Low-Energy Consumption Schemes in Wireless Sensor Networks

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Abstract: - Sensor networks are dense wireless networks consisting of a large number of small-sized, low-cost sensor nodes that are densely deployed either inside the phenomenon or very close to it. Sensor nodes' function is to collect, process, and disseminate critical data while their position need not be engineered or predetermined. This means that sensor network protocols and algorithms must possess self-organizing capabilities. Wireless sensor networks are employed in a vast variety of fields – environment, health, home, civil, military. Sensor nodes have various energy and computational constraints because of their inexpensive nature and ad hoc method of deployment. Considerable research has been focused at overcoming these deficiencies through more low-energy consumption schemes. Three basic schemes have been chosen to be studied in this paper. The motivation of the first scheme is twofold, limiting multi-user interference to increase single-hop throughput and reducing power consumption to prolong battery life. The second scheme focuses on energy-aware routing. The third scheme contributes to dynamically increase the lifetime of the sensor network. The survey attempts to provide an overview of these issues as well as the solutions proposed in recent literature.

Key-Words: - Wireless Ad Hoc Sensor Networks, Power Control, Low-energy Consumption

1 Introduction

Recent advancement in micro-electro-mechanical systems and low-power and highly integrated digital electronics have led to the development of micro-sensors [1-6]. Such sensors are generally equipped with data processing and communication capabilities. The sensing circuitry measures ambient conditions related to the environment, which surrounds the sensor, and transforms them into an electrical signal. The processing of such a signal reveals some properties about objects located in the neighborhood of the sensor. The sensor sends the collected data, usually via radio transmitter, to a command center (sink) either directly or through a data concentration center (a gateway). The decrease in the size and cost of sensors, resulting from such technological advances, has fueled interest in the possible use of large set of disposable unattended sensors. Such interest has motivated intensive research in the past few years addressing the potential of collaboration among sensors in data gathering and processing and the coordination and management of the sensing activity and data flow to the sink. A natural architecture for such collaborative distributed sensors is a network with *wireless* links that can be formed among the sensors in an ad hoc manner. Here, we must say that previously, sensor networks consisted of a small number of sensor nodes that were *wired* to a central processing station. However, nowadays, the interest is focused more on wireless distributed, sensing nodes. But, the question is, why wireless sensing? When the exact location of a particular phenomenon is unknown, distributed sensing allows for closer placement to the phenomenon than a single sensor would permit.

Wireless ad-hoc Sensor Networks have been increased enormously the recent years as they are used more and more in the daily life. In order to guarantee the network existence and increase network lifetime in such environments, various schemes have been proposed regarding the resource allocation, routing and Low Energy consumption. Thus, one of the most important issues for the Wireless ad-hoc Sensor Networks' Survivability is the *Power Control* and therefore the energy consumption. The use of lower power can increase spatial channel reuse, hence increase the overall aggregate channel utilization [11]. It saves the precious battery energy of sensor nodes, reduces co-channel interference with the other neighbors and improves the overall energy consumption, consequently prolonging the lifetime of the sensor network contributing to the collision avoidance.

In this paper, low-energy consumption schemes in wireless ad-hoc sensor networks developed in recent years are explored. The aim is to help better understanding of the current low-energy consumption protocols for wireless ad-hoc sensor networks and point out open issues that can be subject to further research. The paper is organized as follows: Section 2 describes low-energy consumption schemes of the wireless ad-hoc sensor networks proposed. Following, section 3 discusses the factors that influence the Low-Energy Consumption algorithms' selection. Section 4 discusses the selection and decision of low-energy consumption algorithms. Finally, section 5 concludes the research work and points out open research problems.

2 Low-Energy Consumption Schemes of the Wireless Sensor Networks

The issues related to physical and link layers are generally common for all kinds of sensor applications, therefore the research on these areas has been focused on system-level power awareness such as dynamic voltage scaling, radio communication hardware, low-duty cycle issues, system partitioning, energy-aware MAC protocols [8-9]. At the network layer, the main aim is to find ways for energy-efficient route setup and reliable relaying of data from the sensor nodes to the sink so that the lifetime of the network is maximized.

Researchers have been trying to overcome any kind of deficiencies, through considerable research on more energy efficient routing, localization algorithms and system design [10].

Different low-energy consumption schemes for conventional wireless ad-hoc sensor networks have been proposed in the literature in order to ameliorate the deficiencies of the IEEE 802.11 scheme.

A scheme for the energy reduction together prolonging the battery lifetime is presented here [13]. A cross-layer design framework is introduced to the multiple access problems in contention-based wireless ad hoc sensor networks. The motivation for this study is twofold, limiting multi-user interference to increase single-hop throughput and reducing power consumption to prolong battery life. The multiple access problem is solved via two alternating phases, namely scheduling and power control. The scheduling algorithm is essential to coordinate the transmission of independent users in order to eliminate strong levels of interference. On the other hand, power control is executed in a distributed fashion to determine the admissible power vector that can be used by the scheduled users to satisfy their single-hop transmission requirements. This is done for two types of networks, namely time-division multiple access (TDMA) and TDMA/ CDMA (code-division multiple access) wireless ad hoc networks.

The proposed Joint Scheduling and Power Control algorithm is executed at the beginning of each time slot in order to cope with excessive interference levels that might be developed in some slots. This algorithm determines the admissible set of users that can safely transmit in the current slot without disrupting each other's transmission. Thus, the objective is twofold: first, to determine the set of users who can attempt transmission simultaneously in a given slot and second to specify the set of powers needed in order to satisfy SINR (Signal to Interference Noise Ratio) constraints at their respective receivers. This interesting observation has led to the applicability of existing power control algorithms to emerging wireless ad hoc networks.

The experimental work showed that distributed power control algorithms, introduced earlier for cellular networks, are directly applicable to emerging wireless ad hoc sensor networks. Furthermore, the conducted simulated study verifies the theoretical convergence results of the proposed algorithm. This was done, first, under the assumption of a TDMA scheme and later for TDMA/CDMA ad hoc sensor networks. Furthermore, it was shown that the performance of the optimum scheduling policies compared to simple heuristic policies under light and heavy load conditions. The conclusion, from the above mentioned work, is that there is room for performance improvement via introducing distributed, heuristic, and fair scheduling policies within the proposed framework.

Another scheme that achieves an increase of the lifetime of the network is presented here [1], [14]. It is focused on energy-aware routing. Shah and Rabaey proposed to use a set of sub-optimal paths occasionally to increase the lifetime of the network. These paths are chosen by means of a probability function, which depends on the energy consumption of each path. Network survivability is the main metric that the approach is concerned with. The approach argues that using the minimum energy path all the time will deplete the energy of nodes on that path. Instead, one of the multiple paths is used with a certain probability so that the whole network lifetime increases. The protocol assumes that each sensor node is addressable through a class-based addressing which includes the location and types of the nodes. In this protocol, there are three phases:

1. Setup phase: Localized flooding occurs to find the routes and create the routing tables. While doing this, the total energy cost is calculated in each sensor node. For, instance, if the request is sent from node N_i to node N_j, then the N_j calculates the cost of the path as follows:

$$C_{N_j,N_i} = Cost(N_i) + Metric(N_j, N_i) \quad (1)$$

Here, the energy metric used captures transmission and reception costs along with the residual energy of the sensor nodes. Paths that have a very high cost are discarded. The sensor node selection is done according to closeness of the destination. The sensor node assigns a probability to each of its neighbors in routing (or forwarding) table (FT) corresponding to the formed paths. The probability is inversely proportional to the cost, that is:

$$P_{N_j,N_i} = \frac{1/C_{N_j,N_i}}{\sum_{k \in FT_j} 1/C_{N_j,N_k}} \quad (2)$$

N_j then calculates the average cost for reaching the destination using the neighbors in the forwarding table (FT_j) using the formula:

$$Cost(N_j) = \sum_{i \in FT_j} P_{N_j,N_i} C_{N_j,N_i} \quad (3)$$

This average cost for N_j is set in the cost field of the request and forwarded.

2. Data communication phase: Each sensor node forwards the packet by randomly choosing a node from its forwarding table using the probabilities.
3. Root maintenance phase: Localized flooding is performed infrequently to keep all the paths alive.

The described approach is similar to Directed Diffusion (DD) in the way potential paths from data sources to the sink are discovered. In Directed Diffusion, data is sent through multiple paths, one of them being reinforced to send at higher rates. On the other hand, Shah and Rabaey select a single path randomly from the multiple alternatives in order to save energy. Therefore, when compared to Directed Diffusion, it provides an overall improvement of 21.5% energy saving and a 44% increase in sensor network lifetime. However, such single path usage hinders the ability of recovering from a sensor node or path failure as opposed to Directed Diffusion. In addition, the approach requires gathering the location information and setting up the addressing mechanism for the sensor nodes, which complicate route setup compared to Directed Diffusion.

Finally, another important scheme, contributing to dynamic increase of the lifetime of the sensor network, is proposed by Sinha et al. [14]. Once the system is designed additional power savings can be obtained by using dynamic power management (DPM) [14]. The basic idea behind DPM is to shut down the devices when not needed and get them back when needed.

The switching of node states takes some finite time and resource [14]. So we have to carefully use DPM to get maximum life of a sensor node. This shut down yields good savings. But in many cases we may not know beforehand when we need a particular device [15]. So we need stochastic analysis to predict the future events. The following model of sensor deals with switching of node state in power efficient manner.

This model describes the power consumption in different levels of node sleep-states. Each sleep state is characterized by latency and power consumption. The deeper the sleep state, the lesser the power consumption, and more the latency. The system puts the node into sleep state by testing the probability of an event occurring in the corresponding sleep time threshold against system. Node k also updates sleep time threshold after every event. All states must be controlled by the operating system present in the node.

3 Factors that influence the Low-Energy Consumption algorithms' selection

In ad hoc wireless sensor networks, there are several factors that influence the decision for the selection of the proposed algorithm [16], [17]. Consider a wireless sensor network, where all sensor nodes have been distributed in a homogeneous manner. Before the application in different wireless environments and sensors spread, various characteristics and factors are considered:

Sensors' density: It depends on land morphology, battery lifetime of sensors (for small life time, dense distribution is required).

Data Cryptography: the number of levels of cryptography is used. Increasing the security levels, the energy spent is increased and therefore the life-time is decreased.

Data Selection Period: The power control algorithm selection is influenced by the data selection period, taking into account the physical characteristics of the sensor (battery, CPU, etc). The transition from the idle to sleep mode is also considered.

Replacement Frequency: It characterizes how often the sensor may be replaced by other sensors.

Class of Services: Priorities on data delivery are introduced, depending on the crucial character of the information.

Alternative Routing: The existence of alternative routing improves the survivability of communication. It will minimize failures and packet delivery delays. It increases network complexity and the energy spent in each node.

The selection of the power control algorithms and the weight of every factor that influence decision / selection, depends on the operation scheme the sensors are used.

4 Selection and Decision of Low-Energy Consumption Algorithms

The operational lifetime of mobile sensors is increased if the signal transmission power is controlled. The RF power amplifier consumes more than half of the total energy consumed by the Network Interface Card (NIC). From a power consumption standpoint, a smaller transmission power is preferable, which also means a smaller set of next-hop sensor nodes, but, reducing the size of this set may result in loosing network connectivity. Multiple access-based collision avoidance MAC protocols have used fixed transmission power, and have not considered power control mechanisms based on the distance of the transmitter and receiver in order to improve spatial reuse [18].

Considering the limitations arising from the particular character of each wireless sensor network and the weighted factors that influence the selection of the power control algorithms, we may evaluate the conventional schemes use upon the nature of the data that should be collected and transmitted.

As it is presented in the previous section 2, the first scheme emphasizes on the introduction of a cross-layer design framework to the multiple access problem in contention-based wireless ad hoc sensor networks. The motivation for this study is twofold, limiting multi-user interference to increase single-hop throughput and reducing power consumption to prolong battery life. The multiple access problem is solved via two alternating phases, namely scheduling and power control. Thus, this scheduling algorithm is essential for the following reasons:

1. To coordinate the transmission of independent users in order to eliminate strong levels of interference and ,
2. To determine the admissible power vector that can be used by the scheduled users to satisfy their single-hop transmission requirements through power control which is executed in a distributed fashion.

The second scheme presented is focused on energy-aware routing. Shah and Rabaey proposed to use a set of sub-optimal paths occasionally to increase the lifetime of the network. Network survivability is the main metric that the approach is concerned with. The described approach is similar to Directed Diffusion (DD) in the way potential paths from data sources to the sink are discovered. In Directed Diffusion, data is sent through multiple paths, one of them being reinforced to send at higher rates. Thus, this algorithm is essential because it can save energy through the selection of a single path randomly from the multiple alternatives. Compared to Directed Diffusion, it provides an overall improvement of 21.5% energy saving and a 44% increase in sensor network lifetime. However, such single path usage hinders the ability of recovering from a sensor node or path failure as opposed to Directed Diffusion. Finally, the third scheme, contributes to the dynamic increase of the lifetime of the sensor network.

5 Conclusion

The survivability of wireless ad hoc sensor networks is of a great importance in wireless communications. The increasing importance of real-time applications requires more than best-effort services from the underlying networking infrastructure and thus, making the low-energy consumption and QoS provisioning challenge even greater. The complexity and reliance of wireless ad hoc sensor networks application environments require the utilization of power control schemes which will guarantee the network survivability and connectivity. The major goals of the low-energy consumption schemes are:

- Increase of sensor network life time,
- Improvement of wireless sensor network service survivability and availability,
- Guarantee of network connectivity,
- Efficient control energy consumption,
- Improvement of wireless sensor network performance.

Thus, this paper presented conventional low-energy consumption schemes for wireless sensor networks. Our running research work in the wireless sensor networks was not concentrated only in the adaptation or selection of proper power control algorithms, but in the development of a hybrid power control scheme, where it satisfies the dynamically short-time changing requirements. Finally, in the future, the mobility factor should be taken into account since recent advances in sensor fabrication technology, low-power, digital and analog electronics, will allow the construction of mobile sensors. Thus, as the wireless sensor communications will have to handle more information, the sensor nodes must be more dispersed, more mobile and rapidly reconfigured. The development of low-energy consumption schemes in wireless sensor networks has become more than a necessity.

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