Neighbor Based Topology Control Protocol for Prolonging the Lifetime of Ad Hoc Networks

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***Abstract**: Topology control, wherein nodes adjust their transmission ranges to conserve energy is an important feature in wireless ad hoc networks. In this paper we propose a power control protocol based on neighbor detection for conserving energy in the network. Our approach based on the principle of comparison the number of physical neighbors of every node with a desired number of nodes. With bounding the transmission ranges, some benefit in the network have been achieved. We verify through the simulation that the network topologies produced by our protocol show good performance in term of energy consumption and network lifetime.*

Keywords: Ad Hoc Networks, Energy Consumption, Neighbor Detection, Topology Control.

1. Introduction

MAC design is a challenging problem in wireless ad hoc network. IEEE 802.11 MAC protocol [1] is the most popular standard used in wireless ad hoc networks. In spite of it being simple, the 802.11 MAC approach actually use fixed high transmit power that leads to fully connected network and throughput degradation [2].

Topology Control (TC) has been proposed as a technique to increase network capacity and to reduce energy consumption in ad hoc networks [3]. The goal of a TC protocol is to reduce the transmission power level used by network nodes, with the constraint of preserving some fundamental properties of the communication graph. Decreasing the nodes' transmission power with respect to the maximum level potentially has two positive effects:1) reducing the nodes' energy consumption, and 2) increasing the spatial reuse, with a positive overall effect on network capacity [5]. Due to the limited availability of both energy and capacity in ad hoc networks, topology control is considered to be a fundamental building block of wireless networks.

In this paper we focus on energy consumption and trying to minimize the energy cost of a network topology. The main contribution of this paper is transmission power adjustment based on the number of neighbors to reach a desired network topology while preserving the network connectivity. We also regard the physical and topology layer concepts.

The rest of the paper in organized as follows: Section 2 is dedicated to present the system model used in the area of power control and topology control in ad hoc networks. The proposed protocol is presented in section 3. Simulation results presented in Section 4. Finally our main conclusions are drawn in Section 5.

2. System Model

Wireless network is modeled as a graph $G(V,E)$, where the set V of vertices represents the nodes and the edges in E represents the communication links and we model the wireless network as an arbitrary unit disk graph (UDG) $G(V,E)$,wherein a link exist between two nodes *iff* the two nodes are within a unit distance of each other [4]. According to this model, a node pair u and v in the network can have direct communication *iff* their Euclidean distance is not larger than transmission range. When u and v have a direct link, u is said to be a neighbor of v and vice versa [3].

In our network model all nodes have distinct IDs and in our distributed algorithm we assume that nodes use information regarding their one-hop neighborhood. One-hop neighborhood of node u is defined as the set of nodes N_1 that are neighbors of u. This information can simply be collected via the use of periodic message transfer between nodes. Wireless channel is assumed symmetric and obstacle-free, and signal degradation occurs only due to path loss.

Node degree is defined as the number of node's one-hop neighbors in the final communication graph. We recall that the logical node degree is defined as the number of one-hop neighbors in the final communication topology. In must of the literature on topology control, it is argued that this parameter is a measure of the expected contention in the MAC layer. This is not true because the contention depends on the number of nodes in the transmission range of given node, where the transmission range is determined by the transmission power level as set as at the end of topology control protocol execution. We refer to the number of nodes within transmission range of a given node as the node's physical degree. Figure 1 illustrates the difference between logical and physical node degrees. Node u has three neighbors in the communication topology (nodes v, t and z), so its logical node degree is 3. Note that some energy inefficient links are removed in the communication topology (e.g. the link (u,w)), so many nodes such as node w do not contribute to u's logical degree. When u transmit to its farthest neighbor (node z), it interferes with all the nodes within its transmission range. For this reason, node w is accounted for when calculating u's physical degree. In the Figure 1, the physical degree of u is 6 [6].

Commonly used model for RF systems is the path loss model, in which the received power $P_r = P_t.r^{-\alpha}$, where r is the distance between the transmitter and the receiver and α is the path loss component between 2 and 4 and P_t is the transmit

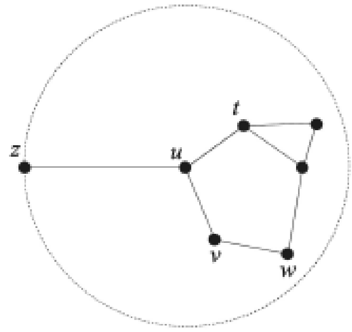

Fig. 1 Difference between logical and physical node degree: node u has logical node degree equal to 3, but its physical node degree is 6.

power. Therefore, the transmit power needed to support a link of length r is $P_{rTH}.r^{\alpha}$, where P_{rTH} is the receive power threshold [8].

The energy consumption of a wireless node has two components: transmitting power and receiving/processing power. The latter is relatively small and usually can be denoted by a constant [6]. Since in the all traffic, every node consumes energy in receiving/processing in each period, we ignore this constant and consider only the energy consumption in transmitting. The total energy consumption of a network can be modelled as the sum of each transmitting node. Each node communicate with the direct neighbors, therefore, all the nodes are transmitting nodes [7]. This paper focuses on the total energy consumption in maintaining the network connectivity, so the total energy based on this model is

$$\textit{total energy} = \sum_{v_i \in V} P_t(v_i) \tag{1}$$

3. Neighbor Detection Topology Control

Topology control in ad hoc networks aims to increase network capacity and conserve energy. In this paper we proposed a distributed topology control algorithm based on number of neighbors. A node grows its transmission power until it finds some neighbors and then its power is adjusted based on number of neighbors. The resulting network topology increases network lifetime by reducing transmission power and decreases interference in MAC by having low node degrees. On the other hand, power decrease may increase the packet loss due to increasing the number of hidden nodes in interference range [8]. Our work is based on LINT (Local Information No Topology). This distributed heuristic algorithm protocol proposed by Ramanathan et al. that uses locally available neighbor information collected by routing the protocol and attempts to keep the degree (number of neighbors) of each node bound [10]. An indirect effect of limiting the number of neighbors is the reduction of power consumption. The magnitude of the power change is a function of desired degree d_d and current degree d_c. LINT calculation leads to:

$$P_d = P_c - 5\alpha \log\left(\frac{d_d}{d_c}\right) \quad (2)$$

Where P_d is the targeted power, P_c is the current transmit power and α is the propagation loss depend on the environment. A node knows the current used power P_c and the current node degree d_c. To bring the degree close to d_d, power can adjusted periodically.

Our proposed algorithm is named as NDPC (Neighbor Detection Power Control) present a dynamic transmit power scheme that attempts to improve network lifetime of multihop wireless ad hoc network. The algorithm works in two steps:

1. Find how many neighbor a node has.
2. Adjust the transmission power according to number of neighbor to create a desired network topology.

Three different methods have been used for choosing a neighbor: (1) connectivity, (2) packet reception rate (PRR) and (3) received signal strength (RSS) methods. A connectivity based method simply counts different sender IDs without differentiating link quality and is easy to implement, but it does not achieve the desired level of connectivity. As a way of choosing a neighbor, a PRR-based or RSS-based method is preferred over a connectivity-based method. This is because PRR-based or RSS-based methods achieve the desired level of connectivity by filtering incoming neighbors that have their metrics (PRR or RSS) better than a certain threshold. A PRR based protocol has advantages in that PRR is directly related to the quality of a link and it doesn't require any special hardware support. However, it has the software overhead of maintaining the neighbor table. A RSS based protocol can determine the quality of a link without much overhead of maintaining neighbor table with assistance from the wireless hardware. One drawback is that RSS is sensitive to the background noise and does not accurately measure the quality of a link. In this proposed protocol, we use RSS based method for calculating the degree of each node that have received the packets.

In order to adjust the transmission power to the appropriate level, we use the notion of an effective neighbor. A node is an effective neighbor of n_a if n_a knows that it can hear n_b, and the number of effective neighbors of n_a is the sum of all the effective neighbors. A node can tell its number of effective neighbors (N) using the following protocol.

1. Each node n_a sends a beacon message.
2. A node that hears the beacon message from n_a with the link quality better than a pre-defined threshold, records the source ID of the message. When the node sends its beacon message, it piggybacks the list of neighbors on the beacon message.
3. Node n_a hears a beacon message from another node and it can tell whether the node has heard n_a by looking at the neighbor list which is piggybacked on the beacon message. Node n_a counts all the nodes that have heard n_a.

By using the trade off between connectivity and physical layer criteria as mentioned in [11] and the adaptive power scheme in [12], after the number of neighbors is found, our algorithm adjusts the transmission power. If the number of neighbors N less than N_d -desired number of nodes– for maintaining the network connectivity, the transmission take place with maximum allowable power and when the number of neighbors is further than N_d, the transmission power decrease according the flowing formula:

$$P_T(t+1) = P_T(default) - \frac{1}{n_{\max}} \times \log_{10}\left(\frac{n_c}{n_{\max}}\right) \times P_T(t) \quad (3)$$

$$P_T(t) \leftarrow P_T(t+1)$$

Where $P_T(t)$ is the previous adjusted power for a packet. Our work set its objective as energy consumption or network lifetime with take into account the connectivity constrain. Network lifetime define as the time elapsed until the first node energy reached to zero. Also the improvement of the throughput from these transmit power control scheme is limited, Energy consumption is

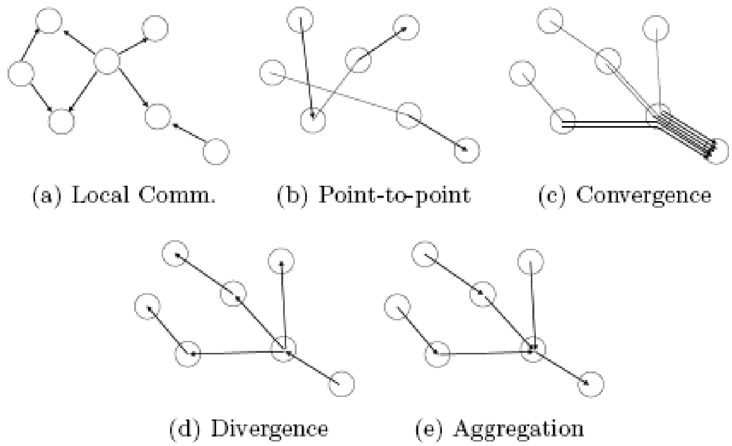

Fig. 2 Different Traffic Pattern

the comparison criteria in this paper and holding the aggregate throughput of the network same when we use fixed transmission power scheme.

4. Simulation Results

We have used ns-2.31 to perform our simulations [9]. Table 1 defines a variety of values and symbols we will use in our simulations [14]. For the evaluation of our power control scheme, we have used different traffic pattern and scenarios. In Section 2, we first use a square topology with different traffic flow between nodes and effect of different distances, desired number of nodes in the lifetime of the network will be studied. Random scenario generated by arbitrary locations of 16 nodes inside a specified physical area and total of 4 flows have been established between transmitters and receivers finally. Simulations are done based on energy consumption and number of alive node in the network.

Table 1. Simulation parameter

Parameter	Value
h_t, h_r	1.5m
G_t, G_r	1m
freq	2.472e9
bandwidth	11Mbps
CPThresh	10.0
CSThresh	5.011872e-12
RXThresh	5.82587e-09
Pt(max)	281mW
CBR packet	512 bytes
Packet Interval	0.02
Initial node energy	30J
Topology	Random, Square
Simulation time	500s

4.1 Effect of Desired Node Degree

Our Algorithm is depending on the number of desired node degree (N_d) as an input parameter. Due to the fact that our decision is based on this value, its proper selection has been leaded to better network performance. In a UDG, when this parameter is set to high value, this means that the higher transmit power is need to reach the neighbors and vice versa. With setting the default transmit range to 100m, the transmit power versus number of detected nodes is illustrated in Figure 3. As we can see, when the number of detected neighbors are same, the scheme with higher N_d, use further transmission power.

Effect of this selection is hard to modelling and lead to an optimization problem. But via the simulation is proved that depending on the network condition and traffic pattern we must select N_d.

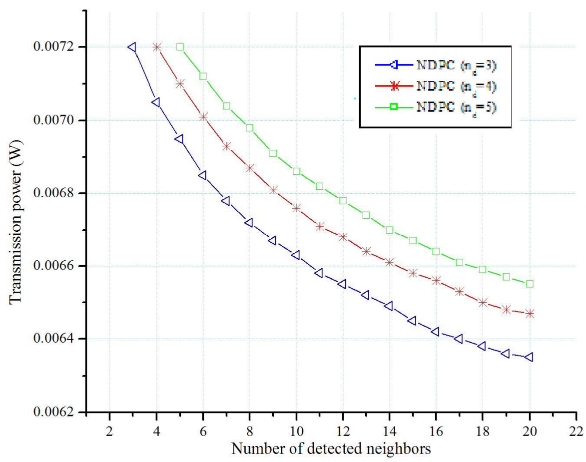

Fig.3 Transmission power versus the number of the detected neighbors

Wireless ad hoc network can use different traffic patterns. The traffic of an ad hoc network can be either single hop or multi hop. Depending on the number of sender and receiver nodes, multi hop traffic pattern can be further divided. Based on these criteria, the traffic pattern categorized to (a) local information, (b) point-to-point routing, (c) convergence, (d) aggregation and (e) divergence. The schematic of these traffic patterns is showed in Figure 2. In our square simulation scenario, we generate all of these traffic patterns. Figures 4 and 5 illustrate the energy consumption and life time of the network. Our simulation result on different network density is presented in Figures 6 and 7.

According to the energy model described in section 2, Figure 4 shows that the energy consumption of our NDPC protocol is better in a static network topology while maintaining the aggregate throughput of the total flows in the network near to each other with variation around 650 Kbps. The lifetime of the network is increased to 180s compare to 115s that have been achieved by IEEE 802.11 protocol. Number of alive node over time indicated in Figure 5.

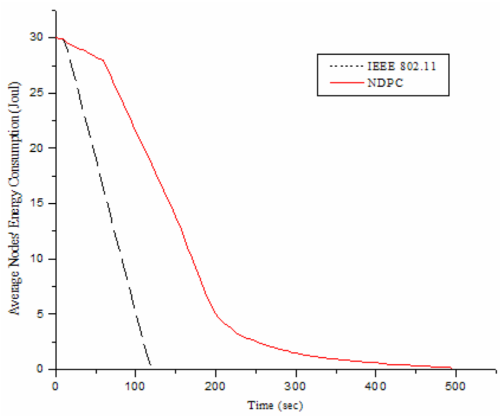

Fig. 4 Average nodes' energy consumption in 16 node square topology

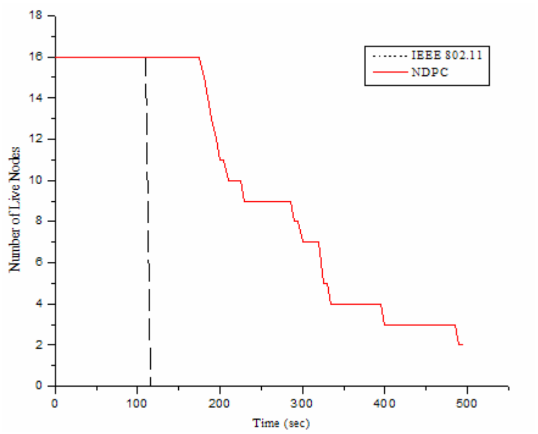

Fig. 5 Number of nodes alive over time in 16 node square topology

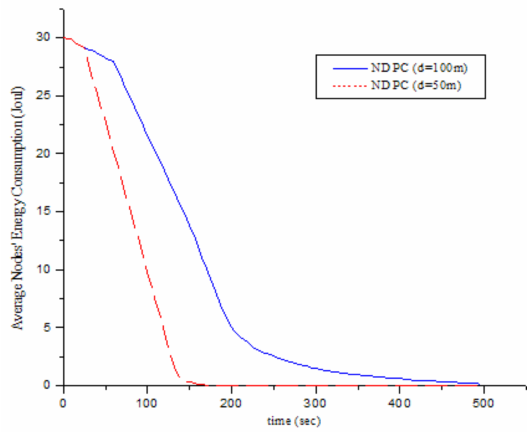

Fig. 6 Average nodes' energy consumption in dense (d=50m) and spares (d=100m) topologies

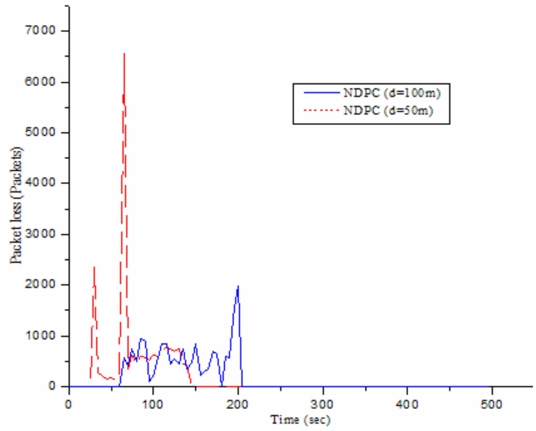

Fig. 7 Packet loss comparison in dense (d=50m) and spares (d=100m) topologies

Another simulation result is based on changing the distance between nodes. In the first scenario the distance between nodes is 100m. With changing this value to 50m, more energy consumption in consequence of further interference and collision have been occurred. Collision imposed more energy consumption due to retransmission policy. Figure 7 shows the packet loss comparison.

4.2 Simulation in Mobile Ad Hoc Network

A random scenario generated by arbitrary location of 16 nodes in an $500m \times 500m$ area and 4 CBR flow have been established between source and destination pairs. Nodes move according to Random Waypoint mobility model [9,13] with the maximum speed of $10m/s$ and pause time is $2s$. With consideration of equation (1), the normalized energy consumption average over all the nodes in the network divided to number of nodes and the number of live nodes versus time have been compared in Figures 8 and 9. NDPC protocol works well in mobile scenario because the

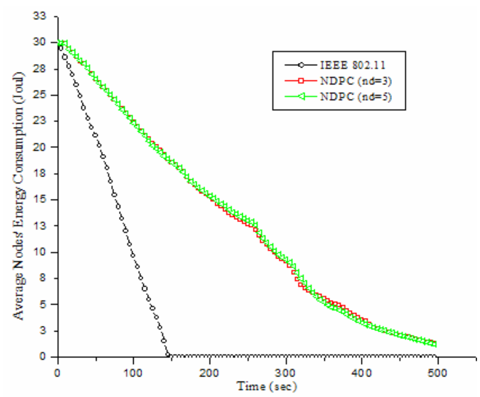

Fig. 8 Average nodes' energy consumption in mobile network with random topology

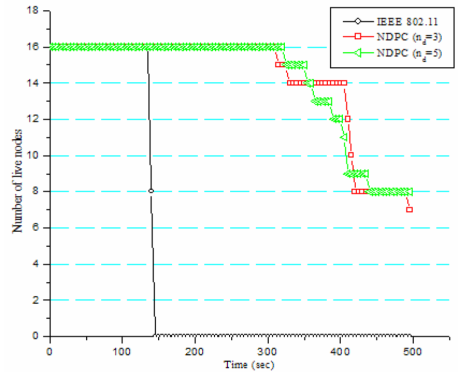

Fig. 9 Number of live nodes over time in mobile network with random topology

movement of nodes change the topology and neighbor detection phase trigger more to execute the power control protocol.

Figure 8 Implies that our proposed protocol achieved a good energy consumption compare to IEEE 802.11 that use fixed transmit power while keeping the aggregate throughput of the network with no significant difference. Figure 9 shows that the lifetime of mobile network with IEEE 802.11 MAC protocol is 140s and with the same scenario and mobility pattern which is worked under our protocol can work 325s.

5. Conclusion and Future works

Topology control is a technique to increase network capacity and to reduce energy consumption in ad hoc networks. In this paper, we proposed a power control algorithm based on number of one hop neighbors. High and low transmission powers are not feasible in wireless ad hoc networks, so we adjust transmit power with consideration of connectivity and physical layers criteria. The outperformance of our protocol in network lifetime and energy consumption is proved via the simulation. Our future work is adaptive selection of desired number of nodes and analytical modeling of this algorithm.

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