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Wireless Sensor Networks for Water Management that supports Differentiated Services

Wael Hosny Fouad Aly

Abstract—The goal of this paper is to make an architecture framework for wireless sensor networks that is used for water management application. The proposed framework focuses on offering differentiated services for sensor nodes. Differentiated services are supported based on the information passed from the sensor node to differentiated service motes. Three differentiated services are offered gold, silver and bronze which are the three types of services that are supported in the model. The architecture also addresses practical considerations in the operation phase, such as monitoring the network during water availability. The proposed architecture is composed of (1) gathering /sensing modules, (2) differentiated service mote modules, and (3) home depot modules. The architecture offers differentiated services, re-configurability, and reliability. Three types of mote modules are supported in this architecture gold, silver and bronze based on the information transferred to the home depot.

Index Terms— Differentiated Services, Fault Tolerance, Motes, Quality of Service, Relay Agents, Reliability, Water Management, Wireless Sensor Networks.

1 INTRODUCTION

Water consumption around the globe has increased seven times in the course of the last century. The level of ground water is declining. It is know that 1.1 billion people across the world live without satisfactory access to clean water. This results in the death of roughly 2 million people per year due to lack of water related diseases. Political stability itself is at risk, as experts predict that upcoming conflicts are most probably about water resources[1][2].

As water supplies became scarcer, there is the need to manage water consumption. Water consumption has increased dramatically in the past decade [3]. Water is a precious resource, it is also considered as a source of conflict among nations [4] [8]. World water commission reports estimates that water usage will increase by one half over the next 25 years [3][4].

Despite growing water scarcity, one can observe an inefficient use of the water resource, especially in the primary sector. Today, agriculture consumes 70% of the fresh water used world wide by human activity. In the Mediterranean basin, agriculture is considered as the sector that can save the most water [3][4].

It is estimated that 40% of the fresh water used for agriculture in developing countries is lost due to evaporation, spills or absorption by the deeper layers of the soil, beyond the plants root's reach [2][3].

- *Dr. Wael Hosny Fouad Aly is currently an Associate Professor at the Computer Science Department in the College of Computer and Information Sciences in the Imam Muhammad Ibn Saud Islamic University, Riyadh, Saudi Arabia, PH-+966-583-633-748. E-mail: drwaelaly@ccis.imamu.edu.sa.*
- *Dr. Aly is also an Associate Professor (on leave) in the Computer Engineering Department , College of Engineering &Technology at Arab Academy for Science & Technology, Alexandria, Egypt*

As a consequence, water related agricultural concerns have come high on the agenda of public and private development aid agencies. Many sectors are concerned with the hydrology, environmental sciences, agrology, or civil engineering.

The paper the organized as follows: Section 2 has a discussion about water management and the technology. Section 3 has the literature review. Section 4 contains the proposed framework. Section 5 has the conclusion and the future work. Section 6 contains the references used.

2 WATER MANAGEMENT AND TECHNOLOGY

Recent advanced research in VLSI circuits and fabrication technologies lead to smaller and more sophisticated devices such as micro sensors that may provide the required hardware for creating sensor networks [19].

These devices are smaller, have better processing power and are energy efficient as well, this in addition to having the ability to be powered by alternative on site sources of energy which are considered powerful and efficient characteristics.

These sensors are composed of a processing unit, a sensing unit, a radio transceiver. They are all connected together using wireless networks. The sensor nodes collect data and forward the observed data with other sensors using short haul radio links with limited range and limited bandwidth to save energy as shown in Fig. 1.

Sensor and sensor networks that are associated with monitoring and sensing capabilities can play an important function in regulating and monitoring the water use and quality in different areas.

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Sensors offer the ability to monitor water, regulate it and also provide near real time information with limited latency about water quality during natural or artificial disasters [19].

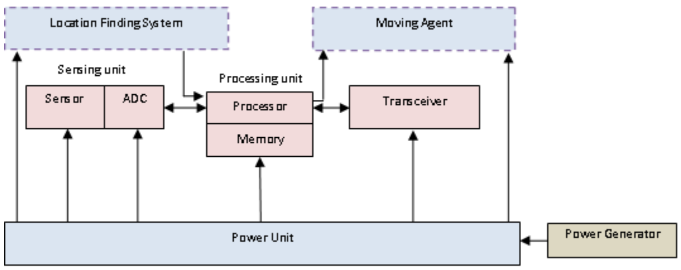

Fig. 1 Internal Structure of a Sensor Node [8]

Finding a way to collect and process relevant data in order to monitor water in a more efficient manner is mandatory. Wireless Sensors Networks (WSNs) would be ideal for applications in remote places with very limited infrastructure because they are fast to deploy, easy to maintain and least intrusive for the local environment [10].

WSNs consist of a crucial part of the future Internet. They play a main role of our everyday life and for many years to come. WSNs applications vary from distributed monitoring systems to smart embedded managing systems.

Hundreds to several thousands of sensor modules are deployed throughout the sensor field. They are deployed within tens of meters of each other [21]. The node density could reach 20 sensing nodes/m^3 [22]. Deploying a high number of nodes densely requires careful handling of topology maintenance and change in three cases: (1) Pre-deployment, (2) Post-deployment [21], and (3) Redeployment [7].

3 Literature Review

Water management has been a hot issue a while ago. Research has been going that focused on handling water management using wireless sensor networks[14][15][17][18][21].

A survey paper on sensor networks is discussed by Akyildiz et al. [8]. The survey contains a group of sensor network protocols and algorithms. Authors in [8] also attempte to investigate the design constraints and explain the use of current tools to meet the design objectives. Akyildiz et al. [8] also elaborate on the communication architecture of the sensor networks and the factors that influence the design of the sensor networks.

We classify the work performed in this area into two classes: The first class depends on an existing wireless network designed to monitor the settings used in agriculture. Examples of projects in this class is: (1) India-Swiss COMMON-Sense Net [10] and (2) Australia's CSIRO Project [5][6]. Both projects focus on the monitoring phase, communication phase, and development phase. These designs assume network as a group of sensing devises, where information read from each device are transferred to a central depot.

The project proposed by Corke et al. [6] focus on monitoring lake water quality. The work is concerned with the application of wireless sensor network technology to long duration and large scale environmental monitoring. The main issue is to construct a system that can be deployed and operated by domain specialists. Corke et. al [6] also used real examples to illustrate the technological difficulties and challenges that are entailed in meeting end user requirement for information gathering systems. Authors in [6] also study applications such as the cattle monitoring, ground water quality monitoring, virtual fencing, lake water quality monitoring and rainforest monitoring. Authors in [6] studied the salinity, water table level, and water extraction rate at a number of bored within sugar cane growing district.

The project proposed by Wark et al. [5] focus on the challenges faced in the agriculture using wireless sensor networks. Examples of challenges studied in this project are the change in climate, lack of water resource, short in labour due to aging of urbanized population. The study in [5] is also concerned with the increase in the societal awareness about issues such as animal welfare, food safety and environmental impacts. The authors in [5] have created a pervasive, autonomous network of cheap, simple devices that learn about their environment and seek to control it for beneficial purposes.

The second class of work depends on the efforts to link people in disconnected regions. As an example of this class is KioskNet project [20]. The project in [20] aims to link people in disconnected areas. It is considered an effort to connect remote clusters of people to the Internet by using routers attached to motorized vehicles. KioskNet project's goal is to provide very low cost Internet access to rural villages in developing countries. This is achieved based on the concept of delay tolerant networking. It uses vehicles, such as buses, to transport data between village structure and gateways in the neighbourhood areas.

The project by Shah el al [19] describes the Aqua-Net model. Authors introduced the concept of a multi-tiered single-hop autonomous sensor communities and a decentralized arbitration mechanism within the sensor communities. The work proposed in [19] claim long idle times between visits from relay nodes and hence enables communication schedules among community members, but if the delay wasn't long enough this would affect dramatically the accuracy of the data sent in the communication schedule. The framework in [19] was intended to provide framework architecture to provide a robust fault tolerant approach for water management in a simple fashion.

Previous work [5][6][7][10][11][20] for water management are not fault tolerant and are not configurable to allow substitution of functional units during natural or manmade disasters.

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4 Proposed Framework

This paper proposes a framework that addresses the challenges faced in deploying and managing a wireless sensor network. Information collection and dissemination system for water management consists of framework and tools that facilitate the collection of different types for parameters of interests

Parameters of interests could be (1) soil moisture, (2) rainfall, (3) underground water, (4) water supply, (5) sunlight, (6) water table, (7) water quality, (8) soil salinity, (9) water flow, (10) discharge, (11) water leakage. Based on the value of these parameters an action could be taken accordingly.

All these parameters are collected in the field. Information is delivered to a host node through a home depot where it can be processed. Network receives commands from host node. Host node performs recalibration based on the received information and priority level of the message. Host node provides different quality of service (QoS) for different types of messages.

Unlike home/industry applications where settings are relatively simple, water management requires huge area of land to be monitored and regulated. These areas are often isolated and may not have access to convenient means of communication. Continuous connectivity with the host is infeasible. Nodes are connected to hosts whenever communication means is available.

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4.1 Model Structure

This paper proposes a flexible framework for water management architecture using wireless sensor network. The framework aims to manage the message passing communication in a wireless sensor network that is concerned with water management. This has an effect on the amount of water saved in order to maximize the overall water gain. The proposed framework is flexible. It consists of a large number of autonomous averaged one-hop sensor clusters, travelling backbone network, and a data reservoir. The averaged one-hop is computed as the estimated value of the total number of hops per cluster. The proposed architecture is fault tolerant and reconfigurable.

The proposed network framework architecture is composed of the following modules as shown in Fig. 2.

1. *Sensing/Gathering Modules:* Sensing nodes are responsible for gathering information. Sensing nodes maybe stationary or moving. Sensing modules are deployed as discussed in section 1. Nodes collect and store information from sensing modules. Reside in all nodes in the network. This module can operate in both sending and receiving fashion depending on the application. Collecting modules are setup at points where messages are gathered and consolidated. Collecting modules have queuing buffers to store the received messages and forward it to the arriving differentiated service mote modules.

2. *Differentiated Services Mote Modules:* Carries information from one location to another. The carriers are also referred to as *mules* in literature. Could be human carrier, animal, or a motorized vehicle, etc. There are three types of relay agents supported in the proposed model based on the QoS. Each sensing module has a differentiated service facility to distinguish between different types of communicating sources based on their QoS based on the water source. This piece of QoS information is sent and consolidated in the message delivery process. The action taken based on the water management parameters such as soil moisture, rainfall, etc as discussed earlier. It is assumed in this model that there are three levels of quality of services supported (gold, silver and bronze)

3. *Home Depot Modules:* Stores messages from wireless sensor nodes to be delivered to the respective hosts and back.

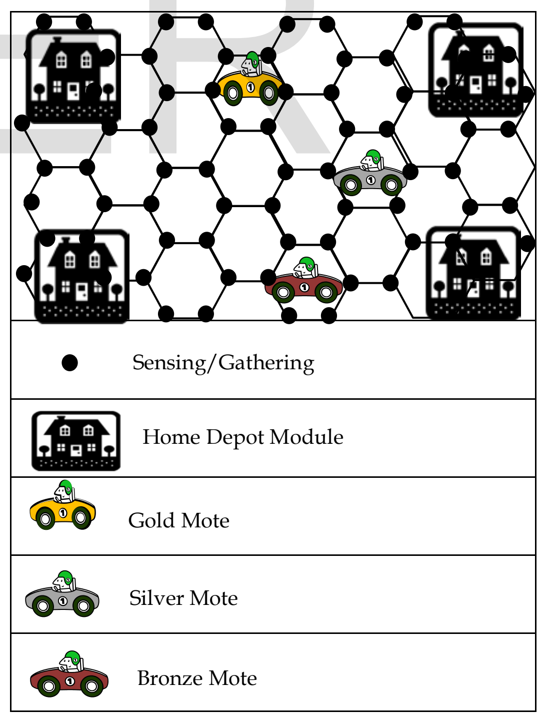

Fig. 2 Proposed Architecture for Water Management Application

Fig. 2 shows the proposed architecture. The architecture is composed of sensing modules that gathers the data from the network and saved it. The sensed data is categorized into

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three classes according to the severity of the message. The sensing modules wait for the corresponding mote to pass by to forward the message to. Once the mote passes by the sensing node, it collects the data saved and forwards it back to the home depot. The home depot in turn has classes of messages in a simple database to be analyzed and manipulated accordingly. The proposed architecture assumes that the number of the gold motes is more than the silver motes. Similarly the number of silver motes is assumed to be higher than the bronze motes. This is considered a valid assumption to differentiate urgent messages and give them more preferences compared to other types of lower priority messages.

4.2 Model Flexibility

The proposed model is flexible in the sense that we are able to substitute the underlying modules as needed and at the suitable conditions. The proposed architecture is abstract enough to be able to exchange the electrical mote module with a physical one, or a module that relies on a different technology. For example the sensing/gathering module could be substituted for another module as long as both perform equivalently.

Motes could be a motorized vehicle and also could be a human, or en electric signal. This feature makes the proposed model flexible. This is given that the availability of the recovering systems that is willing to give the same functionality.

During natural disasters such as floods, in flooded areas most of the areas become inaccessible by any means of transportation and hence the wireless communication could be a substitution.

4.3 Model Robustness

In order to maintain a flexible model, different modules will have different communication restrictions. In the proposed model, we use the clustering behaviour to group a cluster of sensors together based on the location and the communication constraints in addition to their functionality. The proposed model offer a simple grouping of clusters and uses only averaged one-hop sensor clustering that is based on averaging the estimated hop time in the same cluster. Each cluster is in charge of performing the scheduling of messages to be transferred by the motes to be forwarded to the home depot. Also each cluster has to classify its messages into three priority classes based on the message severity.

The model relies on the unused waiting times of the nodes waiting for the motes in making the scheduling. Once the corresponding mote with the appropriate class arrives, the node passes the desired messages to this mote. Each cluster has the responsibility of maintaining the scheduling before the mote arrival. The data collection times of different classes could vary.
The proposed model allows fairness among different clusters. During the waiting times between the mote visits, distributed scheduling decisions are made to consolidate the required information to the appropriate mote with the right class level. Data aggregation times could be unpredictable and different motes have a limited time intervals to communicate with the sensor cluster before passing by the target information. It is the sensor's responsibility to send what it is to be reported. Only averaged on-hops are maintained per cluster to maintain model simplicity.

4.4 Model Infrastructure

It is the wireless sensor network infrastructure that is connecting the sensor clusters to the home depots. Different motes travel through the network routes to the sensor clusters. The routes are as shown in Fig. 2. The routes are connected in many points. Different motes could meet at the same point. Pieces of information traversed from the sensor clusters to the home depot could have more than one path. Consolidation of messages is performed at the points of intersection. The consolidated data is forwarded to the appropriate arriving mote at the point of intersection. This problem is similar to a classical scheduling problem discussed by Somasundara et. al [16] and defined mathematically. Once the information arrives at the home depot module, it is forwarded to the appropriate host.

5 Conclusion and Future Work

This paper has introduced a new architecture that uses Wireless Sensor Networks for managing water resources. The proposed architecture introduces differentiated service motes that transfers different classes of messages from the field to/from the home depot through different network routes. The sensing modules gather the information from the field and waits for the corresponding mote to forward the differentiated information to it. The home depot modules are storage units that store different priority of messages to be used by the host for the proper action. A full mathematical model is being finalized for the architecture discussed in this paper. The mathematical model includes the different levels of priorities according to the message severity being transported

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