Poster: Distributed Topology Control Mechanism for Mobile Ad hoc Networks with Swarm Intelligence

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Mobile ad hoc networks are constrained by the interference of wireless communications and by limited battery lifetime. To address these issues, *topology control* aims to maintain a specified topology so as to reduce interference, reduce energy consumption, and increase the effective network capacity.

We formulate topology control as a (combinatorial) power assignment problem. Let $V = \{v_1, v_2, \ldots, v_n\}$ represent the set of nodes in the network. Each node is equipped with the same finite set P_s of available (discrete) power levels where $P_s = \{p_1, p_2, \ldots, p_k\}$, $p_1 < p_2 < \ldots < p_k$, and $p_k \equiv P_{full}$ (the maximum available transmission power termed *full-power*). Therefore, the complexity of the problem is $O(k^n)$. The network is assumed to be connected when every node is assigned P_{full}, which is the case when no topology control is in effect. Topology control generates power assignment $\{P_{v_i} | \forall v_i \in V\}$ to achieve optimization objectives subject to given connectivity constraints.

Biologically inspired swarm intelligence [1] refers to intelligent behaviors that arise from very simple individual behaviors and interactions, which is often observed in nature especially among social insects such as ants. Although each individual (an ant) has little intelligence and simply follows basic rules using local information obtained from the environment, such as ant's pheromone trail laying and following behavior (a form of indirect communication known as *stigmergy*), globally optimized behaviors, such as finding a shortest path, *emerge* when they work collectively as a group. In general, a swarm intelligence-based approach deposits and maintains pheromone values as new solutions are produced. The pheromone value associated with a solution represents its goodness. Initially, solutions are searched randomly. Gradually, better solutions are preferred in the search and their associated pheromone values increase, which in return further reinforce these solutions. Through such a positive-feedback process, the approach quickly converges to an optimal solution. Furthermore, the exploration capability of swarm intelligence allows new solutions to be discovered in order to accommodate changing environment attributed to mobility, for instance.

In this paper, we describe a novel distributed topology control protocol termed Ant-Based Topology Control (ABTC) for mobile ad hoc networks, which applies the swarm intelligence metaphor to topology control. In particular, ABTC optimize the following two objectives: (1) minimizing the maximum power used by any node in the network, $P_{max} = \max_{i=1}^{n} P_{v_i}$, (MINMAX objective), and (2) minimizing the total power used by all of the nodes in the network, $P_{tot} = \sum_{i=1}^{n} P_{v_i}$, (MINTOTAL objective), subject to connectivity constraints. Moreover, ABTC obtains, with high fidelity, *common* power, *i.e.*, $\forall i, 1 \leq i \leq n, P_{v_i} \equiv P_{compow}$, as a by-product while minimizing the maximum power, where common power is a desirable property for the correct operations of many ad hoc networking protocols. Furthermore, as compared to other topology control algorithms, ABTC does not rely on either hardware support for GPS location and Angle-of-Arrival, or routing information.

ABTC works as follows. Every node periodically executes a neighbor discovery protocol to obtain the current neighbor set. In addition, every node periodically broadcasts an "ant packet" with some transmission power chosen from P_s and the ant packet contains four fields: *originId*, *seqNo*, *totalPwr* and *txPwr*. *originId* is the originator of the ant packet; the pair $< originId, seqNo >$ uniquely identifies each ant packet; *totalPwr* is used to limit the power a node uses augmentally to reach its neighbor P_{hi}, which is its initial value; *txPwr* is the power chosen to originate the ant packet. If the objective is *maximum* power, the power is chosen using Equation. 1; if the objective is *total* power, the power is chosen randomly from P_s. Upon receiving an ant packet, a node discards it if it is not originated from its neighbor or is a duplicate. Otherwise, the node checks if $txPwr$ is less than the $totalPwr$. If so, the node forwards the ant packet $< originId, seqNo, totalPwr - txPwr, txPwr >$; or the packet is discarded. In addition, a node updates the entry corresponding to the pair $< originId, txPwr >$ in its so called "pheromone table," which is updated using Equation. 3. In the meantime, the pheromone table is periodically updated using Equation 4.

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$$P_a(t) = \begin{cases} arg\max_{p \in P_s} \tau_{j,org,p}(t) + \beta * \eta_p & \text{, if } q \le q_0; \\ P & \text{, if } q > q_0. \end{cases} \qquad (1)$$

where, q is a random variable uniformly distributed over $[0, 1]$, q_0 is a tunable parameter in $[0, 1]$, and $P \in P_s$ is the power randomly selected according to the probability

$$prob_{j,org,P}(t) = \frac{\tau_{j,org,P}(t) + \beta * \eta_P}{\sum_{p \in P_s} \tau_{j,org,p}(t) + \beta * \eta_p} \qquad (2)$$

where each node j maintains a pheromone value $\tau_{j,org,p}$ for each originator org and each power level p. η_p is a heuristics defined as $\frac{p+1}{p}$, which contributes inversely with power level p. β balances the relative weights between τ and η. q_0 decides the preference between exploration of new solutions and exploitation of knowledge collected from old solutions.

$$\tau_{j,org,p}(t) \leftarrow \tau_{j,org,p}(t) + \tau_0 \qquad (3)$$

$$\tau_{j,org,p}(t) \leftarrow \tau_{j,org,p}(t) \cdot \left(\frac{1}{2}\right)^{DegradeRate} \qquad (4)$$

where $\tau_0 = \frac{1+P_{hi}}{P_{hi}}$ and $DegradeRate = \frac{PHEROMONE\_INTERVAL}{PHEROMONE\_HALFLIFE}$.
The rationale behind ABTC is as follows. By leveraging proper heuristics, ABTC favors lower power levels. By choosing transmission power based on pheromone table, ABTC converges to the favored common minimized maximum power level quickly as a result of positive feedback; by choosing transmission power randomly, more power levels are explored to minimize the total power, rather than converging to the common power. By updating the pheromone table in response to the periodical arrival of ants, the pheromone table favors the power levels carried by arriving ant packets; by degrading the pheromone table periodically, the pheromone table is kept current, which makes ABTC adaptive to mobility.

We simulate the ABTC protocol using QualNet. Table 1 lists the simulation parameters.

Table 1: Parameters for Simulation Environment

Parameter	Value
Number of Nodes	50
Terrain Size (m×m)	1500×1200
Propagation Path-loss Model	Two Ray
Transmission Power Levels (dBm)	2.58, 5.08, 7.89, 11.05, 13.73, 16.04, 18.10
Transmission Power Ranges (m)	150, 200, 250, 300, 350, 400, 450
Mobility Model	Random Way-point
Nodal Speed (m/s)	0 20 40 60 80
Pause (s)	5
Simulation Time (s)	150

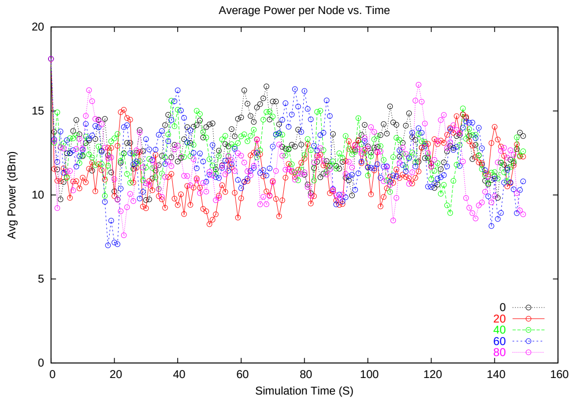

Figure 1: Average Power (MinTotal Objective)

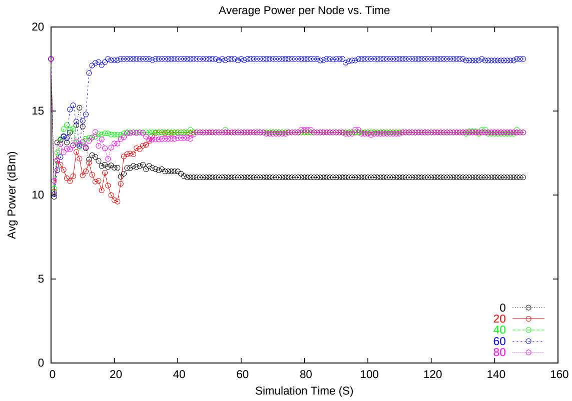

Figure 2: Average Power (MinMax Objective)

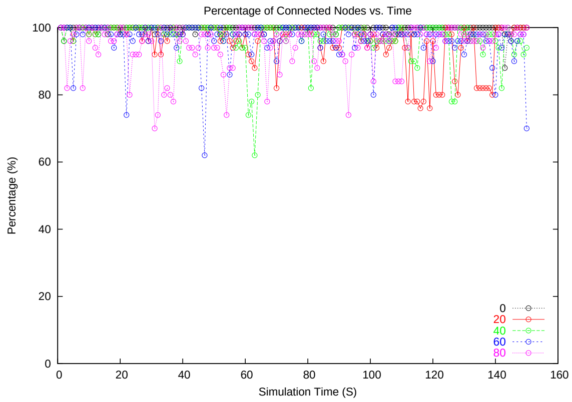

Figure 3: Connectivity (MinTotal Objective)

Figures 1 to 3 demonstrate the average or total power with MinTotal or MinMax objectives under different degree of mobility.

It can be observed from Figures 1 and 3 that ABTC saves around 6 dB, an equivalent of 75% saving in power, compared to the case when every node uses the maximum power, 18.01 dBm, while maintaining connectivity effectively under varied degree of mobility. ABTC therefore adapts well to network dynamicity. Contrasting Figure 2 to Figure 1, it can be deduced that every node tends to use a common power, which is also the minimized maximum power, i.e., ABTC obtains the *common power* property.

Lastly, ABTC is a distributed and scalable protocol since ants originated from every node are limited to its neighbors.

1. REFERENCES

[1] Eric Bonabeau, Marco Dorigo, and Guy Theraulaz, *Swarm Intelligence: From Natural to Artificial Systems*, Oxford University Press, New York, 1999.