Wireless Sensor Network Communication Architecture for Wide-Area Large Scale Soil Moisture Estimation and Wetlands Monitoring

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Abstract

In this report, we investigate the important requirements of communication architecture of wireless sensor networks for wide-area large scale soil moisture estimation and wetlands monitoring and explain the key issues that are faced in the design of the wireless sensor network monitoring strategy.

We review the communication protocols and algorithms in MAC layer and network layer, and examine the standard components in the sensor network architecture. Based on the survey, we recommend the multi-hop and cluster based sensor network communication architecture for the proposed applications. We further study the MAC layer and network layer communication protocols for wireless sensor networks with the applications for wide-area large scale soil moisture estimation and wetlands monitoring.

1. Introduction

The wide-area large scale soil moisture estimation and wetlands monitoring system operates under two applications scenarios, extreme event monitoring for disaster forecast and long term periodic monitoring for scientific data collecting.

In the first phase of this project, our proposed sensor communications network architecture is assumed to monitor the extreme event. Extreme event monitoring represents a class of sensor network applications with enormous potential benefits for scientific communities and society as a whole. Monitoring extreme events to forecast disaster (e.g. flooding) has a tremendous importance in preventing tragedy, damages to infrastructure and property, and business losses.

Wireless sensor network helps prevent the damages by monitoring and forecasting the disaster near the extreme event occurrence time. Soil moisture estimation and wetlands monitoring makes it possible to prevent sudden potential extreme events and life threatening conditions in wide areas. With more efficient and effective observation of environmental processes using large arrays of embedded, networked sensors in a large and wide scale wetland area, it is expected that near real-time disaster event monitoring can reduce the loss of human lives and also provides information to emergency response services.

In the wide wetland areas, the sensor field would be deployed at a few critical regions. Within the sensor field are sensor nodes and monitoring systems interconnected via wireless links. This report aims to propose the wireless sensor network communication architecture for the above application scenario. A complete architecture will need to address a family of specific issues such as topology discovery and management, naming, routing and so on. In this report, we aim to include the hardware, communication protocols, and system architecture for supporting the soil estimation and wetland monitoring system.

1.1 Overview of a Wireless Sensor Networks Communication Architecture

Wireless sensor networks consist of individual nodes that are able to interact with the environment by sensing or controlling physical parameters. These nodes have to collaborate to fulfill their tasks. The nodes are interlinked together and by using wireless links each node is able to communicate and collaborate with each other.

As shown in Figure 1, the wireless sensor network and the classical infrastructure comprises of the standard components like sensor nodes (used as source, sink/actuators), gateways, Internet, and satellite link, etc.

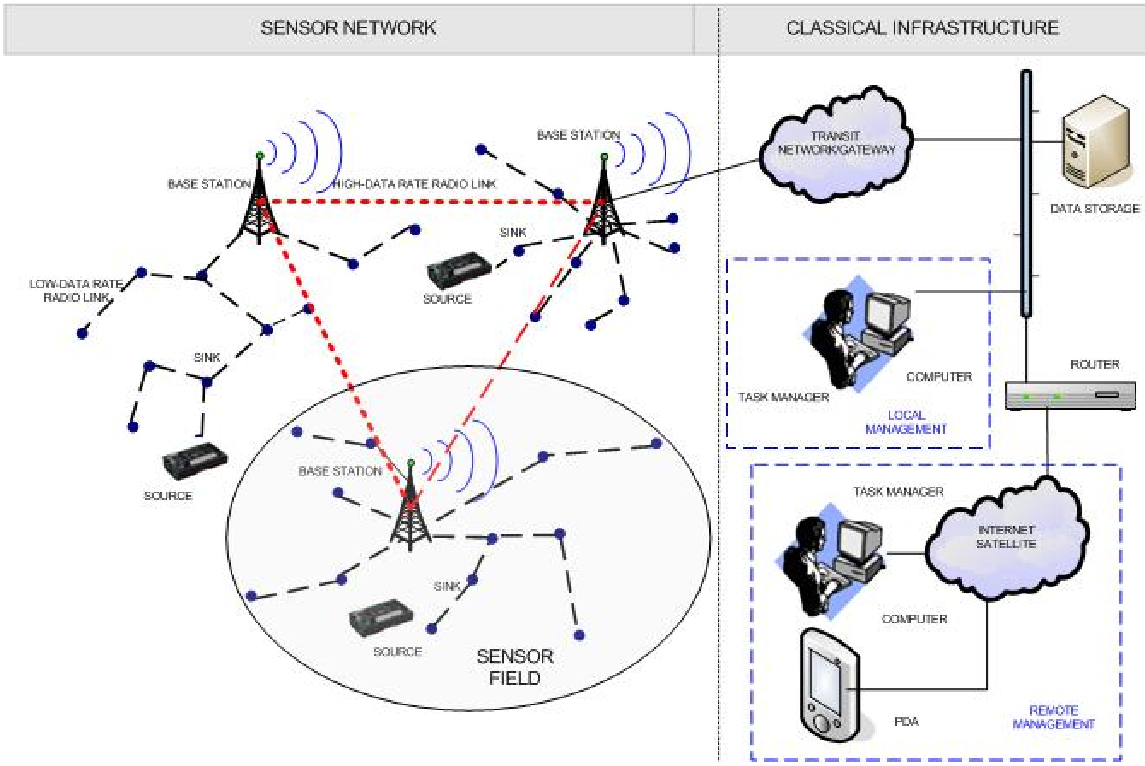

Figure 1. Illustration of sensor network and backbone infrastructure

1.1.1 Sensor nodes

Sensor nodes are the network components that will be sensing and delivering the data. Depending on the routing algorithms used, sensor nodes will initiate transmission according to measures and/or a query originated from the Task Manager. According to the system application requirements, nodes may do some computations. After computations, it can pass its data to its neighboring nodes or simply pass the data as it is to the Task Manager.

The sensor node can act as a source or sink/actuator in the sensor field. The definition of a source is to sense and deliver the desired information (see Figure 1). Hence, a source reports the state of the environment. On the other hand, a sink/actuator is a node that is interested in some information a sensor in the network might be able to deliver.

1.1.2 Gateways

Gateways allow the scientists/system managers to interface Motes to personal computers (PCs), personal digital assistants (PDAs), Internet and existing networks and protocols. In a nutshell, gateways act as a proxy for the sensor network on the Internet.

According to [1], gateways can be classified as active, passive, and hybrid. Active gateway allows the sensor nodes to actively send its data to the gateway server. Passive gateway operates by sending a request to sensor nodes. Hybrid gateway combines capabilities of the *active* and *passive* gateways.

1.1.3 Task Managers

The Task Manager will connect to the gateways via some media like Internet or satellite link [2]. Task Managers comprise of data service and client data browsing and processing. These Task Managers can be visualized as the information retrieval and processing platform. All information (raw, filtered, processed) data coming from sensor nodes is stored in the task managers for analysis. Users can use any display interface (i.e. PDA, computers) to retrieve/analyze these information locally or remotely (see Figure 1).

1.2 System Components and Operations in a Wireless Sensor Network Communication Architecture

In this section, we will explore the left black box in Figure 1, i.e. the sensor field. The components and operations between sensor nodes within the sensor field would be explored. We first describe the wireless sensor network architecture and the communication protocols for the wireless sensor network. This is essential to understand the hardware and software level power savings strategies. One of the intension of this report is to provide a survey of the sensor nodes in literature and recommend the appropriate hardware based on the specific application. We can refer to [41-44] for more information in the detail composite of the hardware.

1.2.1 Sensor Node

As mentioned earlier, the sensor field constitutes sensor nodes. Typically, a sensor node can perform tasks like computation of data, storage of data, communication of data and sensing/actuation of data.

A basic sensor node typically comprises of five main components and they are namely controller, memory, sensors and actuators, communication device and power supply (see Figure 2). A controller is to process all the relevant data, capable of executing arbitrary code. Memory is used to store programs and intermediate data. Sensors and actuators are the actual interface to the physical world. These devices observe or control physical parameters of the environment. The communication device sends and receives information over a wireless channel. And finally, the power supply is necessary to provide energy. In wireless sensor networks, power consumption efficiency is one of the most important design considerations. Therefore, these intertwined components have to operate and balance the trade-offs between as small energy consumption as possible and also the need to fulfill their tasks.

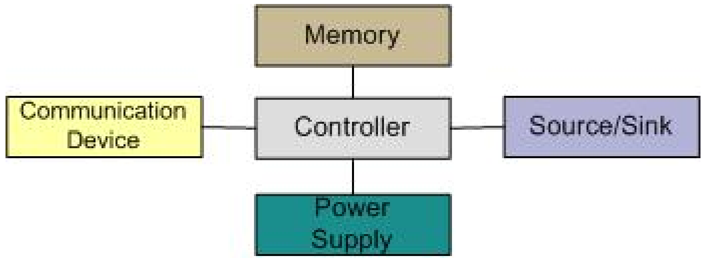

Figure 2. Overview of sensor node hardware components

1.2.1.1 Controller

Microcontrollers used in several wireless sensor node prototypes are Atmel processor and Intel Armstrong processors, etc. In this project, we have consolidated a list of sensor nodes in the literature (see Appendix A). It is noted that mica 2 mote and mica Z mote, and mica 2 dot mote are appropriate nodes suitable for large area wetland monitoring application because of its characteristics. These three motes operation range can out reached up to 500 feet (152 m), and has the lifetime up to 7 years.

1.2.1.2 Communication Device

Communication device is used to exchange data between individual nodes. The communication medium between the two nodes is through radio frequencies (wireless medium). Radio frequency-based communication fits the requirements of most wireless sensor applications because it provides relatively long range and high data rates, acceptable error rates at reasonable energy expenditure, and does not require line of sight between sender and receiver. The 915 MHz and 2.4 GHz industrial, scientific and medical (ISM) band has been widely suggested for sensor networks [3].

For actual communication, both a transmitter and a receiver are required in a sensor node. The essential task is to convert a bit stream coming from a microcontroller (or a sequence of bytes or frames) and convert them to and from radio waves. As half duplex operation is recommended in wireless sensor network [3], a transceiver is generally used. In the transceiver, circuitry includes modulation, demodulation, amplifiers, filters, mixers. The table below summarizes the frequency bands, modulation and data parameters that could be used in the communication medium.

The transceiver must provide an interface that allows the medium access control (MAC) layer to initiate frame transmissions and to hand over the packet from the main memory of the sensor node into the transceiver (or a byte or a bit stream, with additional processing required on the micro controller). In other direction, incoming packets must be streamed into buffers accessible by MAC protocol.

Table 1: Possible Sensor Networks Physical Layers Characteristics

PHY [MHz]	Frequency band [MHz]	Spreading Parameters		Data parameters		
		Chip Rate (kchip/s)	**Modulation**	**Bit rate (kb/s)**	**Symbol rate (ksymbol/s)**	**Symbols**
868/915	868-868,6	300	BPSK	20	20	Binary
	902-928	600	BPSK	40	40	Binary
2450	2400-2483,5	2000	O-QPSK	250	62.5	16-ary Orthogonal

1.3 Communications Protocols between the Nodes of Wireless Sensor Networks

This subsection continues survey the MAC protocols that are developed for the wireless sensor networks. After this review, an appropriate MAC protocol will be preliminary recommended for this project for our application purpose.

MAC protocols control how sensor nodes access a shared radio channel to communicate with neighbors. Traditionally, this problem is known as the channel allocation or multiple access problems.

Though MAC protocols have been extensively studied in traditional areas of wireless voice and data communications (e.g. Time division multiple access (TDMA), frequency division multiple access (FDMA) and code division multiple access (CDMA) [4], ALOHA [5] and carrier sense multiple access (CSMA) [6], sensor networks requirements of a MAC protocols differ from these traditional wireless voice or data networks in several ways. First of all, most nodes in sensor networks are likely to be battery powered and it is often very difficult to change batteries for all the nodes. Second, nodes are often deployed in an ad-hoc fashion rather with careful pre-planning. Hence after deployment, the sensor nodes must quickly organized themselves into a communication network. Third, many applications employ large numbers of nodes. Finally, most traffic in the network is triggered by sensing events, and it can be extremely bursty. All these characteristics suggest that traditional MAC protocols proposed for the past wireless networks are not suitable for wireless sensor networks without modifications [1].

The design of MAC protocols in wireless sensor network depends on the expected traffic load patterns in the application context. For example, if a wireless sensor network is deployed to continuously observe a physical phenomenon like time dependent temperature distribution in a forest, a continuous and low load with significant fraction of periodic traffic can be expected. On the hand, if the goal is to wait for occurrence of an important event and upon its occurrence to report as much data as possible, the network is close to idle for a long time and then is faced with bulk of packets that are to be delivered quickly.

Since this project is designed to detect extreme event (e.g. to forecast flooding), the system thus has to remain operational for months or years while only sensing if a flood has started. Once a flooding is detected, this information must be forwarded to the system management quickly and accurately. Based on the project application requirement, CSMA based MAC protocol is a preferred choice as compared to the TDMA based protocols due to the following reasons:

- TDMA based protocols needs control channels to send scheduling messages to each sensor node in order for each node to get the right time slot, the control message overhead is high, and may wait a lot of energy; also in a small and cheap sensor node, it will be very difficult to implement separate communication channels.

- TDMA based protocols needs very actuate time synchronization requirements; For a small and cheap sensor node like the available from the current technology, it is still very difficult to achieve the very actuate time synchronization between the neighboring nodes; on the other hand, for CSMA based contention protocols, no actuate requirements for the time synchronizations between the node.

Due to the above two major reasons, CSMA based MAC protocols are recommended for the usage in this project application. A review has been done on the MAC layer protocols designed for wireless sensor networks. Please refer to [8-10, 11, 12, 15, 19, 15-17] for further reading.

1.3.1 CSMA MAC Protocols

For CSMA based MAC protocols, the nodes in the network are generally uncoordinated and the protocols operate in a fully distributed manner. In the class of CSMA protocols [6], a transmitting node is always "respectful" to the ongoing transmissions. First the node is required to listen to the medium; this is called *carrier sensing*. If the medium is found to be idle, the node starts transmission. If the medium is found busy, the node defers its transmission for an amount of time determined by one or several possible algorithms. For example, the node draws a random waiting time, after which the medium is sensed again. Before that, the nodes do not care about the state of the medium [6]. Though the CSMA has its advantage as mentioned earlier, it has its disadvantage. For example, CSMA has possibility of packets collision and retransmission. The energy spent on collided packets is wasted and the packets have to be retransmitted.

The two common approaches to solve this issue are: the busy-tone solution and the RTS/CTS handshake.

- Busy-Tone

In the busy-tone solution [46], two different frequency channels are used, one for data packets and the other one as control channel. As soon as a node starts to receive a packet destined to it, it emits an unmodulated wave on the control channel and ends this when packet reception is finished. A node that wishes to transmit a packet first senses the control channel for the presence of a busy tone. If one hears something, the node back-off and transmit later. If it hears nothing, the node starts packet transmission on the data channel.

- RTS/CTS Handshake

In RTS/CTS handshake methodology [47], it uses only a single channel and two special control packets. Suppose that node B wants to transmit a data packet to node C. After B has obtained channel access (for example sensing the channel as idle), it sends a Request to Send (RTS) packet to C, which includes a duration field indicating the remaining length of the overall transaction (i.e. until the point where B would receive the acknowledgement for its data packet). If C has properly received the RTS packet, it sends a Clear To Send (CTS) packet, which again contains a duration field. When B receives the CTS packet, it starts transmission of the data packet and finally C answers with an acknowledgement packet. The acknowledgement (i.e. CTS) is used to tell B about the process of the transmission; lack of acknowledgement is interpreted as collision. Any other station A or D hearing either the RTS, CTS, data or acknowledgement packet sets an internal timer called Network Allocation Vector to the remaining duration indicated in the respective frame and avoids sending any packet as long as this timer is not expired. This way, the ongoing transmission between B and C nodes is not distorted.

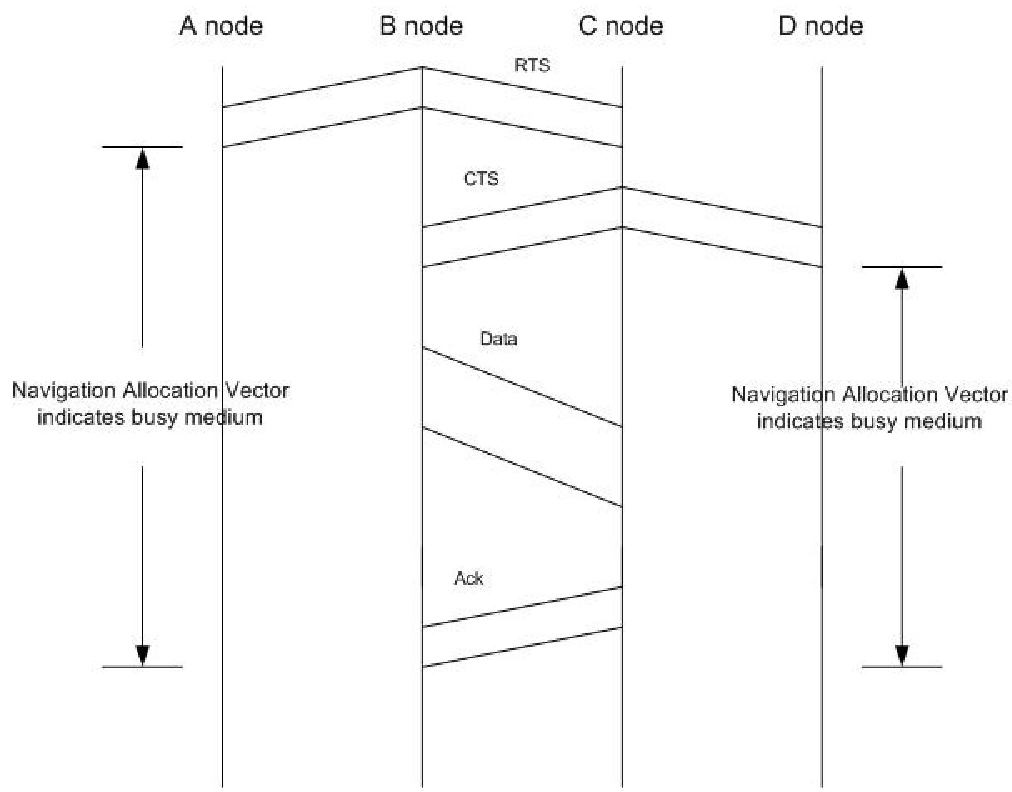

Figure 3. Illustration of RTS and CTS methodology

1.3.2 Recommended CSMA MAC Protocol

However, as mentioned in last subsection, the classical CSMA MAC protocols need modifications in wireless sensor network applications. The main unique requirements in wireless sensor network are first and foremost, the need for wireless sensor network MAC protocols to conserve energy. Further important requirements for MAC protocols are scalability and robustness against frequent topology changes, as caused for example by mobility, deployment of new nodes, or death of existing nodes. The need for scalability is evident when considering very dense sensor networks with dozens or hundreds of nodes in mutual range.

Recall that a transceiver can be in four main states: transmitting, receiving, idling, or sleeping. Hence in order to select/design a high efficiency MAC protocol for wireless sensor network usage, energy consumption properties in these four operational states has to be understood. From literature, it is understood that transmitting is costly, receive costs often have the same order of magnitude as transmit costs, idling can be significantly cheaper but also about as expensive as receiving, and sleeping costs almost nothing but results in a "deaf" node [15].

Most of the CSMA based MAC protocols developed for sensor network is addressing the four issues like transmit, receive, idle listening or overhearing. After understanding the general operation of CSMA based MAC protocol and the energy consumption of the node, we move on to recommend one of the reliable and common CSMA based MAC protocol for sensor network: Sensor-MAC protocol (S-MAC). S-MAC addresses the problem specifically in idling listening and is one of the most well known MAC protocols employed in wireless sensor network. Its basic idea is to put radio to sleep when the node is not in used. However, this makes it difficult for nodes to communicate and the author uses beacons to coordinate sleeping.

- **S-MAC [15]**

In S-MAC, a sleep-listen schedule is created based on time synchronization. And it is specifically designed for wireless sensor network. Clusters (i.e. sensor field) are formed where each node has its own schedule. And the node schedule is shared with its neighbor. Each node has its own wakeup-listen (communicate) and sleep schedule. The S-MAC messaging scenario is shown in the following figure.

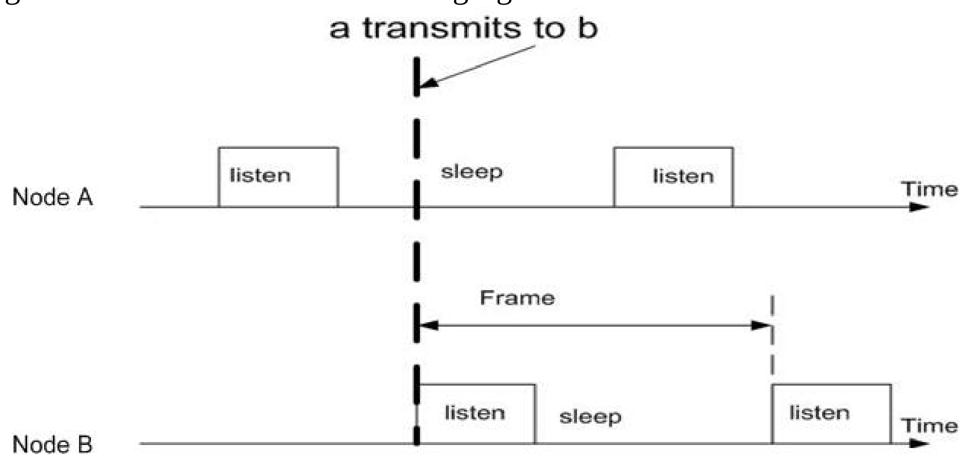

Figure 4. Node A transmit to Node B

For example, if node A wants to send to node B, it just needs to wait for node B's listen cycle to start (see Figure 4). The nodes within a cluster periodically broadcast SYNC packets to synchronize clocks. S-MAC encourages neighbors to adopt identical schedules. When it configures itself, a node listens for a synchronization period, and adopts the first schedule it hears.

Few advantages and disadvantages can be summarized in the following. S-MAC reduces energy wastage caused by idle listening and it can be implemented simply. On the other hand, S-MAC protocol uses broadcast packets as it does not use RTS/CTS dialogue which increases collision probability. In addition, the sleep and listen periods are predefined and constant, and that decreases the efficiency of the algorithm under variable traffic load.

Nevertheless, S-MAC is specifically designed for wireless sensor network and reduces energy from all major sources (i.e. idle listening, collision, overhearing and control overhead), hence it is a relevant CSMA based MAC protocol to be used in this project as a starting point.

1.4 Network Configurations for the Sensor Nodes in the Sensor Field

Another consideration for the sensor network design is the network topology. A survey on the possible network configurations for sensor nodes in the sensor field is performed in this subsection. Two popular sensor networks topologies [18] are depicted in the following.

- Flat networks
  Each node plays the same role and sensor nodes collaborate together to perform sensing tasks.

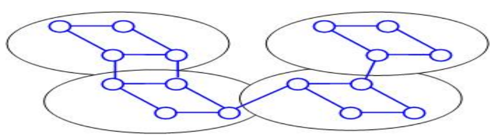

Figure 5. Flat Networks

- Hierarchical Networks
  Higher nodes can be used to process and send the information while low energy nodes can be used to perform the sensing in the proximity of the target.

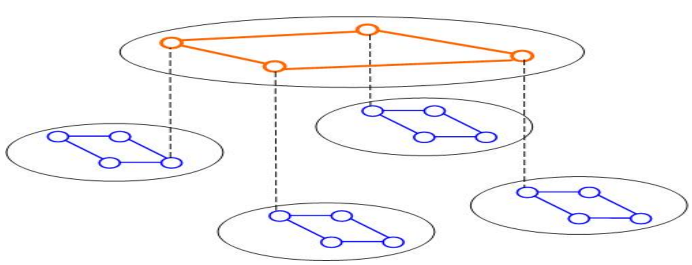

Figure 6. Hierarchical Networks

1.4.1 Network architecture proposed in and between sensor fields

Choosing the correct network architecture is crucial for the sensor network to be reliable and scalable. The architecture must make the network remain active and working effectively as it is designed for. After consideration, two-tier hierarchical network architecture is designed to exchanging data among the nodes in the wide area wetlands area. Two-tier architecture is comprised of lower and upper tiers as depicted in Figure 7.

Figure 7 illustrates the logical organization of the two-tier network topology. Characteristics as well as advantages of this wireless network architecture are explained in following subsections.

1.4.1.1 Lower Tier

Lower tier is comprised of sensor nodes. It is intended that sensor nodes initiate transmissions once they sense an event that meets a criteria. This will reduce unnecessary transmissions due to continuous queries to sensor nodes. In a nutshell, transmissions will begin when a probable disaster event occurs. These event-triggering transmissions will save energy since much of it is expended in disseminating data to destiny.

As shown in figure 7, when a sensor node is within the range of a Local Site Master, it transmits the data directly to it instead of transmitting the information to another sensor node that could be nearer to it. This is intended to make data pass though the least amount of nodes as it reaches the destination. To make this happen, nodes with the greatest range are preferable.

It is desirable in this network architecture that radio transceivers have programmable transmit power control so that only the minimum required power is used when transmitting data. This will also reduce interference between clusters.

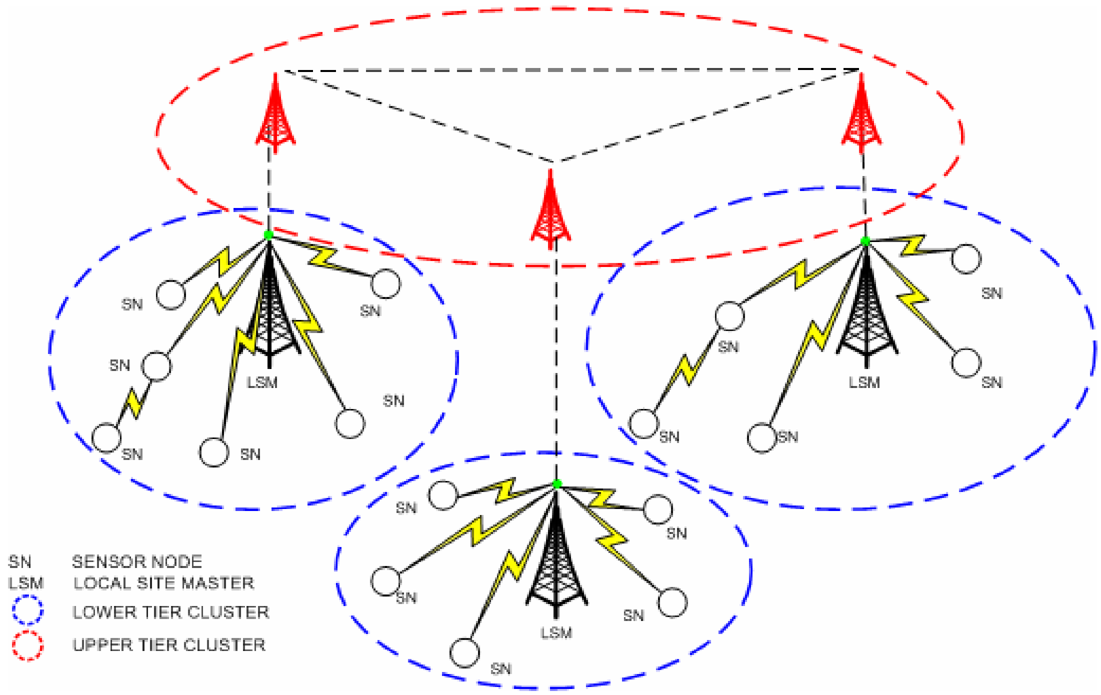

Figure 7. Illustration of Two-tier Network Topology

1.4.1.2 Upper Tier

Upper tier is comprised of Local Site Masters (LSM). Local Sites Masters are also known as Base Stations (BS). Local Sites Masters are not energy constrained and may cache and compress data from their sensors. Local Sites Masters communicate between each other through high data rate links.

The purpose of Local Sites Masters is to transmit the data to the Task Manager, where the information will be computed and further stored for future analysis.

Local Sites Masters have two types of links.

One link radio is to communicate wirelessly to sensor nodes. The bandwidth used for this purpose is 800 and 900 MHz at 19.2 Kbps with a range of 10-300ft [50, 51].

The other link must be a high data rate link that communicates Local Sites Masters via radio, satellite or other media. In order to avoid interference, both links must work on different frequencies. The frequency used is 2.4 GHz at 250 Kbps [50, 51].

1.4.2 Routing Protocols recommended between the nodes in a sensor field

After the network topology has been selected, the next design phase proceeds with the selection of the routing protocol. Routing protocol can simply be defined as the sequence/algorithm in how the data is transmitted from the source node to the sink. Since we require that our sensor network triggers an action whenever a disaster event occurs, we need a protocol where transmissions begin from sensors that measure data. Working with queries from the Task Manager may cause the network to be too slow to react to disaster events.

We have done a comprehensive routing protocols review in literature and we have summarized briefly in this report. Please refer to these references [19, 20, 21, 15, 19, 22-40] for more details on other routing protocols.

Based on our projects application context, we have chosen Sensor Protocol for Information via Negotiation (SPIN). This is because of its quick convergence characteristics between the sensor nodes in the sensor field. Also this routing protocol provides routing robustness and is also scalable [9]. The SPIN algorithm [9] can be understood as follows.

When a node has a packet to send, if it does not have a route to the destination node it initiates the search of a route to the destination node. Thus, a route is searched when needed.

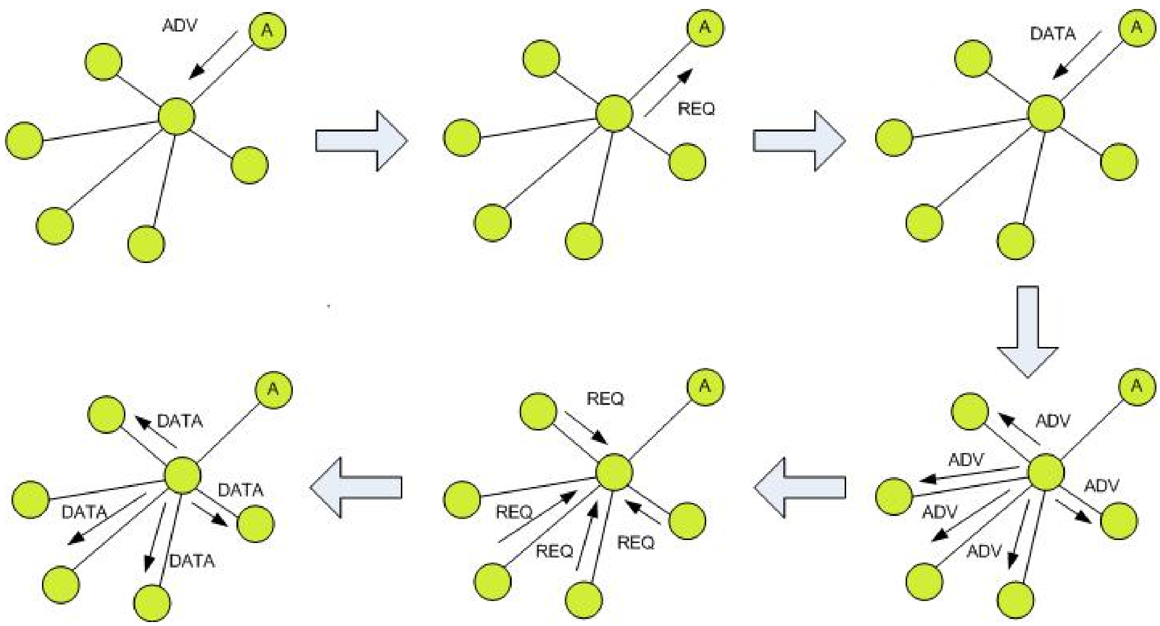

Figure 8 : SPIN Data Dissemination

SPIN protocol consists in a 3-way handshake (ADV-REQ-DATA). The protocol starts when a node has data to disseminate (node A), for example a moisture measure. Then, it sends and ADV message to its neighbors. The neighboring nodes, once receiving the ADV message, decide whether to accept the ADV or not based on if they have already received or requested such ADV message. Nodes that have not received nor requested such ADV, request it by sending a REQ message to the node that initiated the protocol. This node responds with a DATA message. Nodes that receive the DATA message will send it to the entire network in the way described preciously. In this way, the moisture information that could be interesting to prevent a disaster is disseminated to the whole network, arriving finally to the base station and Task Manager that will in turn trigger an action.

2. The Application Problem Formulation

2.1 Introduction

This project assumes that the sensor nodes are embedded in the large-scale soil moisture and wetlands area. These sensors nodes are used to detect extreme event (e.g. flooding etc) and one of our project goals is to propose a wireless sensor network communication architecture for this application.

2.2 Definition of wetlands

Wetlands are regions transitional between terrestrial and aquatic systems where the water table is usually at or near the land surface or the land is covered by shallow water.

A wetland can be characterized by (1) Hydric soils; (2) Hydrophytic vegetation. Hydric soils are defined as soils that are saturated, flooded, or ponded long enough during the growing season to develop anaerobic (i.e. without oxygen) conditions, thereby influencing the species composition or growth, or both, of plants on those soils. Plant life is capable of growing in wet conditions, such as in water or in soil or other substrate that is periodically saturated with water. The presence of hydrophytic plants is one of the indicators used in wetland identification and delineation [45]. Pictorial examples of wetlands are depicted below.

Figure 9. Pictorial examples of wetlands

2.3 Definition of soil moisture

Soil moisture is the ability of a soil to hold water. Soil moisture impacts the distribution and growth of vegetation, soil aeration, soil microbial activity, soil erosion, the concentration of toxic substances, the movement of nutrients to in the soil to the roots [49].

2.4 Extreme Event Detection System Requirements and Assumptions

Remote Management: It is essential to have the possibility to manage the Sensor Network remotely (e.g. via Internet/Satellite) since there might be no personnel dedicated to manage the network. In addition, the client and data processing platform and the physical place of interest location is usually far away from each other. In this wetland monitoring applications we are using Internet to support remote interactions with in-site networks.

Local Management: It is essential during initial deployment and maintenance-tasks and local operations to have also local management. Local management is defined as the ability to query a sensor, adjust operational parameters, or simply assisting in locating devices. Examples of devices used for local management are PDA and laptops.

Sensor Network Longevity: Network components must remain functional for a long time since the wireless sensor do not have the opportunity of getting a new source of energy unless solar power is used as renewable source of energy. Therefore, energy efficiency is one of the very important considerations for wireless sensor network design.

Appropriate sensors: Sensors that can forecast possible disasters effectively must be used. Also, they must work promptly and communicate reliably. Cost efficiency is also an important consideration in the sensor network architecture.

Sensor Node Operation: Communication protocols (e.g. routing and MAC protocols) must be energy aware, reliable, scalable, quick to response in the dissemination of data within the sensor field to the gateway.

Data Storage: Archiving sensor readings for future analysis is mandatory. It is important to have the ability to explore each sensor individually or a subset of them. This data can be stored in the sensor node, gateway (e.g base station, Task Manager) or client processing terminals. This data storage can serve as a feedback data or processing data to further improve the data dissemination in the sensor network application.

2.5 System Evaluation Metrics

After the system requirements are identified, to implement a successful system architecture, system evaluation metrics have to be considered very carefully. These metrics could be used when hardware platforms are compared between each other in order to choose one that fulfills metrics in accordance to our needs [48].

In the following are some of the most important metrics that will be used to evaluate a wireless sensor network.

2.5.1 Lifetime

Sensor nodes will be left in the sensor field unattended and will work with the power supply they have been given. That is why the primary limiting factor for network lifetime is power supply.

In order to maximize lifetime of sensor nodes, the following factors must be taken into account: (1) Radio power consumption, since much of the energy is spent in radio communication, (2) Average energy consumption, (3) Adaptable transmission output power, so it is used the least amount of energy possible to transmit data, (4) Scavenging modules, like piezoelectric and solar cells.

2.5.2 Coverage

Coverage is the ability for a network to cover a large area and still work as expected. This metric is especially important for our project since the areas covered are large and wide-spread. To achieve an adequate coverage: (1) Energy-ware multi-hop communication techniques must be considered as a way to inexpensively enlarge the network and most distant nodes have still communication to the BS through other nodes, (2) Network architecture must be able to scale without compromising the required network performance.

2.5.3 Ease of Deployment and Costs

Sensor network should not be difficult to configure and install. It must be taken into account: (1) A sensor network must configure itself, once installed it should simply work, (2) Sensor network must be able to adapt to environmental conditions and changes, (3) Maintenance costs must not be prohibitive, (4) Network must be able to make self-maintenance, asses performance and quality and indicate any possible problems.

2.5.4 Response Time

For systems where an event triggers an alarm, like ours, response time is crucial. For a sensor node to monitor an event when it has just happened, it must be powered up all the time. Then, data should reach the final destination as soon as possible. That is why the ability to have low response times conflicts with the techniques used to increase network lifetime.

2.5.5 Time Accuracy

A global clock and synchronization is needed in environmental and tracking applications to determine the nature of the phenomenon being measured. It must be possible to order samples and events from sensor nodes. For that purpose, synchronization information must be continuously disseminated to the network. This metric also conflicts with increasing network lifetime. A trade-off should be made not to lose neither time accuracy nor network lifetime.

2.5.6 Security

Security should be implemented in the system by (1) Keeping information private by encrypting data (2) Authenticate data communication (3) making it not possible to interfere with transmitted signals. The more security a system has the more power and bandwidth are spent. For some applications it is important to make a trade-off between security and network resources.

2.6 Individual Node Evaluation Metrics

In following sub-sections individual node metrics are described. This information is useful for the designers to design the low level system architecture (sensor nodes) in accordance to the application requirement [48].

2.6.1 Power

It is required that sensor nodes consume energy in the order of micro amps. Power savings may be achieved by reducing radio activity using low duty-cycle techniques and local computation to reduce data transmissions. Also, events from multiple sensors may be combined by a group of nodes before actual transmission to the rest of the network.

2.6.2 Flexibility

Architecture must be flexible and adaptive. It should be possible to just assemble correct modules of hardware and software for a given application.

2.6.3 Time Synchronization

Time synchronization is needed to support time correlated sensor readings and low duty-cycle operations. A failure in time synchronization will create inaccuracies in sleep-awake periods and will result in larger duty-cycles.

2.6.4 Size and Cost

Sensor node’s size and cost must be low in order to make it feasible to install a sensor network. A cost reduction will result in the ability to buy more nodes and small nodes could be placed in more scenarios.

2.6.5 Computation

Computation can be done in sensor nodes in accordance to the application they are used for. Common processing operations include digital filtering, averaging, threshold detection, correlation and spectral analysis.

2.7 Proposed Sensor Network Architecture

We now describe the system architecture. We proposed a two-tiered, multi-hop architecture as shown below.

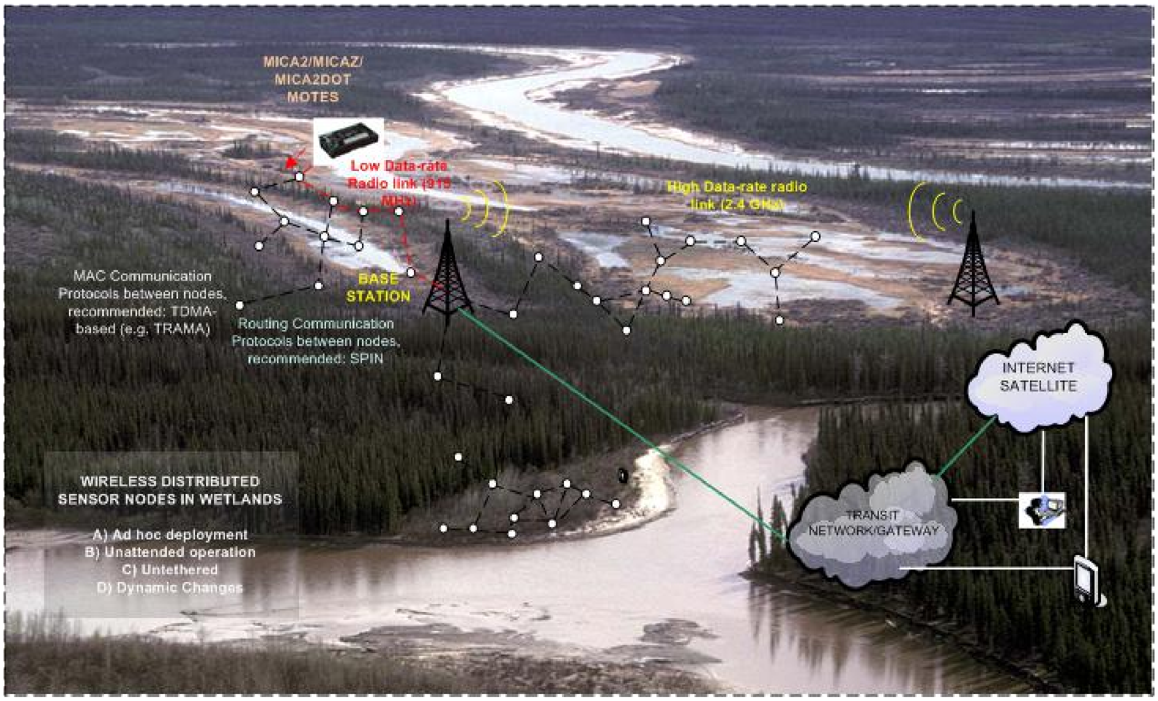

Figure 10. Proposed wireless sensor network for wetland monitoring

As demonstrated in Figure 10, most sensor nodes are deployed in regions where there is no infrastructure at all. A typical way of sensor nodes deployment in this wetland area would be tossing the sensor nodes from an airplane. After deployment, the nodes have to identify its connectivity and distribution, get themselves organized with each other and form a communicative sensor network topology.

Once deployed, sensor networks have no human intervention. The nodes themselves are responsible for reconfiguration in case of any changes. Therefore, it is important to select appropriate sensor node to suit the application purpose. In this project application context, we have selected mica mote/mica Z mote/mica 2 dot mote. The reasons can found in section 2.23.

As shown in Figure 10 the sensor nodes are not connected to any energy source. There is only a finite source of energy in each sensor node. Energy must be optimally used for processing and communication. An interesting fact is that communication dominates processing in energy consumption [23]. Thus, in order to make optimal use of energy, communication should be minimized as much as possible. In this application, we assume MAC and routing communications protocols as CSMA and SPIN respectively. The reason for this selection is mentioned in section 2.3 and section 2.4.2 respectively. In addition, our proposed wireless sensor network system is also envisioned to be adaptable to changing connectivity (for e.g. due to addition of more nodes, failure of nodes etc) as well as environment stimuli.

The lowest level of this proposed sensor network consists of the monitoring system, source and sink. Monitoring system is placed in/near to the location of interest and it will sense potential event occurrence based on the environment parameters (e.g rain, water level, humidity, temperature etc). These monitoring systems may be deployed in patches that may be widely separated (as seen in Figure 10). If high spatial resolution is desired, one can achieved through dense deployment of sensor nodes within the patch. Compared with traditional approaches, which use a few high quality sensors with sophisticated signal processing, this architecture provides higher robustness against component failures.

The computational module inside the sensor node is a programmable unit that provides computation, storage and bidirectional communication with other nodes in the system. The computational module interfaces with the analog and digital sensors on the sensor interfaces, performs basic signal processing (e.g., simple translations based on calibration data or threshold filters), and dispatches the data according to the application needs. Compared with traditional data logging systems, networked sensors offer two major advantages. For example, they can retask in the field and they can easily communicate with the rest of the system. Retasking allows the scientists to refocus their observation based on analysis of the initial results.

As seen in Figure 10, our sensor nodes eventually need to transmit their data through the network gateway. The gateway is responsible for transmitting sensor data from the sensor patch through a local transit network (e.g. Base Station) to the user interface. The Base Station connects to database replicas across the Internet. The environmental data is displayed to scientists through a user interface as depicted in Figure 10.

3. CONCLUSIONS

In this technical report, we investigate the important requirements of communication architecture of wireless sensor networks for wide-area large scale soil moisture estimation and wetlands monitoring and explain the key issues that are faced in the design of the wireless sensor network monitoring strategy. We will study the further details the MAC layer and network layer communication protocols for wireless sensor networks with the applications for wide-area large scale soil moisture estimation and wetlands monitoring.

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Appendix A. Mote Evolution

Mote Type	*WeC*	*René*	*René 2*	*Dot*	*Mica*	*Mica2Dot*	*Mica 2*	*Telos*
Year	1998	1999	2000	2000	2001	2002	2002	2004
								
Microcontroller								
Type	AT90LS8535		ATmega163		ATmega128			TI MSP430
Program memory (KB)	8		16		128			60
RAM (KB)	0.5		1		4			2
Active Power (mW)	15		15		8		33	3
Sleep Power (μW)	45		45		75		75	6
Wakeup Time (μs)	1000		36		180		180	6
Nonvolatile storage								
Chip	24LC256				AT45DB041B			ST M24M01S
Connection type	I^2C				SPI			I^2C
Size (KB)	32				512			128
Communication								
Radio	TR1000				TR1000	CC1000		CC2420
Data rate (kbps)	10				40	38.4		250
Modulation type	OOK				ASK	FSK		O-QPSK
Receive Power (mW)	9				12	29		38
Transmit Power at 0dBm (mW)	36				36	42		35
Power Consumption								
Minimum Operation (V)	2.7		2.7		2.7			1.8
Total Active Power (mW)	24				27	44	89	41
Programming and Sensor Interface								
Expansion	none	51-pin	51-pin	none	51-pin	19-pin	51-pin	10-pin
Communication	IEEE 1284 (programming) and RS232 (requires additional hardware)							USB
Integrated Sensors	no	no	no	yes	no	no	no	yes