Mobility-Aware Distributed Topology Control for Mobile Multi-hop Wireless Networks*

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Abstract. In recent years mobile multi-hop wireless networks have received significant attention and one of the major research concerns in this area is topology control. While topology control problem in ad hoc networks is NP-complete, several heuristic and approximation based solutions have been presented. However, few efforts have focused on the issue of topology control with *mobility*. In this paper, we introduce a new topology control scheme in the presence of mobile nodes. The proposed scheme predicts future proximity of neighboring nodes and applies power control such that the network connectivity is maintained while reducing energy consumption. Simulation results show that the optimal power selection based on location prediction gives better performance in terms of energy and connectivity.

1 Introduction

In a dense mobile multi-hop wireless network each node might have several neighboring nodes. A node in such networks has to decide upon the use of appropriate links intending to attain better utilization of available bandwidth i.e., by allowing concurrent transmissions and energy saving. Selection of such a subset of neighbors for establishing links is the main objective of topology control.

Topology control have been addressed by many researchers with a common goal of achieving an optimal transmission range that can satisfy two contrasting requirements of reduced interference and network connectivity simultaneously. Lower transmission power results in the network to be partitioned. On the other hand, a node with higher transmission power often causes interference and affects overall network capacity and energy [1]. Moreover, the topology control in presence of mobile nodes is a non-trivial problem. Most of the previous work in topology control have not considered mobility, but used a graph model for network analysis [2].

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Our work is motivated by the following two reasons: (1) Node mobility causes network topology to change dynamically. In this situation, by exploiting non-random mobility pattern each node can predict the future state of neighborhood topology and thus a set of minimum transmission powers required to reach its each neighbor. (2) Optimal transmission power selection based on estimated minimum power information from one-hop neighbors produces a robust topology. A robust topology is the one which maintains connectivity through multi-hop communication and as a result, overall coverage region of the network.

Mobility prediction is not a new concept and has been used before in mobile ad hoc networks, for example Link Estimation Time (LET) was previously introduced for estimating link duration and to perform re-routing before the route breaks [3]. In our proposed scheme each node predicts future position of its neighbor nodes and based on this information it estimates the optimal transmission power required to reach them. We assume that each mobile node is aware of its location relative to some coordinate system so that it can calculate distances to its neighbors. For that purpose the availability of Global Positioning system (GPS) [4] would be ideal, but for deployment scenarios where the use of global coordinate system is not feasible other mechanisms for node localization such as Relative Positioning System [5] can also be utilized. It is shown using simulations that the proposed algorithm maintains connectivity while conserving significant energy.

The rest of the paper is organized as follows. Section 2 presents related work regarding topology control in ad hoc networks. Section 3 explains the proposed scheme. Section 4 deals with performance evaluation and finally in Section 5 we provide conclusions and future work.

2 Related Work

According to the taxonomy presented in [2], topology control algorithms can be divided into homogeneous and heterogeneous approaches. Among those that are classified considering heterogeneity are based on location, direction and neighbor information.

In localized algorithms, either a central entity computes a set of optimal transmission ranges and assigns them to individual nodes or each node computes the minimum transmission power in a distributed manner. In [6] two centralized algorithms are presented that focuses on preserving connectivity and bi-connectivity in static network. They require global information to compute topology making them unfeasible for mobile scenarios. It also reports on the two heuristic-based distributed schemes namely Link Information No Topology (LINT) and Local Information Link-State Topology (LILT). Both LINT and LILT utilizes node degree information to adaptively adjust a transmission range. LILT also exploits global link-sate information available from a routing protocol. However, the adjustment of transmission power based on node degree is not very effective because higher degree make nodes to lower their transmission range or vise versa which degrades network connectivity and performance.

Authors in [7], proposed a distributed topology control algorithm for multi-hop wireless networks that constructs neighborhood graphs (RNG) based on the direction information. It increases the transmission power based on angle spanned by the neighboring node. The paper claims that this strategy lowers interference, saves energy and provides reliability. However, it does not address the issue of network partitioning due to change in power levels, heterogeneity and mobility.

In [8], each node in the network computes a strongly connected topology based on local neighborhood and channel propagation model information. Most of the previous research efforts [7,8] used constructions from the field of computational geometry with an overall objective of preserving energy-efficient paths. These implications have been disproved by latest findings that emphasize more on generating interference-minimal topology [9] [10].

The work that is closest to ours is presented in [11]. This work extends previous topology control algorithms for static networks (for example, RNG-based) by making them adaptive to mobility. Our scheme predicts the future state of the topology and estimate an optimal transmission power such that the connectivity is maintained, which is in contrast to [11] where larger than actual transmission range is used to preserve the connectivity. Moreover, we construct a robust topology by controlling power on each node based on location information. To the best of our knowledge, previous research efforts have not exploited topology prediction for power control.

3 Mobility-Aware Distributed Topology Control

The proposed scheme is divided into two main phases. First, each node sends HELLO packets with maximum transmission power (P_{max}) to learn the future state of neighborhood topology. HELLO packets comprise node's predicted position and a list of minimum transmission powers that is required to communicate with its one-hop neighbors at some point later in time. Secondly, each node selects an optimal power level ($P_{optimal}$), such that a neighbor demanding higher transmission power can be reached through one that requires lower transmission power level.

The main idea of our scheme is illustrated in Fig. 1. In Fig. 1(a), the initial topology at some arbitrary time (t_0) is depicted. At this time instant HELLO packets are exchanged among the neighbors with maximum transmission power. Fig. 1(b) shows the predicted future position of the nodes at time ($t_{0+\alpha}$). Nodes 5, 4, 3 and 2 are directly reachable from each other. Fig. 1(c) shows that each node adjusts the power required to reach their neighbor such that the connectivity in future is retained. For example, node 2 computes the required power for nodes 5, 4, 3 and 1. Based on this neighbor information it sets up the link with node 3 and 1.

3.1 Topology Prediction and Transmission Power Estimation Phase

At t_0, each node computes a list of minimum transmission powers required to reach its 1-hop neighbors for time $t_{0+\alpha}$. Time instances t_0 and $t_{0+\alpha}$ represents

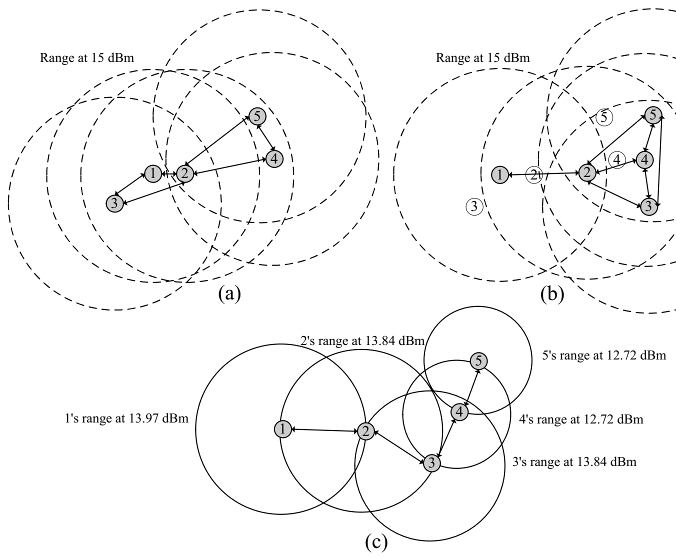


Fig. 1. (a) Initial topology. (b) Predicted topology with maximum transmission range. (c) Topology after transmission power adjustment.

current time and new time, respectively and α is the time increment in seconds. The list is constructed as follows:

A node predicts its own future position given its current position, speed and direction using following two equations, such that:

$$x(t_{0+\alpha}) = x(t_0) \pm s * (t_{0+\alpha} - t_0) * \cos(\theta) \tag{1}$$

$$y(t_{0+\alpha}) = y(t_0) \pm s * (t_{0+\alpha} - t_0) * \sin(\theta) \tag{2}$$

Here ($x(t_{0+\alpha})$, $y(t_{0+\alpha})$) denote the position of a node at $t_{0+\alpha}$, s is the current speed which is bounded by some maximum value, and θ is the direction. Next, future distance to each of its 1-hop neighbors is calculated using Eq. (3). Assume that there are two neighbor nodes, node A and node B, then:

$$d(t_{0+\alpha})_{AB} = \sqrt{(x_A(t_{0+\alpha}) - x_B(t_{0+\alpha}))^2 + (y_A(t_{0+\alpha}) - y_B(t_{0+\alpha}))^2} \tag{3}$$

Finally, we can utilize two-ray ground path loss model to predict the mean signal strength P_r for an arbitrary transmitter-receiver separation distance d [13, 12] based on wireless propagation model given by following equation:

$$P_r(d(t_{0+\alpha})_{AB}) = \frac{P_t * G_t * G_r * (h_t^2 * h_r^2)}{(d(t_{0+\alpha})_{AB})^\eta * L} \tag{4}$$

Using Eq. (4) node A estimates the minimum power required to reach node B, provided that transmission power P_t and the predicted distance $d(t_{0+\alpha})_{AB}$ are known.

3.2 Optimal Power Selection Phase

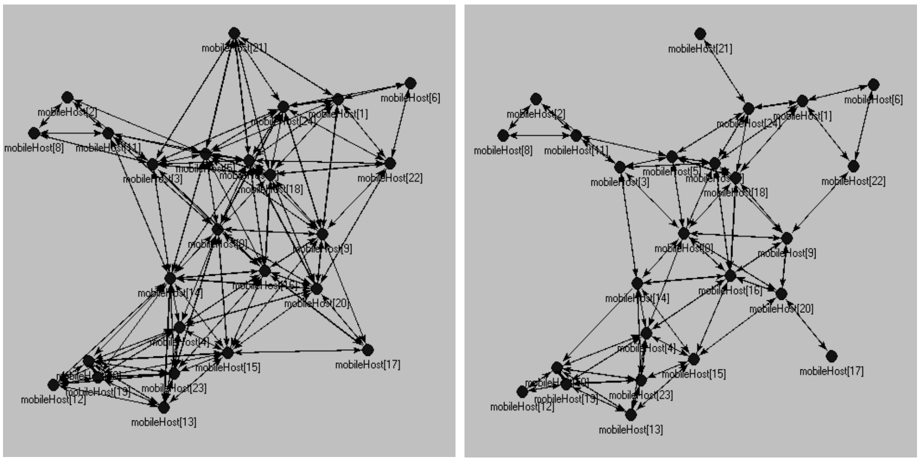
On receiving HELLO packets, each node draws a future topology map in terms of minimum transmission power required to reach its 2-hop neighbors. Each node constructs this topology map by maintaining two data structures. (1) Local view list L consists of two fields, one-hop neighbor's identity and minimum power. (2) Extended view list E includes neighbor's identity, neighbor's-neighbor identity and estimated transmission power.

Using both local view and extended view lists the proposed algorithm selects an optimal power $P_{optimal}$, such that a neighbor requiring higher transmission power can be reached through an intermediate neighbor node. Selection of $P_{optimal}$ is done by comparing transmission power required by node itself and its nearest neighbor to reach the farthest one. If the nearest neighbor does not cover the distant ones, our algorithm searches for another neighbor with relatively higher transmission power, such that the connectivity among all neighbors is retained. Pseudo-code for finding the optimal power is formally given in Algorithm 3.1.

Algorithm 3.1: OPTIMALTXPOWER(L, E)

comment: Node A receives HELLO packet from Node B and P$_{optimal}$ selection.
RECIEVEHELLO(p)
UPDATEEXTENDEDVIEW(p)
UPDATELOCALVIEW(p)
comment: Sort L in descending order of minimum TX power field.
SORTLOCALVIEW$(L, txPower)$
$i \leftarrow 0$
$j \leftarrow L.length() - 1$
comment: Initially Optimal power is set to reach farthest neighbor.
$P_{optimal} \leftarrow L_i.txpower$
if $(j \neq i)$
  then
    while $(j \geq i)$
      do
        $x \leftarrow L_i.nodeID$
        comment: Is Node x reachable from Node L$_j$.nodeID?
        if (REACHABLE$(x, L_j.nodeID)$)
          then
            if $(E_{(L_j,x)}.txpower < E_{(A,x)}.txpower)$
              then $P_{optimal} = E_{(A,L_j)}.txpower$
              else $j \leftarrow j - 1$; *continue*
        $i \leftarrow i + 1$
return $(P_{optimal})$

Fig. 2 illustrates topologies obtained from full transmission power (no topology control) and proposed optimal power selection algorithm. For this simulation instance we have used two-ray ground reflection model on a network size of 25 nodes uniformly distributed over an area of 512 x 512m^2. Fig. 2(a) depicts the



(a) (b)

Fig. 2. (a) Topology in full transmit power. (b) Topology after optimal transmission power level selection.

topology at maximum power (18dBm) with an approximate transmission range of 170 meters (i.e., without topology control), resulting in an average local neighborhood density of 8.08 neighbors per node. For topology controlled network in Fig. 2(b), the average optimal power is 12.07dBm and the average neighborhood density is 4.88. With lower local neighborhood density and transmission power fewer edges are formed while network connectivity is maintained. Furthermore, it requires less energy to communicate.

4 Performance Evaluation

For performance evaluation we implemented and compared our scheme with pure flooding algorithm (no transmission power control) and LINT protocol [6] using network simulator ns-2 [14].

The flooding algorithm runs with a default transmission power level (i.e., 24.5dBm). LINT on the other hand performs transmission power adjustment based on node degree. If the number of neighbors is less then 6, we run LINT protocol in full power and reduce the transmission power gradually as the node degree increases. The choice of discrete power levels is according to the commercially available CISCO Aironet 350 series wireless LAN card [15]. It has six power levels (24, 21, 18, 13, 7 and -3 dBm) where these power levels corresponds to 250, 210, 170, 130, 90 and 50 meters of transmission range, respectively. Table 1 summarizes the values for all the parameters used in our ns-2 simulations.

Two non-random network mobility models namely deterministic and semi-deterministic mobility models are utilized. (1) In Deterministic mobility model,

Table 1. Parameters and their values in ns-2

Parameters	Meaning	Value
G_t	Transmitter antenna gain	1.0
G_r	Receiver antenna gain	1.0
h_t	Transmitter antenna height	1.5m
h_r	Receiver antenna height	1.5m
η	Path Loss Exponent	4
L	System Loss Factor	1.0 (i.e., no loss)
α	Time Increment	10s

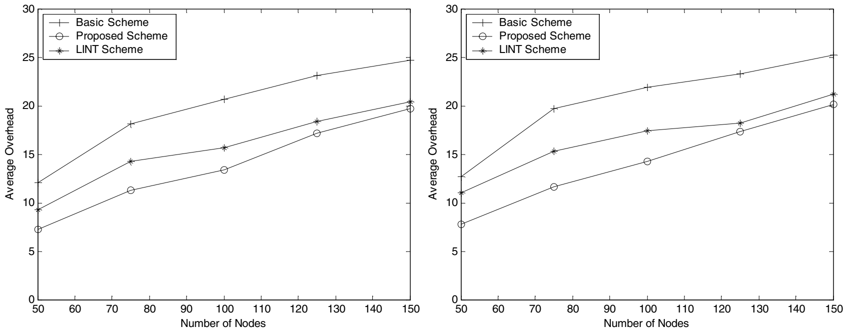
deviation in the movement of the node is set to zero degree. (2) In Semi-deterministic mobility model, deviation is varied from -15 degree to +15 degree, so node movement would vary in 30 degree columnar width. We modified the existing *setdest* program that is included in CMU version of ns-2 [14] for generating our simulation scenarios.

4.1 Simulation Environment

In our simulation model, nodes are randomly placed in a 1000 x 1000m^2 grid. All nodes move around this region from 1m/s to maximum speed of 20m/s with pause time set to 0. Total simulation duration is 300 seconds. In our experiments we have varied the network size from 50 to 150 in increments of 25 nodes. Following metrics have been used for performance evaluation. (1) *Average Overhead*, is defined as the number of packets received per data transmission per node. (2) *Average Transmit power*, is the ratio of total transmission power and network size. Note that HELLO packets are included only in our scheme and LINT. (3) *Delay*, is given as the time elapsed between data sent from the source node and data received at the intended destination.

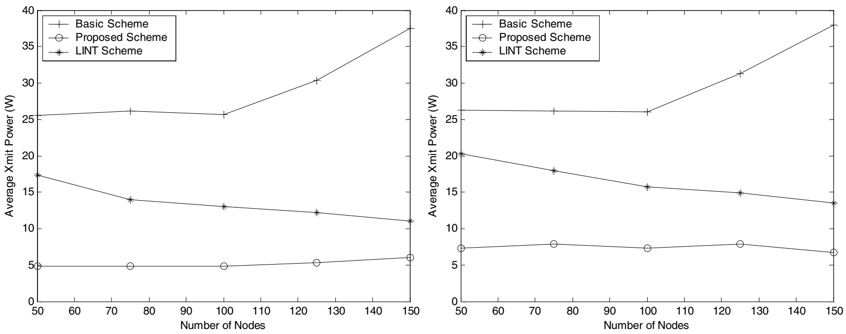
4.2 Simulation Results

We begin by examining the overhead of broadcasting data packets in the networks. Fig.3(a) and (b) plots the average overhead per data transmissions, also averaged over total number of nodes as the function of network size for deterministic and semi-deterministic mobility model respectively. Average overhead of the proposed scheme is consistently lower than the basic scheme and LINT. As described in the previous section the effect of applying topology control causes significant reduction in average local neighborhood density, as a result fewer neighboring nodes forwards the data packets. These facts also helps in undermining the advantages of transmitting at full power, which often forwards packets with less number of intermediate nodes. The same benefits bear for LINT, however whenever network turns into undesirable connectivity, nodes switch towards full transmission mode. Since, each node deviates its direction angle in a relatively smaller columnar width the overhead for both mobility models are quite comparable.



(a) (b)

Fig. 3. Results for Average Overhead. (a) Deterministic (b) Semi-Deterministic Mobility Model.



(a) (b)

Fig. 4. Results for Average Transmit Power. (a) Deterministic (b) Semi-Deterministic Mobility Model.

Fig.4(a) and (b) presents the average transmits power (in Watts) for both mobility models. These normalized results show that the impact of not regulating the transmission power results in a significantly higher power usage as compared to proposed scheme. Our scheme retains connectivity with nodes that are present at the boundary of transmission range with minimal power whereas LINT enforces to operate at higher transmission power levels in this situation. For smaller network sizes LINT has to increase the power of some isolated nodes. The power consumption for semi-deterministic mobility model is comparatively higher than the deterministic model, which is required in order to compensate limited deviation that neighbor nodes can have.

Fig.5(a) and (b), depicts the average delay (in seconds) in proposed scheme and others. Generally, delay incurred is comparatively higher for all while the network is dense. With moderate traffic load, the delay for non-topology controlled network is lower because it takes small number of hops to disseminate packets in the network as compared to topology controlled one. The delay in both mobility models is similar in all schemes.

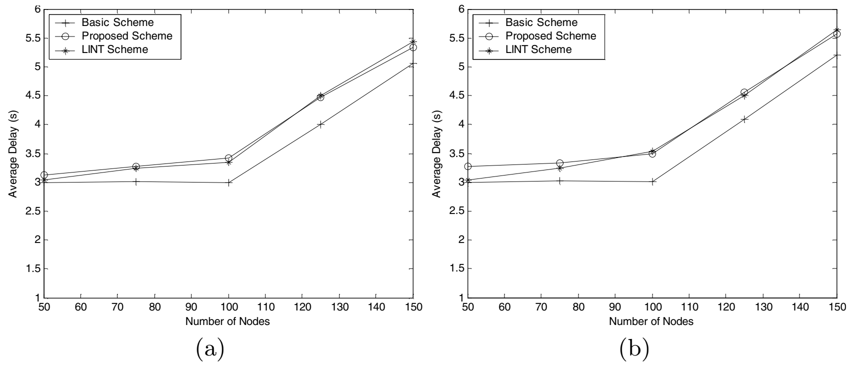


Fig. 5. Results for Average Delay. (a) Deterministic (b) Semi-Deterministic Mobility Model.

5 Conclusion and Future Work

In this paper we have presented a new topology control algorithm in presence of mobile nodes. Our scheme exploits non-random node mobility pattern to predict future state of network topology. Each node runs a distributed algorithm to estimate the minimum power required to successfully communicate with its each neighbor. Finally nodes adjust their transmission power to optimum level to achieve robust topology. Simulation results show that our approach advocates multi-hop communication among nodes for efficient utilization of scarce system resources, such as power and bandwidth in dynamic ad hoc wireless environment. Furthermore, since our protocol operates over a set of discrete power levels, therefore location information is not required to be highly precise. However, another aspect of our algorithm is that it depends upon one-hop HELLO packet, which must be sent periodically with additional neighbor information.

Our future plan is to extend the simulation for different parameters including random mobility model and to apply proposed scheme on link state routing protocols so that the effect of link breakage due to dynamic transmission power level changes can be studied.

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