MIT 6.829: Computer Networks Fall 2017

Lecture 8: Multi-hop Routing

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1 Overview

This lecture covers multi-hop wireless networks, routing and the notion of edge costs in such networks. We also discuss Expected Transaction Count[1], a metric for edge costs.

2 Wireless Network Architecture 802.11

On the average wireless network, paths usually involve only one hop. It is the same case in wireless networks.

There are three types of network architecture commonly observed:

1. **Access Connections:** As shown in Fig. 1, each AP is connected via Ethernet to the rest of the internet or local network. A cellular connection also has a similar structure except that the AP is called base station.
2. **Device to Device connection:** This is usually observed in Bluetooth devices like Apple pods where there is a dedicated connection solely between the two devices in question. This path might not go to the internet at all, but is still usually one hop though
3. **Ad-hoc wireless networks:** These networks usually involve multiple hops across devices like Fig.2 and then have one of them connect to the internet via a gateway. These are useful to expand coverage, leverage peer connectivity for cheap internet access, and for emergency situations as well as political situations (like when Egypt's government blocked connectivity altogether). These networks give you basic connectivity, but the throughput is very low, so they aren't useful for video applications, etc.

   Roofnet is an example of an ad-hoc network. It was started because connectivity in Cambridge was expensive, so students around Cambridge used a multi-hop approach to just route towards the Computer Science building.

3 Single Path Routing

The most common approach is to treat the network as a graph wherein two nodes have an edge if they can communicate. Each edge has a weight that captures cost and reliability. In general, a smaller weight is preferred.

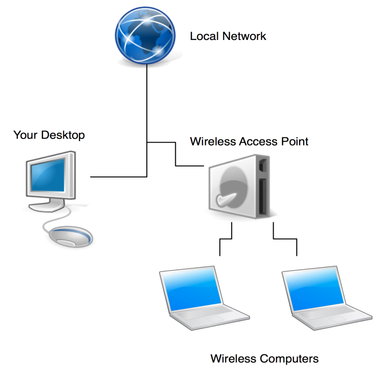

Figure 1: An access connection type of network, where multiple clients (laptops) connect to a single Access Point which connects via Ethernet to the Internet or a local network.

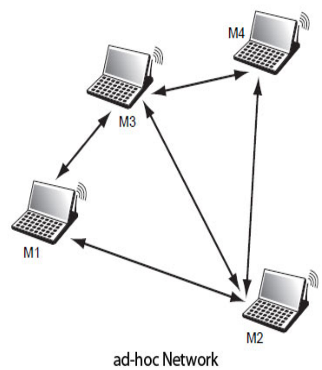

Figure 2: An ad-hoc network where a given computer connects to a number of other devices using them as hops until one of them (say M2) is connected to the internet via a gateway

The goal of a routing protocol is to maximize or minimize a cost that captures the weights. An example is the shortest path protocol that runs on 802.11. The edge cost in this case is the signal strength. Given that wireless is single hop, the path choice is essentially a single choice of which hop to use.

This decision of path choice is generally governed by a number of factors including security, credentials, throughput on each path and the user choice. The default path choice is usually the path with the best RSSI.

Note that, however, representing the network with a graph doesn't capture a number of factors. For instance, a receiver hears from many transmitters with different levels of power, which causes interference. A given sender also broadcasts to all neighbors in a shared medium.

4 Is alternating between 2 Access Points helpful?

Consider a situation where a given client can connect to an AP within Au Bon Pain or one within Starbucks. These APs then have independent connections to Comcast, an internet service provider. The client chooses to constantly alternate between the two APs. Such a set-up is helpful if the

Comcast - Starbucks AP link and/or the Comcast - Au Bon Pain AP link is the bottleneck. This is because it involves two separate bottlenecked links and by alternating, you are filling up both queues alternatively, so only filling up at half the rate instead of congesting just one of them with all the packets. But, this setup will not be useful if the shared medium is the bottleneck. In this case, sending to the Au Bon Pain link right after sending to the Starbucks link just causes interference essentially slowing it down further or causing more overhead to switch.

5 Routing Protocol Choices

To design a good routing protocol, we need a good choice for the edge costs in our graph and a good routing objective. We will explore a few different possible edge costs and routing objectives and their pros and cons.

5.1 Protocol: Minimize Edge Cost where Cost = constant

If we make every link/edge have equal cost (for example, a cost of 1), then a routing protocol that minimizes edge cost on a path simply minimizes the number of hops.

See Fig. 3 for examples showing how well this works.

Pros

- Captures the fact that the medium is shared.

Cons

- Ignores link loss and asymmetry. Interference is different for different transmission directions, as well as for different receivers.

5.2 Protocol: Maximize bottleneck throughput

See Fig. 3 for an example showing that this does not always capture the correct throughput.

Pros

- Good for capturing throughput in wired networks, which have independent links.

Cons

- Ignores the fact that wireless uses a shared medium.

5.3 Protocol: Maximize end-to-end delivery rate

See Fig. 3 for an example showing that this does not always capture the correct throughput.

5.4 Protocol: Minimize Edge Cost where Cost = Expected Transmission Count (ETX)

5.4.1 Calculating ETX

$$P(T_x \text{ success}) = P(\text{Data success}) * P(\text{ACK success}) \tag{1}$$

We often let d_f to denote $P(\text{Data success})$, the forward delivery rate, and we let d_r to denote $P(\text{ACK success})$, the reverse delivery rate. Thus, we have that $ETX = \frac{1}{d_f d_r}$.

Then, the we have the following equation for the ETX of a path.

$$\text{Path } ETX = \sum_{\text{link } \in \text{Path}} \text{link } ETX \tag{2}$$

See Fig. 3 for examples showing that ETX captures the throughput well.

Pros

- Captures throughput of paths for paths shorter than 3 hops.
- Captures link loss asymmetry

Cons

- Ignores potential spacial reuse for long paths (there is less interference beyond 3 hops)
- Does not account for bitrate
- Ignores effect of packet length on loss

This has led to the use of expected transmission time (ETT) instead.

$$ETT = ETX * \frac{\text{Packet Size}}{\text{Bitrate}} \tag{3}$$

References

[1] De Couto, Douglas SJ, et al. "A high-throughput path metric for multi-hop wireless routing" Wireless networks 11.4 (2005): 419-434.

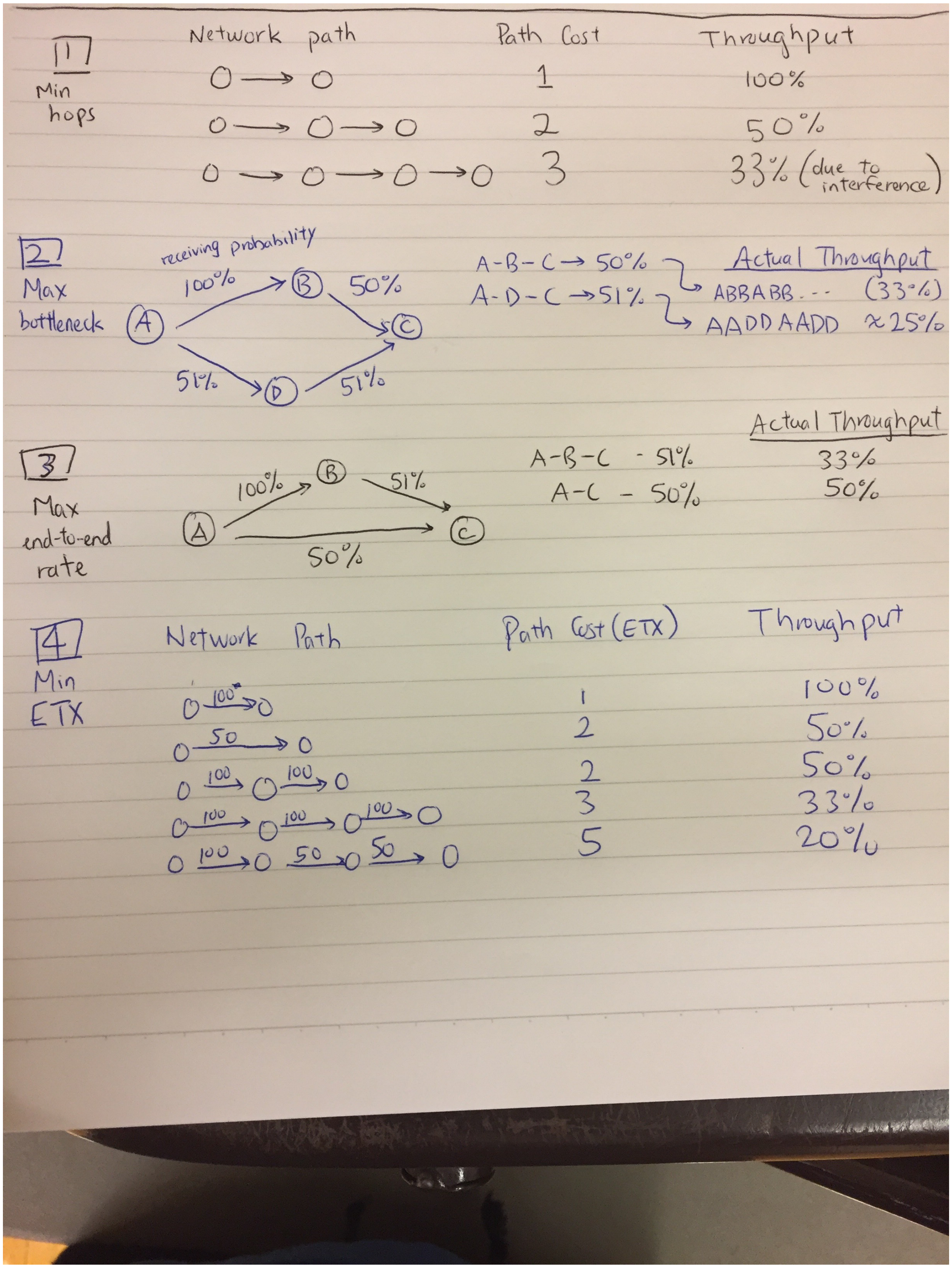

Figure 3: Examples showing different network paths and the throughputs obtained by different routing protocols on each network path.