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Topology Control for Energy Conservation in Wireless Sensor Network

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Abstract

Topology control in Wireless Sensor Networks is an approach to reduce the initial topology of the network in such a way that energy of the sensor nodes may be conserved and the interference among simultaneous transmissions may be reduced. We have described the topology control for heterogeneous WSNs and defined different interference model in heterogeneous WSNs and the techniques to minimize the interference by topology control. These techniques basically depend on removal of link or reduction of the degree of nodes in the graph. The main objective of our approach is to reduce the number of active nodes and active links, during the communication alive to minimize the interference and energy consumption in order to enhance the life time of the network.

Keywords: Topology Control, heterogeneous WSNs and UD graph

1 Introduction

Ad-hoc networks are formed by mobile devices which consist of a processor, some memory, a radio communication unit and a power source (battery or solar cell). Sensor Networks can be considered as specialization of ad-hoc networks in which nodes are equipped with sensors measuring certain physical quantity such as humidity, brightness, temperature, pressure, velocity, acceleration and vibration. Wireless Sensor Networks has a wide variety of applications such as battle field surveillance, target tracking, fire detection, security, oil or gas pumping, habitat monitoring and environment control.

Nodes in Sensor Networks are generally assumed to be autonomous and operate for a considerable time period. In the case of Sensor Networks this time period may be several years. Energy is a scarce resource for those devices which run on battery as energy sources. The improvement of energy efficiency and power management is a critical issue in the WSNs. The energy consumption in WSNs is central issue for the researchers. Energy efficiency and power management is usually characterized before deployment using simulators. The WSNs should be designed so that the system can maintain itself for several months or year, without paying attention and is required to collect and send the accurate information for a long period of time.

Many aspect of the network will affect the energy consumption of WSNs such as the physical electronic design, the MAC protocol and the routing protocol. Energy sources may be affected by physical environmental conditions such as temperature. In WSNs, each device can selectively decide nodes to communicate by adjusting its transmission power or by only maintaining the communication links with some special nodes within its transmission range. Maintaining a small number of communication links will also speed up the routing protocols in addition to possibly alleviate the interference among simultaneous transmission and also possibly save the energy consumption.

Energy consumption and interference can be reduced by topology control in WSNs. Topology control in WSNs can be considered the task of given a network connectivity graph, computing a subgraph with specific desired properties such as connectivity, short stretches, scarcity, low interference or low node degree. Sometime the construction of node clusters and dominating sets of nodes is considered as topology control also. The main goal of topology control is the reduction of energy consumption by sensor nodes to enhance the network lifetime and also the reduction of interference in the network.

Topology control is one of the major techniques used to enhance the network capacity at network level and adjusts the transmission power at node level. Proper adjustment of transmission power not only increases energy efficiency but also reduces the network interference. The topology control protocols minimizes the maximum power used by the nodes and at the same time preserves different network constraints like connectivity (bi connectivity) and K neighbor set etc.

In WSNs, topology control technique is mainly used in order to reduce initial topology of the network to save energy and extend the lifetime of the network. The main objective is to reduce the number of active nodes and active links, preserving the saved resources for future maintenance. Topology control has been divided into two sub problems: topology reduction (change of the initial topology) and topology maintenance (maintenance of the reduced topology) while preserving the characteristics like connectivity and coverage.

In this paper we have considered the topology control for heterogeneous WSNs. Heterogeneous WSNs consist of sensor nodes with different ability, such as different computing power and sensing range. The topology control and deployment are more complex in heterogeneous WSNs as compared to homogeneous WSNs. Firstly we have given a model of heterogeneous WSNs as a simple graph or Unit Disk graph using graph theoretical concepts. In this modeling sensor nodes are considered as vertices and there exist a link between two nodes if they are within the range of each other. Then we have defined different interference models in heterogeneous WSNs and the techniques to minimize the interference by topology control. These techniques basically depend on removal of link or reduction of the degree of nodes in the graph. As we remove the links from the graph, we conserve the energy also. So these techniques reduce the energy consumption as well as interference in heterogeneous WSNs. In this way, the lifetime of the network can be enhanced.

This paper has been organized as follows. In the Section 2, we recall the works that have been carried out in this field. In section 3 we introduce link interference, different models of link interference and approach to minimize it. In Section 4, we introduce node interference, different models defining node interference and algorithm to minimizing it. We define modeling of a wireless sensor network as Unit Disk (UD) Graph, link and node interference in UD graph and techniques to minimize these interferences in Section 5. The last Section 6 contains the conclusion of the work.

2 Related Work

Burkhart *et al.* [1] proposed several methods to construct topologies whose maximum link interference is minimized while the topology is connected or is a spanner for Euclidean length. These are based on finding the connected spanning subgraph of the interference graph. Li *et. al.* [5,6] has proposed many new structures that approximate the Euclidean minimum spanning tree while the structure can be constructed using local information only with *O(n)* messages. K. Moaveni-Nejadgive *et al.* [8] have described various algorithms to construct a network topology for wireless ad hoc network so that the maximum (or average) link (or node) interference of the topology is either minimized or approximately minimized. The reduction of interference is consequently considered as one of the foremost goals of topology control. Almost all these related works, however, considers this issue implicitly: Low interference is often claimed to be a consequence of sparseness or low degree of the constructed topologies. Rickenbac *et al.* [10] studies explicit definitions of interference. Various models of interference (both from a sender-centric and a receiver-centric perspective) were proposed, compared, and analyzed with respect to their algorithmic properties and complexities. The interference model proposed in [7] is based on current network traffic, however, highly depends on the chosen application. The detailed overview of topology control is described in [11]. In many research works, disk model is commonly used [3,4]. They used Unit disk graph model to represent a WSN.

However a fixed communication or sensing range is not practical for a realistic sensor network. Moreover, node deployment in heterogeneous WSNs has to consider the topology control between different types of nodes.

3 Link Interference

We model a wireless sensor network as a weighted undirected simple graph G = (V, E,w) consisting of a set of sensor nodes V (vertex set), set of undirected links E (edge set) $\subseteq$ V×V and a mapping w:V×V→R^+ called a weight function of graph. The sensor nodes are deployed in the targeted area. We consider only undirected links between the nodes. These links represent the communication between sensor nodes and if a node sends a message or some information to any of its adjacent node then the receiver node is also capable to send an acknowledge message to the sender node to verify that the message has been received by it.

In a wireless sensor network, every sensor node has its own transmission power. In this model we assume that each node may adjust its transmission power upto the *maximum power level*. The maximum power level may be different for different sensor nodes. There exist a link between nodes u and v if both are capable to communicate each other i.e. both are in the transmission range of each other or we can say that the Euclidean distance between u and v i.e. $|uv|$ is less than or equal to the maximum transmission radius of both the nodes u and v (R_u and R_v respectively).
i.e. $\exists$ an edge between u and v if $|uv| \leq min \{R_u, R_v\}$.

Let $D(u,r_u)$ be the disk centered at u with radius r_u. It represents the coverage area of node u when the transmission power of u is set at r_u. We define *interference number* of an edge e by the cardinality of the *coverage set* of e and denoted it by $I_L(e)$ and assign it to each edge as weight of that edge. In this way we finally get a weighted undirected graph which represents a wireless sensor network with link interference. It is also called *link interference graph* of the given network. Now we define three link interference models. First is based on Euclidean distances of the nodes, second is based on maximum power level of the nodes and third one is based on current power level of the nodes.

Model 1: In this model Coverage set and interference of an edge is defined in terms of Euclidean distances between the nodes.

$$Cov(e) = \{w \in V \mid w \text{ is covered by } D(u, |uv|) \text{ or } D(v, |uv|)\}$$

$$I_{L1}(e) = |Cov(e)|$$

where $|uv|$ = Euclidean distance between u and v and e is an edge between u and v. [Figure 1]

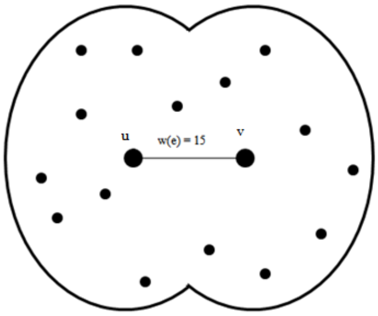


Figure 1: Nodes Covered by an edge $e = (u,v)$ when radius of coverage disk is $|uv|$

Model 2: In this model coverage set and interference of an edge is defined in terms of maximum power level of nodes.

$$Cov(e) = \{w \in V \mid w \text{ is covered by } D(u,R_u) \text{ or } D(v,R_v)\}$$
$$I_{L2}(e) = |Cov(e)|$$

Where R_u and R_v are the maximum power level of the node u and v respectively and e is an edge between u and v. [Figure 2 (a)]

Model 3: In this model coverage set and interference of an edge is defined in terms of current power levels of the nodes.

$$Cov(e) = \{w \in V \mid w \text{ is covered by } D(u,r_{cu}) \text{ or } D(v,r_{cv})\}$$
$$I_{L3}(e) = |Cov(e)|$$

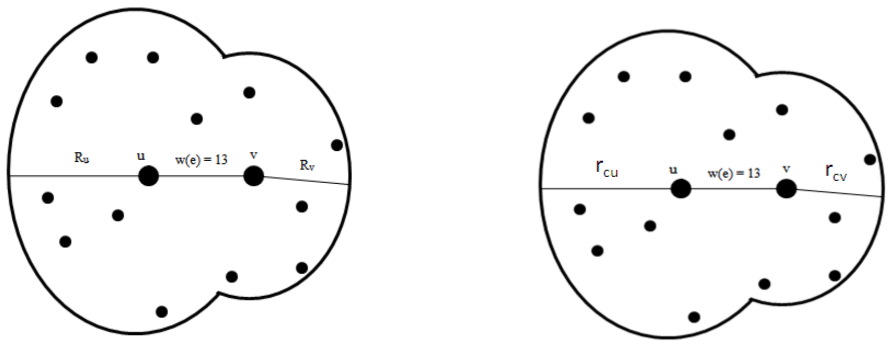
Where r_{cu} and r_{cv} are the current power level of the node u and v respectively and e is an edge between u and v. [Figure 2 (b)]

The *link Interference of the whole network* is defined as,

$$I(G) = \max_{e \in E} w(e)$$

The *average link interference* of the network is defined as,

$$I_{avg}(G) = \frac{\sum_{i=1}^{|E|} w(e_i)}{|E|}$$



(a) (b)

Figure 2: Nodes Covered by an edge *e = (u,v)* when radius of coverage disk is R_u and r_{cu} corresponding to u

Reduction of the link interference:-

To minimize the interference in the sensor network we construct the *minimum spanning tree* of the interference graph of the given wireless sensor network by Prim's algorithm for minimum spanning tree. In this approach, we remove those links from the network which creates more interference than the others. The links which are removed from the network are called *interfering links*. The nodes which are connected by *interfering links* are called *interfering nodes*. To apply this approach practically on the given network we remove interfering links from the network. The transmission power of interfering nodes can be adjusted to remove interfering links. The maximum link interference and average link interference can also be reduced by this approach. Also the *connectivity* of the nodes in the network is preserved in this approach.

4 Node interference

In this section we define interference for each node. We define two types of node interference. First is link based node interference and second is coverage based node interference.

4.1 Link Based node interference:-

Let G = (V,E,*w*) be the link interference graph of the given sensor network where V is the set of sensor nodes, E is the set of links and *w* is the set of link interference. A node *u* may communicate to others node via links incident to it. If there is an edge between nodes *u* and *v* then both are capable to communicate each other via edge *e = (u,v)*. Therefore both *u* and *v* may suffer by interference due to the link *e* i.e. $I_{NL}(e)$. Now we define two link based node interference models. First is based on the maximum link interference experienced by node u and second is based on average of link interference incident to node u.

Model 1: In this model interference of a node u is the maximum link interference in the all links incident to it.

$$I_{NL1}(u) = \max_{e \in E} I(e), \text{ where } e = (u,v) \text{ is the edge incident to } u.$$

Model 2: In this model interference of a node u is defined as the average of the link interference of the entire links incident to it.

$$I_{NL2}(u) = \frac{\sum_{i=1}^{\deg(u)} w(e_i)}{\deg(u)}$$

where $e_i = (u,v_i)$, $i= 1, 2, \ldots\ldots, d(u)$ are edges incident to u.

The *maximum node interference* of the network is given by

$$I(G) = \max_{u \in V} I(u)$$

The *average node interference* of the network is given by

$$I_{avg}(G) = \frac{\sum_{u \in V} I(u)}{|V|}$$

Reduction of the link based node interference:-

The previous spanning tree based approach also reduces link based node interference. Since the interference due to individual node is depends on interference due to links which are incident to it and spanning tree based approach reduces the link interference, so it also reduces the link based node interference in this model. Similarly maximum node interference and average node interference can be reduced.

4.2 Coverage based node interference:-

Model 1: In this model coverage set and interference of a vertex is defined in terms of maximum power level of nodes.

$$Cov\ (u) = \{v \in V \mid v \text{ is covered by } D(u,R_u)\}$$
$$I_{NC1}(u) = |Cov(u)| = deg(u)$$

Where R_u and R_v are the maximum power level of the node *u* and *v* respectively.

Model 2: In this model coverage set and interference of an edge is defined in terms of current power levels of the nodes.

$$Cov\ (u) = \{v \in V \mid v \text{ is covered by } D(u,r_{cu})\}$$
$$I_{NC2}(u) = |Cov(u)|$$

Where r_u and r_v are the current power level of the node u and v respectively.

The *maximum node interference* of the network is given by

$$I(G) = \max_{u \in V} I(u)$$

The *average node interference* of the network is given by

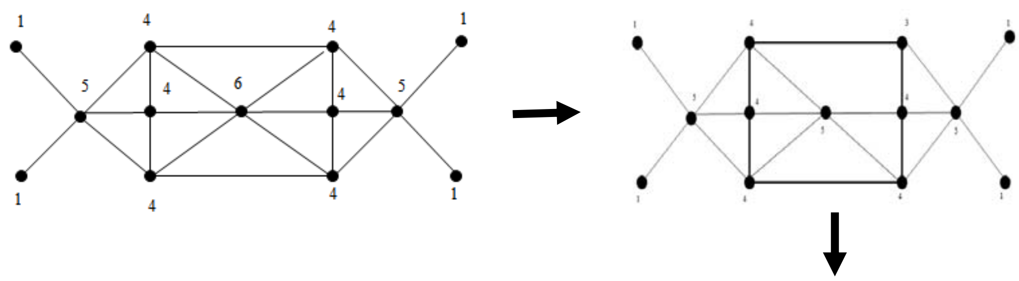
$$I_{avg}(G) = \frac{\sum_{u \in V} I(u)}{|V|}$$

Reduction of the coverage based node interference:-

To minimize the coverage based node interference we proceed as follows:

Step1: Select the highest degree node in the network. Let it be u.
Step2: Arrange all the nodes adjacent to u in descending order of their degrees.
Step3: Select the first vertex in the series. Let it be v.
Step4: a) Remove the edge between u and v unless the graph is disconnected.
b) Else select the next vertex in the series and repeat the Step 4.
Step5: Repeat above steps till we get a spanning tree.

An example of above algorithm is described below:



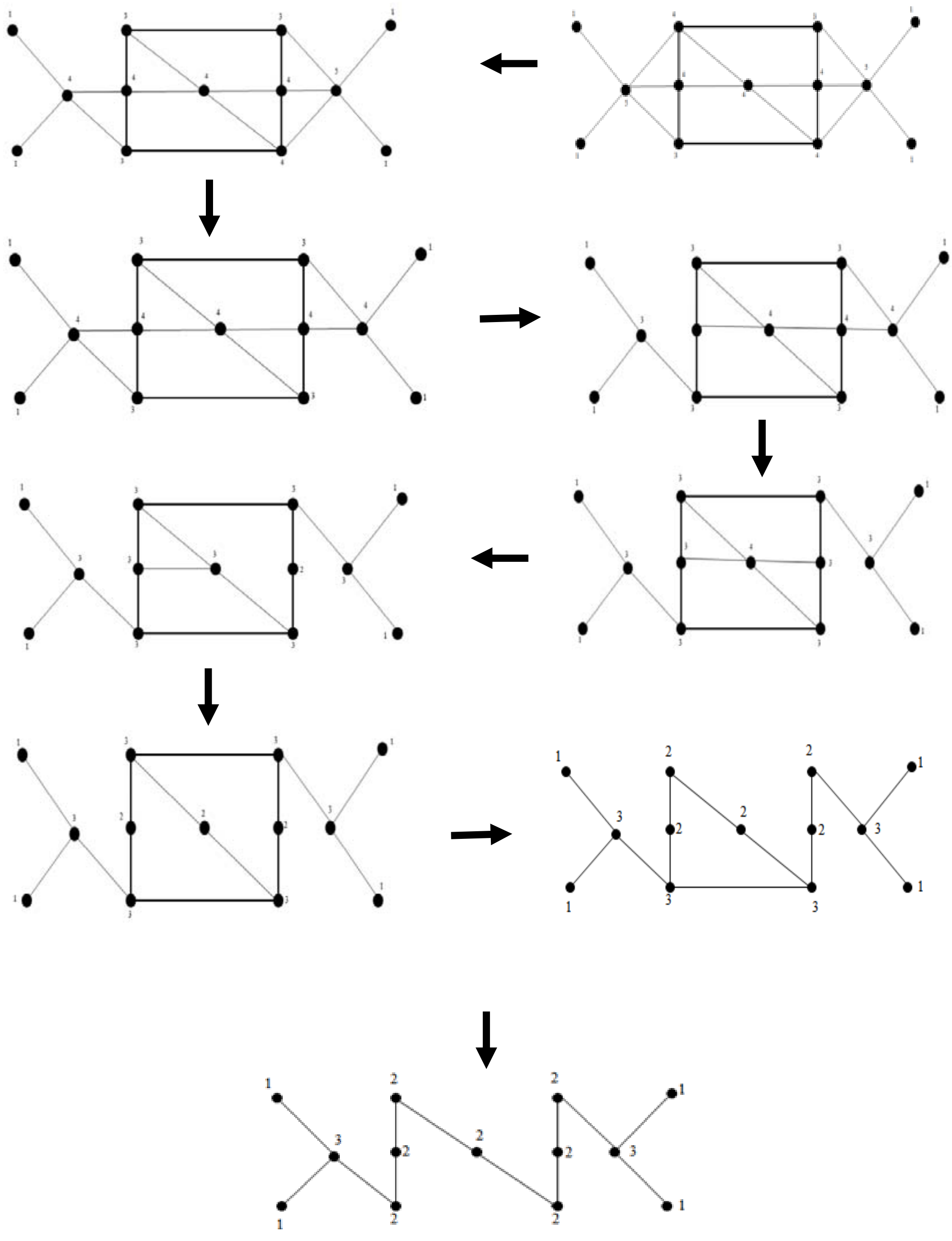


Figure 3: An example of Algorithm to reduce coverage based node interference

5 Unit Disk Graph

A graph G is a Unit Disk graph if there is an assignment of unit disks centered at its vertices such that two vertices are adjacent if and only if one vertex is within the unit disk centered at the other vertex. We denote a unit disk graph by G_{UD}. [Figure 4]

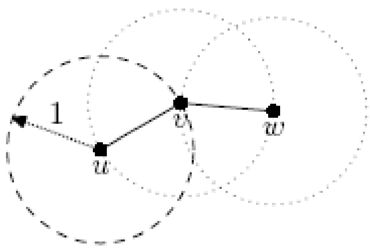


Figure 4: Unit Disk Graph

5.1 Modeling of a wireless sensor network as Unit Disk (UD) Graph:-

A wireless sensor network can be modeled as a UD Graph since the transmission range of sensor nodes is based on Euclidean distance. In this modeling sensors are denoted as vertices. The sensing coverage area of a sensor is represented by a unit disk centered at corresponding vertex. The connectivity between two sensor nodes is determined if the first sensor is within the sensing coverage range of the second sensor. Thus there is an edge between two vertices u and v iff $d(u,v)\leq 1$, where $d(u,v)$ is the Euclidean distance between u and v. In this way UD Graph is most suitable model for a wireless sensor network.

5.2 Link Interference in UD Graph:-

In this model the coverage set and interference of a link is defined in terms of degree of its end vertices.

$$Cov(e) = \{w \in V \mid |uw| \leq 1 \text{ or } |vw| \leq 1\} - \{u,v\}$$
$$I_{LU}(e) = |Cov(e)| = d(u) + d(v) - 2$$

where $|uv|$ = Euclidean distance between u and v and e is an edge between u and v.

The *link Interference of the whole network* is defined as,

$$I(G_{UD}) = \max_{e \in E} w(e)$$

The *average link interference* of the network is defined as,

$$I_{avg}(G_{UD}) = \frac{\sum_{i=1}^{|E|} w(e_i)}{|E|}$$

If the UD Graph model of a network is in the form of Complete Bipartite Graph ($K_{m,n}$) then link interference is,

$$I(K_{m,n}) = m+n-2$$

Similarly if the UD Graph model of a network is in the form of Cycle Graph (C_n) then link interference is,

$$I(C_n) = 2$$

Similarly if the UD Graph model of a network is in the form of Complete Graph (K_n) then link interference is,

$$I(K_n) = 2(n-2)$$

5.3 Node Interference in UD Graph:-

In this model the coverage set and interference of a node is defined in terms of degree of that node.

$$Cov(u) = \{v \in V \,|\, |uv| \leq 1\}$$
$$I_{NU}(u) = |Cov(u)| = d(u)$$

where $|uv|$ = Euclidean distance between *u* and *v*.

Reduction of the Link and Node interference in UD Graph:-

The above algorithm for minimizing the coverage based node interference, also minimize the link and node interference in UD Graph.

6 Conclusion

We have described the topology control for heterogeneous WSNs. After defined different interference model in heterogeneous WSNs, the techniques to minimize the interference by topology control are considered. These techniques basically depend on the removal of links or reduction of the degree of nodes in the graph. This minimizes the interference and energy consumption by reducing the number of active nodes and active links keeping communication alive. In this way, the life time of the network can be enhanced.

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