A lifetime enhancing and QoS provisioning routing protocol for wireless sensor networks

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Abstract

A wireless sensor network typically consists of a very large number of small, inexpensive, disposable, robust, and low-power sensor nodes working cooperatively. In this paper, we propose a routing protocol for wireless sensor networks, which focuses on satisfying QoS constraints while maximizing the lifetime of the networks. Our proposed protocol enhances the network lifetime by distributing the traffic flow over multiple paths, while satisfying the different QoS requirements in a dynamic and decentralized manner. Simulation shows that the network lifetime increases without compromising QoS requirements and throughput.

1. Introduction

In his famous article 'the computer for the 21st century', Mark Weiser envisioned that future computers will be integrated seamlessly into the world, also described as 'ubiquitous computing'. [1] The recent development in wireless networking and communication technology, battery lifetime, microprocessors and memories has led to the decrease in the size and the cost of micro sensors, and now wireless sensor network is no longer a mere theoretical model.

A wireless sensor network typically consists of a very large number of small, inexpensive, disposable, robust, and low-power sensor nodes working cooperatively. Sensor network promises solution to many difficult tasks such as military surveillance, hazardous environment monitoring (deep water, hazardous industrial sites, volcanic area, etc), home automation, inventory management, etc. [2]

Although realization of sensor networks requires ad hoc networking techniques, existing routing protocols and algorithms for traditional wireless ad hoc networks do not meet the requirements of sensor networks for several reasons. [3] First, the number of sensor nodes in a sensor network is much greater than the nodes in an ad hoc network, while the computational capacities and memory of sensor nodes are more limited. Secondly, an ad hoc network is infrastructure-less, and communication occurs between any two end nodes, while a sensor network is typically formed around one or more base stations, and all the data generated are sent back to the base

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station. [4] Finally, sensor nodes are prone to failures.

So far, the primary design concern for sensor networks has been network lifetime and energy efficiency. Also, with the rapid development of video and imaging sensors, QoS criteria such as latency or data reliability have to be considered, magnifying the difficulties related to network lifetime enhancement. [5]

In this paper, we propose a routing protocol for wireless sensor networks, which focuses on satisfying QoS constraints while maximizing the lifetime of the networks. Our proposed protocol enhances the network lifetime by distributing the traffic flow over multiple paths, while satisfying the QoS requirements in a decentralized manner. Simulation shows that the network lifetime increases up to 20% without compromising QoS requirements and throughput.

The rest of the paper is organized as follows. Section 2 briefly reviews the related works. The proposed routing protocol is introduced in section 3, and verified by simulation in section 4. Finally, conclusion is drawn in section 5.

2. Related Works

Routing in mobile ad hoc networks (MANETs) is a challenging task due to various limitations such as bandwidth, power constraints, security, physical vulnerability, etc. Studies on routing protocols for MANETs are a relatively new field, but surely gaining popularity.

Numerous routing protocols have been suggested for MANETs, but these routing protocols are not efficient to be used in wireless sensor networks due to several differences. One of the most distinctive characteristics of sensor networks is that the computational ability and battery capacity of a sensor node is much lower than that of other ad hoc network nodes. Another unique aspect of sensor networks is that unlike other MANETs, all the sensor nodes in sensor network send packets to a base station or base stations only. Finally, extending network lifetime is the most important design issue, and throughput or fairness are of less importance.

Many existing routing protocols use multiple routing paths to forward packets. The benefits of using multipath include load balancing and resilience to unexpected node failures. Besides using multipath for network lifetime enhancement, several routing protocols take QoS constraints into consideration as well. Lou proposed an N-to-1 multipath routing protocol, [4] which focuses on data reliability and security. MMSPEED [6] is a multipath and multispeed routing protocol, which satisfies multiple QoS requirements in a decentralized manner. De et al. proposed a routing protocol which combines the idea of selective preferential forwarding, which attempts to forward packets along a predetermined best path, and selective random forwarding, which uses different alternative routes randomly. [7]

3. Proposed Algorithm

One of the most distinctive characteristics of sensor networks is that a sensor network is typically formed around one or more base stations, and all the data generated are sent back to the base station. In other words, all the routing paths lead back to the base station, therefore the route path is basically a spanning tree rooted at a base station.

In this section, we present the path setup process and the data collection process respectively.

3.1 Path Setup

Path setup process can take place periodically or triggered by a certain event or message from sensor nodes. Path setup is initiated at the base station by flooding route setup beacon packets. The general structure of route setup packets is {*Id, parentId, hopCount, state*}. *Id* is the unique identification number given to each node prior to deployment; *parentId* is the unique identification number given to its parent node, and this field is used to prevent loop; *HopCount* is the minimum number of hop counts to the base station from that node; *State* shows the state that particular node is in, such as energy level.

The initial route setup messages broadcasted by the base station are received by neighboring sensor nodes. Upon receiving these messages, they in turn send out their own route setup messages in the form of {*Id, ParentId, hopCount, state*}. When the *ParentId* field in the received packet equals its own sensor ID, that packet is discarded in order to prevent the formation of loops. Each sensor nodes generate path setup messages only once in a single path setup process. Path setup messages are propagated in this manner until all the sensor nodes are connected.

Meanwhile, when a sensor node receives a route setup message, it stores this information in the memory allocated for parent nodes information in the form of {*parent ID*, *hopCount*, *signalPower, score*}. *Parent ID* is the unique identification number of its parent node, which can be extracted from the path setup message; *hopCount* is the minimum number of hop counts to the base station when that particular node is selected as the next node; *signalPower* is the magnitude of the signal power received, which can be used to measure the channel condition i.e. the stronger the signal power, the better the channel condition. *Score* is a degree of usability of that particular parent node in choosing the next node, and will be explained in more detail when we discuss the routing process.

Once the path setup process is completed, each sensor node evaluates its parent nodes. Of all the parent nodes in the memory, the smallest number of hop counts to the base station is denoted as *minHopCount*. For each parent nodes, its number of hop counts to the base station is subtracted by *minHopCount*, and is denoted as *hopCountDifference*. Finally, its *score* field is multiplied by *usageDecreaseRatio*, which is the measure of decrease in the likeliness of using that particular node as the next hop, to the power of *hopCountDifference*. If 2 or more parent nodes have the same *hopCount*, the node with the biggest *signalPower* is considered a ‘better’ node.

3.2 Data Collection

In sensor networks, data packets are generated periodically or triggered by certain events, and are collected at the base station. In this paper, we made the assumption that every sensor generates data packets periodically. Moreover, this paper assumes that the network consists of two types of sensor nodes with different two different QoS requirements. For simplicity, we denote these sensors as low QoS sensors and high QoS sensors respectively. We also make a further assumption that low QoS sensors are much larger in number than high QoS sensors, and individual high QoS sensors generate more packets than low QoS sensors. Below, we elaborate on the differences between the routing of packets with different QoS requirements.

3.2.1 High QoS Packets

Previous works in [8] [9] show that transmitting packets along a predetermined best route while keeping alternative routes for failure recovery can reduce the overhead of periodical path setup in case of path failure without compromising the throughput. In our protocol, high QoS packets are transmitted along the best path, and when a parent node drains out of energy or failure occurs, an alternative path from the candidate parent node list is taken as the next hop.

In our protocol, the 'best' path is the parent node with the smallest number of hop counts to the base station among the parent nodes with *score* field greater than 0. If tie occurs, the parent node with the largest *signalPower* field is chosen. This way, the number of hops taken for the packets to reach the base station can be predetermined.

The obvious disadvantage of this method is that some of the nodes along the best paths run out of energy more quickly than other nodes, which can lead to disconnected nodes, hence shorter network lifetime. However, for packets generated by high QoS sensors, meeting QoS requirements weighs heavier than enhancing network lifetime, and from the previous assumption that the number of high QoS packets is much smaller than that of low QoS packets, this can be tolerated.

3.2.2 Low QoS Packets

In multipath routing, packets are sent along multipath in order to achieve load distribution, hence network lifetime enhancement. It is also known that multipath routing is more resilient to route failures. Numerous researches have been done on the design of multipath routing protocol [10], [11]. However, little work has been done on considering the dynamic state of the parent nodes when routing packets along multipath. Our algorithm considers two aspects, namely, differences in hop count to the base station and the energy state. In what follows, we present the path selection algorithm for low QoS packets and show how the hop count and energy state have been taken into consideration.

3.2.2.1 Path Selection In choosing the next parent node, all the *score* fields of parent candidates are summed up and we denoted this value as *totalScore*. Next, a random number between 0 and *totalScore* is generated, and the *score* of each parent candidates are subtracted from *totalScore* one at a time, until this value gets smaller than 0. The parent candidate, which makes the subtracted figure smaller than 0, is then chosen as the next node.

This random selection method is based on the idea that the *score* field is the likelihood of using that node as the next step. For example, if the *score* of a parent candidate is twice as big as another candidate, it will be chosen as the next node twice as often.

3.2.2.2 Hop count to the base station As discussed in section 3.1, after the spanning tree has been set up, each nodes compute their own *score* values by using the differences in hop count to the base station and a given parameter *usageDecreaseRatio*. *usageDecreaseRatio* is not a universal constant but an empirical value, and may require a tuning process to obtain the optimal value. For very densely populated sensor networks, this value may be large because there will be plenty of neighboring nodes with the same number of hop count to the base station. On the other hand, for sparsely populated networks, a smaller value will be more appropriate to distribute the packet flow.

3.2.2.3 Energy State In sensor networks, communicating with parent nodes prior to sending data packets to check the channel state imposes too much overhead. In our proposed routing protocol, every time a certain sensor node's energy level changes significantly, it broadcasts its own energy state in the form of {*Id, newEnergyState*}. *Id* is the unique identification number given to that specific node; *newEnergyState* is the field indicating that the energy state of the sender sensor has changed. Neighboring nodes, upon receiving this message, check their parent nodes list, and if there is a match, change the *score* value for that particular parent node by multiplying by *energyDecreaseRatio* and send fewer packets along that route as a result. *energyDecreaseRatio* is a given parameter similar to *usageDecreaseRatio* in a sense that they both determine the characteristics of routing algorithm, and are not universal.

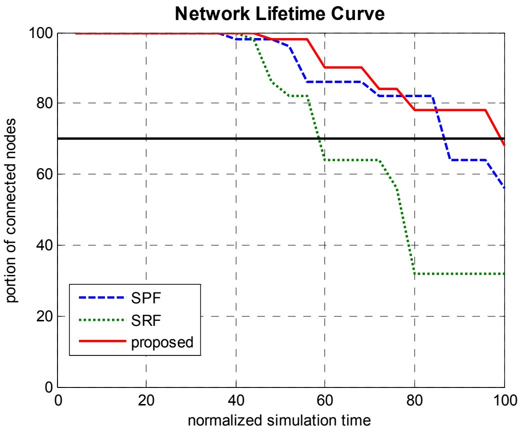
4. Simulation

4.1 Simulation Setup

The proposed algorithm was tested and verified using a MATLAB simulation. In the experiments, the sensor network consists of 5 high QoS and 45 low QoS sensors in a 100 x 100 meter square area. The transmission range is set to 25m. The base station is located at the midpoint of one side of the test field. The maximum number of parent nodes a node keeps is set to 3. A single high QoS sensor generates 3 times more packets as a single low QoS sensor. High QoS sensor nodes do not involving in forwarding packets from other nodes, but only generate data packets. Low QoS sensor nodes generate and forward at the same time.

For a qualitative performance evaluation, the proposed routing protocol is compared against existing routing protocols, namely, selective preferential forwarding (SPF) and selective random forwarding (SRF). As discussed in previous sections, SPF attempts to forward packets along a predetermined best path, and SRF uses different alternative routes randomly.

4.2 Simulation Results

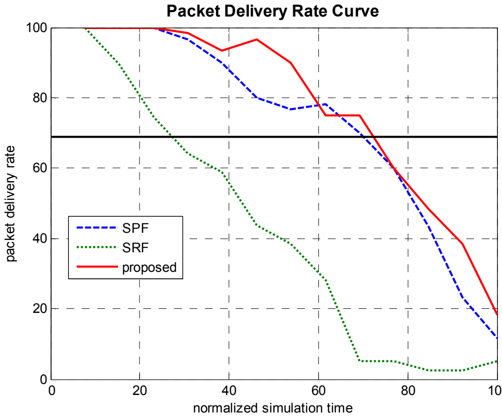


[Figure 1]

Figure 1 shows the network lifetime curve for densely populated and sparsely populated sensor networks respectively. This curve shows the average portion of sensor nodes still connected to the base station as the simulation time goes by. Notice that the network lifetime for SRF is far lower than SPF and our proposed algorithm. This is mainly due to the fact that SRF does not take the quality of the next hop into consideration. As a result, data packets tend to take longer to reach the base station than other 2 routing protocols, hence consuming more energy.

For convenience, we denote the time taken until only Ω portion of sensor nodes are still connected to the base station as Ω lifetime. For densely populated sensor networks, as in figure 3, repeated simulations show that the Ω lifetime when Ω = 70% is 100 for our proposed algorithm, and approximately 80 for

SPF, units in normalized simulation time. This is mainly due to the fact that when SPF is used as the routing protocol, all the packets are routed along the best paths, and the 'bottleneck nodes' tend to get deprived of energy much faster than other nodes. Consequently, these nodes get disconnected earlier than other nodes, and this may trigger a portion of the whole network to be disconnected, shortening the network lifetime.



[Figure 2]

Figure 2 shows the packet delivery rate curve, which shows the portion of total data packets successfully delivered to the base station as the simulation time goes by. This curve takes transmission error rate, portion of connected nodes, and routing efficiency into account, but does not depict the transmission delay of packets. Figure 2 shows that the packet delivery rate of our proposed protocol is on average higher than that of SPF or SRF. This is due to the fact that thanks to the extended life time, more sensor nodes are able to send packets to the base station.

5. Conclusion

In this paper, a routing protocol for wireless sensor networks, which focuses on satisfying QoS constraints while maximizing the lifetime of the networks is proposed.

Our proposed protocol combines two existing well-known routing methodologies, namely, selective preferential forwarding and selective random forwarding, in a dynamic and decentralized manner. Our protocol uses a simple scoring system on deciding the next hop, taking the dynamic nature of sensor nodes into account. Due to its simplicity and conciseness, it can easily be implemented on sensor nodes with very limited computational abilities.

The performance of our proposed protocol is validated by simulation. Simulation shows that the network lifetime is up to 20% superior to simple selective preferential forwarding, without compromising the latency and throughput.

Our future works include considering multiple base stations and multiple QoS requirements. We will also investigate how to consider the portion of high QoS data packets and low QoS data packets when choosing the next hop. Finally, following the current trend of using sleep-mode for energy conservation, we will extend our protocol to consider sleep cycle of neighboring nodes when forwarding data packets.

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