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Geometric Model and Topology for Design and Deployment of Secure Communication System in Sensor Networks

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Abstract:
Geometric model helps us to acquire various practical features of wireless sensor nodes and is employed for performing the required calculations, computations and the simulations. The graph contains horizontal and vertical structures, a grid and makes us easy to plot a real world network on any surface where the nodes will be interconnected in any direction. The surface can be plane or rough. In the real world the surfaces will include any largest plane like a desert or a playground. Emerging developments in the field of Sensor Networks have made it possible to combine the sensing ability, wireless communicating interfaces & microprocessors into tiny devices that allow embedding computational power in random environments. The geometric model and sensor graphs help in creating an exact prototype of the system under development and to eliminate various possible shortcomings that may appear after the real world deployment. For a network deployed for secure communication in sensor networks, before deployment, it is very essential to have the maximum knowledge of topology engineering. The area upon which the deployment is required needs to be seen through the geometric perspective along with the network density. Denser sensor networks needs a more care in terms of connectivity, deployment and coverage.

Keywords: *Geometric Model, Sensor Graph, Topology, SNI, Connectivity, Density etc.*

1. Introduction

Designing a system with standard security and authenticated communication capabilities requires a set of selective tools and techniques designed and embedded in a systematic manner. The messaging packets arising from sensor nodes acquired over a period of time in any environment require a suitable preventive shield for safe arrival at the receiving end. A wireless sensor network contains a cluster of nodes placed at different distances having fixed or varying inter-node length. Having geometric model with a precise network type and topology will be really of a grand importance for design and deployment of sensor network for secure communication. The remarkable reduction in the size of electronic and its components has revolutionized the wireless communication to maximum possible limits. This resulted not only in the production of various other communication networks like wireless cellular networks which completely trust on a permanent and fixed kind of infrastructure but also resulted in the development of wireless sensor communications for hand held and portable computing devices. Various such interfaces including IEEE 802.11, ZigBee, and Bluetooth etc. also support ad-hoc networks in which various devices are capable to connect with each other without any supporting mechanism and infrastructure. However, there are many wireless sensor network designs that completely rely upon the support of base station (BS). To have a suitable network, we simultaneously require the better topology to arrange and rearrange the sensor nodes as per the project requirements. We have many kinds of such network topologies and each of them has a unique output. Depending upon the model requirements we will use the better topology services respectively. For the successful development of a secure network the geometric model, topology, SNI and other attributes are of a great importance. Connectivity of nodes is one of the most essential issues of these graph representations. For the wireless sensor network, it is preferable to have the sensor all nodes restricted in a single large connected network. There exists an inter-node path between every pair of sensor nodes which is useful for communication and administration purposes from server.

2. Geometric Model

We need to consider the geometric model for representation of the sensor network deployment topology in the plane as descriptive graph. Its vertices describe the sensor node search at its given separate location and there exists an edge between the two vertices for any respective communication between nodes through a wireless path. These links need to be symmetric and the range of communication must be equal for all sensor nodes. The deployment model can be random where all the sensor nodes are distributed randomly within a constrained area on any given surface. However, there is another form known as Uniform Random Distribution (URD). This uniform random distribution can be best used in real world deployments and also provides the best information regarding any large class real world networks deployed in any environment. Geometric model helps us to fetch the practical properties of sensor networks and also provides us a useful abstraction for performing various computations and simulations on every sensor network. Connectivity of nodes is one of the most essential issues of these graph representations. For the wireless sensor network, it is preferable to have the sensor all nodes restricted in a single large connected network. There exists an inter-node path between every pair of sensor nodes which is useful for communication and administration purposes from server, as shown in *figure 1*. The sensor network also contains some isolated or passive nodes which are of least importance as long as they are not in need. However, their presence is very important and is used against failed or damaged nodes in the network. They do not communicate with base station unless not being put into active mode in the network. There must be a maximum possible transmission range which can be demonstrated or derived here by a given density i.e. the number of nodes per unit area. If a transmission range is provided, then we can derive the required density. In this work we presume a realistic view of wireless sensor networks. Let's assume a large number of sensor nodes along with a possible failure rate in terms of damages and other factors. Doing this with a high degree of probability, we will find that with the passage of time the node failures will result in isolation of the other sensor nodes in a network. This can be avoided using extra number of sensor nodes in the network that are mostly kept on standby for further use, as and when required by the network. The necessary protocols that we introduce will function within a closed group network with all the network components inter connected properly.

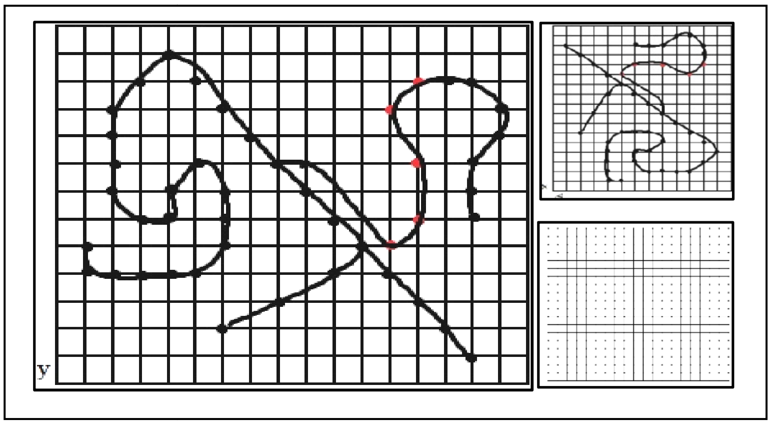

Figure 1: Geometric representation deployment at varying surfaces

3. Small Sensor Networks (SSN)

The random graphs that are not limited to any 2-D surface can be also used for designing relationships between various real world entities. We have low range social sensor networks that can be distinguished by a strong connectivity of neighboring nodes without having short paths between any pair of sensor nodes. The large clustering coefficient can be represented using a strong connectivity with neighborhood nodes and is defined as a probability of two connected sensor nodes having a common neighbor. There are various long range inter-node connections that do not have a common neighbor and are enough to guarantee the short-path inter-node lengths between any pair of sensor nodes. These inter-node short paths are mostly difficult to utilize efficiently because the long range connections are mostly unknown. The small sensor networks are not directly applicable for describing the network communication relationships in certain wireless sensor networks, but the neighborhood in such sensor networks is highly recommended and prescribed by the spatial closeness of the sensor nodes. On the other hand, various long range inter-node connections cannot be created due to limited range of communication in wireless sensor networks. We consider the two aspects of introducing the small sensor network characteristics into sensor network Firstly to establish a long-range communication link using additional communication paths by using a few pairs of sensor nodes with a wired connection or by connecting wires to the sink. It gives the concept of heterogeneity and the wired nodes will to face more loads in comparison to wireless nodes. In wired cases an additional energy is required and also unusable in for aerial deployment or hanging deployments at huge mountains. From the security point of view, such sensor nodes provide relatively a high valuable target for attacks. The approach to establish a small-sensor network is that it does not affect the physical level and is only established in a virtual manner. The inter node pairs are connected logically to each other at the application level. This logical linking involves the introducing the nodes in a simple order to identify each other or by establishing a paired key mechanism. It provides some kind of shortcuts that can be used in decreasing the length of communication path in the network. Acquiring the data and information using network shortcuts is more efficient.

4. Sensor Network Graphs (SNG)

SNG is used to determine and analyze the security properties of sensor networks. They can also be used to provide direction for producing Simulated Network Models (SNM) and guarantee that a randomly generated simulated network is connected with a high level of probability. For having a number of nodes distributed uniformly on any plane surface i.e. square or circle etc. The radius of the communication is constant and it needs to be independent of its location and neighborhood nodes. Our real world network deployment in any area is controlled and constrained; while as the sensor nodes that are located near the border areas of the deployment area have less number of neighbors than those of deployed far away from border. There are the chances of certain error when such a formula is applied in a realistic situation. When we take simulations, then we are able to neutralize such border effects by having nodes that are far away placed from the border. For a plane area like square deployment area having *w* asside length, we might consider such nodes that are placed within the square area determined by the communication radius (R) and (*w*-R). R is the communication radius of sensor nodes deployed in the square area. Sensor nodes can have different and varying values based on the criteria that whether they are the nodes of inner side or the outer ones. However, the sensor nodes closet the border are usually of lower value to the application than those of inner nodes. This estimation is done upon an observation that outer sensor nodes are not interconnected densely and are thus concerned in small number of conversations than those of inner sensor nodes. While considering the security perspective, all the outer nodes are of big importance because they act at frontline and are thus more helpful in terms of event sensing and attack observations etc. In certain cases, when the sensor network deployment area is not accessible, then these outer nodes are utilized properly and they serve as entry points for communication in the sensor network. Keeping in view their importance, it is highly recommended to keep them shielded and protected irrespective of any cost considerations.

4.1. Node Density

Let's consider $\boldsymbol{A}$ as the size of the network deployment area on a plane surface and $\boldsymbol{N}$ as the number of deployed sensor nodes or the network size, thus the density can be determined as the number of sensor nodes per unit area as:

$$\rho = \frac{\boldsymbol{N}}{\boldsymbol{A}}$$

4.2. Reachable Neighboring Nodes

Let's consider radius $\boldsymbol{R}$ be the uniform communication radius of sensor nodes in the deployed area, the probable number of neighbors that are directly reachable can be determined as:

$$\boldsymbol{d_1} = \frac{\boldsymbol{\pi R^2 N}}{\boldsymbol{A}}$$

This equation describes well about the sensor nodes that are placed far away from the border line of the deployment area. $\boldsymbol{d_1}$ determines the nodes that are directly reachable i.e. reachable by one hop.

$$\boldsymbol{d_k} = \frac{\boldsymbol{\pi (kR)^2 N}}{\boldsymbol{A}}$$

This determines the number of all expected neighbors reachable in the deployment area within $\boldsymbol{k}$ hops denoted by $\boldsymbol{d_k}$.

4.3. Inter-Node Length

In the lower densely populated network the path length can be slightly longer but not much straight. The longest path on a unit square can be determined as:

$$\frac{\sqrt{\boldsymbol{2}}}{\boldsymbol{R}}$$

When the sensor nodes are densely deployed per unit area, many hops will be required to span the node distance from one corner to the opposite of the area. However, in a less dense graph, we expect that the longest path will not be much straight and is thus slightly longer than the highly dense deployment. Let's consider a disk of size *A* having a diameter: $2\sqrt{A/(2\pi)}$, and we can determine the number of hops in the longest path as:

$$\boldsymbol{L_{max}} = \frac{\boldsymbol{2\sqrt{A/(2\pi)}}}{\boldsymbol{R}}$$

While in the real world deployments we hardly find any area that is completely regular in shape and several parameters need to be considered while deployments i.e. network connectivity and the coverage area. Such areas include deployments in forest, deserts, mountains and oceans etc. All these areas are completely irregular and need a careful deployment planning and design.

4.4. Node Connectivity

For a given sensor network having n >> 1 nodes, with a homogeneous node density ρi.e. nodes per unit area, all the sensor nodes are connected to the network with a probability *p*, while as the radio range $r_0$for all the deployed nodes will be:

$$\boldsymbol{r_0} \geq \frac{\sqrt{\boldsymbol{-1n(1-p^{1/n})}}}{\boldsymbol{\rho\pi}}$$

Following are shown various deployment figures describing the sample network deployments generated using geometric model. These are the prototypes of real world network design and deployments and some of these figures may not appear in actual shapes in real world, but are considered very beneficial for quantitative computation and evaluations. Figure 2 (a) shows the deployment in the desert like areas, whereas (b) is shows the deployment on roads and streets or around a building block etc. The figure (c) is a U-shape figure and can be deployed in any such area like building floor of any large campus etc. It is noteworthy to mention here that various fundamental qualitative results in this work are not affected in any way using the actual topology.

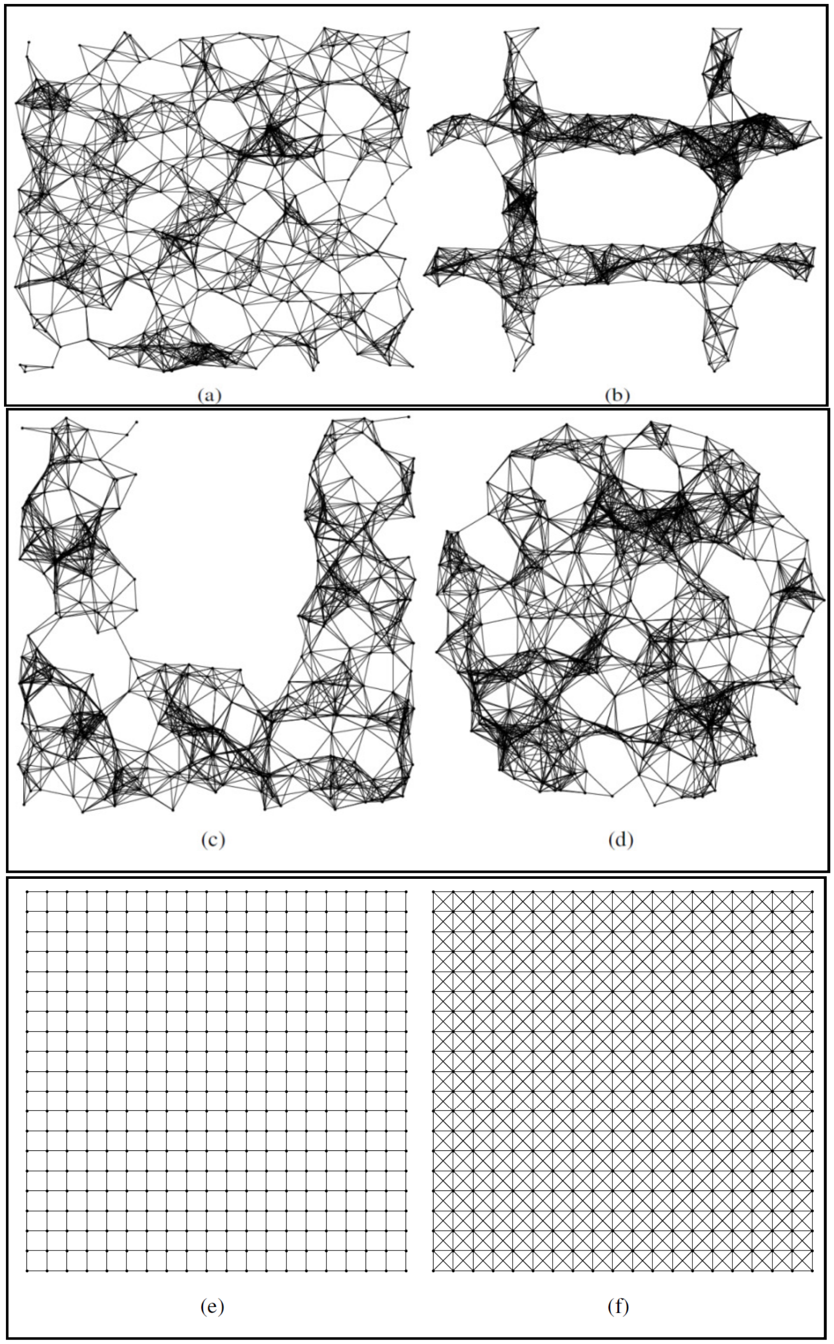

Figure 2 (a-f): Sample real world deployments based on geometric model.

5. Sensor Network Topology

In order to have a secure and authentic communication system, we need to harness the power of network topologies in a professional way. Topology is systematic feature that allows us to arrange and place a large number of sensor nodes in any desired order. Before deployment, it is very essential to have the maximum knowledge of topology engineering. It will work as a fundamental building block for our sensor network project. The area upon which the deployment is required needs to be seen through the geometric perspective along with the network density. Denser sensor networks need a more care in terms of connectivity, deployment and coverage. However, the connectivity of sensor nodes is one of the big issues, but it is mostly desirable to have all the sensor nodes limited to single connected network topology. Inter-node communication path between every pair of sensor nodes is established so that it can exchange large volumes of data in a smaller span of time. Time and distance are the two major difficult factors that can be eased with the help of best possible topology design. We have given some of the topologies below and the best topology single or mix, suitable for pour project is discussed in detail.

5.1. Linear Topology

This topology is required to arrange the nodes of a network in a linear fashion preferably from small to medium distances. This topology is better suited for deploying the sensor nodes along a straight long path like a highway or any straight road across any desert, forest or river. This topology is least reliable in the traditional wired networks and any damage in the middle of the connecting lines, the remaining of the network will get disabled. However, our all the work in this project is completely independent of wires.

5.2. Star Topology

Sometimes we have a lot of areas to be covered in a polygonal shape like a star. Such areas need careful engineering of the node establishment. All the end nodes in this topology are connected to each other in a star like manual connection establishments using dedicated Ethernet or any other faster medium of connectivity. This topology provides alternate pathways for connection of the nodes in a sensor network. In case of the node failure or any physical damage, communication is not halted and can be carried ahead without any major disturbance using multiple-alternate network pathways.

5.3. Round Net Topology

This is neither a linear nor a circular topology; it has end to end connectivity in any rounded form. It can be used to surround any larger area somewhat in a semicircular fashion. The only difference in between the linear topology and this topology lies in their physical order and the area. In case of any middle node destruction, half of the network is lost. Sever can correspond only up to the line of connectivity of sensor motes.

5.4. Square Topology

This topology is used in the housing and organizational buildings for various purposes. In this topology, all the motes are placed around any such area or a building accessed remotely by sensor station. This topology has an additional cluster node at the diagonals thereby dividing the entire established network into two equal diagonals.

5.5. Mesh Topology

This topology has a unique feature and lasts very long in case of highest disastrous conditions in terms of physical damage, node compromise, data loss, theft, cable tampering etc. It provides two or more than two connections between sensor nodes. It is costlier and more reliable than the above discussed topologies.

5.6. Cloud Topology

Sometimes we need many discrete networks at multiple places with different topologies in a very large and geographically irregular area. Considering any such may include forest, river, residential places, mountains etc. We form and place many different topologies in these geographically different areas. All these networks are operated by a single remote server at base station. These separate networks are connected to each other via cluster nodes. Every network topology has its own cluster node. The cluster nodes are programmed to communicate with the base station using duplex mode. Connecting these discrete sensor networks with each other via corresponding cluster nodes forms a cloud of multiple networks known as cloud topology of sensor nodes. This topology is very costly and is much suitable for military, space exploration, oil & gas industries and wildlife operations.

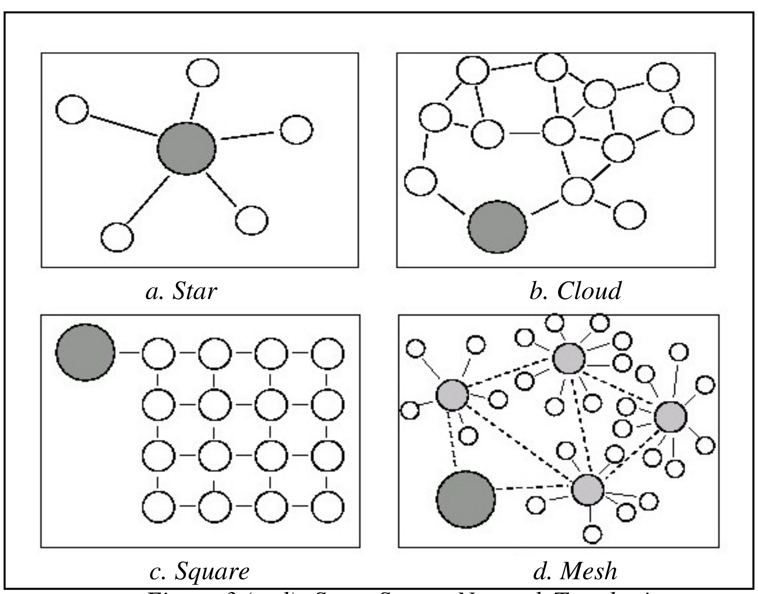

Figure 3 (a-d): Some Sensor Network Topologies

6. Conclusion

The geometric model helps to get the various practical attributes of sensor nodes in any given networks, besides being used to achieve abstraction for performing the required calculations, computations and the simulations. The graph contains horizontal and vertical structures, a grid and makes us easy to plot a real world network on any surface where the nodes will be interconnected in any direction. The surface can be plane or rough. In the real world the surfaces will include any largest plane like a desert or a playground. The deployment can also be done on mountains, water bodies, oceans, forests etc. Topology is provided that allows us to arrange and place a large number of sensor nodes in any desired order. The topology engineering is a unique technique to pick and choose a particular type or multiple features from various topologies in order to build a strong system of communication in sensor networks. The geometric model and sensor graphs help in creating an exact prototype of the system under development and to eliminate various possible shortcomings that may appear after the real world deployment. Any or many of these topologies can be used as per the requirements. It is also possible in our work to add an additional network to any existing network as a child network. A main network can have many child networks communicating to the parent network via cluster nodes or end sensor nodes. Besides topology engineering, we need to have a networks that can be put into use using WSN technology for authentication mechanism for transfer of data packets and sensing of critical events.

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