Topology Control in Wireless Sensor Networks: A Survey

Ranjan Kumar Mahapatra and N. S. V. Shet

Abstract Topology control is found to be a prominent strategy, to prolong the lifetime of WSNs. It helps to control the power consumption of the sensor nodes. In this paper, topology construction and topology maintenance are taken into account as a part of review of topology control. Topology construction algorithms encompass to frame the reduced form of topology. Topology maintenance helps in providing a reduced topology intermittently, as soon as the current topology becomes no longer optimum. Simulation results demonstrate that sensor node battery lifetime can be prolonged by the appropriate use of topology control.

Keywords Wireless sensor networks (WSNs) · Topology control
Topology construction (TC) · Topology maintenance (TM) · Energy
Lifetime

1 Introduction

Wireless Sensor Networks [1] is now of intensive interest in several applications due to lightweight, cheap and can be communicated via wireless technologies. At the same time, among so many existing constraints (computational limitation, energy resources, etc.), limitation in battery lifetime of the sensor is one of them. Here ultimate goal for topology control is, to have reduced number of active nodes as well as active links so as to preserve those resources for future use. Topology control [2, 3] is generally defined as the technique of controlling the transmission power of the sensor nodes, without altering the network characteristics such as connectivity as well as coverage. Here maintenance [4] of the network topology

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should be included so as to conserve energy even after a long time of network deployment. Hence basic operation in wireless sensor network is topology control which describes how efficiently wireless sensing field is monitored. It also explains about the mutual connection that exists between two sensing nodes. The remainder of the paper is arranged as follows: Sect. 2 explains about the taxonomy of topology control in brief. Section 3 explains the simulation work and results obtained and finally conclusions were drawn in Sect. 4.

2 Taxonomy of Topology Control

Figure 1 shows the general taxonomy of topology control.

2.1 Topology construction (TC)

It is the technique to build the reduced topology, i.e. the initial reduction of the sensor network topology. Once the initial topology is carried out and the nodes are located at random places, the administrator normally does not possess any control over the design of the deployed network. In general, the number of redundant nodes is more over a dense area:

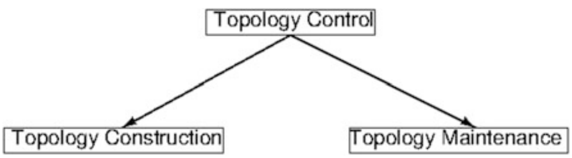
- Which in turn increases the number of message collisions.
- Multiple copies of the required information are generated.

Modifying the above parameters, topology of the network can be controlled. In this paper, we have put emphasis on one of the transmission range based algorithm (i.e. KNeigh algorithm for simulation purpose) and one hierarchical-based protocol (cluster based LEACH). Simulation work shows that reduction in no of active nodes helps in preserving battery life.

2.1.1 LEACH protocol

Clustering is a process, where one node is chosen to act as a cluster for several neighbour sensor nodes. Maximum lifetime can be attained by the introduction of level of hierarchy based on the application requirement. LEACH protocol [5, 6] is

Fig. 1 Taxonomy of topology



one of them to solve the issues of limited lifetime and energy of the sensor nodes efficiently. LEACH protocol was presented by Heinzelman [7] in 2000. Here threshold distance of transmission be

$p_0 = \sqrt{\frac{E_{fs}}{E_{amp}}}$ is considered.

The energy consumption model for the radio transmitter is shown in Fig. 2.

$(E_{Tx}(L, p))$ and $(E_{Rx}(L))$ separated by the distance p to send L bit message is given by;

$$\begin{aligned}(E_{Tx}(L,p)) = LE_{\text{elec}} + LE_{\text{fs}}p^2, \quad \text{if } p \le p_0 \\ LE_{\text{elec}} + LE_{\text{amp}}p^4, \quad \text{if } p \ge p_0\end{aligned} \tag{1}$$

$$(E_{Rx}(L)) = LE_{\text{elec}}, \tag{2}$$

where $E_{\text{elec}} \rightarrow$ Consumption of energy per bit, $E_{fs} \rightarrow$ the free space power loss, $E_{\text{amp}} \rightarrow$ the multipath power loss with acceptable bit error rate.

Idea: Sensor nodes can take the decision independently in the deployed sensor field whether to become a cluster head with a certain probabilities. Also it can elect cluster head periodically, which will lead to the prolonged network lifetime with reduced amount of spent energy.

Threshold value is given as:

$$\begin{aligned}T(n) = \frac{n}{1 - s \times \left[r \times \text{mod}\frac{1}{s}\right]} \text{ if n} \epsilon \text{ H,} \\ =0; \text{ otherwise}\end{aligned} \tag{3}$$

where s $\rightarrow$ desired percentage of the Cluster Head (CH), r $\rightarrow$ current round, H $\rightarrow$ set of nodes that have not become CH in the previous round.

LEACH operation comprise of rounds and each round starts with a set-up phase (organization of clusters) followed by a steady-state phase (data-transfer). Here overhead is minimized.

- Advertisement Phase [8, 7].
- Cluster Set-up Phase.
- Steady-state Phase.

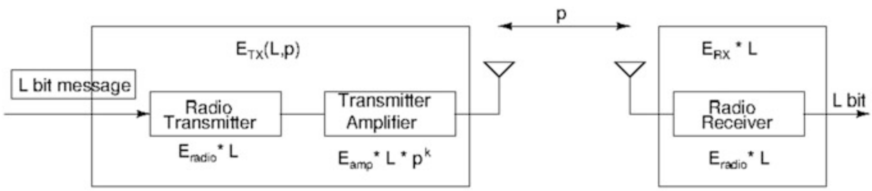


Fig. 2 Radio energy dissipation model

Performance evaluation of LEACH

Evaluation of routing protocols can be done in several ways. There is no such specific standard which exists. Numbers of rounds became the key parameter of the network lifetime when the first dead node appears. The time at which sensor nodes activity starts until the first dead sensor node appears, is generally termed as working time of the network. Here in this model, random distribution of 100 nodes in the area 200 × 200 m^2 has been deployed. Figure 3 shows the network lifetime for leach protocol after 3500 rounds. Simulation was performed using MATLAB R2012a.

Until the first dead sensor nodes appears in the network, no of rounds were counted. So the number of rounds becomes the key parameter for the sensor node network lifetime.

2.1.2 KNeigh Protocol

Here in our study, we assume that every node is associated with its K closest neighbours in the network.

In the paper [9], the KNeigh protocol [10, 11] was a distributed implementation for the computation of symmetric K-neighbour subgraph GK—based on the technique of distance estimation (RSSI [12], ToA [13]).

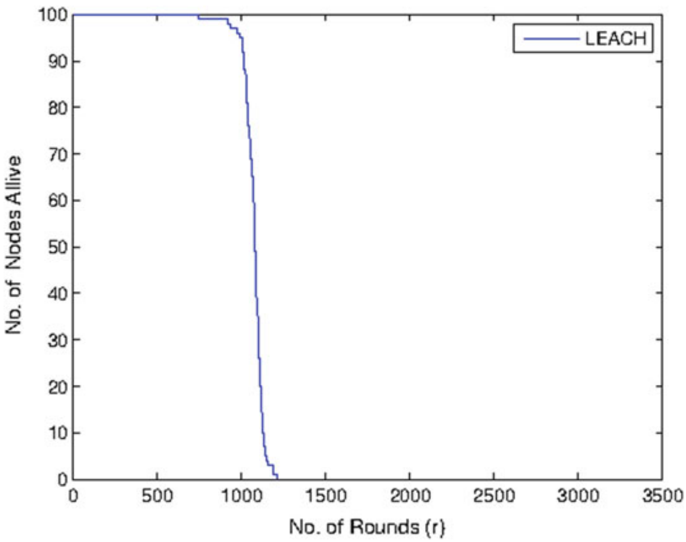


Fig. 3 Lifetime

Following are some of the features of KNeigh protocol

- Static nodes were used.
- All the nodes possess same maximum Tx power.
- It is simple and distance information between nodes are used.
- Network connectivity for the worst case is not guaranteed.

2.2 Topology Maintenance (TM):

From time to time, TM switches the reduced topology, when the existing current topology is not the optimum one. It is normally the iterative procedure of constructing, restoring and switching to new reduced topology until there is no more reduced topology. Sub-division of topology maintenance is shown in Fig. 4.

Static TM: This technique is normally pre-planned. Calculation of all the different topologies are done during the 1st topology is constructed. After all the topologies are built, they are stored in the memory for the future switching purpose as and when necessary. Some of the drawback of static TM is listed below

- Static TM takes additional time during the topology construction phase.
- It is very difficult to know a priori that, how much energy will be consumed by the topologies and their sensor nodes.

Dynamic Topology: This maintenance calculates a new reduced topology on demand, i.e. generates the TC mechanism as and when necessary.

- To trigger a reduced topology, dynamic TM mostly have, more as well as better information regarding the network (advantage).
- This technique consumes additional resources as many times they run (disadvantage). Hence both TC and TM must be energy efficient.

Hybrid TM: It utilizes static TM approach first by calculating all different reduced topologies at TC phase.

- If the sink possesses no connectivity, then hybrid TM utilizes dynamic TM by triggering new reduced topology on demand.

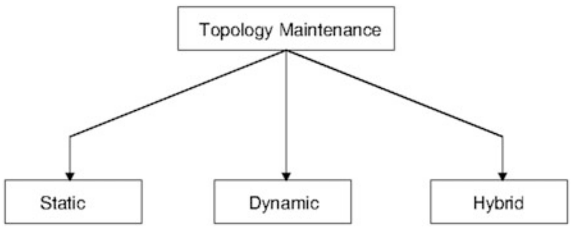


Fig. 4 Sub-division of TM

2.2.1 Topology Maintenance Algorithm

Classification of TM algorithm is shown in Fig. 5.

- DGTRec: This algorithm wakes up all the nodes which are inactive. Here existing reduced topology will be reset. Then a TC protocol is applied.
- Hence dynamically topology is reset. As shown in Fig. 6, consider that node P sends a packet to node R, which is at distance d. Here we have assumed that node R falls within the transmission range of node P at maximum power. Hence direct radio communication between nodes P and R is feasible. There is another node Q within the region K circumscribed by the circle having diameter d which intersects both P and R.

Here $d1 < d$ and $d2 < d$, so it is possible to send a packet from node P to node R via node Q as a relay

If we consider the signal is propagating from node P to node R in accordance with the free space model. Here $P_{PR\text{direct}} \propto d^2$ and $P_{PQR} \propto \{d_1^2 + d_2^2\}$.

From the triangle PQR, Φ is the angle opposite to PR. So by the geometry we derive

$$d^2 = d_1^2 + d_2^2 + 2d_1 d_2 \cos \Phi \quad (4)$$

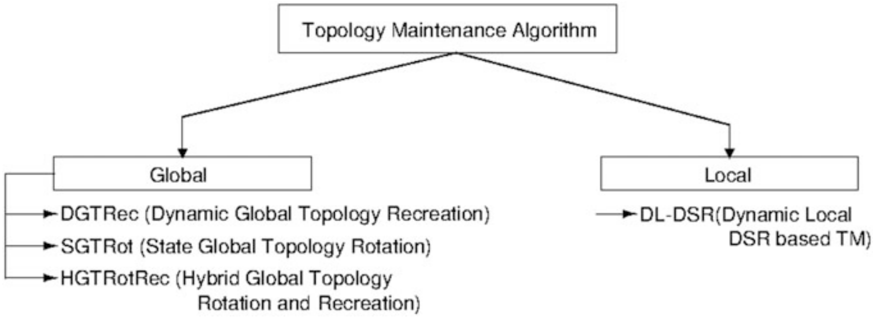
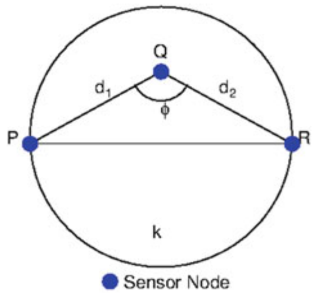


Fig. 5 Classification of TM algorithm

Fig. 6 Multihop communication for reduced energy



$$\text{As}\, Q\, \varepsilon\, K \;\Rightarrow\; \cos \Phi < 0$$

$$\Rightarrow d^2 = d_1^2 + d_2^2 \qquad (5)$$

Hence short, multi-hop path between sender and receiver is always desirable for radio communication, instead of long, energy-inefficient edges in regard with energy point of view.

3 Simulation and Results

The purpose of this experiment is to obtain the benefit of topology control by the implementation of topology control as well as topology maintenance. Here simulation is performed by the help of I.H.U. VLabs. While evaluating the performance, we had the assumption

- Architecture for sensor network used was 2D.
- Deployed sensor nodes have no information about their own location as well as about neighbours and there is no packet loss.

Parameters used for our simulations purpose is shown in Table 1.

Figure 7 shows the deployment of the 100 nodes.

Area of communication/sensing can be found in Fig. 8.

While simulating, link connectivity between nodes is shown in Fig. 9.

After simulation is over, the reduced topology with less number of active nodes is shown in Fig. 10.

Table 1 Parameter details

Parameters	Values
Deployment area	600 × 600 m
No of nodes	100
No of sinks	1
Sensing radius	20 m
Bit error rate	0
Node energy distribution	Constant and 100 mJ max
TC protocol	kNeigh Tree
K	6
TM protocol	DGETRec
Sensing and data protocols	Simple S and D
Data forwarding protocol	Simple forwarding
Node mobility	Simple random walk

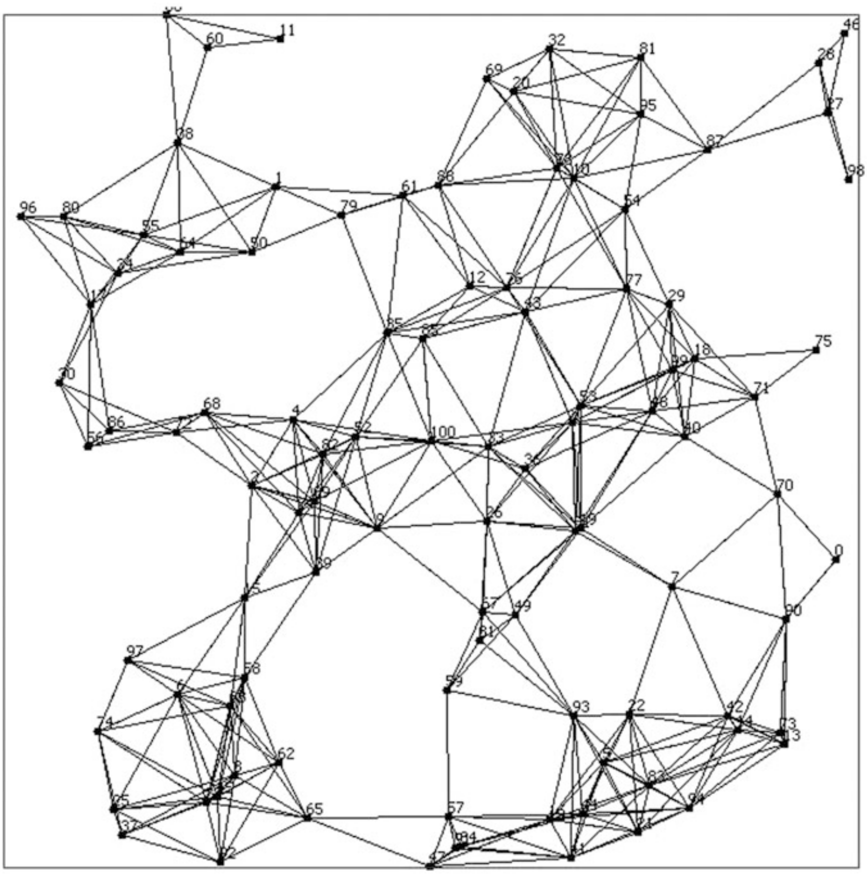


Fig. 7 Node deployment

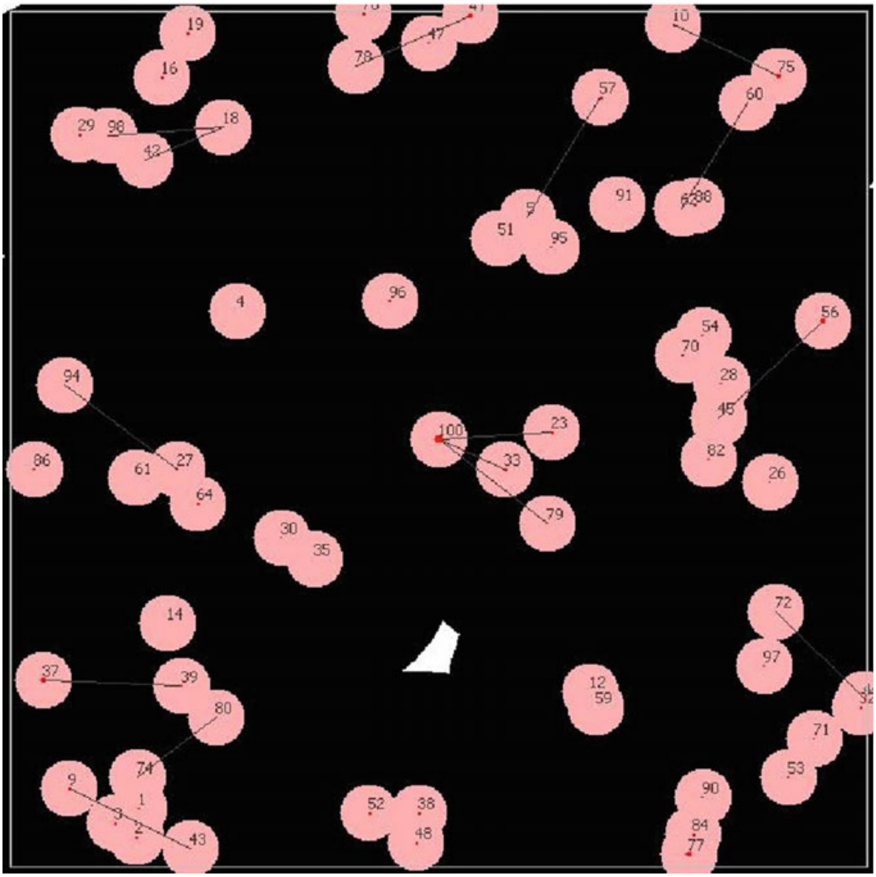


Fig. 8 Node topology with filled area

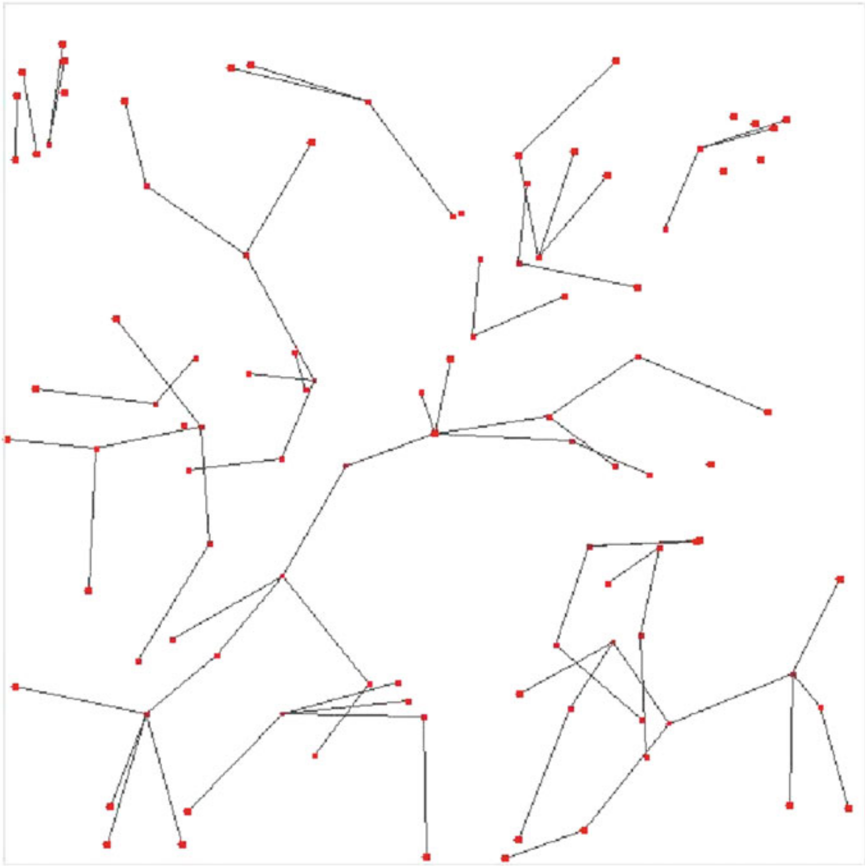


Fig. 9 Node topology with connectivity

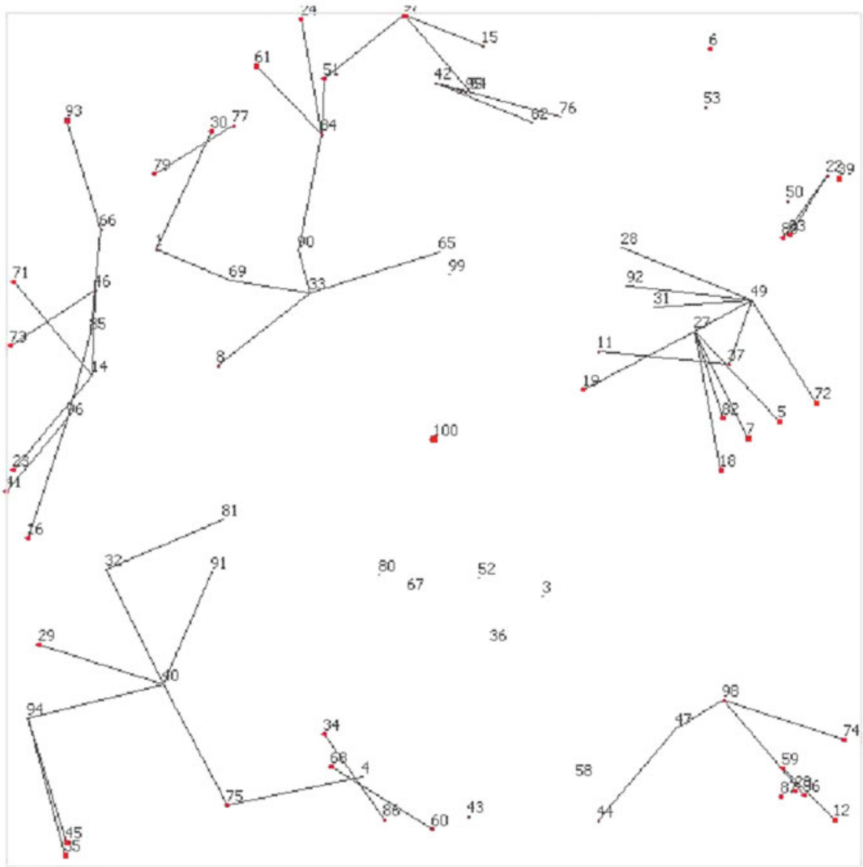


Fig. 10 Reduced node topology with less active node

4 Conclusion

In this paper, a brief survey was conducted on topology control in wireless sensor networks. Detailed taxonomy of topology control is studied and some of the protocols were used for simulation works. This survey allowed us to understand the need for topology control, to have a better network lifetime with conservation of energy. An important conclusion is that, we can achieve better network lifetime if we reduce network topology.

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