International Journal of Research Studies in Computer Science and Engineering (IJRSCSE)
Volume. 1, Issue 3, July 2014, PP 64-68
ISSN 2349-4840 (Print) & ISSN 2349-4859 (Online)
www.arcjournals.org

Lifetime Maximization in Wireless Sensor Networks by Joint Contention and Sleep Control

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Abstract: *We consider the problem of determining the transmission power assignment that maximizes the lifetime of a data-gathering wireless sensor network with stationary nodes and static transmission power levels. In this paper, we propose a joint control scheme to maximize network lifetime in wireless sensor networks with joint contention and sleep control. For the contention resolution of sensor nodes in the network, we consider the p-persistent contention protocol. Also, the sleep control is introduced with the probability of turning off the transceiver of a sensor node. Using the probabilities of contention and sleep, we formulate the network lifetime maximization problem to satisfy the throughput requirement and each link's signal to noise interference ratio (SINR) requirement. Finally, we demonstrate that the proposed scheme improves the lifetime of wireless sensor networks compared to the existing schemes.*

1. INTRODUCTION

Wireless sensor network is an emerging technology of great interest to many of the academic units and research centres worldwide. Wireless sensor network have been widely used for many applications. A sensor network is composed of multiple sensor nodes that communicate with each other via a wireless network and the data of each node are integrated. During the operation of a sensor network system, the number of available sensor nodes deployed at the beginning of the operation normally drops over time due to reasons such as harsh environments, energy draining-out and damages. As the number of sensor nodes continues to decrease in the network , the quality of sensing may drop to a level that is below the system requirement. It may leading to a system level performance degradation.

Wireless sensor networks (WSNs) are applied to various types of applications because of flexible and easy installation of sensor nodes. However, due to the finite battery power in the sensor nodes, WSNs are suitable for an application with the low throughput requirement unlike cellular networks and mobile ad hoc networks. Because of the battery dependency of WSNs, there have been many results for the efficient battery usage of the sensor nodes, i.e., increasing the network lifetime, in the last decade. Madan *et al.* [1] have established the lifetime maximization framework of WSNs with the time division multiple access (TDMA) based medium access control (MAC) protocol. They have considered the throughput requirement and the power constraint. Moreover, Wang *et al.* [2] have presented a method for the maximized lifetime using a decomposition of the sensor node sets.

We consider a WSN composed of nodes with sensing, processing, and communicating functions integrated into a small unit with a finite energy supply. These nodes are to be deployed in large numbers without close human supervision, possibly into unfriendly territory, for various information gathering tasks. Within its energy limits, the WSN must sense, process, and transmit information to a base station or sink node, where a remote end-user can access it. Since communication is often the most expensive operation for a sensor node, an efficient algorithm to route the data gathered is crucial to efficiently use the limited energy . For instance, if every node transmits its data directly to the sink node, nodes with little data to send will be left with unused energy while data can be stranded in a node that depleted its energy. In addition, since the limited energy in effect limits the life of the network, the WSN can not spend much time coordinating a routing policy and must reach an efficient data gathering mechanism rapidly. If not it would spend a significant percentage of its lifetime operating inefficiently.

Since the TDMA-based lifetime maximization is only applied to a small size of WSNs because of difficulty to achieve the global synchronization and to allocate time slots with the spatial reuse of frequency [1], it is necessary to consider the contention-based MAC protocol for the lifetime maximization problem. Zhu *et al.* [3] have analyzed a tradeoff between the network utility maximization and the lifetime maximization with the *p*-persistent contention-based MAC protocol. However, the waste of energy is inevitable due to the idle listening and collision. This waste of energy can be reduced by turning off the transceiver of a sensor node, i.e., sleep control . Initially, Ye *et al.* [4] have proposed the sleep control of WSNs with the contention-based MAC protocol. The authors of [5] have provided a framework of joint sleep control and routing under the collision free assumption. Also, the authors have provided an algorithm to find the optimal sleep duration with the minimum energy consumption, but the network lifetime is not maximized. Recently, although the results of virtual backbone scheduling have been proposed, they control the contention and the sleep control individually.In this paper, we consider the lifetime maximization problem in the WSN with joint contention and sleep control.

The major contributions of paper are two-fold. Firstly, we formulate the lifetime maximization problem using the *p*persistent contention probability and the sleep probability while guaranteeing the throughput requirement and the signal to noise interference ratio (SINR) requirement. Secondly, we provide a sub-gradient-based algorithm [8] and show that the lifetime is improved compared to the previous results.

2. System Description

We consider a wireless sensor network described by the graph, $G = (N, L)$, where N is a set of the sensor nodes and L is a set of the network links associated with the sensor nodes. We assume that network traffics are originated in the source nodes, and are destined to a common sink node using multihop transmission. The path between the source node and the common sink node is assumed to be fixed. For simplicity, we assume that the transmit power of the sensor node is equal to each other. Finally, we assume that the sensor node in the WSN cannot transmit and receive concurrently to avoid the self-interference in cross-layer design of wireless sensor network.

The cross-layer approach emerged recently still necessitates a unified cross-layer communication protocol for efficient and reliable event communication that considers transport, routing, and medium access functionalities with physical layer (wireless channel) effects for WSNs. Here, we overview a new communication paradigm, i.e., cross-layer module (XLM) for WSNs [3]. XLM replaces the entire traditional layered protocol architecture that has been used so far in WSNs. The basis of communication in XLM is built on the *initiative* concept. The initiative concept constitutes the core of XLM and implicitly incorporates the intrinsic functionalities required for successful communication in WSN. A node initiates transmission by broadcasting an RTS packet to indicate its neighbors that it has a packet to send. Upon receiving an RTS packet, each neighbor of a node decides to participate in the communication through *initiative determination*.

3. Network Lifetime Maximization

Critical to any wireless sensor network deployment is the expected lifetime. The goal of both the environmental monitoring and security application scenarios is to have nodes placed out in the field, unattended, for months or years. The primary limiting factor for the lifetime of a sensor network is the energy supply. Each node must be designed to manage its local supply of energy in order to maximize total network lifetime. In many deployments it is not the average node lifetime that is important, but rather the minimum node lifetime. In the case of wireless security systems, every node must last for multiple years. A single node failure would create a vulnerability in the security systems.

In some situations it may be possible to exploit external power, perhaps by tapping into building power with some or all nodes. However, one of the major benefits to wireless systems is the ease of installation. Requiring power to be supplied externally to all nodes largely negates this advantage. A compromise is to have a handful of special nodes that are wired into the building's power infrastructure. In most application scenarios, a majority of the nodes will have to be self powered. They will either have to contain enough stored energy to last for years, or they will have to be able to scavenge energy from the environment through devices, such as solar cells or piezoelectric generators [14, 15]. Both of these options demand that that the average energy consumption of the nodes be as low as possible. The most significant factor in determining lifetime of a given energy supply is radio power consumption. In a wireless sensor node the radio consumes a vast majority of the system energy. This power consumption can be reduced through decreasing the transmission output power or through decreasing the radio duty cycle. Both of these alternatives involve sacrificing other system metrics.

Since we consider that the WSN operates the *p*-persistent contention-based MAC protocol, all the sensor nodes should determine the contention probability. As shown in [3], we also assume that the time is divided into slots and each sensor node transmits packets randomly with the contention probability at each slotted time. Note that all the packets are not transmitted successfully due to the collision of multiple transmissions, which do not occur with the TDMA-based MAC protocol. Thus, in order to achieve the successful transmission between a sender node, t_l , and a receiver node, r_l , of link $l \in L$, the sender node should not receive any packets and the receiver node should not transmit any packets. Note that this principle of successful transmission is used to formulate the constraints of both the throughput requirement and the SINR requirement.

3.1 Throughput Requirement and Power Constraint

To meet the multi-year application requirements individual sensor nodes must be incredibly low-power. Unlike cell phones, with average power consumption measured in hundreds of milliamps and multi-day lifetimes, the average power consumption of wireless sensor network nodes must be measured in micro amps. This ultra-low-power operation can only be achieved by combining both low-power hardware components and low duty-cycle operation techniques.

Like the contention probability, we propose that the sleep probability is determined in each node at the beginning of each time slot. Thus, each sensor node determines both whether the node turns off the transceiver or not and whether the node transmits the packets or not. Note that since we consider the sleep probabilities of nodes, the successful transmission should require that both the sender node and the receiver node turn on the transceiver. Let q_l be a contention probability of link *l* and μ_v be a probability of turning on the transceiver of sensor node $v \in N$, i.e.μ_v := 1−the sleep probability. Then, the total probability of successful transmission of link *l* between the sender node, t_l , and the receiver node, r_l , is described as follows:

$$f_1(q,\mu) = q_1\mu_{t1} \times \mu_{r1} \prod_{k \in L_{out}(r1)} (1-q_k) \times \prod_{k \in L_{in}(t1)} (1-\mu_{tk}) + \mu_{tk}\big((1-q_k)\big), \forall l \in L$$

Where $L_{out}(v)$ a set of the outgoing is links of node *v* and $L_{in}(v)$ is a set of the incoming links of node *v*. The probability is composed of three parts. For successful transmission, the sender node transmits the packets with the probability, $q_1\mu_{t1}$. Also, the receiver node should not transmits any packets but turns on the transceiver that is described by $\mu_{r1}\prod_{k\in L_{out}(r1)}(1-q_k)$. Finally, the sender n_ode should not receive any packets that is described by $\prod_{k\in L_{in}(t1)}(1-\mu_{tk}) + \mu_{tk}\big((1-q_k)\big)$. The transmission requires a certain amount of power consumption of each sensor node, which includes the power leakage ratio of the transmitter circuit.

3.2 Optimization Problem

The Lagrangian, V , for the optimization problem in is formulated with the global knowledge, the sub gradient algorithm of (22)-(24) can be updated at each node using both the node's information and the exchanged information from adjacent nodes, i.e., partially distributed as shown in [3], [6]. Hence, there exists optimality loss compared to the fully centralized solution due to the limited information. If we consider more nodes for reducing the optimality loss, the overhead to obtain the information is increased. We will focus on the issue of power consumption and scalability in the future work.

4. SIMULATION RESULTS

In this section, we show the convergence of the proposed algorithm and the effectiveness of the contention and sleep control compared to the existing results of [3] and [5]. We consider the wireless sensor network which consists of 9 flows and 20 sensor nodes in Fig. 1. We set that all point to- point links in Fig. 1 are in a same broadcast medium, but the network allows the concurrent transmissions of weakly interfering links. The fixed path gain, $G_{t_k r_l}$, is set to $d_{t_k r_l}$ where $d_{t_k r_l}$ is the distance between the sender node, *tk*, and the receiver node, *rl*. The distance between adjacent nodes is set to 50 m. P_r and P_s are set to 14.4 mW and 7.2 mW for all sensor nodes, respectively [4].

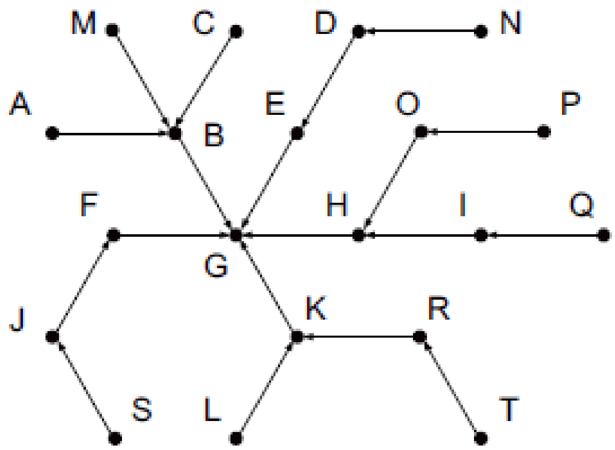

Fig1. *Network Topology*

In Fig. 2, we confirm that the network lifetime decreases when the transmit power increases and the throughput requirement increases. Note that all the throughputs are similar to the throughput requirements in previous methods. Compared to the result of [3], the proposed scheme improves network lifetime due to the consideration of the sleep of sensor nodes. The result of [5] considers the sleep of sensor nodes, but the fixed idle listening time and the collision free assumption lower the network lifetime. Although the contention probability of [3] is severely low for increasing the network lifetime, network lifetime is not maximized. Thus, we claim that the proposed joint contention and sleep control greatly improves the network lifetime. Finally we can say that, the proposed scheme improves the lifetime of wireless sensor networks compared to the existing schemes.

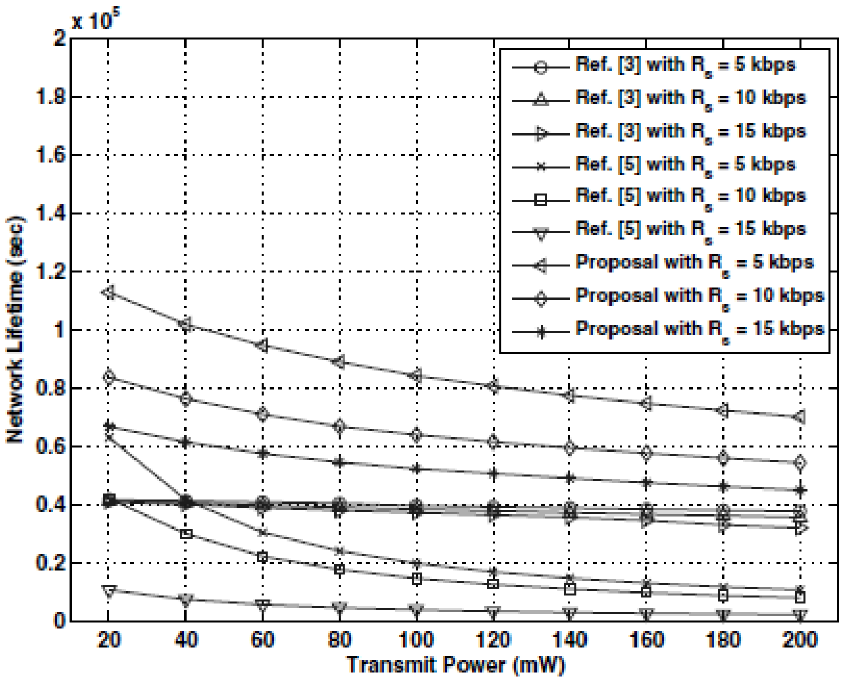

Fig2. *Network Lifetime in various cases of fixed transmit powers*

5. CONCLUSION

We propose a joint contention and sleep control scheme in the wireless sensor network. We consider the effect of the throughput requirement and energy constraint with the contention and sleep control, then we formulate the optimization problem for achieving the maximized lifetime. Using the probabilities of contention and sleep, we formulate the network lifetime maximization problem to satisfy the throughput requirement and each link's signal to noise interference ratio (SINR) requirement**.** With the log transformation and the subgradient algorithm, we present the algorithm to achieve the maximized lifetime.

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