Sleep based Topology Control A Probabilistic Algorithm

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Abstract- **Topology control aims to provide more spatial reuse and power conservation while keeping network's connectivity. However just a few number of efforts have focused on the issue of topology control with mobility. Some topology control algorithms try to provide more energy conservation by sleeping the redundant nodes. This paper presents a probabilistic algorithm to determine whether a node has to sleep or not. We have simulated our proposed algorithm in both of static and dynamic networks. Our results show that the proposed algorithm outperforms CEC, which is a well-known sleep-based topology control algorithm. Further, our proposed algorithm has a simpler implementation and less overhead.**

I. Introduction

Recent technological advances have led to the emergence of small, low-power devices with limited processing and wireless communication capabilities. Adhoc networks are a type of wireless networks that don't have any wired infrastructure. The most important challenge in these networks is the limited battery of each node and many topology control algorithms have been proposed to mitigate this problem.

Topology Control (TC) maintains a topology with certain properties (e.g., connectivity) while reducing energy consumption and/or increasing network capacity [1]. The importance of topology control lies in the fact that it critically affects the system performance in several ways. For example, as shown in [2], it affects network spatial reuse and traffic carrying capacity. One way to accomplishing topology control is to sleep redundant nodes of the network, where topology control is defined as the problem of sleeping the redundant nodes in such a way that the network is connected, and the energy-cost of the topology is minimized. Power control affects the energy usage of communication, thus impacts on battery life, which is a critical resource in many mobile applications.

In addition, topology control impacts on contention for medium. However by sleeping the redundant nodes of the network, collisions can be mitigated as much as possible. This paper, presents a localized probabilistic sleep based topology control algorithm. As our simulation results show, our proposed algorithm outperforms CEC [3], which is a well known topology control protocol.

The rest of this paper is organized as follows: A taxonomy of topology control is given in the section two. Algorithm of CEC is described in the section three. The proposed algorithm is described in the section four. Simulation results are provided in the section five, and finally conclusion is drawn in the section six.

II. Topology Control

A. *Topology Control in Protocol Stack*

Many algorithms have been proposed for topology control in different layers of protocol stack. For example some protocols like CEC, GAF [3], ASCENT [4], LEACH [5] use information from the routing layer and its above layers to identify redundant nodes, and some protocols like PAMAS [6] and STEM [7] use mac layer information. However, most researchers believe that topology control places between mac and routing layers of the protocol stack. Because mac level protocols have a very small view of the network. Thus higher layer topology control algorithms can be more efficient.

B. *Transmission Range Based Topology Control*

From this perspective, topology control tries to obtain the minimum transmission range that can keep network connected. These algorithms can be divided in two categories: homogeneous or non-homogeneous. In the former case, all nodes use same transmission range. But in the latter one each node can use a different transmission range and more energy conservation can be provided. Non-homogeneous algorithms can be divided into three classes: neighbor-based, location-based or direction-based range assignment [1].

In location-based algorithms, nodes have their exact location information and using this information, try to build a good topology. In this class, nodes have to be equipped with more hardware (e.g., GPS). That is, location-based algorithms have hardware cost and some overhead, for calculating the exact location of nodes. R&M [8] and GAF protocols are examples of this class.

In direction-based algorithms, nodes don't have any exact information about their location but they can detect their neighbor's direction. In this scheme nodes have to be equipped with direction-antennas. CBTC [9] is an example of this class.

In neighbor-based algorithms, nodes have some information about their neighbors (e.g., ID) and are able to order them according to some criterion (e.g., distance or link quality). Kneigh [10] and XTC [11] protocols are examples of this class. Comparing these classes, neighbor-based class has less cost, but its information quality is lower. In fact choosing

between these classes is a trade of between cost (hardware and overhead) and better information. It is obvious that when better information is provided, better topology control can be obtained. However, gathering information has cost. In the other words, a good topology control tries to obtain a better topology with less information. In the mobile adhoc networks, nodes can move. Therefore topology control has to be done more times (in periodical or per packet manner). In this case location-based class is not suitable, due to its overhead.

C. *Sleep Based Topology Control*

From this perspective, topology control tries to save more energy through setting the redundant nodes in the sleep mode. These algorithms can be divided in two categories: clustering and non- clustering.

Non-clustering algorithms don't use any clustering technique to identify the redundant nodes. STEM, AFECA [12] and ASCENT are examples of this class. In Sparse Topology and Energy Management (STEM), each node resorts to a second radio as a paging channel. When a node needs to send a packet, it pages the next node in the routing path. This node then turns on its main radio so that it can receive the packet. In AFECA, a node turns off its radio for an amount of time proportional to the measured number of neighbors. By using this approach, as density increases, more energy can be conserved. In ASCENT, each node measures its local connectivity based on the neighbor threshold and packet loss threshold to decide whether it has to remain active or go to the sleep mode.

Clustering algorithms use clustering techniques to determine whether a node can sleep or not. That is, after clustering, the cluster head node remains active and other nodes of the cluster go to the sleep mode. However, some nodes will remain active to act as communication bridges between cluster heads (gateway nodes). GAF and CEC are examples of this class. Geographic Adaptive Fidelity (GAF) identifies redundant nodes by their physical location and a conservative estimate of radio range. GAF is deployed in the virtual grid topology, where in each cell of the grid, one node remains active to keep network connected. Cluster-based Energy Conservation (CEC) directly observes radio connectivity to determine redundancy and so can be more aggressive at identifying duplication and more robust to radio fading. This algorithm consists of three phases: 1-cluster-head selection, 2-gateway selection and 3-duty cycle determination.

III. CEC Protocol

In applications where geographic location information is not available GAF fails. Therefore, CEC was proposed to solve this problem of GAF. As it is shown in [3], CEC outperforms GAF. CEC is a neighbor-base and cluster-based sleeping topology control that tries to build a good topology using less information. In CEC the cluster formation takes place in the following manner:

- Initially each node broadcasts a discovery message along with its node ID and estimated lifetime.
- After receiving discovery messages from neighbors, those nodes that have the longest life time among their neighbors, declare their self as a cluster-head and broadcast a cluster-head message to inform their neighbor.
- If a non cluster-head node received the cluster-head message from more than one cluster-head, declares itself as a gateway node and broadcasts a gateway message to inform its neighbors.
- Except the cluster-head and gateway nodes, all nodes that have at least one cluster head are powered off to conserve energy.
- After re-clustering interval (RCI), in the next re-clustering, the entire clustering process is reiterated.

RCI is some fraction of cluster's life time (LTc). Note that for gateway selection from multiple gateways, the gateway with the longest lifetime has a higher priority and other redundant gateways can go to the sleep mode.

IV. A Probalilistic Algorithm

In this section a probabilistic sleep based topology control algorithm is described, where each node estimates the probability of its sleep mode according environment condition. For this estimation, we can use distance and number of neighbors as input parameters. It is obvious that sleeping probability of a particular node u increases as number of its one hop neighbors that have a longer life time (stronger neighbors) increases. Also sleeping probability increases as the mean distance between u and its stronger neighbors decreases. On the other hand, as one can imagine received power decreases as distance increases. Therefore location information necessity can be omitted by using the reception and transmission powers. A pseudo code is given below:

- Initially, d=1.
- Each node u, broadcasts a discovery message along with some information like its ID, the estimated lifetime and transmission power.
- After receiving discovery messages from all of the neighbors, each node estimates its sleeping probability.
- Each non-cluster head node that has heard at least from one cluster head go to the sleep mode, according the estimated probability.
- After RCI, in the next re-clustering, increase d as d+1 and go to the step b.

As mentioned before, each node u uses number of stronger neighbors and received power to estimate its sleeping probability. For this purpose it calculates Wn and Wr as below:

$$Wn = \frac{N_d}{N_d^{\max}} \tag{1}$$

$$Wr = \frac{R_d}{R_d^{\max}} \tag{2}$$

$$0 \le W, R \le 1 \tag{3}$$

Where Wn is weight of stronger neighbors, Wr is the obtained weight for the received power from stronger neighbors, N_d is number of stronger neighbors, $N_d^{\max}$ is maximum value of N_d, R_d is the received power fraction and $R_d^{\max}$ is maximum value of R_d, through d steps. R_d can be computed as below:

$$R_d = \frac{\sum_{i=1}^{N_d} \frac{rx_{i,d}}{tx_{i,d}}}{N_d} \qquad (4)$$

Where, "the ith stronger neighbor's hello message" is transmitted with $tx_{i,d}$ and received with $rx_{i,d}$ watt. Finally, the sleeping probability is computed as below:

$$P_{sleep} = W_n \times W_r \qquad (5)$$

Finally, a node sleeps if rand(P_{sleep})>rand(1-P_{sleep}), where rand is a randomize function.

V. Simulation

For network simulation, we used OPNET, which is a powerful simulator in the network field. We have also used all the default settings, predefined in the OPNET for IEEE 802.11b standard model. For example, the data rate is 11 Mbps and the bandwidth is 2.4 GHz. Signal propagation model used in our scenarios, is free space-line of sight, which is also predefined in the OPNET. One of the basic features of a mobile adhoc network (MANET) is that nodes move according to the some mobility model. For MANETs the random way-point model (RWP) [13, 14] is, by far, the most popular mobility model. Therefore we used RWP as the mobility model. The speed (m/s) and pause time(s) parameters of all nodes are set as uniform(0,10) and constant(1), respectively. However in the static network we don't have any mobility.

Several scenarios have been created to test the performance of the proposed power control algorithm. However due to the massive amount of data to be processed, strictly a simulator issue, number of nodes was limited to 15 and used as a proof-of concept. Nodes are placed in a 500*500 meter area non-uniformly. In our scenarios, four nodes generate traffic, one node is destination and other nodes are used just as bridge between source and destination. The packet inter arrival time in the source nodes, is equal to poisson(1). We tested our proposed algorithm in both of the static and dynamic networks. Note that another important specification of our static network is number of neighbors and network density. As mentioned before number of nodes is limited to 15 and we assumed that at first each node has at least one neighbor. Results are shown in the following figures.

VI. Conclusion

A probabilistic algorithm was proposed in this paper called PSToC. Comparing with CEC, our proposed algorithm can provide more amount of received traffic while its received bits per watt is more. Also it provides these results with less overhead. Therefore it outperforms CEC. It has also a simpler implementation. Each node decides to go to the sleep mode only when it finds itself a redundant node while those that are far from their cluster head remains active to relay the messages. Therefore delay is reduced. In fact, the received data per second is increased. In the other words, each node that is far from its stronger nodes remains active and it can be neither cluster head nor gateway. Therefore it provides better connectivity and consequently more amount of traffic is received.

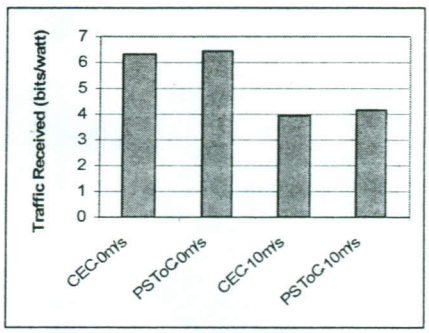


Fig. 1. Traffic received per watt in the CEC and PSToC.

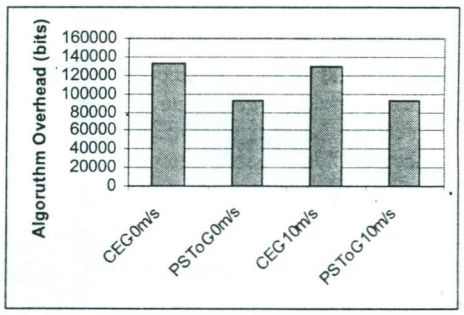


Fig. 2. Algorithm overhead of the CEC and PSToC.

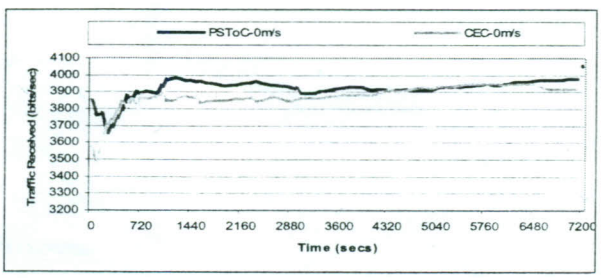


Fig. 3. Average traffic received per second in a static scenario.

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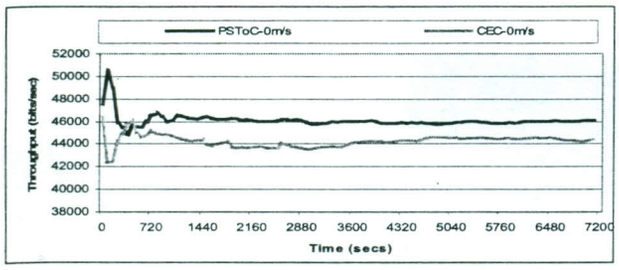


Fig. 4. Average throughput in a static scenario.

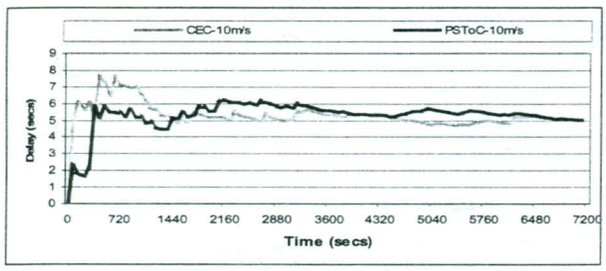


Fig. 5. Average delay in a scenario with mobility.

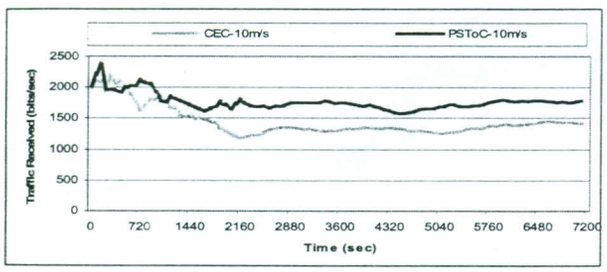


Fig. 6. Average traffic received per second in a scenario with mobility.

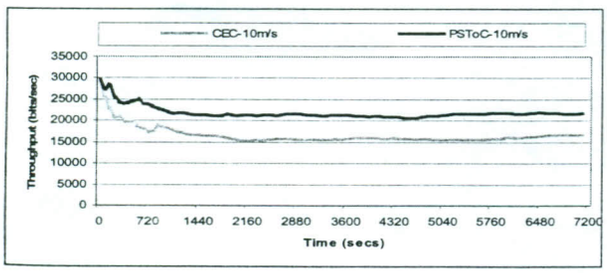


Fig. 7. Average throughput in a scenario with mobility.

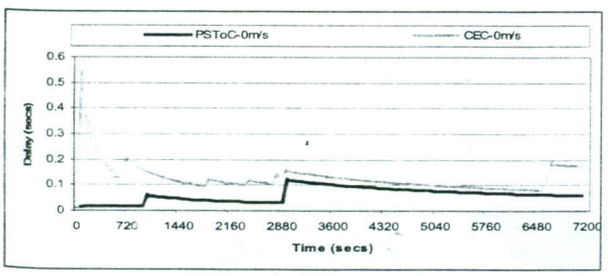


Fig. 8. Average delay in a static scenario.

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