size, unobtrusiveness, and expendability of wireless sensor nodes make them ideal candidates for detection and monitoring systems. The wireless nature of the network eliminates the need for cabling, which reduces the overall cost of the system and makes it more convenient to place the sensor nodes at otherwise inaccessible locations.

We are currently working on two main projects; flood detection for low water bridges, and wildfire monitoring. Both projects are based on wireless sensor networks, but each has unique requirements in terms of network topology

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and number of nodes. Despite the differences in the two projects, we try to apply a common approach to the extent feasible. For example, both projects share the same data transfer mechanisms, transmission protocols, and dependability improvement techniques.

In the flood detection project, we currently have a device that detects the occurrence of a flood and responds by transmitting an SMS message to a predetermined destination. Our goal is to expand the system by adding more nodes on the bridge, and hence more functionality to the monitoring system. A wireless sensor network here would add scalability to the system, where the temperature and humidity of a larger area as well as vibrations and stress conditions on a large bridge could be monitored.

We have developed a specialized simulator for our proposed wildfire detection system, and initial results are promising. Our goal however is to generalize the simulator to enable its application to wireless sensor networks used in other domains, in particular structural and environmental monitoring.

3. Requirements of the System

In this section, we describe a number of considerations that are important to the design of a general purpose wireless sensor network for structural and environmental monitoring.

- *Low power consumption.* Batteries are currently the only power source for wireless sensor nodes; therefore, power conservation is an important issue. A suggested technique for reducing power consumption is to enable sensors to use a "sleep mode," to which the sensor node switches whenever it is not transmitting or receiving information. Solar panels can also be added to the device to prolong the maintenance-free field life.

- *Low cost.* As the number of nodes in the system increases, the cost per node becomes an important issue. For the flood detection application, the number of nodes per bridge ranges from as few as 5 nodes to as many as a hundred nodes. The target price per node is therefore \$20-\$30. For the wildfire detection application, thousands of nodes are typically needed, due to the vast area being monitored and the high level of redundancy required. A typical value is 150-200 nodes per acre [2], which limits the target price per node to \$1-\$2.

- *Software upgradability and hardware scalability.* The system is expected to be functional for years, and periodic maintenance is required for proper operation of the system. Software tends to change frequently as bugs arise in the system and modifications are necessary to ensure continuity of operation. Also, as projects differ in the number of required nodes, our building blocks will be designed to accommodate any desired number.

4. The Main Challenge

The main challenge in the proposed research is to build the basic block upon which everything will be constructed. The basic block in a network is a node. More specifically, a node in this sense is a hardware unit that provides a basic set of functionalities; *sensing*, *processing* and *communication*.

The extent of functionality for each node may differ from one application to another, or from one node to another in the same application. In a star topology, a basic node is needed as a coordinator. This node will have higher processing capabilities than the other nodes, while the leaf nodes will only need to have sensing and transmission capabilities to be able to send their data to the coordinator node. A GSM or CDMA modem will also be added to the coordinator node to allow for long range communication using the existing cellular network.

In mesh networks, we will need a third type of node. The function of this type will be to relay information between the coordinator and leaf nodes located at a distance. Relay nodes will have better communication capabilities than leaf nodes; however, data analysis and processing is still performed by the coordinator. The IEEE 802.15.4/Zigbee [8] standard has two types of devices available; a full functional device (FFD) that could be used as a coordinator or a relay node, and a reduced function device (RFD) that could be used as a leaf node.

5. The Main Tasks of the Proposed Research

5.1 Design and testing of the basic functional block

Our first objective is to design the basic functional block that we will use in our network. The block in this sense will be a simple board with several slots available for mounting devices. *The main challenge in this task is to keep the block as general as possible.* The basic sensing, processing and transmission capabilities will have specified slots in the block so they can be added or removed at the user's convenience. This implies the need for even smaller basic standardized blocks such as RF-transceivers, processors and sensors that are mounted in the empty slots of the block.

5.2 Testing the functional blocks in different network configurations

This task follows naturally after the first task. In addition to ensuring that each block is functioning correctly, the system as a whole needs to operate according to specifications. This includes *selecting suitable transmission protocol, routing mechanisms and network topologies.* As the topology may differ from one application to another, a general system should be capable of operating properly under a range of network topologies. *Scalability of the system should also be addressed here;* as the applications may vary, and we intend to adjust the size of the network to suit the needs of the applications.

5.3 Developing a general purpose network simulator

In addition to the hardware design, we will also develop a general purpose simulator to model our proposed system. The purpose of the simulator is to validate the techniques used throughout the development stage. The simulator consists of an environment simulator, a sensor detection simulator and a network simulator. The network simulator is the most important, as it will allow us to experiment with different types of networks and routing protocols and verify our techniques for increasing the system dependability. This part of the simulator will be based on existing networks simulators such as NS-2 [7] and TOSSIM [4].

5.4 Developing techniques for power conservation to reduce power consumption

All nodes are battery powered, and since batteries have limited lifetime, it is important that we save power and have the battery last as long as possible. *Power conservation will be taken into account in all the stages of our design.* Choosing microcontrollers with low power consumption and "sleep mode" capability helps achieving our goal, while using code optimization techniques can also help reducing the code size and consequently the power consumption.

5.5 Developing techniques to increase the overall system dependability

In this task we go beyond the basic functionality of the system to explore the system dependability. To increase the system dependability, we will employ node redundancy to reduce the impact of node failure. Software techniques can also be used for improving the system dependability. For example, rolling back to a previously determined recovery point at the occurrence of a failure and data encoding and decoding are two useful techniques for increasing the system dependability. Hardware and software co-design will also be incorporated in our work in order to model and predict the dependability of the overall system. In developing the predictive model, we will begin by identifying suitable metrics for measuring dependability of both hardware and software of the system.

6. Conclusions

The objective of the proposed doctoral research is the development of a general purpose framework for wireless sensor networks. This framework will be able to carry out monitoring for a wide range of applications. In order to main generality, we face several challenges. The main challenge is to construct a building block out of which we can build the complete network. Testing the building blocks separately and then testing different network topologies are of main importance in the construction of our general purpose system. After that, our focus will be on increasing the dependability of our system. In parallel, we will also develop a general purpose simulator for the system to aid in the design and testing at various stages of development.

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