Hindawi Publishing Corporation
Journal of Computer Networks and Communications
Volume 2016, Article ID 2861904, 11 pages
http://dx.doi.org/10.1155/2016/2861904

Research Article

A Hybrid Energy Efficient Protocol for Mobile Ad Hoc Networks

Niranjan Kumar Ray[1] **and Ashok Kumar Turuk**[2]

[1] *Department of Computer Science & Engineering, Silicon Institute of Technology, Bhubaneswar 751024, India*
[2] *Department of Computer Science & Engineering, National Institute of Technology, Rourkela 769008, India*

Correspondence should be addressed to Niranjan Kumar Ray; niranjan_ray2000@yahoo.co.in

Received 30 November 2015; Accepted 7 April 2016

Academic Editor: Liansheng Tan

We proposed an energy conservation technique called Location Based Topology Control with Sleep Scheduling for ad hoc networks. It uses the feature of both topology control approach and power management approach. Like the topology control approach, it attempts to reduce the transmission power of a node, which is determined from its neighborhood location information. A node goes to sleep state based on the traffic condition as that of power management approach. In the proposed scheme, a node goes to sleep state only when its absence does not create local partition in its neighborhood. We preformed extensive simulation to compare the proposed scheme with existing ones. Simulation results show that the energy consumption is lower with increase in the network lifetime and higher throughput in the proposed scheme.

1. Introduction

Wireless ad hoc networks do not require any preestablished network infrastructure. They are more suitable for deployment in areas where a fixed backbone network infrastructure is inflexible and/or economically nonviable. Mobile ad hoc networks (MANETs) have variety of applications such as emergency communication services, military communication, and environmental monitoring. However, they suffer from many challenges such as *unpredictable mobility*, *restricted battery power*, *limited bandwidth*, *multihop routing*, and *security*. Efforts are being made to address the above issues.

As nodes in MANETs are battery operated, energy efficiency is important design criteria for the longevity of the network. If a node runs out of battery, its ability to route the network traffic gets affected which in turn adversely affects the network lifetime. Network lifetime of MANETs can be enhanced by either maximizing the battery power of nodes or minimizing the total power consumption in the network. Though a considerable progress has been made in the battery technologies in recent years, it is incomparable with the progress made in semiconductor technology yet. This difference has created a gap between the amount of energy needed to operate in a wireless environment and the battery capacity that powered the nodes. Hence, it necessitates the requirement of power conservation techniques to enhance the network lifetime. Such techniques can be applied at different layers of protocol stack.

Nodes in MANET usually transmit packets with maximum power. A packet transmitted with maximum power may reach the destination with lesser number of hops but can decrease the channel utilization and the remaining energy of the node to a greater extent. Energy saving can be done at the node level by adjusting the transmission power to a lower level [1–4]. In recent years, many techniques have been proposed to conserve energy in MANETs. Topology control approach is one among them. The primary objective of topology control algorithms is to adjust the network topology by reducing the transmission power at node level and at the same time maintaining the network connectivity. In other words the objective of topology control approach is to remove the energy inefficient links at the node level by reducing the transmission power. The major design goal in most of the topology control protocols is to minimize the maximum power used by a node. Other design goals are to improve the network performance such as throughput, network lifetime by alleviating contention, and interference in the network. In this paper we have proposed an energy efficient technique, where nodes are put into sleep state depending on their connectivity information, and transmission power is determined from the location of next-hop node. The proposed scheme inherits the merit of both topology control approach and power management approach. A node in this scheme goes to sleep state only when its absence does not create local partition in its neighborhood.

The rest of the paper is organized as follows. In Section 2, few of the power control techniques are briefly discussed. Proposed technique is described in Section 3. In Section 4 simulation results are presented and conclusion is drawn in Section 5.

2. Related Work

Energy conservation strategies for MANET can be broadly classified into two types: (i) power management approach and (ii) topology control approach. In power management approach a node remains in one of the three possible states: (a) *active*: participating in the network traffic by sending and/or receiving packets, (b) *idle*: waiting for the traffic, and (c) *sleep*: switching off its radio transceiver for a particular period and wakeing up at the end of the period. Among the above three states, sleep state consumes lesser amount of energy. Therefore, power management based protocols put as many nodes as possible into sleep state to save energy. However, they are more prone to network disruption. This is because, as the nodes goes to sleep state, the connectivity may be lost. Few representatives of power management approach are discussed in [5–9].

Topology control approach conserves energy by adaptively adjusting the transmission power while maintaining the network connectivity. Most of the topology control protocols require information like location, direction, neighbor, and so forth, to construct the topology. Location information can be obtained by means of global positioning systems (GPS) or other positioning methods. The directional information can be obtained by using angle-of-arrival (AOA) technique. Location based techniques produce more accurate topology but are associated with higher hardware cost. In order to reduce the hardware cost some of the techniques assume that a subset of nodes are equipped with GPS while other nodes get their location information by exchanging message with GPS enabled nodes. Few topology control protocols are discussed below.

Topology optimization for different topologies and communication pattern is addressed by Santi [10]. Protocols like *Geographical Adaptive Fidelity* (GAF) [11] and SPAN [12] save energy by maintaining a connected dominating set (CDS). GAF identifies the routing prospective nodes and redundant nodes. Redundant nodes are switched off to save energy. In SPAN, few nodes are selected as coordinator, which stay/awake continuously and perform multihop packet routing. Nodes not selected as coordinator remain in power save mode to conserve energy. SPAN saves energy by putting few nodes into sleep state, while communication takes place through coordinator. Bao and Garcia-Luna-Aceves [13] proposed a topology management scheme called *Topology Management by Priority Ordering* (TMPO) [13], which is based on CDS and minimum determining set (MDS). TMPO uses two-hop neighborhood information to determine CDS and MDS.

Sahoo et al. [14] proposed a distributed power control protocol that constructs a power saving tree without taking the nodes local information into account. In their proposed approach, network topology is maintained by controlling the transmission power. Topology based on neighborhood information is constructed in *Adaptive Neighbor-based Topology Control* (ANTC) proposed by Mir and Ko [15], where the transmission range is determined adaptively in order to maintain connectivity. Based on the local connectivity, each node selects a backbone that guarantees a hierarchical topology structure. In the scheme proposed by Sheu et al. [16] transmission power is calculated considering sender maximum power, receiver minimum power, and the signal strength of the received packet. Both LFTC and ANTC do not put the node into sleep state to save energy. Gui and Liu [17] proposed a technique to optimize the delay and energy. They modeled link delays as a function of signal to interference noise ratio of the receiving node and its packet forwarding time in the link. The sum of delay and energy consumption is considered as the weight of an edge, and their objective was to find the minimum weight sum of any edge.

A prediction based data reduction strategy for sensor network is proposed in [18]. In this approach a hierarchical least mean square (HLMS) adaptive filter mechanism is used to maximize the lifetime of sensor nodes. Energy saving is achieved by reducing the actual data transmission between a source-sink pair. Both source and sink predict the value of sensed data; if the error is acceptable then sink can use predicted value. Otherwise the source will transmit the sensed data to sink. HLMC acheives better energy saving. However, in dynamic environment when link failure occurs due to node mobility its energy saving is a major concern. A tree based broadcast algorithm for wireless ad hoc network is proposed in [19]. The protocol uses two-hop neighborhood information through the exchange of *Hello* message to construct broadcast tree. The node in the broadcast tree assigned channels in a time-oriented way such that the message forwarded in the broadcast tree is collision free. Simulation results suggest that the protocol achieves lower broadcast redundancy and higher reachability.

A distributed energy efficient multicast routing algorithm is proposed in [20]. The protocol maximizes the lifetime of a source based multicast tree by considering both hop count and energy efficient metric. A weight is assigned to the cost metrics to assign the priority. This helps the protocol to use the cost metrics more efficiently.

A topology control technique *CoopSink* for ad hoc network is proposed in [21]. *CoopSink* considers cooperative communication (CC) employing decode-and-forward approach. CC is used to reduce energy consumption in the network and also provides efficient route to the destination node. The authors claim that *CoopSink* improves the network connectivity and has lower energy consumptions compared to other protocols. X-LMST, an extension of local minimum spanning tree (LMST), is proposed in [22]. Objective of X-MST is to build an energy efficient spanning tree to improve network lifetime. A cost function is proposed to measure the energy efficiency of a node. Network lifetime is enhanced by avoiding the transmission through energy critical nodes.

Two topology control techniques, node-to-cluster topology control (NCTC) and cluster-to-cluster topology control (CCTC), are proposed in [23]. NCTC and CCTC define two different types of links. In both schemes, cooperative links are employed to connect the clusters obtained by the initial topology. Higher energy saving and connectivity are maintained by NCTC and CCTC considering transmitter and receiver cooperation. However, both are based on centralized approach.

The protocols discussed in this section do not put the node to sleep state to save energy.

3. Proposed Work

In this section, we proposed a power conservation technique for ad hoc network, called *Location Based Topology Control with Sleep Scheduling* (LBTC). The proposed technique takes into the account the merits of both topology control and power management approach. It uses variable transmission power, like the topology control approach. A sleep scheduling mechanism is introduced where nodes are put to sleep state like the power management approach. However, a node in the proposed scheme goes to sleep state only when it is satisfied that its absence will not create a local partition in its neighborhood [24]. Section 3.1 describes the network model and notation used. The proposed scheme is presented in Section 3.2 and analyzed in Section 3.3.

3.1. Network Model and Notation. Wireless ad hoc network is modeled as a graph $G = (V, E)$, where V represents the set of nodes and E represents the set of edges. Network consists of n number of heterogeneous nodes randomly deployed in the network. Each node has a unique identity (ID) and is equipped with omnidirectional antenna. It is assumed that nodes are location aware and can calculate their relative distance to their neighboring nodes. Let $P_{\max}(u)$ be the maximum transmission power, let $P_{\min}(u)$ be the minimum transmission power, and let P_u be the transmission power of a node $u \in V$. Initially nodes transmit with maximum power $P_{\max}$. We assumed that transmission power $P(u)$ can be adjusted between the maximum and minimum value; that is, $P_{\min}(u) \leq P(u) \leq P_{\max}(u)$. Let P_{uv} be the minimum transmission power required to communicate between nodes u and v, which can be computed as $P_{uv} = D^{\beta} + C$, where D is the Euclidean distance between u and v, β is the path loss exponent, where $2 \leq \beta \leq 4$, and C is a constant. Let $G = (V, E)$ be the initial topology of the network and let $G' = (V, E')$ be the topology, obtained when the transmission power control mechanism is applied at nodes. We have further assumed that links are symmetric and the power control technique is applied within the neighborhood of a node.

3.1.1. Neighbor Set. One-hop neighbor set of node u denoted as N_u^1 is defined as the set of nodes that have a direct link to u, when it transmits with power $P(u)$, $P_{\min}(u) \leq P(u) \leq P_{\max}(u)$.

Two-hop neighbor set of node u denoted as N_u^2 is defined as the set of nodes that have a direct link to the nodes in the set N_u^1. This is represented as

$$N_u^2 = \bigcup_{x \in N_u^1} N_x^1. \tag{1}$$

The *common node* between u and v is denoted as $ComNode_{uv}$. A node is said to be a common node between u and v when it lies in the intersection area of nodes u and v. This is represented as

$$ComNode_{uv} = \left\{ i \mid i \in \left\{ N_u^1 \cap N_v^1 \right\} \right\}, \tag{2}$$

where N_u^1 and N_v^1 are the one-hop neighbor set of nodes u and v, respectively.

3.2. Location Based Topology Control with Sleep Scheduling (LBTC). The proposed scheme operates in two phase. First phase is the *link selection* phase, while the second is the *sleep scheduling* phase. In the *link selection* phase a node determines its transmission power. In *sleep scheduling* phase a node decides whether to go to sleep state or not depending on the present traffic condition and neighborhood connectivity. A node goes to sleep state only when it satisfies that its neighbors are reachable from each other without its active participation.

3.2.1. Link Selection Phase. In this phase a node u determines its transmission power that is enough to reach any of the nodes in the set N_u^1. Nodes periodically broadcast a *Hello* message with $P_{\max}$, which contains sender *ID* and location information of the sender. On receiving *Hello* message a node computes the transmission power required to transmit to the sender of the *Hello* message and updates its *vicinity* table which is maintained at each node. The structure of the vicinity table is as follows:

SenID.

LocInfo.

MinCost.

ComNode.

DirCost.

LinkType.

The meaning of each field in the vicinity table is explained as follows.

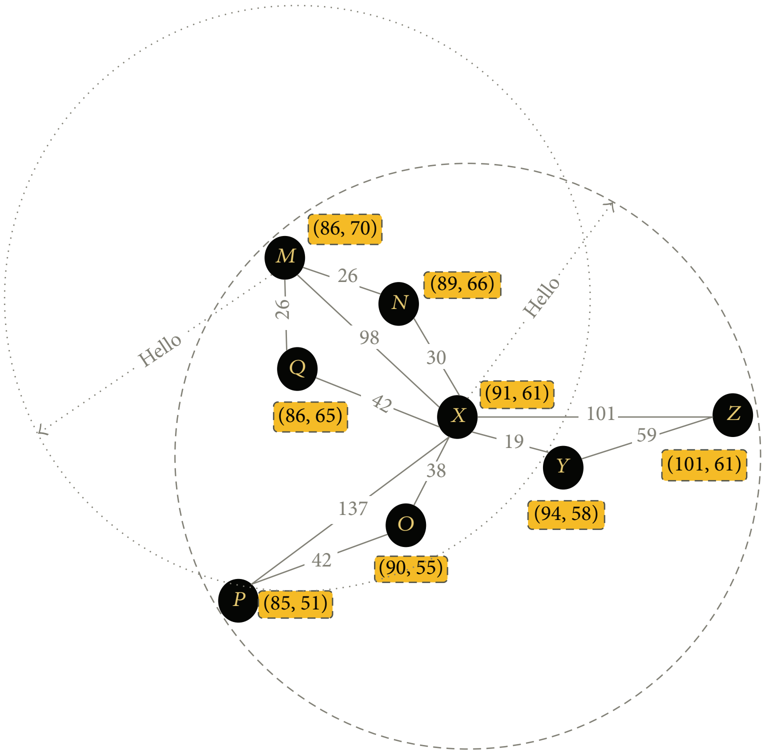


Figure 1: Nodes with location information.

SenID. It is identity of the node (Node ID), from which *Hello* message is received.

LocInfo. It is location information of the sender of *Hello* message.

DirCost. It is link cost from the node to the sender of the *Hello* message.

MinCost. It is minimum link cost between the current node and the sender. Current node is the node that is updating its vicinity table. Initially the value in this field is set to that of *DirCost*. This value is updated when there exists common node i between the current node and *SenID* such that transmission cost from the current node to *SenID* node through node i has lower total transmission cost than the *DirCost*.

ComNode. This field records the common node i through which there exists an energy efficient path between the current node and *SenID*. It is updated when there exists a common node i between u and v such that $P_{ui} + P_{iv} < P_{uv}$.

LinkType. It indicates whether the link between the current node and *SenID* is direct (one-hop) or indirect (more than one-hop). For direct the entry is *zero*, else it is *one*.

Initially, the vicinity table is empty and is updated when a node receives a *Hello* message from its neighbors. To illustrate the updation of vicinity table we consider Figure 1. Let node X with its current location (91, 61) receive a *Hello* message $(Z, (101, 61))$ from node Z, where coordinate (101, 61) is the current location of node Z. Then, the vicinity table of node X is updated as shown in Table 1. Node X computes the *DirCost* between itself and Z, which is computed to be 101, assuming $\beta = 2$ and $C = 1$. *DirCost* and *MinCost* field is set to 101 and the *LinkType* to *zero*. *ComNode* is set to *null* as no common node between X and Z exists at this stage.

Table 1: Vicinity table (node X) after receiving message from Z.

SenID	*LocInfo*	*MinCost*	*ComNode*	*DirCost*	*LinkType*
Z	(101, 61)	101	—	101	0

Table 2: Vicinity table (node X) after receiving message from neighbors.

SenID	*LocInfo*	*MinCost*	*ComNode*	*DirCost*	*LinkType*
Z	(101, 61)	101	—	101	0
Y	(94, 58)	19	—	19	0
M	(86, 70)	98	—	98	0
N	(89, 66)	30	—	30	0
P	(85, 51)	137	—	137	0
O	(90, 55)	38	—	38	0
Q	(86, 65)	42	—	42	0

Vicinity table of node X after receiving *Hello* message from all its neighbor is shown in Table 2. After gathering information about its neighbor, node X determines whether there exists any *ComNode* between itself and its neighbor. Nodes Y, N, and O are the *ComNode* between X and Z, X

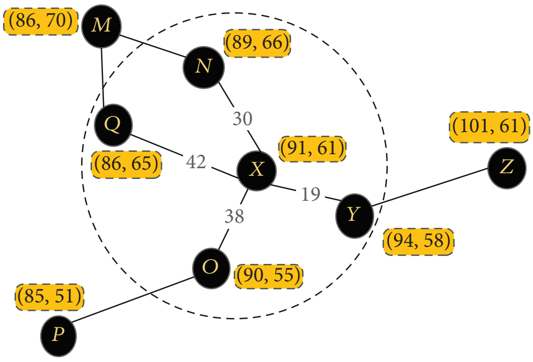


FIGURE 2: Resulting topology of node X after link selection phase.

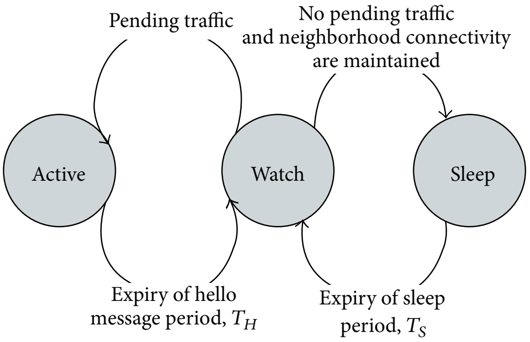


FIGURE 3: State transition in LBTC.

and M, and X and P, respectively. There can be more than one node within the transmission range of a pair of nodes. Only that node is selected as the *ComNode* through which the cost between the pair of nodes is minimum. For example, nodes N, O, P, and Q are within the transmission range of nodes X and M. But node O is selected as the *ComNode* between X and M. After obtaining the *ComNode*, node X updates the *LinkType*, *ComNode*, and *MinCost* field in its vicinity table. The updated vicinity table is shown in Table 3. From the table it is observed that the cost of transmitting from X to Z through node Y is 78, whereas the direct cost is 101. Similarly, the cost of transmitting from X to P through O is 80, whereas the direct cost is 137.

TABLE 3: Vicinity table (node X) after determining the *ComNode* between itself and its neighbor.

SenID	*LocInfo*	*MinCost*	*ComNode*	*DirCost*	*LinkType*
Z	(101, 61)	78	Y	101	1
Y	(94, 58)	19	—	19	0
M	(86, 70)	56	N	98	1
N	(89, 66)	30	—	30	0
P	(85, 51)	80	O	137	1
O	(90, 55)	38	—	38	0
Q	(86, 65)	42	—	42	0

From the updated vicinity table, node X computes its transmission power for which it considers only those nodes where the *LinkType* field is set to *zero*. Node X considers nodes Y, N, O, and Q as the *LinkType* field to these nodes which is set to *zero*. The transmission power of a node is the maximum value in the *DirCost* field of those nodes considered for computing transmission power. Node X determines its transmission power, which is the maximum value in the *DirCost* field of nodes Y, N, O, and Q; that is, $\max(19, 30, 38, 42) = 42$. The resulting topology as seen by node X after the *link selection* phase is shown in Figure 2. It is observed that node X has lesser number of one-hop neighbors than previous as seen in Figure 1.

3.2.2. Sleep Scheduling Phase. In this phase a node decides whether to enter into sleep state or not, depending on the traffic pattern and neighborhood connectivity information. A node remains in one of the following three states: (i) active, (ii) watch, and (iii) sleep. In *active* state nodes participate in data communication and periodically broadcast a *Hello* message. After the expiry of *Hello* message period, T_H, nodes enter into a *watch* state. In *watch* state, a node decides whether to go to *active* state or to *sleep* state. In *active* and *watch* state the radio transceiver of a node is turned on, whereas it is turned off in *sleep* state. A node in sleep state wakes up at the end of sleep time, T_S, and enters into *watch* state. The state transition diagram between states is shown in Figure 3. In

```
(1) $Q$: No. of neighbor of $u$, where $u$ executes the algorithm
(2) $X(n)$: Is a set maintained for node $n$, where $n \in N_u^2$
(3) CM: Connectivity matrix of order $Q \times Q$
(4) /* Initialize */
(5) $\forall x, y$ CM$[x][y]$ = FALSE
(6) $X(n) \leftarrow \emptyset$
(7) procedure Local connectivity
(8)   for $i \in N_u^1$ do
(9)     for each $j \in N_i^1$ do
(10)      if $j \in N_u^1$ then
(11)        Set CM$[j][i]$ = CM$[i][j]$ = TRUE
(12)      else
(13)        $X(n) = X(n) \cup \{i\}$
(14)      end if
(15)    end for
(16)  end for
(17)  for $n \in N_u^2$ do
(18)    if $|X(n)| \geq 2$ then
(19)      $\forall (a, b) \in X(n)$
(20)      Set CM$[a][b]$ = CM$[b][a]$ = TRUE
(21)    end if
(22)  end for
(23)  /* Adjust CM */
(24)    if CM$[x][y]$ = CM$[y][z]$ = TRUE then
(25)      Set CM$[x][z]$ = TRUE
(26)    end if
(27)    if $\exists (a, b) \in N_u^1$ and $CM[a][b] = FALSE$ then
(28)      goto active state
(29)    else
(30)      goto sleep state
(31)    end if
(32) end procedure
```

Algorithm 1: Sleep eligibility algorithm.

Table 4: Simulation parameters.

Simulator	QualNet 4.5
Terrain-dimension (meters)	1500 * 1500
Number of nodes	50–100
Node speed	Max = 10 m/s, min = 0 m/s
Traffic type	CBR
Channel frequency	2.4 GHz
Mobility model	Random waypoint
Propagation limit	−111 dbm
Transmit current	220 mA
Receive current	180 mA
MAC protocol	802.11b
Size of packets	512 bytes
Initial battery capacity	300 mAH

the watch state, a node decides whether to go to active state or sleep state. If the node has some pending traffic, it returns to *active* state; otherwise it executes a *sleep eligibility* algorithm, to check whether it can enter into the sleep state.

When a node goes to sleep state it may create a local partition, within its neighborhood. For example, a critical node on a path, when goes to sleep state, creates a local partition. This is because when a critical node goes to sleep state, all paths through that node are broken, and any ongoing traffic through that node gets disturbed. Therefore, before going to sleep state, a node checks whether its absence will create any local partition. In the *watch* state a node checks for the local partition. If the node has no traffic to participate and its absence does not create a local partition, then the node goes to sleep sate. A node in *watch* state, having no traffic to transmit, executes the sleep eligibility algorithm given as Algorithm 1.

Assuming that Δ is the maximum degree of a node, the running time of steps (7)–(16) is $O(\Delta^3)$. In steps (17)–(22), node u does the following for each of its N_u^2. If the length of $X(n) \geq 2$, for each pair of $(a, b) \in X(n)$, it initializes $\mathrm{CM}[a][b] = \mathrm{CM}[b][a]$. Maximum length of $X(n)$ will be Δ. So the running time of steps (17)–(22) is $O(\Delta^2)$. Running time of steps (24)–(26) and (27)–(31) are constant. So total running time of Algorithm 1 is $O(\Delta^3)$.

3.3. Analysis

3.3. Analysis. In this subsection, we analyze the network connectivity in the proposed scheme.

Theorem 1. *If two nodes are connected before the link selection phase, then they are also connected after the link selection phase.*

Proof. Let $G = (V, E)$ be the network topology before the *link selection* phase and let $G' = (V, E')$ be the network topology after the *link selection* phase. We have to show that, for any $u, v \in V$, if there exists a path in G, then there also exists a path from u to v in G'.

Since G is connected, for any $u, v \in V$, there exists a path from u to v in G. Let the path be $u \overset{k}{\rightarrow} v$, where k is the number of links in the path from u to v. We show by means of induction that there also exists a path from u to v; that is, $u \overset{k'}{\rightarrow} v$, with k' being number of links in G', where $k' \geq k$.

Let $k = 1$, which means that node v is within the transmission range of node u in G. In G', v will be in either one-hop or two-hop neighbor of u. Therefore, a path from u to v exists in G'.

Let us assume that it is true for $k = n$; that is, there exists a path in G from u to v with n number of links. Therefore, there also exists a path from u to v in G', and the number of links in the path is greater than or equal to n.

Let $k = n + 1$; then the path from u to v with $n + 1$ number of links in G is shown in Figure 4.

The path in Figure 4 can be interpreted as two subpaths one from u to v' with n number of links and the other from v' to v with single link in G. From the induction hypothesis, we know that if there exists a path from u to v' in G with n links then there exists a path from u to v' in G'. From the basis, we know that if there exists a path from v' to v with single link in G then there exists a path from v' to v in G'. Hence there

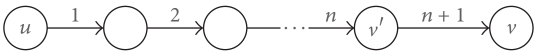
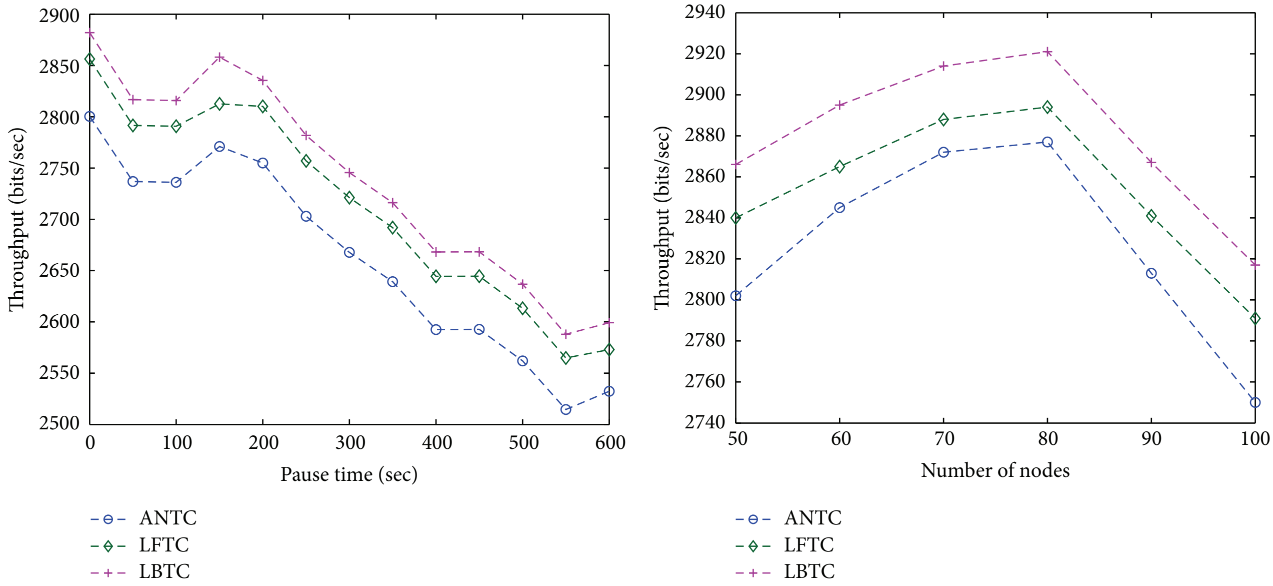
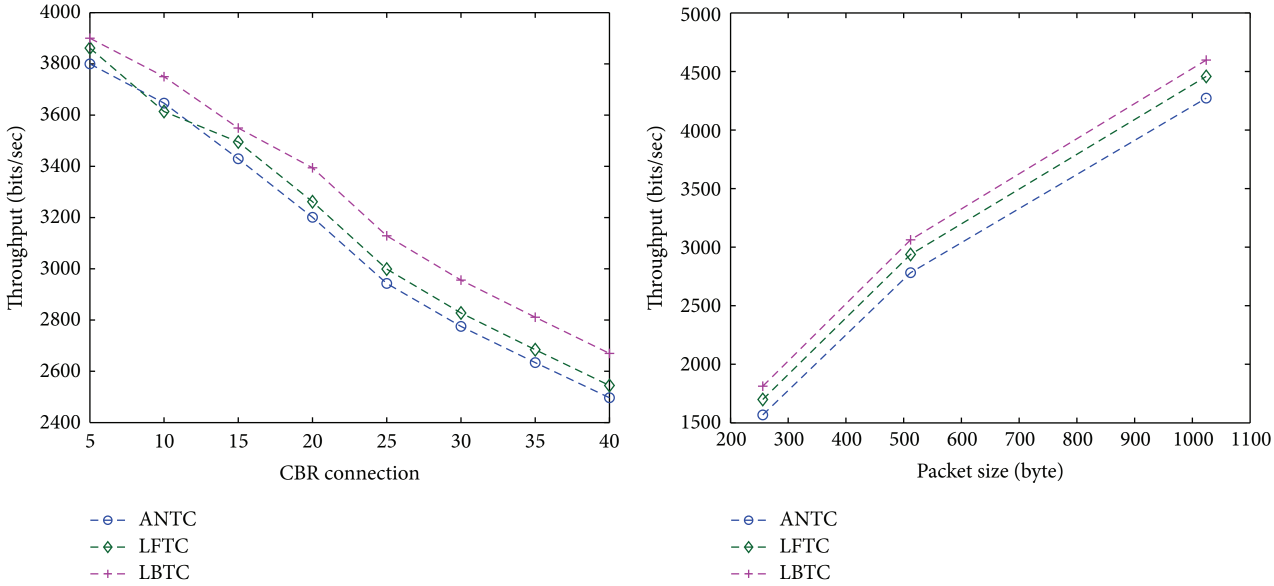


Figure 4: Exemplary network.



(a) Throughput versus pause time

(b) Throughput versus number of nodes



(c) Throughput versus CBR connection

(d) Throughput versus packet size

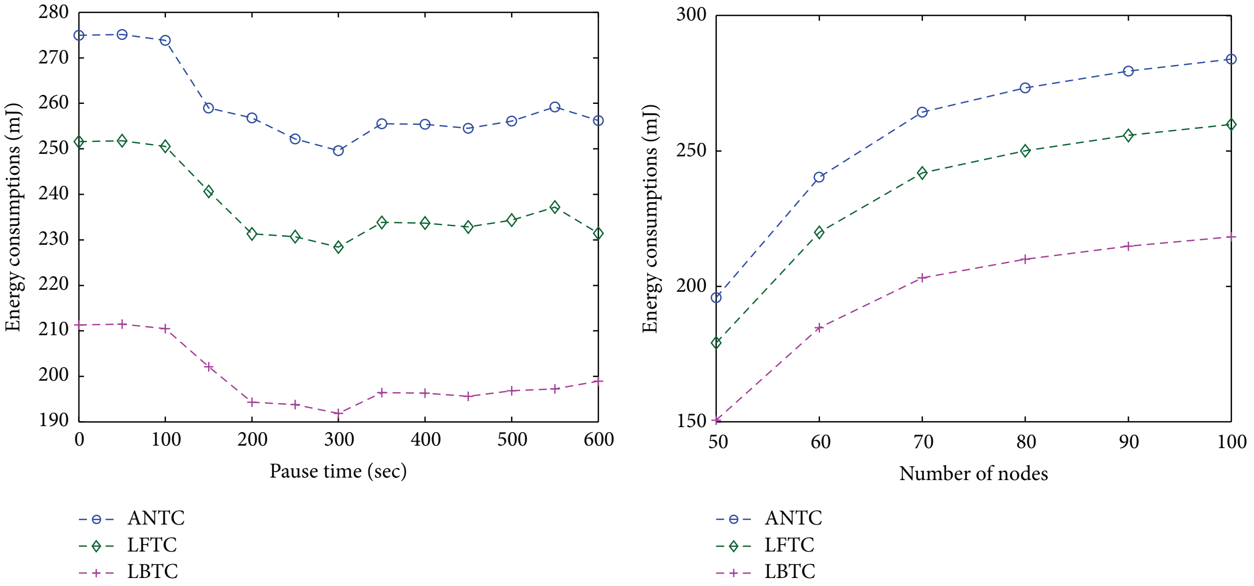
Figure 5: Network throughput.

exists a path from u to v in G'. Therefore if G is connected then G' is also connected. $\square$

In the *sleep scheduling* phase each node checks the local connectivity within its neighborhood. Partition in a network means global partition, which is not the same as that of local partition. In the process of maintaining local connectivity there always exists a node redundancy due to false alarm of network partition. Therefore, connectivity is always maintained in the proposed scheme.

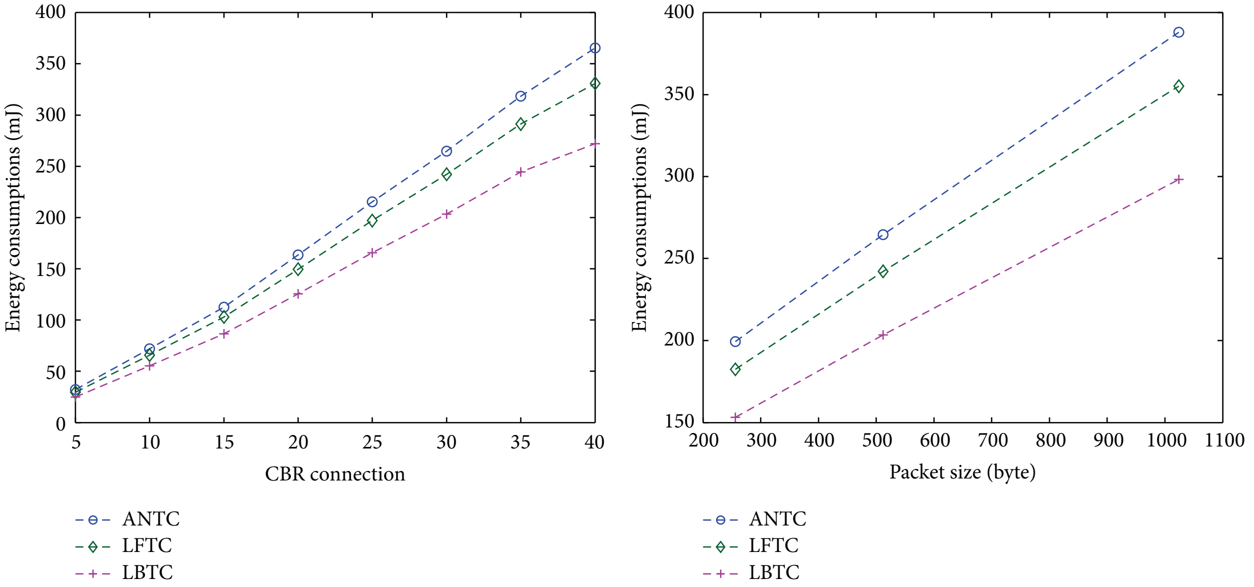
4. Simulation and Comparison

We simulated the proposed technique using QualNet 4.5 [25] simulator to evaluate its performance. The parameters considered for simulation are shown in Table 4.



(a) Energy consumption versus pause time

(b) Energy consumption versus number of nodes



(c) Energy consumption versus CBR connection

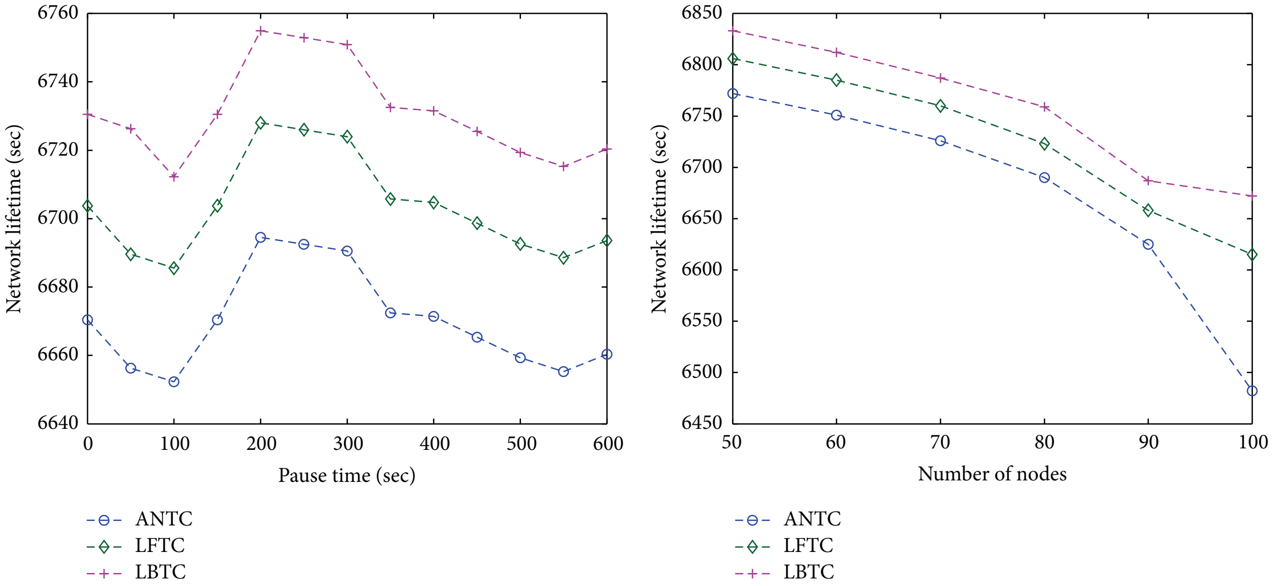
(d) Energy consumption versus packet size

Figure 6: Energy consumption.

For the comparison, we consider two topology control protocols, LFTC [16] and ANTC [15]. Lifetime of *Hello* message is set to *two* sec and *Hello* message interval to *one* sec. The following metrics were considered for performance evaluation.

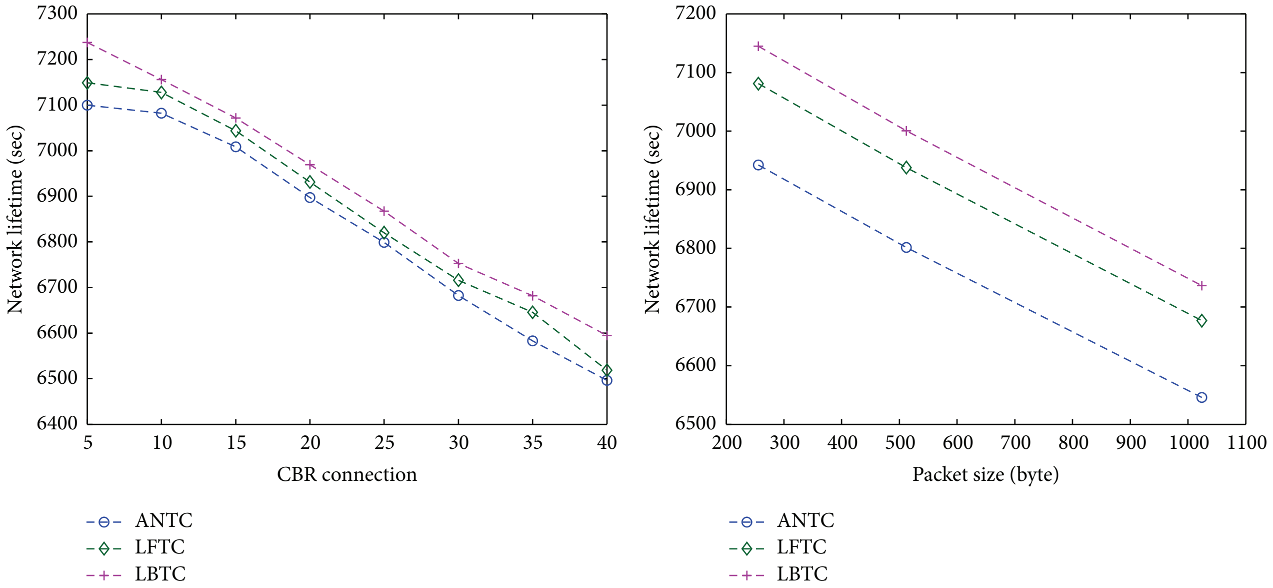
4.1. Throughput. We plot the throughput versus pause time, number of nodes, CBR connection, and packet size in Figures 5(a), 5(b), 5(c), and 5(d), respectively. From Figure 5, it is observed that a higher throughput is attainable in the proposed scheme. Higher throughput is attributed to the increase in longevity of the network due to proper adjustment of transmission power in the *link selection* phase and energy saving in the *sleep scheduling* phase.

4.2. Energy Consumption. Energy consumption determines the effectiveness of energy saving scheme. We consider the energy model in [26] for measuring the energy consumption. The plot for energy consumption versus pause time, number of nodes, CBR connection, and packet size is shown in Figures 6(a), 6(b), 6(c), and 6(d), respectively. It is observed from Figure 6 that the proposed LBTC scheme has lower energy consumption. This is because LBTC selects energy efficient links and nodes are put to



(a) Network lifetime versus pause time

(b) Energy consumption versus number of nodes



(c) Energy consumption versus CBR connection

(d) Energy consumption versus packet size

Figure 7: Network lifetime.

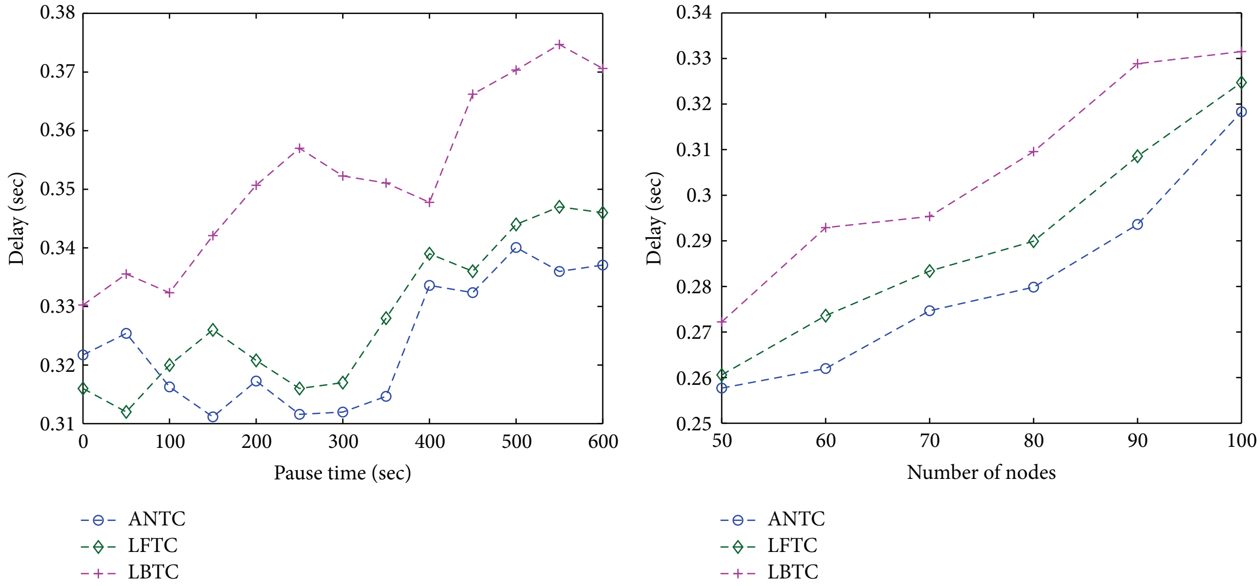
sleep state, if they do not actively participate in ongoing transmission.

4.3. Network Lifetime. The plot for network lifetime versus pause time, number of nodes, CBR connection, and packet size is shown in Figures 7(a), 7(b), 7(c), and 7(d), respectively. It is observed that LBTC gives a superior network lifetime because it is energy efficient.

4.4. Delay. The plot for delay versus pause time, number of nodes, CBR connection, and packet size is shown in Figures 8(a), 8(b), 8(c), and 8(d), respectively. From Figure 8, it is observed that LBTC has higher end-to-end delay as compared to LFTC and ANTC. This is due to increase in hop count as nodes transmit with lower power. This observation is consistent with the published report that the average end-to-end delay increases when the transmission power control mechanism is applied [27].

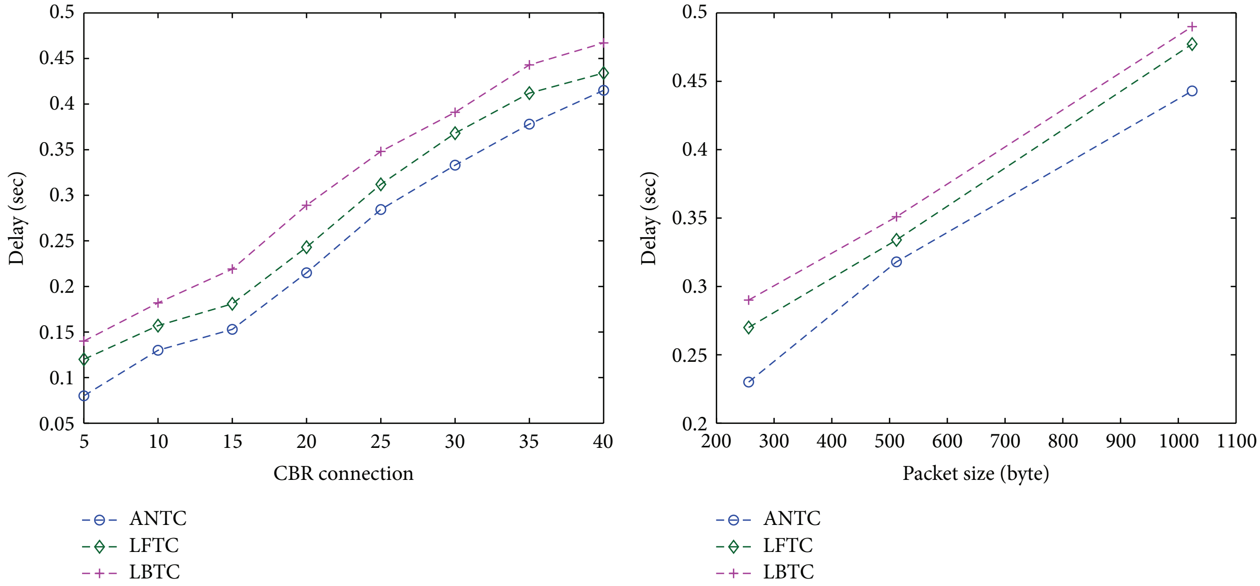
5. Conclusion

In this paper, we proposed a hybrid energy efficient protocol called LBTC for ad hoc network. The proposed protocol considers the merits of both topology control scheme and



(a) End-to-end delay versus pause time

(b) End-to-end delay versus number of nodes



(c) End-to-end delay versus CBR connection

(d) End-to-end delay versus packet size

FIGURE 8: End-to-end delay.

power management scheme. It selects energy efficient links, and nodes which do not actively participate in communication are put to sleep state. LBTC is compared with two existing schemes and observed that it is more energy efficient and delivers higher throughput. However, the end-to-end delay is higher. This is because as the transmission power is controlled, packets take more number of hops to travel the destination. In future, we intend to reduce end-to-end delay with enhancing the network lifetime.

Competing Interests

The authors declare that they have no competing interests.

References

[1] M. Krunz, A. Muqattash, and S. J. Lee, "Transmission power control in wireless ad hoc networks: challenges, solutions, and open issues," *IEEE Network Magazine*, vol. 18, no. 5, pp. 8–14, 2004.

[2] M. Chiang, "Balancing transport and physical layers in wireless multihop networks: jointly optimal congestion control and power control," *IEEE Journal on Selected Areas in Communications*, vol. 23, no. 1, pp. 104–116, 2005.

[3] J. Gomez and A. T. Campbell, "Variable-range transmission power control in wireless ad hoc networks," *IEEE Transactions on Mobile Computing*, vol. 6, no. 1, pp. 87–99, 2007.

[4] X. Zhang, A. Anpalagan, L. Guo, and A. S. Khwaja, “Energy-efficient cooperative MAC protocol based on power control in MANETs,” in *Proceedings of the IEEE 29th International Conference on Advanced Information Networking and Applications (AINA ’15)*, pp. 48–53, IEEE, Gwangju, Republic of Korea, March 2015.

[5] IEEE 802.11 Working Group, *Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specification*, IEEE, 1999.

[6] G. De-yun, Z. Lin-juan, and W. Hwang-cheng, “Energy saving with node sleep and power control mechanisms forwireless sensor networks,” *The Journal of China Universities of Posts and Telecommunications*, vol. 18, no. 1, pp. 49–59, 2011.

[7] S. Wu, P. Tseng, and Z. Chou, “Distributed power management protocols for multi-hop mobile Ad Hoc networks,” *Computer Networks*, vol. 47, no. 1, pp. 63–68, 2005.

[8] R. Zheng and R. Kravets, “On-demand power management for ad hoc networks,” *Ad Hoc Networks*, vol. 3, no. 1, pp. 51–68, 2005.

[9] N. K. Ray and A. K. Turuk, “A review on energy efficient MAC protocols for wireless LANs,” in *Proceedings of the 4th International Conference on Industrial and Information Systems (ICIIS ’09)*, pp. 137–141, Peradeniya, Sri Lanka, December 2009.

[10] P. Santi, “Topology control in wireless ad hoc and sensor networks,” *ACM Computing Surveys*, vol. 37, no. 2, pp. 164–194, 2005.

[11] Y. Xu, J. Heidemann, and D. Estrin, “Geography-informed energy conservation for Ad hoc routing,” in *Proceedings of the 7th Annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom ’01)*, pp. 70–84, Rome, Italy, July 2001.

[12] B. Chen, K. Jamieson, H. Balakrishnan, and R. Morris, “SPAN: an energy efficient co-ordination algorithm for topology maintenance in Ad Hoc wireless networks,” *ACM, Wireless Networks Journal*, vol. 8, no. 5, pp. 481–494, 2002.

[13] L. Bao and J. J. Garcia-Luna-Aceves, “Stable energy-aware topology management in ad hoc networks,” *Ad Hoc Networks*, vol. 8, no. 3, pp. 313–327, 2010.

[14] P. K. Sahoo, J.-P. Sheu, and K.-Y. Hsieh, “Power control based topology construction for the distributed wireless sensor networks,” *Computer Communications*, vol. 30, no. 14-15, pp. 2774–2785, 2007.

[15] Z. H. Mir and Y. Ko, “Adaptive neighbor-based topology control protocol for wireless multi-hop networks,” *EURASIP Journal on Wireless Communications and Networking*, vol. 2012, article 97, 2012.

[16] J. Sheu, S. Tu, and C. Hsu, “Location free topology control protocol in wireless ad hoc networks,” *Computer Communications*, vol. 31, no. 14, pp. 3410–3419, 2008.

[17] J. Gui and A. Liu, “A new distributed topology control algorithm based on optimization of delay and energy in wireless networks,” *Journal of Parallel and Distributed Computing*, vol. 72, no. 8, pp. 1032–1044, 2012.

[18] L. Tan and M. Wu, “Data reduction in wireless sensor networks: a hierarchical LMS prediction approach,” *IEEE Sensors Journal*, vol. 16, no. 6, pp. 1708–1715, 2016.

[19] L. Tan, X. Zhan, J. Li, and F. Zhao, “A novel tree-based broadcast algorithm for wireless ad hoc networks,” *International Journal of Wireless and Mobile Computing*, vol. 1, no. 2, pp. 156–162, 2006.

[20] S. Zhao, L. Tan, and J. Li, “A distributed energy efficient multicast routing algorithm for WANETs,” *International Journal of Sensor Networks*, vol. 2, no. 1-2, pp. 62–67, 2007.

[21] T. F. Neves and J. L. Bordim, “Topology control in cooperative ad hoc wireless networks,” *Electronic Notes in Theoretical Computer Science*, vol. 302, pp. 29–51, 2014.

[22] D. Shang, B. Zhang, Z. Yao, and C. Li, “An energy efficient localized topology control algorithm for wireless multihop networks,” *Journal of Communications and Networks*, vol. 16, no. 4, pp. 371–377, 2014.

[23] K. Moon, D.-S. Yoo, W. Lee, and S.-J. Oh, “Receiver cooperation in topology control for wireless ad-hoc networks,” *IEEE Transactions on Wireless Communications*, vol. 14, no. 4, pp. 1858–1870, 2015.

[24] N. K. Ray, *Techniques to enhance the lifetime of mobile ad hoc networks [Ph.D. thesis]*, National Institute of Technology, Rourkela, India, 2013.

[25] Qualnet 4.5, 2008, http://www.scalable-networks.com/.

[26] L. M. Feeney, “An energy consumption model for performance analysis of routing protocols for mobile ad hoc networks,” *Mobile Networks and Applications*, vol. 6, no. 3, pp. 239–249, 2001.

[27] P. Siripongwutikorn and B. Thipakorn, “Mobility-aware topology control in mobile ad hoc networks,” *Computer Communications*, vol. 31, no. 14, pp. 3521–3532, 2008.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