ARTICLE IN PRESS

Simulation Modelling Practice and Theory xxx (2010) xxx–xxx

Contents lists available at ScienceDirect

Simulation Modelling Practice and Theory

journal homepage: www.elsevier.com/locate/simpat

Energy-aware weighted graph based dynamic topology control algorithm

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ARTICLE INFO

Article history:
Received 30 May 2010
Received in revised form 31 August 2010
Accepted 18 September 2010
Available online xxxx

Keywords:
Network lifetime
Weighted graph
Topology control

ABSTRACT

In this paper a new energy-aware weighted dynamic topology control (WDTC) algorithm is proposed to extend the lifetime of wireless network and balance the nodes' energy consumption. The idea is that each node builds its local minimum spanning tree (MST) based on the energy-aware weighted graph and the network topology is adjusted accordingly. It was proved theoretically that the topology under WDTC algorithm could preserve the network connectivity and a sufficient condition for the degree of no more than 6 was also given. Simulation shows that WDTC algorithm can effectively prolong the network lifetime and has good topological features.

1. Introduction

Due to the emergence of affordable and portable wireless communication devices and the advances in the wireless communication techniques, wireless networks attract much attention nowadays [1]. However, battery-powered wireless networks are typically troubled with limited energy supplies and serious radio interference. Therefore, energy conservation and radio interference reduction are becoming two core issues in wireless networks.

Topology control could effectively solve the two problems. The main idea of topology control is that, instead of transmitting with the maximal power, nodes collaboratively determine their transmission power and generate the network topology by forming the proper neighbor relation under certain criteria, with the purpose of maintaining connectivity while reducing energy consumption and radio interference [2]. As the basis of designing effective high-layer protocols, ideal network topology should be connected, sparse, light weighted, and fault-tolerant while having bounded degree, small diameter and small load factor [3]. According to these criteria, researchers proposed many topology control algorithms [2,5–17].

Topology control algorithms construct a sparse spanning subgraph in an edge-dense graph, while most of algorithms aim to optimize the energy consumption. It is proved that this problem in two and three-dimensional networks is NP-hard [4]. Some sparse geometric structures such as minimum spanning tree (MST), Relative Neighbor Graph (RNG), Gabriel Graph (GG), Delaunay triangulation (DT) and Yao-Graph (YG) have been used for topology control. Li and Hou [2] proposed the Local MST (LMST), which is a fully distributed and localized protocol. LMST builds a connected global MST-like topology with only bidirectional links. The authors also proved that the degree of each node is bounded by 6. LMST outperforms the most topology control algorithms, which will be shown in Section 2; Borbash and Jennings [5] proposed a distributed protocol (denoted RNG), aiming to construct a RNG of the network. The algorithm can preserve the network connectivity and shows satisfactory performance in the term of network diameter; Wattenhofer and Zollonger

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doi:10.1016/j.simpat.2010.09.002

[6] proposed a distributed cone based topology control protocol called CBTC, which uses direction information to build topology and can preserve the connectivity of the network. Wang et al. [7] presented a localized algorithm for constructing GG of the given network. The topology constructed under this algorithm has a constant bounded power stretch factor; Li [8] proposed a distributed topology control algorithm, utilizing Yao-Graph to build a topology with a constant length and power stretch factor; Li [9] presented a localized protocol based on Delaunay triangulation. The constructed topology is a planar 2.5-spanner of the original graph.

There are other neighbor-based protocols such as MobileGrid [10], LINT [11], k-neighbor [12] and XTC [13]. These algorithms restrict the number of the neighbor into a certain interval. In some cases, the network connectivity can not be guaranteed. Additionally, some topology control algorithms [14–17] focusing on mitigating interference have been presented recently.

All these mentioned algorithms perform well to a certain extent in reducing energy consumption and radio interference. However, the sparseness of the topology constructed under these algorithms and the uneven distribution of the transmission power for each node resulted in unbalanced energy consumption of each node during the service of network. In addition, the network topology is not adjusted with the energy accordingly in these algorithms. This leads to high energy consumption by minority of nodes and low consumption by major nodes. The unbalance seriously constrains the network lifetime. If the topology is adjusted dynamically with the node energy consumption, and then the transmission power, as well as the traffic load, for each node will be redistributed accordingly, the network lifetime will be effectively extended. Literatures [18–20] have shown that the network lifetime could be prolonged to some extent by adjusting the unbalanced node energy consumption. Unfortunately, the topology qualities in terms of logical degree, physical degree, and transmission radius degrade a lot relative to LMST. In this paper, we propose a weighted graph based dynamic topology control algorithm WDTC derived from LMST algorithm. Compared with previous algorithms [18–20], WDTC is superior to them in the following two aspects: (1) the topology constructed by WDTC inherits the attractive features from LMST such as lower logical degree, lower physical degree, lower transmission radius and bidirectional property (2) a sufficient condition for bounding the logical degree by 6 is given.

The rest of paper is organized as follows. In Section 2, we first analyze LMST and explain its advances to other known topology algorithms, and then present WDTC algorithm. In Section 3, we theoretically prove the connectivity of the topology generated by this algorithm, and give a sufficient condition for bounding the degree by 6. After that, we demonstrate the effectiveness of WDTC through simulation in Section 4 and conclude the paper in Section 5.

2. WDTC algorithm

Since WDTC is based on LMST, we will introduce LMST and compare it with some known topology algorithms at first. LMST has three salient properties: (1) the topology constructed preserves the network connectivity; (2) the node logical degree in the resulting topology is no more than 6; and (3) the topology has only bidirectional links.

In this section, simulation results will demonstrate that the topology constructed by LMST has the best performance in terms of logical degree, physical degree and transmission radius among the most present algorithms.

However, in LMST-built MST-like topology, the traffic load and the transmission power distributions for each node are greatly unbalanced. As a result, the energy consumption of node is badly unbalanced so that the network lifetime is limited.

To address the disadvantage of LMST, a fully localized and distributed protocol called WDTC is proposed to extend the network lifetime, while the topology quality of WDTC is almost competitive to LMST.

2.1. LMST algorithm

We denote the wireless multi-hop network as an undirected simple graph $G = (V, E)$, where V is the set of nodes, $E = \{(u, v) : d(u, v) \leqslant d_{\max}, u, v \in V\}$ is the set of edges, $d_{\max}$ is the maximal transmission rang of each node. The node location is given. The visible neighborhood for each node is defined as $NV_u = \{v \in V(G) : d(u, v) \leqslant d_{\max}\}$. $G_u = (NV_u, E_u)$ is denoted as the induced subgraph of G. LMST is composed of the following four steps.

(1) Information collection: Each node periodically broadcasts a Hello message with its maximal transmission power to get the visible neighborhood NV_u. Node u constructs its G_u using the neighbor location information.
(2) Topology construction: Each node builds its local MST of the geometric graph G_u. Node u takes one-hop on-tree nodes in its local MST as its neighbors in the resulting topology G_0. Thus each node has determined its neighbor set and the network topology G_0 is generated.
(3) Determination of transmission power: Each node adjusts its transmission power so that it can reach the farthest neighbor.
(4) Construction of topology with only bidirectional edges: Some links of G_0 may be unidirectional. Two ways can achieve a topology with only bidirectional links: (1) to enforce all the unidirectional edges in G_0 to be bidirectional (2) to delete all the unidirectional edges in G_0.

2.2. Performance evaluation of LMST

In this part, we present several sets of simulation results to show the advances of LMST compared with CBTC and RNG, two other algorithms closest to LMST. It has been proved that for any set of points N in the plane, RNG(N) $\subseteq$ GG(N), RNG(N) $\subseteq$ DT(N) and RNG(N) $\subseteq$ YG(N) [21], so we do not compare LMST against the algorithms in [6–8]. The reason why we do not compare LMST with MobileGrid [10], LINT [11], k-neighbor [12] and XTC [13] is that these algorithms can not guarantee the network connectivity in all the cases. Other algorithms mentioned in section one aim to optimize the interference instead of the energy, so it is unnecessary to compare LMST with these algorithms.

We will evaluate six performance metrics for LMST, CBTC and RNG, including:

(1) Average/maximum logical degree: a lower average/maximum logical degree usually means a simplified routing topology and implies less routing control message exchanges.
(2) Average/maximum physical degree: a lower average/maximum physical degree usually implies less contention, lower interference and higher network capacity.
(3) Average/maximum transmission radius: a smaller average/maximum transmission radius means more energy efficiency.

N nodes are randomly distributed in a 1000 m × 1000 m region and each node's transmission range is d_{max} = 250 m. The node number n varies from 80 to 200. Each data point is the average of 1000 simulation runs. The performance of the topologies derived from CBTC, RNG and LMST is shown in Fig. 1. We can see that LMST outperforms CBTC and RNG in all six metrics. Fig. 1a and b show that the average logical and physical degree under LMST decrease as the node number n increases, while the other two algorithms are on the contrary. Fig. 1c and f depict the average and maximum transmission radius respectively. It is shown that building a topology by LMST consumes the least energy among all three algorithms. From Fig. 1e, it could be observed that the maximum physical degree of the topology generated form LMST varies slightly with the node density while that of others increases obviously.

Simulation results show that the topology under LMST outperforms CBTC and RNG in routing overhead, interference and energy efficiency.

LMST generates a topology close to the global minimum spanning tree (MST). As we know, a tree has the least edges among all the connected spanning subgraghs. The sparseness of the topology will result in the elimination of redundant routing paths between source and destination, so the traffic load of each node is seriously unbalanced. In addition, each node has different transmission radius only determined by the network node location, thus the power of each node for transmitting a package is also greatly different. Based on the fact that the traffic load and transmission radius determine each node's energy consumption during a certain period, node energy consumption distribution in LMST is severely uneven. The minority of nodes are drained of energy prematurely while the majority of nodes have enough energy to work. The energy imbalance among nodes restricts the network lifetime. Fig. 2 shows the average node energy consumption distribution of 100 topologies built by LMST during a period of T. The number of nodes is 100, 150 and 200 respectively. We denote the

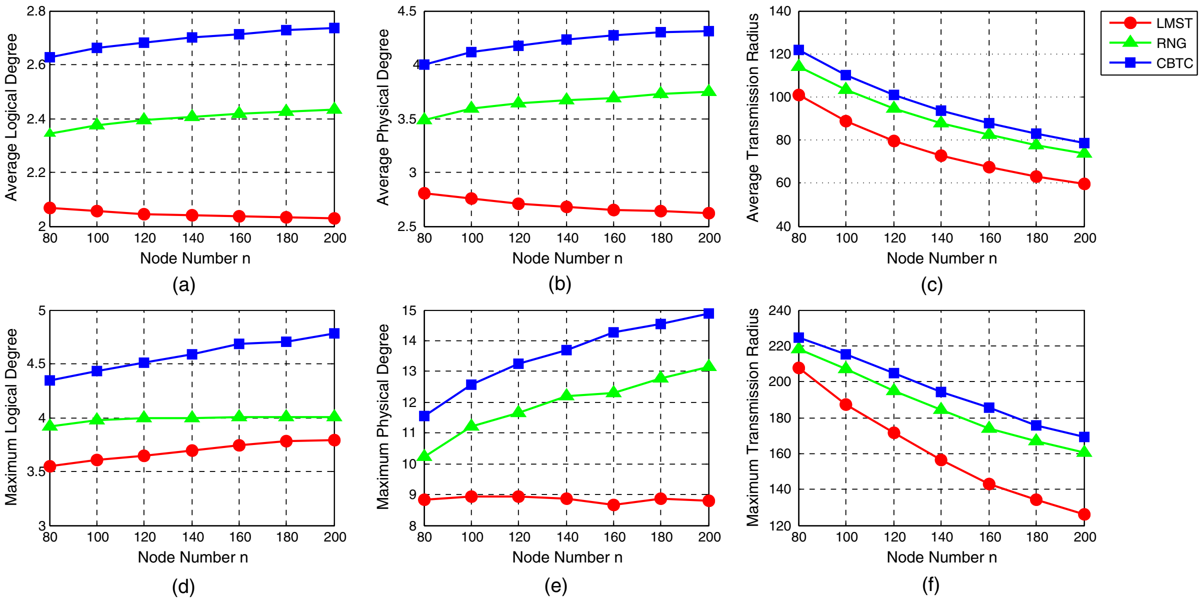

Fig. 1. Performance evaluation of LMST.

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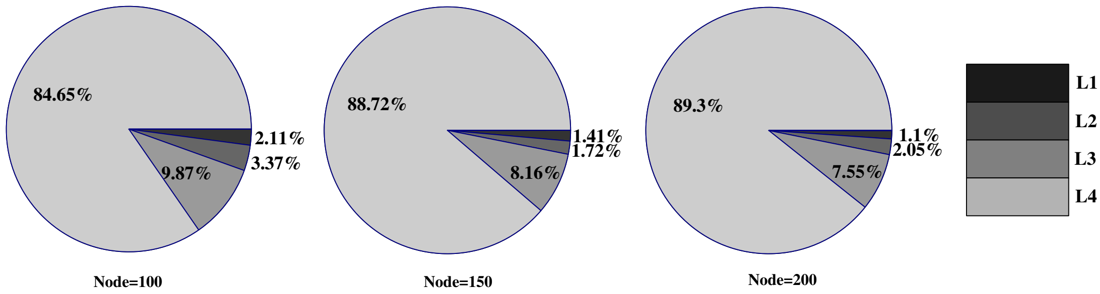

Fig. 2. Energy consumption distribution.

maximum energy consumption of all nodes as P_{max}, and then we divide the interval [0 P_{max}] into four equal subintervals, L1, L2, L3 and L4 respectively. L1 = (75%P_{max} P_{max}]; L2 = (50%P_{max} 75%P_{max}]; L3 = (25%P_{max} 50%P_{max}]; L4 = [0%P_{max} 25%P_{max}].

For example, in the case that the node number is 200, only 1.1% nodes lie in L1 while the majority nodes of 89.3% stay in the low energy consumption level L4. These 1.1% nodes will exhaust their energy in advance, and thus impact the normal network work. Meanwhile 89.3% nodes have great potential. To address this disadvantage, we propose a solution in the next part.

2.3. WDTC

As mentioned above, LMST has the disadvantage of unbalanced energy consumption and limited network lifetime. The topology generated by LMST does not change as long as the node location keeps unchanged. Consequently, the minority of nodes keep their high energy consumption all the time until they die from energy exhaustion, while the majority of nodes have enough residual energy. To make the cumulative energy consumption distributed uniformly among nodes, the topology should be adjusted accordingly. A new topology incurs a new traffic load and new transmission radius distribution among nodes. The value of the total node energy consumption thus fluctuates in different periods. Consequently, the network lifetime will be prolonged and the accumulative energy of all nodes will tend to equilibrium.

For this purpose, we present WDTC algorithm, which adds energy information to the construction of topology instead of the only geometric information as LMST does. In WDTC, the geometric graph is changed into a weighted graph through an edge weight function. Then each node builds the MST in the new weighted graph. At each period, the edge weight is different so that the resulting MST is different too. The main idea is shown as Fig. 3.

At initial time T_0, as shown in Fig. 3a, node u builds its local MST T_{u0} in a geometric graph G_{u0} as LMST does. Node u' neighbor set is $\{v_1, v_2, v_3\}$ in the resulting topology. At the time T_1, G_{u0} has been changed to a weighted graph G_{u1} that contains energy information through edge weight function $W(T_1)$. Node u constructs a new MST T_{u1} in G_{u1}. Now node u' neighbor set is changed to $\{v_1, v_2\}$. Similarly, at the time T_2, node u' neighbor set is $\{v_1\}$. Node u changes from a node of degree 3 at T_0 to a leaf node at T_2. Accordingly, the transmission radius of node u decreases from $|uv_2|$ to $|uv_1|$, where $|uv_2|$ and $|uv_1|$ denote the Euclidean distances between node u and node v_2, v_1 respectively. These changes are driven by the variation of the cumulative energy consumption of each edge's two end vertices at different time. The details are given as follows.

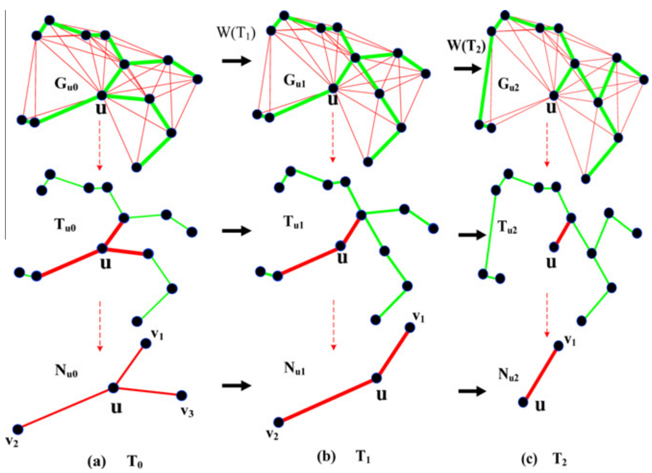

Fig. 3. Main idea of WDTC.

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(1) Each node periodically broadcasts a Hello message with its maximal transmission power. The message should contain the id, position and residual energy of the node.
(2) Node u assigns each edge of G_u a weight by weight function W. We define the weight function as $W(u, v) = W(d_{uv}, E_u, E_v) > 0$, $d_{uv} \leqslant d_{\max}$, where d_{uv} is the Euclidean distance between u and v, and E_u, E_v are the residual energy of u and v respectively. The function W should be an increasing function of the variable d_{uv}, and a decreasing function of the variable E_u, and E_v. The edge weight should reflect the communication cost on the edge. In this paper, we define W as $W(u, v) = d_{uv}^{\alpha}(1/E_u + 1/E_v)$, where d_{uv}^{α} represents the energy consumption for transmitting data packets between u and v with a distance of d_{uv}. The weight function is symmetric, i.e., $W(u, v) = W(v, u)$, which can guarantee a topology with only bidirectional links. We hope that the edge with small node residual energy should have high weight. The definition of $W(u, v)$ meets the requirement.
(3) Each node Calculates MST WT_u of G_u by Kruskal algorithm [22] in the sense of weight $W(u, v)$. MST WT_u reflects both the edge length and the node energy consumption information. Therefore, the neighbor set of node u can vary periodically according to the distance and the energy consumption, and the energy consumption tends toward equilibrium finally.

2.4. Overhead analysis of WDTC

In WDTC, each node periodically broadcasts a Hello message with the maximal transmission to collect its visible neighbor's location and energy information. It was known that LMST also need to periodically broadcast a Hello message with the maximal transmission power to reconfigure the topology subject to the mobility of the node. There are two cases: one is that WDTC and LMST have the same frequency of rerunning topology construction. In this case, WDTC does not incur any extra energy consumption and computation overhead since the residual energy information can be piggy-backed with the location information in the exchange message. The other case is that the frequency of topology reconstruction under WDTC is much higher than LMST where the nodes are assumed to be stationary. In LMST, it is assumed that the node broadcasts the Hello message with the maximal transmission power only once at the very beginning. As to WDTC, each node periodically broadcasts the Hello message to gain its neighbor energy information. The energy consumption incurred in each period by the extra Hello message, denoted by $cd_{\max}^{\alpha}$, should be contained in the total energy consumption. Then the residual energy at time T_{n+1} is calculated by $E_u(T_{n+1}) = E_u(T_n) - E(T_{n+1} - T_n) - cd_{\max}^{\alpha}$, where $E(T_{n+1} - T_n)$ is node u's energy consumption for data transmission during the time interval of $(T_{n+1} - T_n)$. The simulation results, which will be given in Section 4, are all based on the second case.

As to computation overhead in the second case, we know that for an individual topology construction, in both WDTC and LMST, each node u builds its local MST of the graph with the same vertices and edges, so WDTC and LMST have the same time complexity of $O(e\log e)$ [22], where e is the number of edges. Therefore, if the topology is reconfigured for M times in WDTC, the computation overhead of WDTC will be M times of LMST. The extra computation overhead achieves the extension of the network lifetime.

3. Theoretical base of WDTC

This section aims to state and prove that the topology under WDTC algorithm is connected at each time, and then to present a sufficient condition to guarantee that the node degree is bounded by 6.

Denote the topology constructed by WDTC in each period as $G_w(nT)$, $n = 0, 1, 2, \ldots$, where T is the topology adjustment period.

Lemma 1. Given $W(u, v) > W(u, w)$ and $W(u, v) > W(v, w)$, then there is no edge (u, v) in $G_w(nT)$.

Proof. By the definition of $W(u, v)$ in last section, then we have $d(u, v) \leqslant d_{\max}$, $d(v, w) \leqslant d_{\max}$ and $d(u, w) \leqslant d_{\max}$, so triangle $\Delta uvw \in G_u$. By Kruskal algorithm, edge (u, w) and (v, w) are judged if belonging to the MST WT_u before edge (u, v). There are three cases:

Case1: Both (u, w) and (v, w) do not belong to WT_u, which implies that node u and node w have been in the same connected component, so have node v and node w. Then node u and node v belong to the same connected component, so (u, v) does not belong to WT_u. Then (u, v) is not an edge in $G_w(nT)$.

Case 2: Both edge (u, w) and edge (v, w) belong to WT_u. Assume that (u, v) also belongs to WT_u, then graph WT_u contains a cycle, which contradicts with the fact that WT_u is a tree. So (u, v) does not belong to WT_u. Then (u, v) is not an edge in $G_w(nT)$.

Case 3: Only one of (u, w) and (v, w) belongs to WT_u. Assume $(u, w) \in WTu$ and $(v, w) \notin WT_u$. Before edge (u, v) is checked, node v and node w have been in the same connected component, and given $(u, w) \in WT_u$, node u and node w also belong to the same component. Therefore node u and node v belong to the same component. So (u, v) does not belong to WT_u. Then (u, v) is not an edge in $G_w(nT)$. In the case of $(u, w) \notin WT_u$,$(v, w) \in WT_u$, we can get the same result similarly. □

Theorem 1. Given graph G is connected, then $G_w(nT)$ is connected.

Proof. Lemma 1 guarantees that we could use the same approach with literature [4] to the proof of this theorem. The details of proof process can be found in literature [4] about the proof of Theorem 2. □

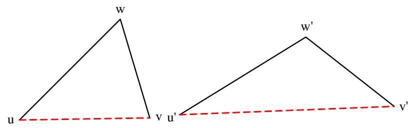


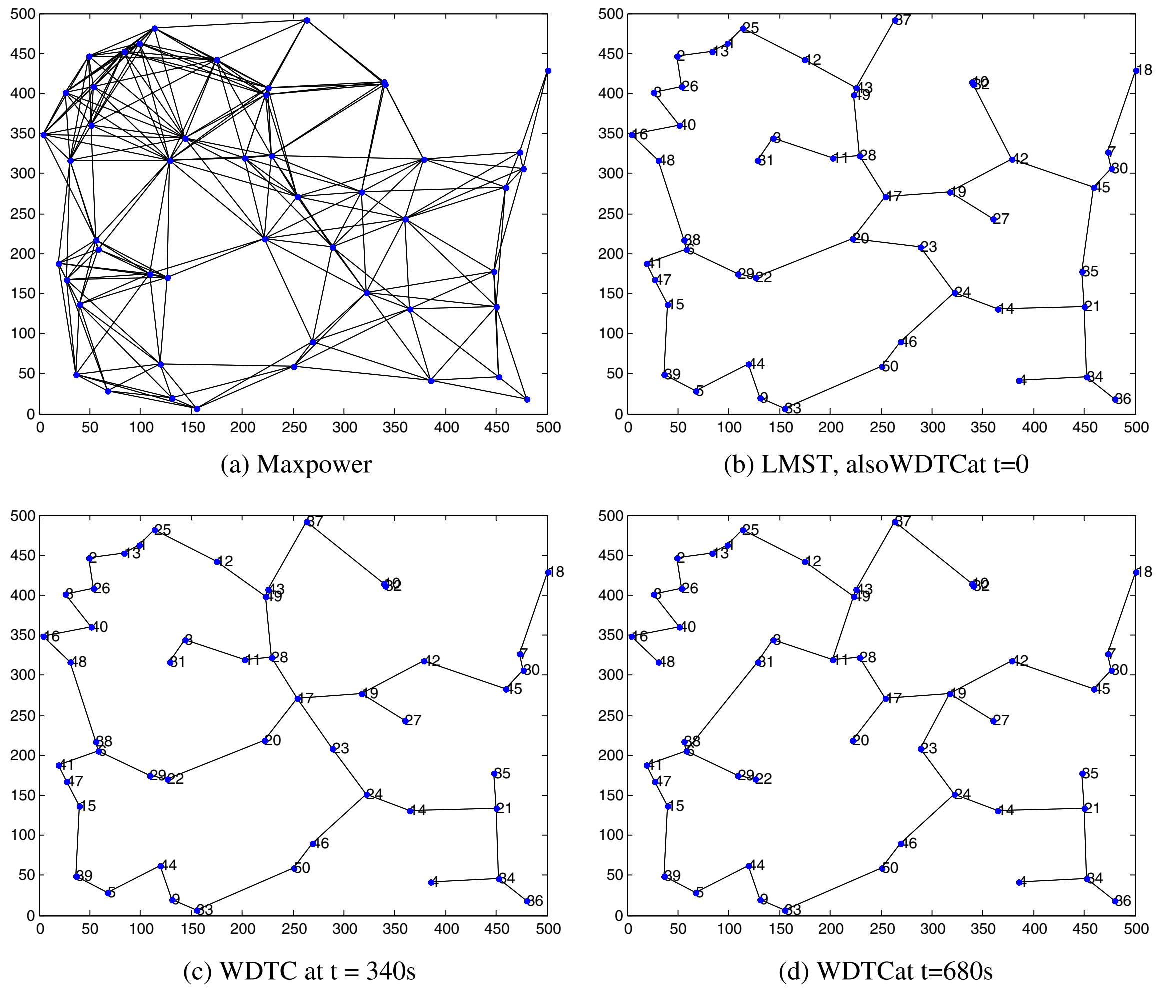
Fig. 4. Auxiliary graph for proving Theorem 2.

Table 1
Simulation parameter.

c	α	S (s)	T (s)	C (J)
2.5×10^{-8}	4	0.5	20	20

By Theorem 1 we know that WDTC can preserve the connectivity of G. How about the node degree? Analysis shows that if the weight function $W(u, v)$ satisfies the triangle inequality principle, i.e., $W(u, v) \leqslant W(u, w) + W(v, w)$, the degree is bounded by 6. However this condition is too stringent. Here we give a weaker one by Theorem 2.

Theorem 2. *For any triangle Δuwv, where $\angle uwv < \frac{\pi}{3}$, if when $W(u, v) > W(u, w)$ and $W(u, v) > W(v, w)$, $W(u, v) \leqslant W(u, w) + W(v, w)$ holds at the same time, then the degree of any node in $G_w(nT)$ is bounded by 6.*



(a) Maxpower
(b) LMST, alsoWDTCat t=0
(c) WDTC at t = 340s
(d) WDTCat t=680s

Fig. 5. Topology evolvement by WDTC.

Proof. For any node w, if the degree of w in the graph $G_w(nT)$ is more than 6, the case of the left figure in Fig. 4 will be seen, where (u, w) and (v, w) are two edges of $G_w(nT)$, and we have $\angle uwv < \frac{\pi}{3}$ in Δuwv. By Lemma 1, we have $W(u, v) > W(u, w)$ and $W(u, v) > W(v, w)$, otherwise (u, w) and (v, w) will not be edges of $G_w(nT)$. If $W(u, v) > W(u, w)$ and $W(u, v) > W(v, w)$ is given and $W(u, v) \leqslant W(u, w) + W(v, w)$ holds at the same time, we can construct another geometric graph $\Delta u'w'v'$ by rotating and stretching the edges (u, w) and (v, w) such that $d(u', v') = W(u, v)$, $d(u', w') = W(u, w)$ and $d(v', w') = W(v, w)$. It is easily seen that we have $d(u', v') > d(u', w')$ and $d(u', v') > d(v', w')$ in triangle $\Delta u'w'v'$, thus $\angle u'w'v' > \frac{\pi}{3}$. So the degree of w' is bounded by 6. Obviously the two graphs are isomorphic, so the degree in $G_w(nT)$ is bounded by 6. □

4. Simulation results

The reason we propose WDTC on the basis of LMST is not only that WDTC can prolong the network lifetime but also that the topology qualities under it are almost competitive to LMST, the most attractive topology control algorithm. In this part, we will evaluate the effectiveness of WDTC through calculating four performance metrics, i.e. network lifetime, average logical degree, average physical degree and average transmission radius. We will compare WDTC with LMST and EDTC [18], algorithms closest to our work. In EDTC, considering the residual energy information, each node builds a rooted shortest path tree, but the topology constructed is asymmetric. We do not compare WDTC against the work in [19,20] because the former is a centralized algorithm and the latter needs global information.

At first, to demonstrate how WDTC works we consider a scenario in which 50 nodes are randomly in a 500 m × 500 m region and the node transmission range is 150 m. Two-ray ground propagation model, i.e., $P = cd^{\alpha}$, is used to calculate the power for transmitting data between two nodes of distance d. For the fairness, half of the nodes are randomly assigned to be sources while the other half to be destinations and the assignment is rerun once every s seconds. Each source node transmits data packets to the destination at the rate of 2 packets/s. Packet size is 1024 bit and the transmission rate is 106 bits/s. Each node has the same energy capacity C. The topology reconstruction period is T. We adopt Dijkstra [23] algorithm for routing and edge weight is $P = cd^{\alpha}$, and assume that the MAC protocol is ideal. The parameter values are listed in Table 1. Denote that some parameter values are equaled to those in the literature [18] for the fairness of the comparison. Network lifetime is defined as the time from the initial to the first node of energy exhaustion.

The dynamic topology evolvement by WDTC is shown in Fig. 5. At $t = 0$, as shown in Fig. 5b, the same topology is gained by LMST and WDTC. The topology varied with the node residual energy distribution from Fig. 5b–c and then to Fig. 5d.

The history curves of the maximum cumulative node energy consumption, average logical node, physical degree and transmission radius are shown in Fig. 6. It is observed that the maximum cumulative energy consumption history curve

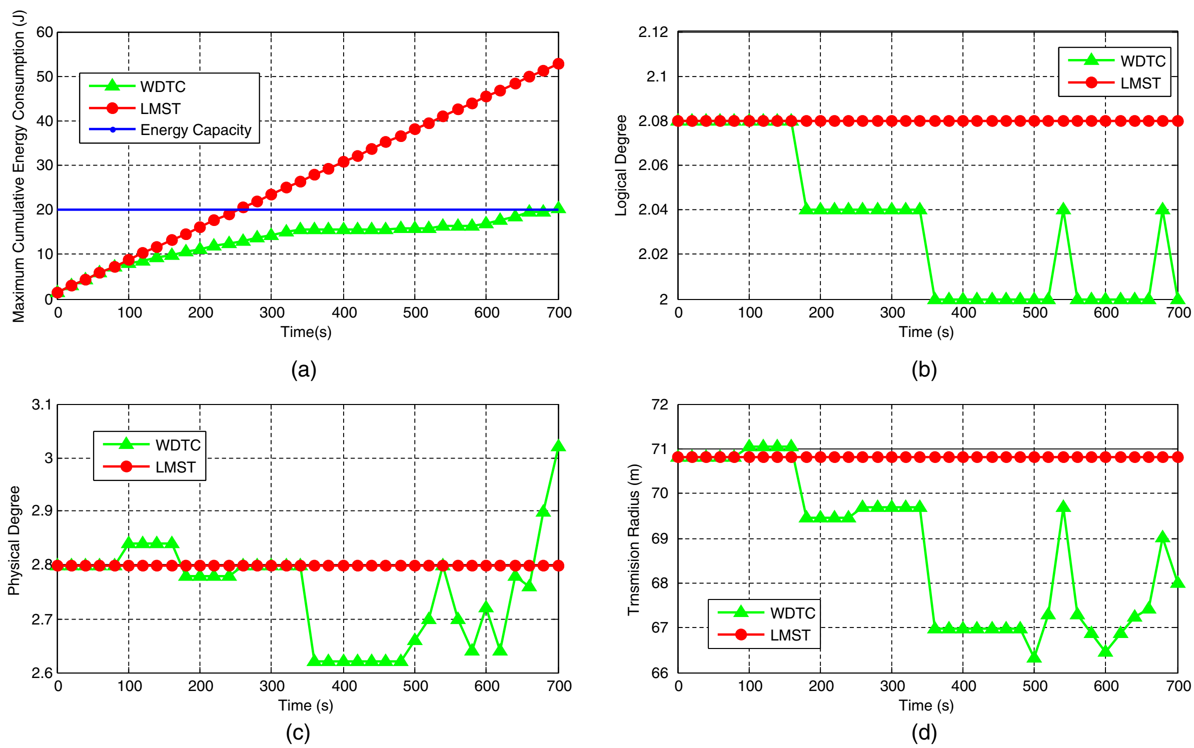


Fig. 6. Performance history of WDTC and LMST.

Table 2
Simulation parameter.

c	α	s (s)	T (s)	C (J)
2.5×10^{-8}	4	0.5	20	100

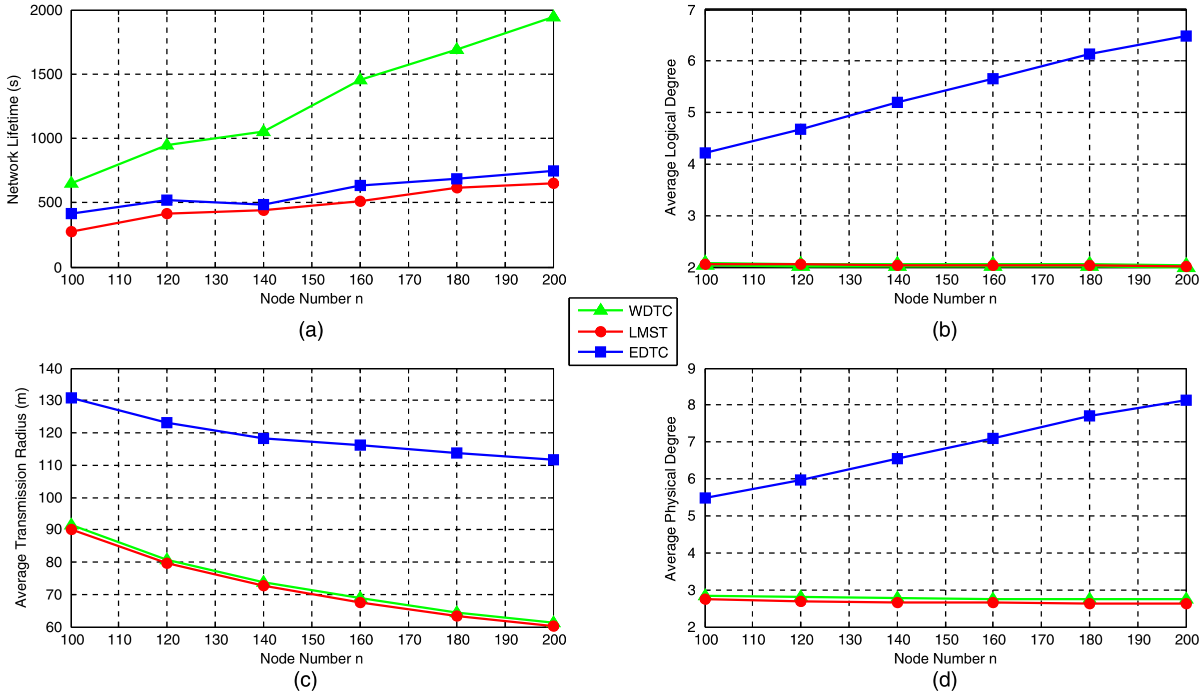


Fig. 7. Performance comparisons among WDTC, LMST and EDTC. (a) Network lifetime. (b) Average logical degree. (c) Average transmission radius. (d) Average logical degree.

is linear in LMST from Fig. 6a. At the time about 250 s, a node is exhausted of energy. Therefore, the network lifetime under LMST is about 250 s. However in WDTC, the maximum cumulative energy consumption history curve slightly increases and the energy exhausted node emerges at 700 s. So the network lifetime by WDTC is 700 s, which has been prolonged greatly compared with LMST. Fig. 6b–d depicts the performance in terms of logical degree, physical degree and transmission radius respectively. We can see that the logical degree under WDTC is smaller than LMST from Fig. 6b. The physical degree and transmission radius in WDTC are higher than LMST only at certain time as shown in Fig. 6c–d.

In the next simulation, we will evaluate the performance of LMST, EDTC and WDTC in terms of network lifetime, average logical degree, average transmission radius and average physical degree. N nodes are distributed in a 1000 m $\times$ 1000 m region. The transmission range of each node is 250 m. Other simulation parameter values are shown in the Table 2. We vary the number of nodes n from 100 to 200. Each data point is the average of 20 simulation runs.

The performances of LMST, EDTC and WDTC are shown in Fig. 7. Fig. 7a shows that the network lifetime in WDTC is much longer than the other two algorithms and increases obviously with the increasing of node number. LMST has the shortest network lifetime. The average logical degree derived by WDTC is slightly smaller than LMST while EDTC has the highest as shown in Fig. 7b. In addition, in contrast to EDTC, the logical degree in both LMST and WDTC decreases with the increasing of node number. We can observe from Fig. 7c–d that the average transmission radius and physical degree under WDTC are slightly higher than LMST and that of EDTC are the highest. The physical degree in both LMST and WDTC decreases with the increasing of the node number while that in EDTC increases obviously.

The simulation results demonstrate that the network derived by WDTC has the longest lifetime, at the same time, the performance of WDTC is almost competitive to LMST.

5. Conclusion

In this paper, we present an effective localized dynamic topology control (WDTC) algorithm with the aim of network lifetime extension. The WDTC algorithm is derived from LMST algorithm by changing the Euclidean graph in which the MST is built into a weighted graph considering the node energy information. We analytically prove that the topology generated by

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WDTC preserves network connectivity at any time in addition to providing a sufficient condition for the node degree of 6 as the upper bound. Since the weighted graph where the MST is constructed varies dynamically leading to the adjustment of topology, the nodes with high energy consumption will not keep their high consumption volume all the time. Consequently energy consumption is redistributed among nodes and tends to seek equilibrium. Simulation results show that WDTC algorithm effectively prolongs the lifetime of network and preserves the good topological qualities of LMST in terms of small degree and low transmission radius. With the increase of node density the network lifetime is extended more significantly.

The theorems presented in this paper show that the change from a Euclidean graph to a weighted graph may not degrade the topology performance such as connectivity, which gives us an inspiration that for many geometric structures, if the connectivity is not damaged by this change, we can adopt general weighted graph instead of Euclidean graph in the design of topology control algorithm to use more kinds of information through defining a proper edge weigh function.

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Please cite this article in press as: R. Sun et al., Energy-aware weighted graph based dynamic topology control algorithm, Simulat. Modell. Pract. Theory (2010), doi:10.1016/j.simpat.2010.09.002