Poster Abstract: Revisiting the Lifetime of Wireless Sensor Networks

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ABSTRACT

Prolonging the lifetime of wireless sensor networks (WSN) is one of the most important goals in the sensor network research. A lot of work has been done to achieve this goal; however, current definition of lifetime is either superficial or impractical. In this paper, we take the first step to modeling the lifetime of a wireless sensor network by considering the relationship between the whole sensor network and individual sensors, as well as the importance of different sensors based on their positions. We envision that the proposed lifetime model can be used to evaluate energy-efficient protocols and algorithms, which is validated by simulation results.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design-Wireless Communication

General Terms

Theory, Performance, Management

Keywords

Lifetime, Wireless Sensor Networks

1. PROBLEM STATEMENT

The physical constraints of the battery-backed sensors and the prohibitive costs to replace failure sensors in large-scale sensor networks make energy a crucial consideration to prolong the lifetime of sensor networks. Many efforts have been made to achieve this goal by using energy efficient protocols; however, none of them has a detailed analysis of the lifetime of sensor networks, which prevents us from thoroughly understanding the efficiency of these proposed protocols.

Currently, the lifetime of a sensor network is defined as the time for the first node as in [1, 2, 3] or a certain percentage of network nodes as in [6] to run out of power. However, these definitions are not satisfactory. The former is too pessimistic since when one node fails the rest nodes still can provide appropriate functionality. While the latter does not consider the difference of the importance of sensors in the sensor network. We argue that lifetime is an application-specific concept. To this end, we propose a novel lifetime definition by considering the relationship between the lifetime of a single sensor and that of the whole sensor network, the importance of sensors at different positions, and the connectivity of the sensor network.

2. LIFETIME OF SENSOR NETWORKS

The lifetime of a wireless sensor network (denoted as LSN) is an application-specific, flexible concept. However, we can abstract and define a remaining lifetime of a wireless sensor network (denoted as RLSN) first, which is defined as the weighted sum of the lifetime of individual sensors (denoted as RLIS) of all the sensors in the sensor network. Given that, we can define the LSN for three major application categories: *active query, event-driven,* and *passive monitoring*.

In an active query like applications, the LSN can be defined as the maximum number of queries the sensor network can handle before the sensor network terminates. For an event-driven application, the LSN can be defined as total number of events the sensor network can process before the termination of it. For passive monitoring, the LSN can be defined as the total amount of time before the sensor network terminates. The termination of the sensor network is defined as the time when the RLSN starts to keep stable that implies that the sensor network loses connectivity or the number of sensors with zero RLIS exceeds a threshold which means that the sensor network becomes useless.[1] Next, we in turn describe several key concepts in our proposal.

Remaining Lifetime of Individual Sensor is defined as the remaining normalized energy of the sensor at some moment, N_m. Here the initial sensor energy is normalized as 1. The energy is consumed when the sensor receives or sends messages, so RLIS of the sensor is the total initial energy of each sensor minus the consumed energy. So, we have

$$L(j) = 1 - \sum_{i=1}^{N_m} \frac{\epsilon_{jiq} * N_{jiq} + \epsilon_{jir} * N_{jir}}{E_j} \tag{1}$$

where N_m is the sequence number of queries processed in active query, the sequence number of events handled in event-driven and the amount of time used in passive monitoring; $L(j)$ is RLIS; and E_j is the initial energy of sensor j.

We borrow the same energy model and symbols (ϵ_{jiq} and ϵ_{jir}) used in [2] to calculate the energy consumption of each message transmission. To calculate $L(j)$, we should also calculate N_{jiq} and N_{jir}, the number of going through messages, which is related to the probability, P_{ji}, of the message go through the jth sensor in the ith query. Observed from the sensor network that the sensors near the sink have more chance to consume energy than the far away ones, we define the probability as

$$P_{ji} = \frac{1}{\pi(2\lfloor \frac{d_{jis}}{r} \rfloor + 1)r^2\rho} \frac{N_n - \pi {d_{jis}}^2 \rho}{N_n} \tag{2}$$

where N_n is the number of total sensors and d_{jis} is the distance from the jth sensor to the sink. r is communication range and ρ is the density of the sensors. The deduction of formulas in this poster are available in the technical report of this paper [5]

Importance of Sensors (IMP). We observe that the failure[2] of sen-

[1] Here, we assume the energy consumption of regular maintenance overhead is negligible, and will be considered later.

[2] Currently, we consider only the failure resulted from the deplete of energy.

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sors will cause the sensor network to act improperly, but the level of the damage it causes is different. For the same number of failure sensors, the damage may be very slight when the sensors are far from the sink and be very serious when the sensors are located near to the sink. So we define IMP as

$$w_j = c\frac{1}{{d_{jis}}^2} \quad (3)$$

Here c is a constant and w_j denotes for IMP.
The remaining lifetime of the whole sensor network ($\mathcal{L}$) is defined as the weighted sum of the RLIS of all sensors.

$$\mathcal{L} = \sum_{j=1}^{N_n} w_j L(j) \quad (4)$$

Based on the RLSN,*the lifetime of wireless sensor networks* can thus be deduced as

LSN = { $N_m \mid \mathcal{L}(N_m - 1) < \mathcal{L}(N_m)$ & $\mathcal{L}(N_m + 1) = \mathcal{L}(N_m)$ or $N_{fail} \geq \theta$ } (5)

where θ is a pre-defined threshold of maximum number of the failure sensors in the sensor network and N_{fail} is the number of the failure sensors. And $\mathcal{L}(N_m)$ is RLSN at moment N_m.

3. AN EXAMPLE OF USING THE MODEL

In this section we will use our model to compare two types of query protocols, direct query (`denoted as Traditional`) and indirect query (`denoted as IQ`), which is proposed by in [4]. In `Traditional`, queries are routed from the data sink to its destination (one or more sensors) using an energy efficient path or an alternative path based on other performance metrics. While in `IQ`, the data sink randomly selects a sensor as the query delegate and forwards the query to the delegate. Then the delegate conducts the query processing on behalf of the data sink and sends aggregated replies back to the data sink.

Variables	Location	`Traditional`	`IQ`
RLIS	$0 < d < r$	$1 - \frac{8280N_m}{10^6}$	$1 - \frac{2149N_m}{10^6}$
RLIS	$d = 7r$	$1 - \frac{2000N_m}{10^6}$	$1 - \frac{2149N_m}{10^6}$
RLIS	$d = 14r$	$1 - \frac{1670N_m}{10^6}$	$1 - \frac{2149N_m}{10^6}$
RLSN	—	$\frac{21733-69N_m}{10^6}$	$\frac{21733-46N_m}{10^6}$

Table 1: Comparison of Traditional and IQ.

According to the defined model, we deduce the lifetime formula for both query protocols. After we assign practical values of sensor parameters obtained from Berkeley motes to the formula, we get the deduced results listed in Table 1. The deduction procedure is available in the technical report version [5]. Table 1 denotes the RLSN and RLIS of different sensors using two query protocols. In the table, we can find that the sensor network using the `IQ` protocol has larger RLSN than that of using `Traditional` as shown in last row by providing a global optimization to balance the load to the whole sensor network as shown in the first three rows, where the sensors at different location have different RLIS in `Traditional` and have same RLIS in `IQ`. Thus LSN of `IQ` is longer than that of `Traditional`.

3.1 Validation

To validate the correctness of our model, we conduct a comprehensive simulation using the Capricorn, a large-scale discrete-event wireless sensor network simulator developed at Wayne State University. The comparison of RLSN and LSN are demonstrated at Figure 1 and 2 separately. In Figure 1 x-axis is the number of queries and y-axis is the value of RLSN and in Figure 2 x-axis represents the initial energy of sensors while y-axis denotes the value of LSN. The result shows that LSN increase with the increasing of initial energy in both cases, but that of using `IQ` increases as several times fast as that of using `Traditional`. RLSN drops with more queries been processed while that of using `Traditional` drops much faster. The RLSN keeps unchanged after 300 queries are processed in `Traditional`, which denotes that the sensor network loses connectivity. The simulation result matches what we get from the model.

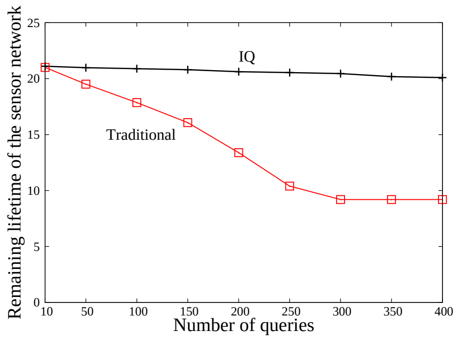

Figure 1: Comparison of RLSN.

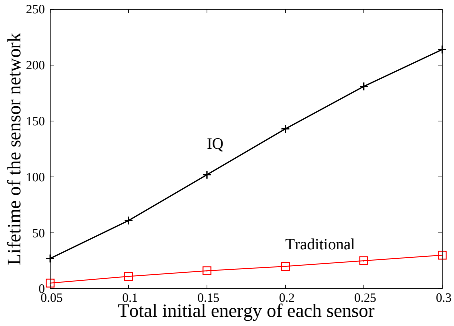

Figure 2: Comparison of LSN.

4. FUTURE WORK

Given the proposed lifetime model, we plan to extend our work in two-fold. On one hand, we will extend the model by considering the link quality, MAC protocols, topology control, and network coverage. On the other hand, we will use this model to guide the development of more energy-efficient protocols and evaluate the efficiency of existing protocols.

5. REFERENCES

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