Minimum-Energy Mobile Wireless Networks

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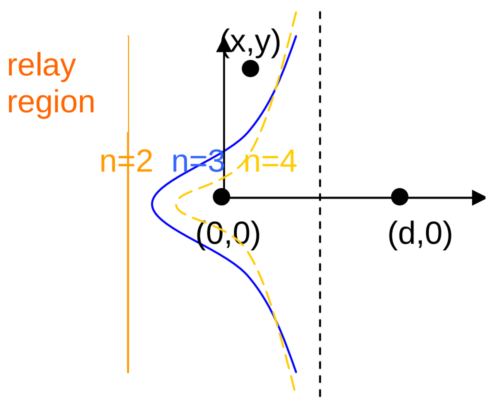
Introduction

Multi-hop wireless networks, especially sensor networks, are expected to be deployed in a wide variety of civil and military applications. Minimizing energy consumption has been a major design goal for wireless networks. It can allow longer battery life and mitigate interference. Much research has been done to find topology control protocols that allow nodes to communicate using minimal transmission power while ensuring network connectivity.

Path loss power consumption model

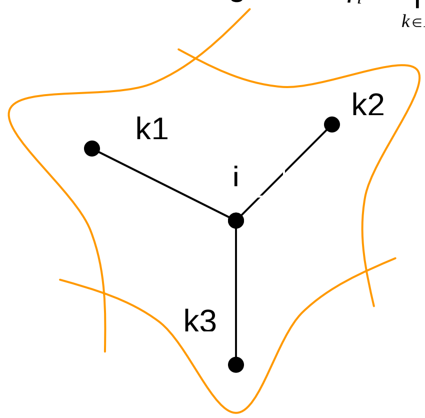
The received signal averaged over large-scale variations has been found to have a distance dependence well modeled by $1/d^n$ $(n \geq 2)$. Relaying transmission between nodes may result in lower power consumption. The relay region is that area where relaying a message via a neighbor node saves energy over transmitting the message directly.

- Relay region $R_{i \to r} = \{(x, y) \mid P_{i \to r \to (x,y)} < P_{i \to (x,y)}\}$



$$(\sqrt{x^2 + y^2})^n + d^n + C < (\sqrt{(x-d)^2 + y^2})^n$$

- Enclosure and neighbors $\eta_i = \bigcap_{k \in N(i)} (R^c{}_{i \to k} \cap D)$, $N(i) = \{n \mid (x_n, y_n) \in \eta_i\}$



- Enclosure graph is defined as the graph whose vertex set is wireless nodes and whose edge set is links within the enclosure
- Theorem – the enclosure graph is strong connected.

Enclosure graph guarantees connectivity of the entire network while maintaining minimum power consumption. Rodoplu et al. [1] develop a distributed algorithm for finding the enclosure graph. However, its computational complexity is quite demanding and requires specifying a deployment region. Furthermore, it is coupled with a radio propagation model. Due to the large influence of environmental factors on radio frequency communications, radio propagation models can be notoriously inaccurate.

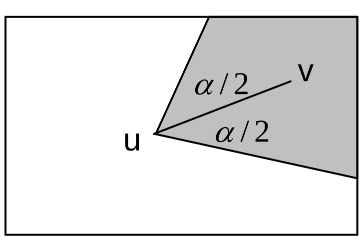
Cone-based topology control

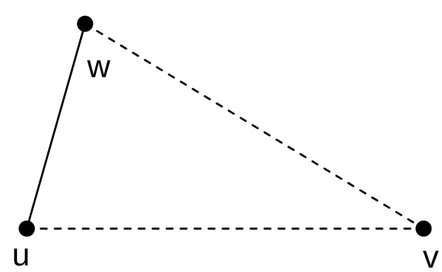
Wattenhofer et al.[2] introduce a cone-based topology control that builds a connected graph by letting nodes find close neighbor nodes in different directions. Then it eliminates non-efficient links using the relay region model.

Briefly, it works as follows. Each node u beacons with growing power p. If node u discovers a new neighbor node v, node u will put v into its local set of neighbors $N(u)$. Node u will continue to grow the transmission power until the neighbor set $N(u)$ is big enough such that, for any cone with angle α there is at least one neighbor v, or until node u hits the maximum transmission power p.

Theorem – Let G(V,E) be the graph constructed by cone-based topology control. Let G'(V, E') be the connection graph when all nodes always beacon with maximum power. We have $\alpha \leq 2\pi/3$, then G will be connected whenever G' is connected.

Proof: Assume graph G is not connected, while G' is. Then there exists at least a pair of nodes (u,v) such that there is no path between the pair. Let w be a neighbor node of u, therefore $\overline{uw} < \overline{uv}$. We construct a triangle of the nodes u, v, w. Because of nonconnectivity of (u,v), (v,w) is unconnected too. Without loss of generality, assume $\overline{wv} > \overline{uv}$. A basic triangle result is $\angle u > 3/\pi$. This contradicts cone-based algorithm invariant – in any cone with angle α there is at least one neighbor v, so G must be connected if G' is.





Proposed work

Both algorithms find a connected graph with small degree. The advantage of Rodoplu's algorithm for finding the enclosure graph is there is no need for a directional beacon. One advantage of the cone-based algorithm is reduced complexity. Yet another paper, Li et al. [3], computes the Voronoi region to find Delaunay neighbors. Our proposal is to study these topology control methods considering realistic radio propagation models [5].

Many studies consider a path loss exponent n=2. However, in outdoor urban situations, the path loss exponent is close to 4. Indoor propagation depends on, among other things, the building type [4]. Thus, there is a difference between buildings with reinforced concrete walls (bad for radio propagation), wood walls or partitions (better for propagation), and open warehouses or auditoriums (best).

References:

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