Lifetime in Wireless Sensor Networks

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Abstract

The following paper deals with criterion used to measure communication protocol efficiency in Wireless Sensor Networks. As energy is a crucial characteristic of those networks, it is necessary to pay attention both to the energy consumption and to the distribution of energy consumption, when using communication protocols, so as to increase the lifetime of the whole network. Our aim is to present and discuss criterion designed to analyze communication protocol effectiveness. When designing, for example, communication protocols, it is really important to measure performances with a suitable metric according to our application, else it would be difficult to analyze and to improve a protocol. In this paper, we draw a list of existing criterion, and then introduce two new ones : Average Node Percentage and Monitored Interest Point Percentage. We also point out the relevance regarding the required application for each criterion.

Keywords : *Wireless Sensor Networks, Lifetime, Energy, Failure, Time To First Fail, Operative Node Percentage, Monitored Interest Point Percentage.*

1. Introduction

As a consequence of recent advancements in Micro-Electro-Mechanical Systems and wireless communications, a new kind of network has come to the fore: *Wireless Sensor Networks* (WSN). In those networks, nodes can gather information from their environment, such as temperature, gas leak, etc. They can also communicate, thanks to their wireless communication device, with other nodes (their neighbors) in their transmission range. WSN are also composed of at least one special node, called the base-station, or sink, the purpose of which is either to centralize collected data from the WSN, send queries in the network, or connect the WSN to other networks. WSN recently attracted a lot of attention because of their range of applications. They can be used in a many different fields, monitoring tasks either for the military, or the environment, security, health-care, and habitat automation [1].

Considering all the characteristics of wireless sensors is important when designing new communication protocols. Each node is equipped with sensing, computing, and communication modules; as sensors are autonomous, they have to be equipped with batteries. Wireless Sensor Networks can be deployed in many kinds of environments and without infrastructures. So almost proposed algorithms need to be localized algorithms, i.e. nodes have to take decisions according to their local knowledge.

WSN are also extremely energy constrained: sensors are small and use tiny batteries to provide energy. Communication in WSN is generally considered much more energy consuming than computing or sensing [8]; hence a major concern is to minimize the energy consumption due to communication, while achieving

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the desired network tasks. Therefore it is necessary to design efficient communication protocols in order to provide the best network lifetime.

However lifetime in WSN is still not very well defined; *what does lifetime in WSN mean?*

Choosing a good lifetime criterion is very important when designing new protocols. With a good lifetime metric, you are sure to analyze exactly what you need, and so you can really optimize your protocol. There is no definition of lifetime suitable to all kind of applications in Wireless Sensor Networks. The choice of one or another criterion depends clearly on your application requirements.

We can find in the literature various possible criterion to analyze communication protocols designed for WSN. After a brief presentation of ways to save energy in Section II, Section III is devoted to existing criterion; the Energy-Efficiency criterion which is often used to measure performances of communication protocols in WSN and the Time To First Fail criterion, that is to say the more suitable and much commonly-used definition of lifetime in WSN found in the literature. Section IV is dedicated to new criterion First, an extension of the TTFF criterion, the Operative Node Percentage. This criterion does not focus on first failure only, but also on average Operative Node Percentage regarding to time. And second, the Monitored Interest Point Percentage criterion, which is suitable for studying communication protocols in monitoring applications. Section V ends the paper.

2. Energy Savings

Before studying existing and new criterion defining lifetime in WSN, let us first of all see how energy is consumed in WSN and thus potentially saved. Various ways to save energy on nodes exist, often depending on their capabilities and required application.

We only list here several ways to save energy according to communication in this section, but it is also possible to reduce energy consumption while computing, sensing or moving. We can find many ways to decrease energy consumption when sensors are communicating:

- sometimes sensors can adjust their transmission power in order to save energy. If the distance between the sender and the receiver is less than the maximum transmission range, the sender node reduce its energy consumption. In the most commonly-used energy consumption model [11], the energy consumption function J as a function of transmission range r, is defined as follows: $J(r) = r^{\alpha} + c$.
- when no adjustments of transmission range is possible, the easiest way to reduce energy consumption when communicating is to reduce the number of hops to route a message towards destination, or to reduce the percentage of sending nodes when broadcasting.
- some kind of sensors can switch off their radio so as to reduce energy consumption. It is possible to schedule nodes to go to sleep, so that other nodes remain active for the sensing and communicating tasks [3]. This kind of method will lead to save energy on nodes, implying a better network lifetime.
- with required hardware, directional emissions can also be considered, that is to say nodes can choose their angle of emission. This can directly lead to consume less energy, and also to avoid some collisions when communicating.

Previous list is not exhaustive. Indeed we can find many other energy consumption models, like considering energy consumption of the receiving task, or energy consumption according to the size of sent messages.

3. Existing Criterion

This section is dedicated to the description of the most used criterion proposed to analyze performances of communication protocols found in the literature.

3.1. Energy-Efficiency (EE)

Energy-efficiency is the most used criterion to analyze communication algorithms, and many energy-efficient algorithms have been suggested recently [5, 7]. In this category, the approach is to minimize the total-consumed energy in order to achieve communication tasks. For a given task, you have to compute the energy consumption when randomly-selected nodes detect an event and try to send a message to the base-station.

This criterion is not a lifetime criterion. It only increases network lifetime indirectly: this way is not suitable to perform communication protocol measurements. For a given energy-efficient routing protocol, the path used to route a message from a node to the base-station is always the same whatever the remaining energy on nodes is. Obviously, if the same nodes are always selected to route messages their batteries will then be quickly depleted, and this will lead to reduce network lifetime.

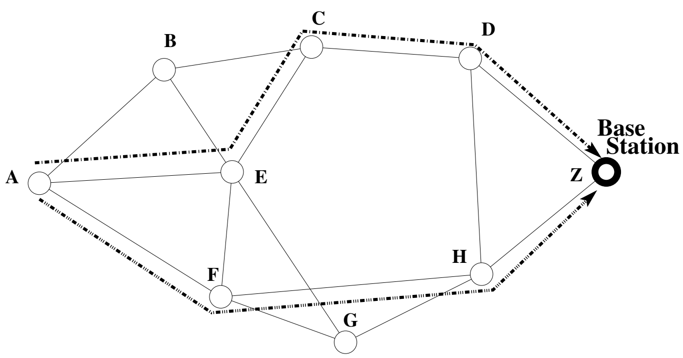

Figure 1. A Wireless Sensor Network with 8 nodes and a base station, and two different paths between node A and Base Station: $\{$A, F, H, Z$\}$ and $\{$A, E, C, D, Z$\}$.

Figure 1 represents a Wireless Sensor Network with 8 nodes and a base station. When a node detects an event, we want the bas e station to get this information. For example, when node A detects an event, the path used to route the message towards destination is always $\{A, F, H, Z\}$. This kind of algorithm, selecting always the same path, whatever the remaining energy on nodes is, will lead to deplete quickly nodes A, F and H battery.

Lets point out that a node without any energy can partition the network and then affect network connectivity; figure 2 illustrates this case. The similar problem takes place when the same nodes are always selected to broadcast messages.

Whatever the definition of network lifetime, an Energy-Efficient protocol only focus on the reduction of energy consumption for a given task.

3.2. Time To First Fail (TTFF)

The most known and most frequently used metric in the literature is the Time To First Fail (TTFF) [4, 10, 6]. This definition of lifetime was given by Chang and Tassiulas in [2].

Definition 1 Time To First Fail *is the lifetime criterion which measures the number (or the time) of communicating tasks achieved before any nodes in the network runs out of its battery energy.*

Contrary to Energy Efficiency criterion, it is not necessary to focus only on energy consumption when trying to propose an efficient algorithm regarding to TTFF metric.

The main idea to provide efficient communication protocols regarding the TTFF criterion generally consists in using energy-efficient algorithms while trying to balance energy consumption on nodes, in order to deplete nodes batteries less quickly.

Probabilistic algorithms can be used, such as Basic Probabilistic Routing BPR [12]; they balance energy consumption between nodes using alternate paths chosen thanks to probabilistic algorithms. On the other hand, thanks to an estimation of the remaining energy on nodes you can also choose to transmit messages towards a neighbor with a lot of energy, as in [9]. These kind of methods will delay the first death of a node.

On figure 1, when node A detects an event, a communication protocol should try to alternate paths used to route messages towards Base Station to provide a good communication algorithm regarding to TTFF criterion. For example, using paths $\{A, F, H, Z\}$ and $\{A, E, C, D, Z\}$. This will distribute energy consumption along both paths, leading to a better network lifetime.

It is important to note, that some nodes are "more important" than other nodes. For example on figure 2, if node C runs out of its battery energy, this will lead to partition the network, avoiding nodes A, B and D to communicate with the Base Station even if they still have energy. On the other hand, node K failure will not prevent other nodes work properly. So, first failure does not always imply network partitioning. When our application needs that all sensors have to be alive, this criterion is suitable, else we should use next definition of lifetime.

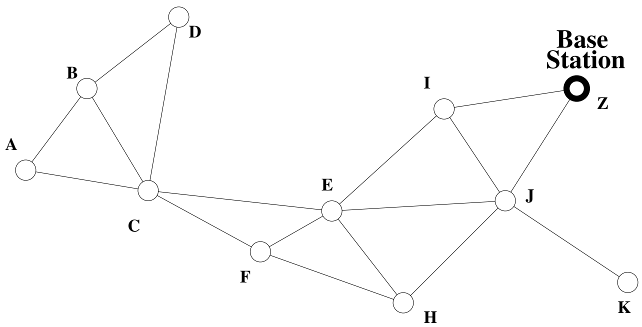

Figure 2. Another WSN with 10 sensors and a base station. Node C failure will partition the network; node K failure will not. Node K seems to be less important.

Remark: An efficient algorithm regarding to TTFF criterion should obviously be also efficient regarding to EE criterion.

Other criterion can be found in the literature but they seems to be less used. For example, the time till the last sensor dies is another definition. A better definition regarding to WSN requirements, based on the percentage of alive sensors in the network have been proposed but does not seem to be used in many papers [6]. Authors proposed to choose a threshold, defining the needed percentage of sensors required to consider the network alive.

4. New Criterion

The most known and used criterion to analyze performances of communication protocols have been presented in previous section, so let's see how we can improve these criterion to give a better network lifetime definition regarding to our application.

4.1. Operative Nodes Percentage (ONP)

Unless if the failure of only one node is a disastrous state regarding our application requirements, TTFF criterion seems to be insufficient.

Definition 2 *An* **inoperative node** *is defined as a node which either does not have enough battery to work properly, or cannot communicate with the base-station. Conversely, an* **operative node** *works properly and can communicate with the base station.*

Definition 3 *We define the* **Operative Node Percentage** *criterion (ONP) as being the percentage of operative nodes as time goes by.*

Regarding to required application the study of the average percentage of the remaining operative (or inoperative) nodes (ONP) seems more suitable. If one sensor or more become inoperative, this may lead to partitioning the network. Thus, even if a sensor is alive, it shall be considered as useless if it cannot communicate with the base-station. If the same protocol keeps on working after first failure, different strategies to balance the remaining energy on nodes, as well as approaches to increase network lifetime, may imply different results.

For example on figure 2, if node C runs out of its battery energy, we have to consider nodes A,B and D has being inoperative nodes, even if they still have energy. They can not communicate with base station because the network is partitioned, so if an event occurs near them, they will not be able to warn the Base Station. That's why we do not count the average number of alive nodes as in [6], but the average number of *operative nodes!*

Thanks to ONP, it is possible to assess WSN lifetime from TTFF until there is nearly no more operative nodes. This definition of lifetime may be more suitable than TTFF to measure performances of communications protocols because the failure of only one node is generally not critical.

4.2. Monitored Interest Points Percentage (MIPP)

Wireless Sensor Networks are mostly used to monitor interest points or areas; for example so as to send an alarm when an event occurs near a sensor. Figure 3 illustrates this.

With ONP criterion we have proposed to measure the average percentage of operative nodes as time goes by. It is not always useful to consider all the nodes of our network: some nodes are only used to relay messages. The only thing we want to measure when we are monitoring interest points or areas, is how many time can we receive information about interest points.

So we propose to extend the previous criterion (ONP), to bring about a good way to analyze monitoring protocols. Let's consider a set of interest points (or area).

Definition 4 *A* **monitored interest point** *is a point which belongs to the perception range of at least one node (the perception range for a given sensor being the range in which this sensor can detect events), provided that the node can successfully communicate with the base-station.*

Definition 5 *We define* **Monitored Interests Points Percentage** *(MIPP) lifetime criterion as the time during which either the percentage or the totality of interest points are still monitored.*

Figure 3 illustrates a WSN with interest points. If all nodes are alive, the totality of the interest points are monitored. But if there is a failure on some nodes, this may imply less monitored interest points. If node H have no more energy, only one interest point is not monitored now. But if node I is dead too, the whole five interest points of the bottom are not monitored. MIPP criterion allows us to measure accurately how many time we can monitor a percentage of a given set of interest points.

When working on monitoring applications, we believe that it would be a good idea to analyze performances of a given routing protocol associated with a deployment algorithm.

5. Conclusion

Energy is the most crucial resource in WSN, and lots of communication protocols have been developed to save in many different ways energy expenditure. In this paper, our goal was to define what lifetime in WSN is, in order to analyze communication protocol performances. In the literature, the Energy-Efficiency criterion is often used to measure the performances of protocols; but nevertheless it seems all the more insufficient since it indirectly increases WSN lifetime. We presented various criterion of analyzing communication protocol performances as regards network lifetime. We first remind the definition of TTFF criterion, and then propose two new ways to analyze communication protocol performances: ONP and MIPP criterion. Regarding to requiered application, each criterion can be interesting, but for example, when when designing communication protocols for monitoring applications, the most suitable criterion is probably MIPP.

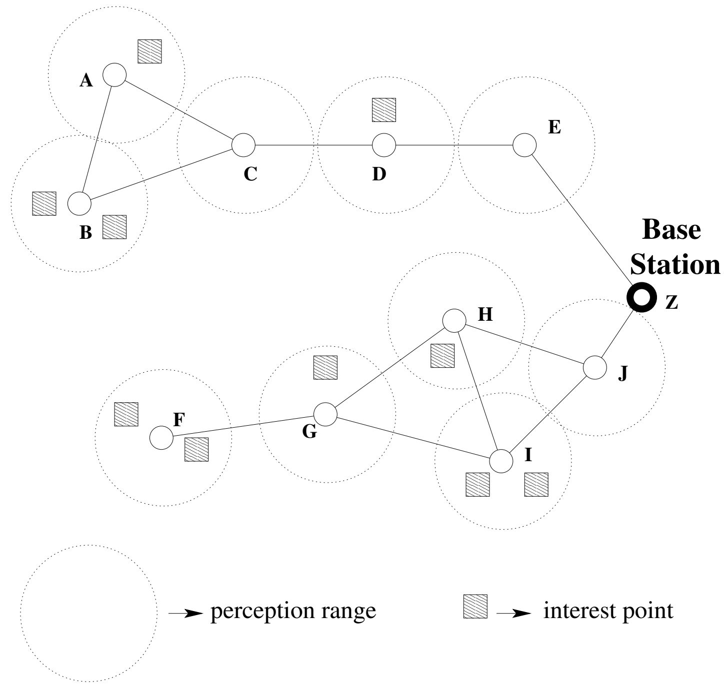

Figure 3. A WSN with 10 nodes and 10 interest points to monitor. For example, if node C or node G runs out of their battery energy, 3 interest points will not be monitored.

We can have several ideas that may lead to design new efficient communication protocols on the lifetime issue: new ways to balance energy consumption on nodes, taking *geographic positions of inoperative nodes* into account, or determining *key nodes* whose failure will lead to partition the network and thus affect network connectivity.

Those previously presented criterion are made to measure performances of communication protocols for WSN but they can obviously be applied to all ad-hoc networks with energy constraints. It should be interesting to assess the most common communication protocols with those criterion, to analyze their performances as time elapses.

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