

## Problem Set 4

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1. **(Multi-hop mesh routing, 24 points):** Answer the questions below using simple topologies involving as few nodes as possible. Refer to [ETX] and [ExOR] if necessary.
  - (a) Give an example of a topology and link loss rates where end-to-end retransmissions requires at least 10 times more transmissions than hop-by-hop retransmissions. Assume that hop-by-hop retransmissions continues to use link-layer retransmissions on each link until the packet is successfully transmitted across the link. End-to-end retransmissions only rely on retransmissions from the source.
  - (b) Give an example of a topology and link loss rates where least-hop-count routing results in at least 5 times more transmissions than ETX routing.
  - (c) Give an example of a topology and link loss rates where traditional routing achieves less than a third of the throughput (or equivalently requires three times more transmissions) compared to opportunistic routing. As above, assume that the coordination in opportunistic routing is perfect and incurs negligible overhead. Hint: Start with the simple example of a two-hop network consisting of a source, a set of relay nodes, and a destination, as in the slides on opportunistic routing.
  
2. **(DTN routing, 18):**
  - (a) Explain the difference between replication routing (e.g., RAPID) and opportunistic routing (as in mesh networks) in a few sentences. In particular, state under what network conditions does each technique help and what performance metric each technique improves.
  - (b) Consider a DTN formed by 11 buses in a town (e.g., DieselNet). Suppose one of the buses (say bus 1) never goes to the town center, but the remaining 10 buses do. Suppose the first bus meets each of the other buses on average once every hour, i.e., bus 1 meets bus 2 on average once every hour, bus 1 meets bus 3 on average once every hour, and so on. Suppose each of the other 10 buses go to the town center once every 2 hours on average. What is the delay involved in sending a file from bus 1 to an access point (AP) in the town center? Assume that each meeting is sufficiently long for the file to be transferred from bus to another bus or the AP. Furthermore, ignore the effect of any meetings between the other 10 buses, i.e., use only the meetings involving bus 1 or the AP in your calculations.
  - (c) Explain what an *on-demand* ad hoc network routing protocol means and under what conditions it is preferred over a traditional (proactive) routing protocol. You would need to do some self-reading online to answer this question. An example of an on-demand routing protocol is the AODV (ad-hoc on-demand distance vector) protocol.

3. **(CSMA/CA, 24 points):** Consider the canonical four-node topologies shown in Figure 1 with two simultaneous senders just about to send a frame each. Assume that the wireless channel has a capacity of  $C$ . Assume that in hidden terminal scenarios, two colliding transmissions result in a goodput of zero at each receiver experiencing a collision. In each of the following cases, what is the aggregate goodput achieved by both senders assuming that they use CSMA/CA as in 802.11, and what is the goodput achievable by an ideal MAC protocol? In each case, say if it is a hidden terminal scenario, an exposed terminal scenario, or neither (i.e., 802.11 is ideal and will achieve an aggregate goodput of  $2C$ ).

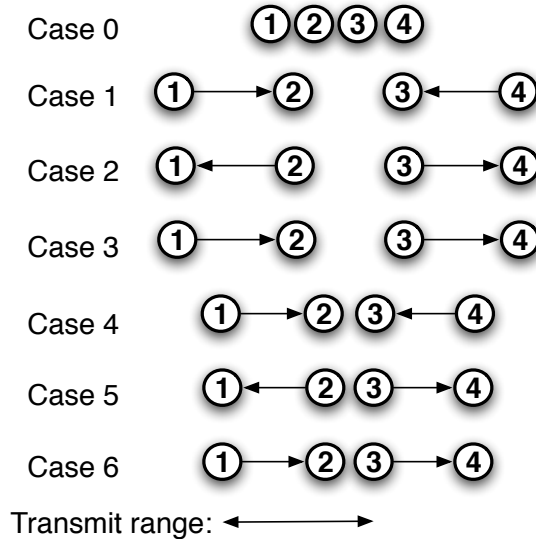


Figure 1: Canonical four node cases with two simultaneous senders. In Case 0, pick any two nodes as senders and the other two as the receivers.

- RTS/CTS is turned off. In hidden terminal scenarios, assume that random backoffs are insufficient to resolve a collision, i.e., retransmissions continue to collide and result in a goodput of zero at each colliding receiver. Note however that the ideal protocol will achieve a goodput of  $C$  in such a case as it would serialize the two transmissions.
- RTS/CTS is turned on according to the default specification, i.e., a node defers transmission either upon hearing an RTS or upon hearing a CTS for some other node.
- RTS/CTS is turned on with the following implementation: a node defers transmission upon hearing a CTS for some other node, but ignores RTS packets.

4. **(Wireless measurement, 40 points):** In this question, you will evaluate the performance of TCP and UDP over a wireless network. The evaluation will be performed on a real wireless ad-hoc testbed deployed on the 2nd floor in the computer science building. The testbed has 12 nodes. Each node has an ethernet address and a wireless address. The ethernet address is  $192.168.0.X$  and the wireless address is  $100.0.0.X$ , where  $X$  is the node number.  $X \in \{1, 2, 3, 5, 7, 8, 10, 12, 13, 15, 19, 20\}$



You can login to the nodes using their ethernet addresses. For example, if you want to login to node 1, you first ssh to the gateway machine of the testbed `ssh cs653@ming.cs.umass.edu`, with password `cs653`. You then ssh to node 1 using its ethernet address: `ssh userY@192.168.0.1`, with password `userY`.  $Y$  is the user number, corresponding to each student.  $Y \in \{1, 2, \dots, 10\}$ . You can use the same user number as your rank in the gradesheet. Please use an entry in the file `~/NAMES` on `ming.cs.umass.edu` to let others know which user number you are going to use.

You will use `iperf` to do the following wireless experiment, using the nodes' wireless addresses. For example, if node 1 is the client, and node 5 is the server, then you can run `iperf -c 100.0.0.5` on node 1.

- Evaluation of UDP and TCP over a one-hop wireless path:** Use `iperf` to measure the goodputs of UDP and TCP over a one-hop wireless path between a pair of nodes. Choose node pairs with varying distance (the floor plan with the locations of the nodes is attached) and measure the goodput at different distances. Plot a goodput graph of UDP and TCP with x-axis as the distance and y-axis as the goodput. Why UDP is doing better than TCP? Describe how the goodput of TCP changes with distance, and explain why.
- Evaluation of UDP and TCP over a multi-hop wireless path:** Use `iperf` to measure the goodputs of UDP and TCP over a multi-hop wireless path. Measure the goodput of UDP and TCP and plot the goodput graph as above. Explain why TCP and UDP perform differently over one-hop link and over the multi-hop link.

You can use OLSR (<http://www.olsr.org/>) to find a multi-hop path. For example, for the following topology, there is a one-hop path between node 1 and 5, and node 5 and 3, but there is no one-hop path between 1 and 3. If you run OLSR on all the three nodes: `/home/userY/olsrd -f /home/userY/olsrd.conf`, you will find that node 1 and 3 can ping each other through 5 (checking the routing table), and thus forming a two-hop path.



**Attention:** Make sure there is no `olsrd` running when you do the one-hop experiment, and make sure you kill the `olsrd` process (`killall olsrd`) when you finish the multi-hop experiments. Also, we can't guarantee all nodes work normally. :) If you can't find enough working nodes to do your experiments, email Xiaozheng [xztie@cs.umass.edu](mailto:xztie@cs.umass.edu).