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Description	

2-hop Scheme for Maximum Lifetime in Wireless Sensor Networks

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Abstract— **In wireless sensor networks (WSNs), sensors usually form a tree topology and the sensed data are transmitted to a sink using multihop communication fashion. The tree topology works effectively in handling the traffics towards the sink. However, this tree topology aggravates the waste of network resources. In particular, sensors close to the sink will overuse the energy for transmitting other sensed data and led to the residual battery drained faster. In this paper, we propose a novel 2-hop scheme to balance the energy consumed among sensors in the network by assigning each sensor a transmission probability. Simulation results reveal that our proposed 2-hop scheme outperforms the conventional scheme in term of network lifetime and data gathering delay.**

I. Introduction

Nowadays, wireless sensor networks (WSNs) are used in a wide range of applications such as in environmental applications (e.g., habitat monitoring, fire detection), health applications (e.g., monitoring patient's biomedical data). In practical, sensors in such networks use small batteries and are expected to operate for a long time. However, replacing or recharging the batteries of the sensors is impractical after they have been deployed. Therefore, how to save energy of the sensors and how to prolong the network lifetime are the important considerations while deploying the WSNs.

A plethora of research has been conducted in relation to maximizing the network lifetime of WSNs. This leads to many algorithms to prolong network lifetime. For explanation purpose, we classify them into three types. One is routing approach, e.g., Rezayat et al. [1] proposed power-aware routing protocol to reduce energy consumption by selecting minimum-energy routing routes for sending packets. The second kind is sleep management approach, e.g., Ma et al. [2] used a contiguous link scheduling scheme to periodically turn off radio circuit to avoid idle listening. The last is energy balancing approach, e.g., Zhang et al. [3] exploited the tradeoff between direct transmission and next-hop transmission to balance the energy consumed among sensors.

A tree topology is constructed based on a tree-based routing (TBR) protocol [4], which works effectively in handling the traffics towards the sink. However, this TBR protocol aggravates the waste of network resources. In particular, sensors close to the sink will overuse the energy for transmitting other sensed data and led to the residual battery drained faster. On the other hand, the sensors (especially leaf sensors) may not be able to perform the direct transmission because a huge amount of energy is required to send their packets. Consequently, the direct transmission does not work well in practical. Thus, we propose a novel 2-hop scheme, which prolongs the network lifetime and minimize the data gathering delay by exploiting the next 2-hop transmission.

The primary goal of our work is to balance the energy consumed among sensors in the network by assigning each sensor a transmission probability, so that the network lifetime can be prolonged and the data gathering delay can be minimized. Our contributions are as follow: first, we exploit the advantage of next 2-hop transmission to send a packet with a transmission probability of ρ. Second, we can find optimal transmission probability for each node, so that energy consumption is balanced and network lifetime is maximized for both chain and binary tree topologies. Third, our proposed 2-hop scheme is easy to implement and feasible for the large-scale network of WSNs.

The remainder of this paper is organized as follows. We discuss the background and research problem in Section II. Section III introduces a core idea of the proposed 2-hop scheme. Section IV gives the system model that uses in this research. Then, we numerically analyze how the 2-hop scheme can prolong the network lifetime and minimize the data gathering delay on the topology networks of chain and binary tree in Section V. Section VI also presents the simulation studies of 2-hop scheme in the general tree networks. Finally, Section VII conclude our research.

II. Background and Research Problem

A. *Wireless Sensor Networks*

WSNs are a network of nodes that cooperatively sense and may control the environment enabling interaction between persons or devices and the surrounding environment through wireless link. The sensed data is forwarded, possibly via multiple hops, to a sink that can use it locally or is connected to other networks (e.g., Internet). At the network viewpoint, WSNs can adopt one of the three topologies: star, tree or mesh. In the star topology, WSNs work effectively in collecting traffics using a single hop fashion. However, the tree topology works effectively in handling the traffics towards the sink using a multihop fashion. The mesh topology gives a high reliability for WSNs to deliver the traffics from one end to another end.

Simply to say, the way that a message is routed from one node to another depends on these topologies.

B. Tree-based Routing

TBR protocol [4] that is a kind of proactive routing protocols builds a tree-topology network when a sink in the WSNs is configured. Before a sensor could send its traffic to another sensor inside the WSNs, the topology tree is constructed in order to link all the participating sensors. This topology tree formation begins when the sink starts to periodically broadcast a root announcement (RANN) message by increasing the sequence number in every announcement. The sensor receiving the RANN caches the originated sensor address of the corresponding RANN as a potential parent, and rebroadcasts the RANN with an updated cumulative metric. After waiting for a pre-defined period of one second for other arriving RANNs from all possible parents, the sensor selects one parent with the best-metric for its path to the sink from all the possible parents, and updates its route table in which, for instance, the latest message sequence number. Then, the sensor that has the known path to the sink also registers itself by sending a route reply (RREP) message with the sink as the destination address in the RREP message field. Each sensor in the tree-topology network maintains its own route table, which has entries for recent route towards the destination sensor. If the route is not used within the specified time, route table timeout must be at least the maximum of three times of $RANN\ interval$, it is deleted. With the tree-topology and table-driven routing, any sensor can participate and communicate with each other in the network.

C. Research Problem

There are two basic transmission patterns in WSNs that a sensor can utilize to transmit data to the sink: direct transmission and multihop transmission. Direct transmission, where data is directly transmitted to the sink without any intermediate sensor, is very energy-expensive and may quickly drain out the sensors' batteries, especially for those located far away from the sink. In real deployment, to avoid sending large data over long distance, multihop transmission is required. This multihop transmission drains less energy at each sensor; however, the load at sensors near the sink becomes big, for they have to handle more data from the others. As a result, they quickly run out of battery, causing a decreased network lifetime. This phenomenon is called the unbalanced energy consumption problem due to the multihop transmission.

III. Proposed 2-hop Scheme

The core idea of our proposed scheme is to aggravate the waste of network resources of the tree topology, which is used the multihop transmission for collecting sensed data in the WSNs. In particular, sensors close to the sink will overuse the energy for transmitting other sensed data and led to the residual battery drained faster. Thus, we propose a novel 2-hop scheme, which prolongs the network lifetime by exploiting the next 2-hop transmission (see Fig. 1). Sensor D forwards a

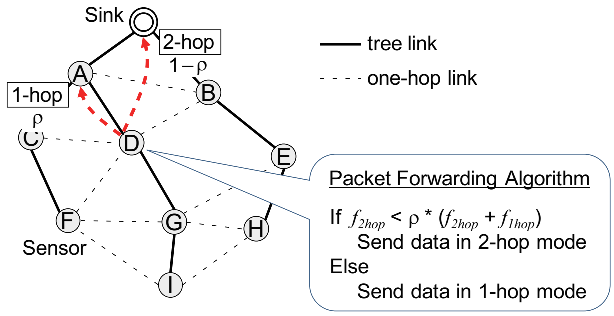

Fig. 1. Based on the packet forwarding algorithm, sensor D forwards a data packet to the sink with probability $1-\rho$ and forwards a data packet to sensor A with probability of ρ.

packet to next 2-hop neighbor (i.e., sink) with a transmission probability of $1-\rho$ and forwards a packet to next 1-hop neighbor (i.e., sensor A) with a transmission probability of ρ. By this way, 2-hop transmission does not consume plenty of energy as the aforementioned direct transmission.

IV. System Model

We consider the WSNs in which both the sensors and the sink are static after deployment. We assume that the sink always has sufficient power supply, while the sensors are powered by batteries and it is unfeasible to replace or recharge those batteries after deployment.

A. Data Gathering Cycle Model

Our analysis is for data gathering sensor networks where each sensor periodically transmits its sensed data to the sink. In most data gathering applications, usually the time between two adjacent data transmission cycles (duty cycles) is long, may be several minutes, hours or even days. Therefore, to avoid idle listening, sensors usually turn off their radio circuits when there is no data to transmit. In our model, we assume that a synchronized sleep/wake up scheme like S-MAC [2], T-MAC [5] or contiguous link scheduling [6] is exploited. The process in which all sensors wake up, generate the sensed data and transmit the data to the sink is defined as one *Data Gathering Cycle* (DGC). In one DGC, we assume that each sensor generates only one packet and sends that packet, together with all packets forwarded to it by other sensors, to the sink.

B. Energy Model

First-order radio model that proposed in [7] has been widely used to measure energy consumption in wireless communications. The energy consumption to transmit one m-bit packet is $\epsilon_t(d) = (\epsilon_{elec} + \epsilon_{amp} * d^{\alpha}) * m$, where ϵ_{elec} is the energy spent by electronic circuit to transmit or receive one data bit, ϵ_{amp} is the transmission amplifier and α is the propagation loss exponent. While receiving data, only the receiving circuit is invoked and the energy to receive one m-bit packet is $\epsilon_r = \epsilon_{elec} * m$. In this research, because a synchronized sleep/wake up scheme is used to avoid idle listening, energy consumption for idle listening becomes much smaller compared to energy

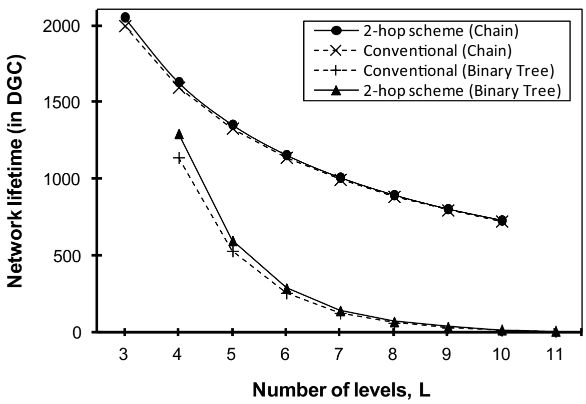

Fig. 2. The network lifetime as a function of number of levels for chain and binary tree topologies.

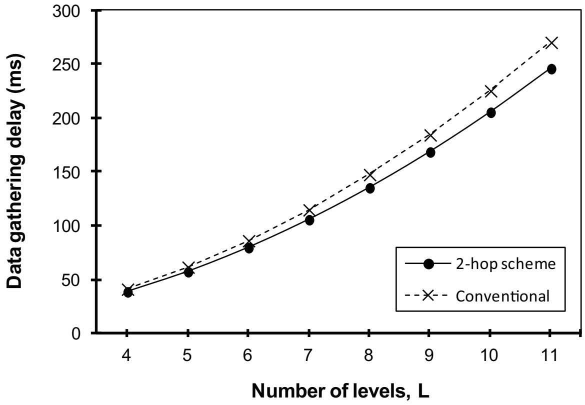

Fig. 3. The data gathering delay as a function of number of levels for chain topology.

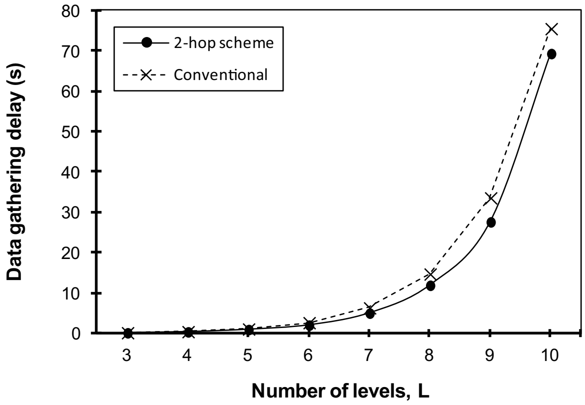

Fig. 4. The data gathering delay as a function of number of levels for binary tree topology.

consumption for transmitting and receiving data, thereby we do not consider that kind of energy consumption. Moreover, compared with data communication, other kinds of energy such as energy for data processing in sensors, etc. are much more smaller, and are not taken into account.

C. Communication Model

Communication model in our work is similar to [3], but instead of using direct transmission, we use 2-hop transmission. Specifically, sensor i forwards a packet to sensor $i-1$ using hop-to-hop transmission with probability, p_i and transmits the packet to sensor $i-2$ using 2-hop transmission with probability, $1-p_i$. p_i is called the transmission probability of sensor i and p_i is assigned for sensor i.

V. Theoretical Analysis

Let consider WSNs that are consisting of N sensors $S_1, S_2, S_3, \cdots, S_N$. At initial deployment time, the battery levels in all sensors are assumed to be the same. The energy consumption of S_i in one DGC is denoted by ε_i. The energy consumed by S_i in the whole network lifetime is denoted by ξ_i. For a random variable λ, we denote by $E[\lambda]$ its expectation value. That means, $E[\varepsilon_i]$ is the expected energy consumption of S_i in one DGC and $E[\xi_i]$ is the expected energy consumption of S_i in the whole network lifetime.

A network is said to be energy balanced if each sensor has the same expected energy consumption in the whole network lifetime, i.e.,

$$E[\xi_i] \quad = \quad E[\xi_j] \qquad i,j = 1,2,\cdots,N \tag{1}$$

In our scheme, when p_i is large, S_i tends to send a packet in hop-to-hop transmission, so $E[\xi_i]$ is small. When p_i is small, a packet is more likely to be transmitted in 2-hop transmission, and $E[\xi_i]$ is large. Therefore, by assigning small probabilities for sensors far from the sink, and large probabilities for those close to the sink, energy consumption can be balanced for sensors in the network. The optimal transmission probability for each sensor can be computed if we apply Theorem 1.

Theorem 1. *$E[\xi_i] = E[\xi_j]$ if and only if $E[\varepsilon_i] = E[\varepsilon_j]$ $\forall i,j = 1,2,\cdots,N$.*

Proof. Because the transmission probabilities are not changed once the network starts to operate, then the expected energy consumption in a DGC is equaled to those in other DGCs. Let T be the total number of DGCs in the whole lifetime, then $E[\xi_i] = TE[\varepsilon_j]$. Thus, $E[\xi_i] = E[\xi_j] \iff TE[\varepsilon_i] = TE[\varepsilon_j] \iff E[\varepsilon_i] = E[\varepsilon_j]$.

We conduct the theoretical analysis of 2-hop scheme for both chain and binary tree topologies. We assume the initial battery level is 30 J. We also assume that transmission ranges of 1-hop and 2-hop are 20 m and 40 m, respectively. The propagation loss exponent, α = 3.5, ϵ_{elec} is 50 nJ/bit, and ϵ_{amp} is 100 pJ/bit/m$^{\alpha}$. The packet size, m is 1024 bits.

Figure 2 shows the network lifetime as a function of number of levels for chain and binary tree topologies. In this paper, the network lifetime of WSNs is defined as the time elapsed since the network started operating until one sensor run out of battery. At the network level is 4, 2-hop scheme is increased the network lifetime about 28.5% and 12.6% compared to that with conventional scheme for chain topology and binary tree topology, respectively.

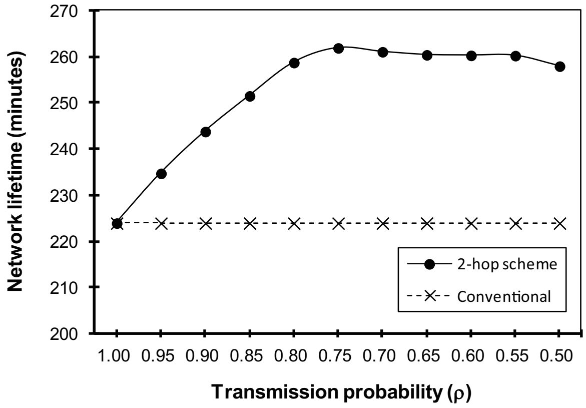

Fig. 5. The performance of 2-hop scheme and conventional scheme for the network lifetime as a function of transmission probability.

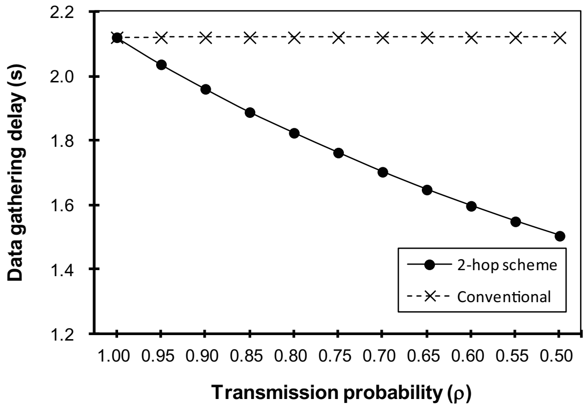

Fig. 6. The performance of 2-hop scheme and conventional scheme for the data gathering delay as a function of transmission probability.

Figure 3 and 4 show the data gathering delay as a function of number of levels for chain topology and binary tree topology, respectively. The data gathering delay of one DGC is defined as the time for all packets from all sensors to be received by the sink. In this paper, to avoid signal interference, at one time, we assume that only one sensor transmits data using the prefect time division multiplexing. As we can see at the network level is 10, 2-hop scheme is reduced the data gathering delay about 8.8% and 8.2% compared to that with conventional scheme for chain topology and binary tree topology, respectively.

VI. Simulation Studies

We investigate the performance of 2-hop scheme in general tree networks. The sink is located at the center of network coverage, whereas sensors are randomly placed. We use the first-order radio model with the propagation loss exponent of 3.5. Our traffic model is a constant bit rate (CBR), which is sent at every 10 seconds. For comparison purposes, 20 simulation scenarios with different random topology are averaged.

Figure 5 and 6 show that the proposed 2-hop scheme attains a higher network lifetime and a lower data gathering delay compared to the conventional scheme. This is because the sensors at the level two can transmit the data packet directly to the sink rather to the sensors at the level one. As a result, the sensors at the level one can save their batteries to forward other data packets, in which this leads to the longer network lifetime and shorter data gathering delay. In Fig. 6, the 2-hop scheme achieves the maximum network lifetime of 16.94% when the transmission probability is 0.75. Meanwhile, the 2-hop scheme accomplishes the minimum data gathering delay of 29.04% when the transmission probability is 0.5.

TABLE I

Simulation parameters and settings

Network protocol	TBR
Number of sink nodes	1
Number of sensor nodes	100
Network coverage	100 m × 100 m
Transmission range	20 m
RANN interval	15 s
Traffic type	Constant bit rate
Data gathering cycle	10 s
Data payload size	104 bytes
Data header size	24 bytes
Energy model	First-order radio
Propagation loss exponent	3.5
Radio electronic, ϵ_{elc}	50 nJ/bit
Transmit amplifier, ϵ_{amp}	100 pJ/bit/m$^{3.5}$
Initial battery capacity	30 J

VII. Concluding Remarks

In this paper, we have addressed the problem of imbalance energy consumption for data collection in the WSNs. We have proposed the 2-hop scheme to balance the energy consumed among sensors in the network by assigning each sensor a transmission probability. This leads to the network lifetime can be prolonged and the data gathering delay can be minimized. Numerical results reveal that our proposed 2-hop scheme is very beneficial and outperforms the conventional scheme with the network lifetime improvement of 16.94% and the data gathering delay deduction of 16.87% when the transmission probability is 0.75 in the general tree networks.

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