On the Impact of Network Topology on Wireless Sensor Networks Performances - Illustration with Geographic Routing

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Illustration with Geographic Routing

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ABSTRACT

Wireless Sensor Networks (WSN) are composed of constrained devices and deployed in unattended and hostile environments. Most papers presenting solutions for WSN evaluate their work over random topologies to highlight some of their "good" performances. They rarely study these behaviors over more than one topology. Yet, the topology used can greatly impact the routing performances. This is what we demonstrate in this paper. We present a study of the impact of network topology on algorithms performance in Wireless Sensor Networks and illustrate it with geographic routing. Geographic routing is a family of routing algorithms using nodes coordinates to route data packet from source to destination. We measure the impact of different network topologies from realistic ones to regular and unrealistic ones through extensive simulations. Studied algorithms are common geographic greedy algorithms with different heuristics from the literature. We show that different topologies can lead to a difference of up to 25% on delivery ratio and average route length and more than 100% on overall cost of transmissions.

Categories and Subject Descriptors

C.2.1 [**Network Architecture and Design**]: Distributed networks, Network topology, Wireless communication; C.2.2 [**Network Protocols**]: Routing Protocols

Keywords

Wireless Sensor Networks; Internet of Things; Smart Cities; Geographic Routing; Network Topologies

1. INTRODUCTION

Wireless sensor networks consist of sets of mobile wireless nodes without the support of any fixed infrastructure.

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Such wireless sensor networks offer great application perspectives. Sensors are tiny devices with hardware constraints (low memory storage, low computational resources) that rely on battery. Sensor networks thus require energy-efficient algorithms to make them work properly in a way that suits their hardware features and application requirements.

Low power sensor nodes have limited transmission power, thus they can communicate only to a limited number of nodes. This set of nodes is called the neighborhood of the node. In order to send messages at longer range, nodes are using multi-hop communication. Multi-hop communication means that data will need to be routed from source to destination by other nodes. An efficient way to route messages is to use nodes position information. A node uses an heuristic based on its own position, its neighbors positions and the destination position in order to choose the next hop for the route. Since nodes uses an heuristic based on nodes position it is legitimate to question on how nodes position will interfere on geographic routing protocols performances and behavior.

Many routing algorithms are evaluated only a random topology. Sometimes only one random topology is used meaning that results are dependent to this particular topology. For some other routing algorithms performances are evaluated using several random topologies, but even with more topologies studied, properties of topologies remain similar and results are then still dependent on those properties.

This is why we wanted to evaluate the impact of network topology on geographic routing protocols in wireless sensor networks. Knowing if topology has an impact on algorithms performances and how it impacts these performances would be helpful for geographic routing algorithms design. In this article we study different position based routing algorithms in combination with different network topologies. We outline that network topology have an impact on performance of geographic routing algorithms and show that they should be studied using topologies relevant to the target application topology or on several different topologies if not applicable.

The rest of the paper is organized as follows: Section 2 present relative work concerning topology impact on networks and WSN. The motivation to do this work is develop in Section 3. The studied algorithms and topologies are described in Section 4. Section 5 describe how we conducted simulations. Results are given in Section 5 then discussion is made in Section 6. We finally conclude in Section 7.

2. RELATED WORK

Lots of research and performance studies have been made on protocol evaluations or energy consumption analysis. However there has been little research on network topology impact on WSN protocol performances. Most of the research on the topic focuses on how to efficiently place nodes on a field to achieve the best performances for a given algorithm.

In [1], Dhillon and Chakrabarty focus on effective nodes placement for maximizing coverage and surveillance while Dasgupta et al. [2] propose a solution to place nodes to maximize the network lifetime. Some works study algorithms to place and to move nodes in order to get field coverage and network connectivity like Wang et al. in [3] and [4].

Younis and Akkaya compiled research in this field in a survey covering different techniques of nodes placement for area covering, energy consumption optimization and network connectivity [5]. They covered static nodes placement and nodes relocation after initial placement. Differentiation between data nodes, relay nodes and multi purpose nodes is also addressed in this survey. They highlight that nodes position has an impact on network lifetime and fault-tolerance.

Another field of research study the impact of topology but does not deal with wireless sensor networks but on the Internet topology [6, 7].

Some simple nodes placement scenarios are explored in [8] to study sensors network lifetime theoretical bounds and how far data gathering techniques are from these bounds. In this study it is assumed that nodes have an initial amount of energy and this energy decreases when a node receive, send or sense. It is also assumed that the network lifetime ends when a given region of the field is not covered anymore.

Ishizuka and Aida study random node failure and battery exhaustion on stochastic topologies with different properties in [9]. They highlight the performances differences between different topologies although they are all random placement.

Finally, in [10], Vassiliou and Sergiou study the impact of different topologies on three congestion control algorithm. They showed disparity in performances regarding network topologies especially on packet delivery.

3. MOTIVATIONS

We have shown with the literature overview that the impact of the topology on wireless sensor networks is not a highly studied topic. A lot of proposals focus on improving a given aspect of some protocol or algorithm. Only a few of them consider the network topology as an important aspect of designing algorithms for wireless sensor networks.

In this paper we first claim that network topologies can be of really different kinds. Even if they have similar properties (number of nodes, area, degree ...), those topologies have different behaviors. We show that those topologies impact differently Wireless Sensor Networks algorithm performances in particular with geographic routing algorithms. Especially data delivery, route length and energy spent have different behavior on those different topologies. We want to show that algorithms for Wireless Sensor Networks have to be designed with the topology and the application in mind.

4. ALGORITHMS AND TOPOLOGIES

The studied algorithms are different variants of greedy geographic routing algorithms. The difference between variants is the heuristic used to go from one node to the next one. The variants of the algorithm we use are *Greedy* [11], *MFR* [12], *NFP* [13] and *Compass*. Fig. 1 summarizes how the different algorithms choose the next hop within their neighborhood.

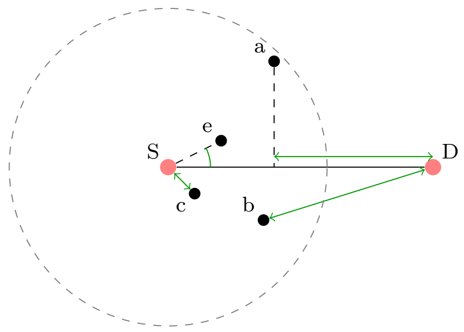

Figure 1: Comparison of geographic algorithms. Node a is chosen by *MFR*, node b by *Greedy*, node c by *NFP* and node e by *Compass*

The simulations are performed on five different topologies. They are chosen to be different each other and representative of either what can be found in articles where simulation are performed or real world situations.

The different topologies are : *random* (Fig. 2), *city* (Fig. 3) and its variant *small city*, *city grid* (Fig. 4) and *random hole*.

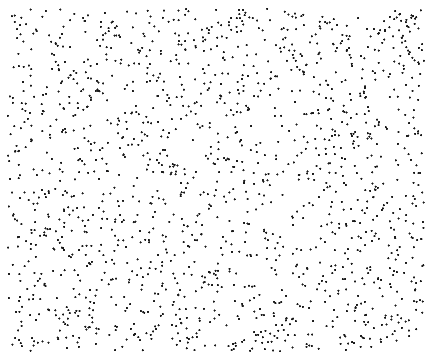

Figure 2: An example of random topology

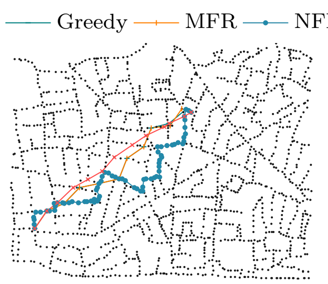

Figure 3: City topology with routes examples

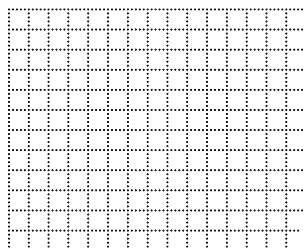

Figure 4: City grid topology

All these topologies have one connected component. It means that for any node in the network it is possible to reach any other node also in the network using a multihop route.

5. SIMULATIONS

The impact on topologies is measured using the WSNET simulator[1]. For each topology and algorithm combination, we measure the delivery ratio, the average route length and the overall energy cost. The delivery ratio is the amount of data messages received divided by the amount of data messages sent for the whole network. The route length is the number of steps a data message needs to go from the source to destination. The overall cost is the sum of the cost of all messages sent in the network. The cost of a transmission is defined as $r^\alpha + C$ where r is the set range in meter, α and C are constants and depends on the hardware and the propagation model as defined in [14]. To vary the nodes degree we vary their range from $25m$ to $50m$ by steps of $5m$.

To model a data traffic, every 15 ms a source and a destination are chosen randomly to route one data packet. The size of a data packet is arbitrary set to 10 bytes plus the header size of 88 bytes.

Each combination of topology and algorithm is run 50 times. Error bars on curves symbolize a 95% confidence interval. Table 1 summarizes the simulation parameters.

Parameter	Value
α	4
C	2^8
Duration (s)	60
Mac	idealmac
Interferences	none

Table 1: Simulation parameters

5.1 Delivery ratios

Fig. 5 and 6 compare delivery ratio over different topologies for all studied algorithms. Due to space limitation, delivery ratios for *MFR* and *Compass* are not shown but results are similar to *Greedy*. They show the delivery ratio according to the average nodes degree of the network. We see on these figures that for low degrees (15) the *city* topology and the *city grid* topology show a difference of 25% on delivery ratio performance with the NFP algorithm (Fig. 6).

Delivery ratio for the *city grid* topology is almost 100% regardless of the method. It is explained by the fact that there is almost no dead end in this topology. A node will almost always find a forwarding neighbor in the direction of the destination. The only counter example is on the edge of the network. On Fig. 4, if a source node at the end of a branch (after the last intersection) sends a message to a destination node on another end branch the message may be routed towards the end of the branch and fails at this point.

These figures also depict the fact that the denser the network is, the highest the delivery ratio is. We see that a denser network also mitigates differences between topologies while allowing increasing delivery ratio.

5.2 Average routes length

Fig. 7 and 8 depict the average route length of successfully routed packet. *Compass* and *MFR* are not shown but results are really close to *Greedy*. For *greedy*, *MFR* and *Compass* (Fig. 7), all topologies except *small city* get similar results. The *small city* topology gets lower route length because the network diameter is lower than other topologies.

[1]http://wsnet.gforge.inria.fr/

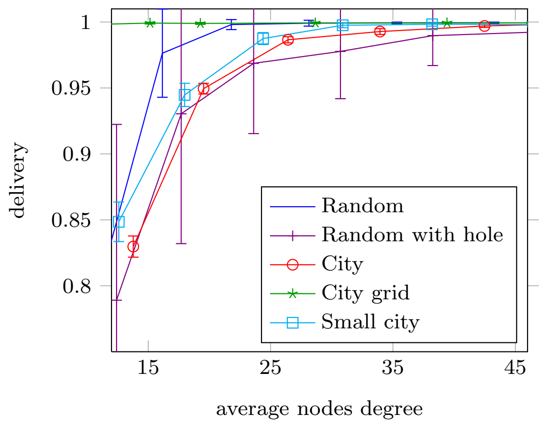

Figure 5: Delivery ratio for Greedy routing.

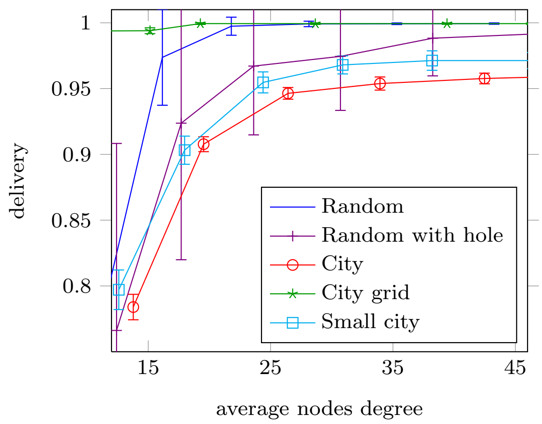

Figure 6: Delivery ratio for NFP.

The only routing method that shows significant differences is the *NFP* algorithm (see Fig 8). Excluding the *small city* topology (because of the lower network diameter), results show differences of up to 20% between the *random* topology and the *city* topology.

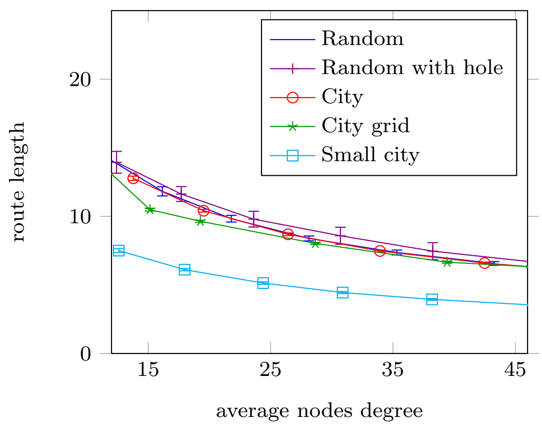

Figure 7: Average route length for Greedy routing.

5.3 Energy cost

Due to its lower diameter, for all studied algorithms there is a difference of 150% to 300% between *small city* and the closest topology concerning the global cost. The *NFP* rout-

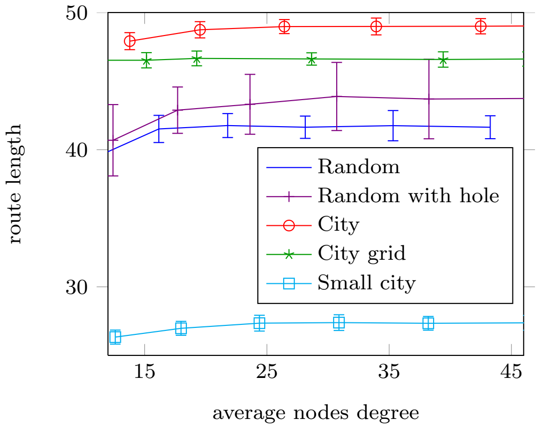

Figure 8: Average route length for NFP

ing algorithm shows important differences against different topologies concerning the overall cost that can go up to a factor of 10 between *small city* and *random*. For *NFP*, *city grid* topology shows a constant cost, this is because the chosen neighbor is the closest to the current node and in this topology, the closest neighbor is always at a constant distance. For *city* topology the closest neighbor is no more at a constant distance but the variation between two neighbors is lower than for *random* and *random hole* topologies. This is why *NFP* is less efficient on *city* than *city small* topologies but still performs better than on *random* and *random hole* topologies.

6. DISCUSSION

Regarding the results we analyzed in the previous section we can say that depending on the kind of topology we target and the properties we want (energy consumption, delivery ratio) the best algorithm is not always the same. If we consider that the delay is an important point for instance we will avoid the *NFP* algorithm as the route length is more than twice than other algorithms. In this context if we now want to optimize the energy consumption we will need to consider the topology as we may find that the best algorithm (excluding *NFP*) depends on topology. Indeed for a *city* topology, the best choice is *Greedy* but for the *city grid* topology *Compass* is the best.

When designing and testing their algorithms people often choose a random topology. This choice can be made for the convenience (it is easy to set in a simulator), because they do not suspect that there can be big differences with other topologies or because they do not target any specific application. It is important in the designing process to consider the targeted application in order to guide the design to the targeted performances on the targeted topology.

7. CONCLUSION

We have seen along this article that the impact of the topology should not be neglected. Indeed, we highlighted differences in performances of up to 25% concerning data delivery ratio and route length and differences up to 100% concerning overall cost of transmission. These results show the significance of network topology and highlight the fact that this aspect should not be under-evaluated.

This article shows that the chosen topology has a significant impact on algorithms performances in wireless sensor networks. Design of efficient algorithms in wireless sensor networks should always take the network topology and targeted into account.

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