

Routing Algorithms for Wireless Sensor Networks in Smart Cities

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Abstract

Wireless Sensor Networks (WSNs) are one of the most important parts of the advancements in smart city planning. The sensors provide valuable data about various metrics, such as air quality and traffic status. These measurements must be collected at a centralized data center to evaluate and create analysis results. Sending these messages is the responsibility of the network. Nodes inside a network are usually resource constrained. When the energy grid is not available, a portable energy source is required. To avoid long distance communication requiring high energy, multi-hop communication is recommended inside networks. The routing of the messages must consider the energy use of a node, of the whole network and the probability of the message received by the central base station. This paper focuses on such algorithms, focusing on the typical grid layout of a smart city.

Keywords: *communication, IoT, routing, smart city, WSN*

1 Introduction

Advancements in information technology made it possible to create detailed analysis of different processes in several key areas, such as industrial manufacturing processes, environmental observations and traffic control. This requires large amount of data, which is processed by different Big Data frameworks. This data is measured by different sensors placed at strategical locations and collected at a base station over some form of wired or wireless network, creating a wireless sensor network.

The surge of IoT and low-cost sensor devices drove the installation price of such a network lower. These networks are self-configured and dynamic, making them easy to set up and robust against sensor failures. The network consists of multiple nodes, each node containing one or multiple different types of sensors, and a communication device to send and receive messages from the network. A network typically consists of between 5 and 5000 nodes based on the number of needed measurements and the coverage area of the sensors.

To keep the costs down, each node is usually resource-constrained with limited computational power, and in some cases, limited energy source. Because of this, multi-hop communication is usually preferred, where transmission occurs through multiple intermediary nodes. When the power source is limited (for example, running on a battery), the goal is to keep the nodes working for as long as possible without needing to recharge them.

2 Related Work

In the literature, several different algorithms have been proposed to handle multi-hop routing in wireless sensor networks. LEACH [1] periodically assigns nodes to be cluster heads randomly whose responsibility are collecting the messages from the sensors close to them. After receiving the messages, the cluster heads combine these into a single packet, and apply a compression algorithm before sending it to the base station. The compression and two-hop communication reduce the energy needed for the communication. The cluster head approach is advantageous when the base station is placed somewhere near the wireless sensor network.

PEGASIS [2] creates a chain between the nodes close to each other. At every round, the measured values are aggregated and sent towards one particular node through the chain, which in turn transmits to the base station. This

transmitting node is changed after every message sent. PEGASIS is mainly used when only aggregated data is needed at the base stations (such as minimum, maximum and average value), and the base station is placed farther away. In this algorithm, the nodes themselves handle the aggregation process, and only one node communicates with the base station at a time, reducing the energy needed for the long-distance communication. However, this algorithm is highly inefficient if the base station must receive every measured value.

E2MR2[3] is an advanced routing algorithm designed specifically for sensor networks in smart city configurations. The algorithm uses a model based on link loads to minimize the network's bit energy consumption parameter.

Most of the routing algorithms suppose a model where the transmission of a packet is only based on the length of the message and the distance of the communication. However, wireless communication is usually lossy, and so the packet can be lost. Our goal is to provide a model where a quality-of-service criteria can be met providing a guaranteed probability of successful message transmission.

3 Model

To derive algorithms and conduct simulations, we first defined the following: our network consists of a base station and N stationary nodes, each of which might want to send a message to the base station. Nodes can be placed randomly or according to some pre-defined topology without any kind of obstruction, so every node can send and receive message from every other node. A randomly generated network can be seen on Fig. 1. We also assume that the nodes are energy limited, and each node starts with an initial energy E.

We assume that for a given transmission, the sending node can choose how much energy it plans to use, which determines the probability of a successful transfer according to the Rayleigh fading model, which will be explained later. Our Quality-of-Service criterion is that the base station must receive the message sent by the node with a given probability, denoted by the P_s probability value. The model runs as long as this criterion can be accomplished, meaning that there is enough energy left in the nodes to complete the transmission with the given probability.

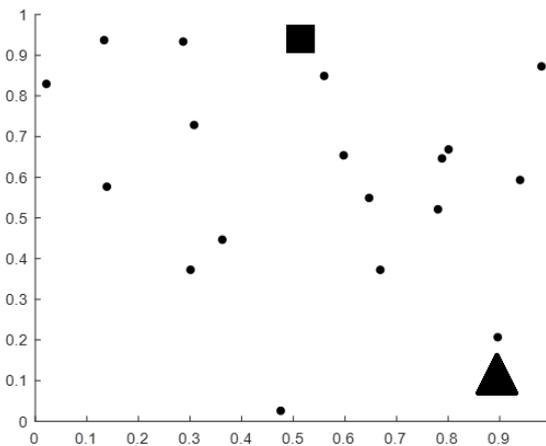


Fig. 1 An example of a randomly generated wireless sensor network. The square represents the base station, while the triangle shows the next node sending a message.

To calculate the probability of successful transmission, we based our equation on the Rayleigh fading, which is a statistical model for the effect of a propagation environment on a radio signal.

$$g_{ij} = -d_{ij}^{\alpha} \frac{\theta \sigma_z^2}{\ln P_{ij}} \quad (1)$$

As can be seen, the energy needed for a given transmission (g_{ij}) is a function over the distance between the nodes (d_{ij}), environmental and transmission factors (θ, σ_z, α), and the probability of the successful transfer (P_{ij}). Since the nodes are stationary, we can simplify this equation to the following formula:

$$g_{ij} \ln P_{ij} = \omega_{ij}, \quad (2)$$

where ω_{ij} is a constant value between two nodes in the network.

4 Energy aware routing algorithm

After defining our model, we started developing algorithms to route messages between nodes in a multi-hop scenario. For this, we needed to decide which property of the network should be optimized. Our first idea was to minimize the energy used during the multi-hop transmission while maintaining the quality-of-service criteria. This however resulted in a static routing algorithm, where the energy used during a transmission would not depend on the energy levels of the nodes.

To solve this, we have decided to incorporate the current energy level of the nodes. This is accomplished by maximizing the lowest node energy level after a transmission happens. This way, higher-energy nodes will be more likely chosen, and they will participate with more energy. We have proved that the lowest node energy level is maximized if and only if the energy levels of the nodes participating in the transmission reach an equilibrium.

Another property of our routing algorithm is the maximum number of hops allowed in a transmission. While higher number of hops will usually provide a higher common node energy level for any given transfer, it will also require more energy due to the number of nodes participating. We differentiate between different strategies by calling it k -hop routing, where k is the maximum number of hops allowed.

5 Topology based routing

In many situations the topology of the network has a special structure and this structure can be used to further optimize the routing algorithm.

A practical example for a given network structure is the ZalaZONE facility which is a large test field of sensor networks used to test autonomous and self-driving cars. The test field has a *smart city area* where the sensors are distributed in a grid, which is similar to larger city layouts as can be seen on Fig. 2.



Fig. 2 Comparison of the layout of ZalaZONE and New York

6 Results

To test our algorithm, we have implemented the model and algorithm in Matlab. For testing our proposed algorithms, we have devised different configurations and scenarios. In every simulation, we have chosen the environmental constants to be the same, so we can compare the results between different executions. We have placed the nodes based on the model of the ZalaZONE Smart City Area. We have also chosen the ω_{ij} values so that sending a message diagonally can only be done with significantly higher energy usage. With this setup, we have run 100 different simulations, and calculated the average number of messages successfully sent on the network.

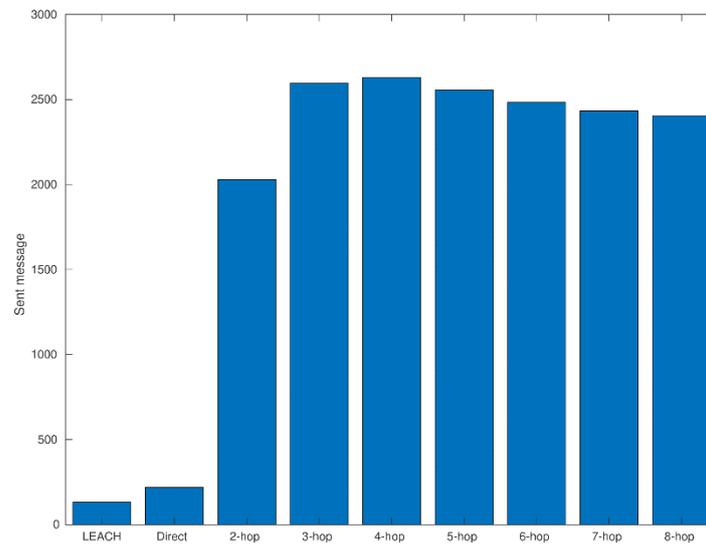


Fig. 3 Results of different k -hop algorithms and LEACH

As can be seen on Fig. 3, the k -hop algorithms outperformed both Direct sending and LEACH algorithms. Unfortunately, while the LEACH algorithm was implemented to also prefer the main axes, where transmission is easier, the random cluster head selection results in situations where not every column or row is covered. Due to this, sending messages to cluster heads, and transmission between cluster heads and base station will require higher energy use. Meanwhile, our k -hop routing algorithms can always choose an optimal path for message transmission. It can also be seen that in the case of the ZalaZONE layout with the given parameters, 4-hop routing seems to be the optimal strategy.

7 Conclusion

In this paper we have looked at different routing algorithms for energy aware IoT data communication in smart city layouts. As can be seen, most algorithms ignore the lossy nature of wireless transmission. Our proposed algorithm provides a quality-of-service criteria for successful message transmission. We have also seen that the k -hop algorithm could be applicable for wireless sensor networks in smart city layouts.

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