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# Energy-aware weighted graph based dynamic topology control algorithm

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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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[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 $G_0$.