Distributed Routing and Scheduling in Resource-Limited Wireless Ad Hoc Networks with Connectionless Traffic

Tolga Girici/Anthony Ephremides

Motivations

Ad Hoc wireless networks:

- Don't have a fixed infrastructure
- Must operate in an energy-efficient way.

Therefore give rise to some novel trade-offs, which can be exploited.

- Can show a better performance with layer integration and decentralized operation.

Objectives

- Finding distributed algorithms and link cost metrics for distributed scheduling and routing, which take into account the limited resources and local congestions in wireless ad hoc networks.
- Investigating the effects of integrated approach to scheduling and routing.

Routing

- Considering the limited resources (e.g. energy and transceivers) and location-dependent congestion, the following link cost metric can be used for distributed Bellman-Ford routing:

$$M = \begin{cases} \dfrac{W_p \times P_{ij}}{P_{\max}} + \dfrac{W_e \times (E_{init} - E_j^R)}{E_{init}} + W_d \times \left(\dfrac{Q_{ij}}{1+Q_{ij}}\right) & \text{if } E_i^R, E_j^R \neq 0 \\ \infty & \text{otherwise} \end{cases}$$

Where P_{ij} is the required transmission power from nodes i to j; E_{init} is the initial energy and E_j^R is the remaining energy of node j. Q_{ij} is the queue size of the directed link between nodes i and j. Finally W_p, W_e and W_d are the weighting parameters.

- By using this link cost metric paths that require less energy, that are uncongested and that contain nodes with higher remaining energy are preferred in routing.

Scheduling Algorithms

Constraint: Each node has single transceiver and no two links sharing same node can be activated simultaneously. **S** is the set of links that are activated together, without conflict.

Centralized Algorithm:

1. Order nodes according to their weights. (**W_i** for node i) and scan the nodes in that order.
2. For node i, this time, order **X_{ij}**, where X_{ij} is the weight of link (i,j) and j is a neighbor of node i.
3. Scan the links (i,j) in that order, **if** $S \cup \{i,j\}$ is feasible, **then** let $S \cup \{i,j\}$.

Distributed Algorithm:

1. Run the distributed Minimum Spanning Tree (MST) Algorithm using the weights X_{ij} and form tree **T.** Set color of all nodes to white.
2. Leaf nodes in the tree (k) communicate with their parents (l) in the tree s.t. $\{k,l\} \in T$. **If** $S \cup \{k,l\}$ is feasible **then** let $S \cup \{k,l\}$.
3. **If** $\{k,l\} \in S$ **then** color(k)=color(l)=red
4. After this, each white node "m" communicates with its parent "n" on the tree, and: **if** color (n)=white **then** $S \cup \{m,n\}$
5. Repeat steps 3,4 until no more nodes can be added.

- Each time a transmission is made between nodes i and j, between links (i,j) and (j,i), argmax$\{Q_{ij}+Q_{ji}\}$ is preferred.
- i) MST Algorithm can be applied in a distributed fashion.

  ii) Each node only needs to communicate only with its one-hop neighbor to learn its color.
- $\sum_{(i,j)\in T} X_{ij}$ is minimum for MST, hence; $\sum_{(i,j)\in S} X_{ij}$ is close to optimal.

Scheduling Metrics

$W_i = \sum_{k \in R(i)} (Q_{ik} + Q_{ki})$ W_i is used in the centralized algorithm. It promotes the congested nodes.

$$X_{ij} = \begin{cases} \dfrac{c_q}{Q_{ij}+Q_{ji}+1} + \dfrac{c_d \times (Q_{ij}+Q_{ji})}{\sum_{k\in R(i)}(Q_{ik}+Q_{ki}) + \sum_{k\in R(j)}(Q_{ij}+Q_{ji})+1} + \dfrac{c_e \times P_{ij}}{P_{\max}} & \text{if } i \in R(j) \\ \infty & \text{otherwise} \end{cases}$$

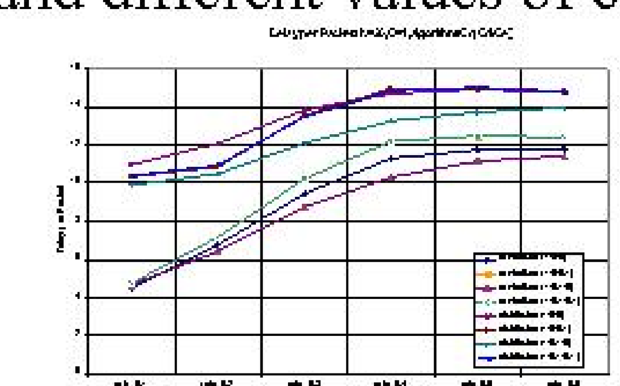
Links with minimal power and long buffer are promoted in scheduling. Here, Q_{ij} is the length of queue from i to j, c_q, c_d and c_e are the weighting factors.

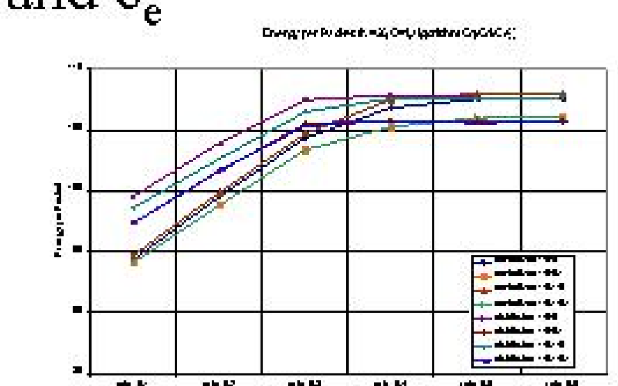
- If a low-power link {i,j} is promoted in scheduling, then:

1. Q_{ij} decreases.
2. Therefore, link {i,j} is preferred in routing, which decreases the energy expenditure.

Simulations

Simulation Conditions: E_{init} is enough to keep all nodes alive during the simulation. New packet arrival rate is λ/Node. Each node has a single transceiver. (C=1) Simulations are made for changing arrival rates and different values of c_q,c_d and c_e





From the simulations we see that:

- As the load increases, performance of distributed algorithm converges to that of centralized algorithm.
- Increasing c_e and c_d from 0 to 0.1 decreases the energy and delay respectively. Here routing and scheduling act together to reduce delay and energy expenditure .

Conclusion

Routing and scheduling in a resource-limited Ad Hoc wireless network is studied. Our results indicate that the low-complexity distributed algorithm performs comparably well w.r.t the centralized algorithm.