



# 6.808 Mobile and Sensor Computing

aka IoT Systems

## Lecture #6

### Mesh Networks & Multi-Hop Routing

- Pset 1 due March 5
- Laptops/iPads are fine if you are taking notes for the class (but not for other work)

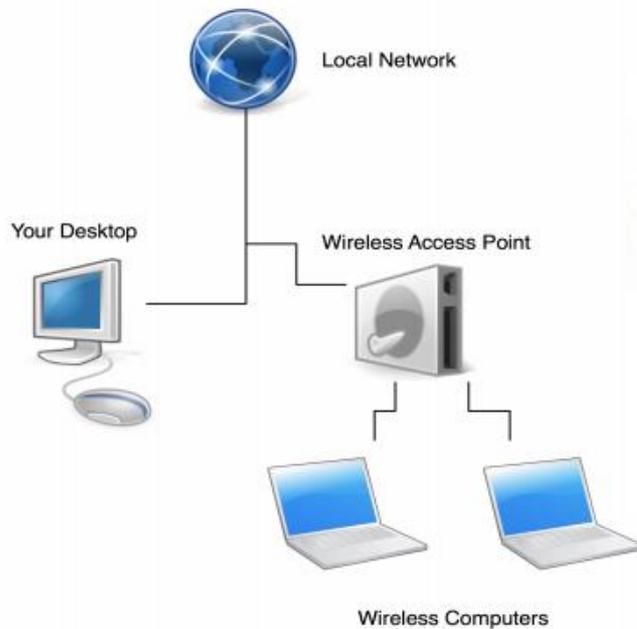


These are tentative slides that we uploaded for students who are interested in taking notes on the slides. The final lecture will be re-uploaded after the class.

# Wireless Network Architectures

There are 3 kinds of wireless network architectures

Access Network



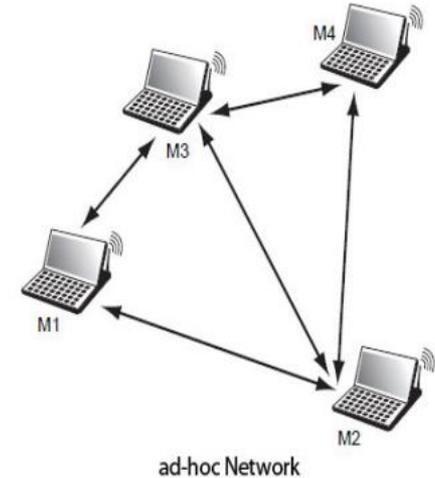
e.g., WiFi, cellular

Device-to-device



e.g., Bluetooth

Ad Hoc Network



e.g., leverage P2P to reach internet (crises)

One-hop

Multi-hop

# RoofNet

## Networking From the Rooftop

MIT researchers are developing new routing strategies for a wireless network that hops data in the roofs of the city.

by **Erico Guizzo**

Aug 29, 2003

A few weeks ago, MIT graduate student Shan Sinha canceled his broadband Internet service. Now his Net connection comes through the chimney. From

## 7 YEARS AFTER ROOFNET, MIT AND CSAIL CHOOSE MERAKI FOR WIRELESS LAN

February 17, 2010

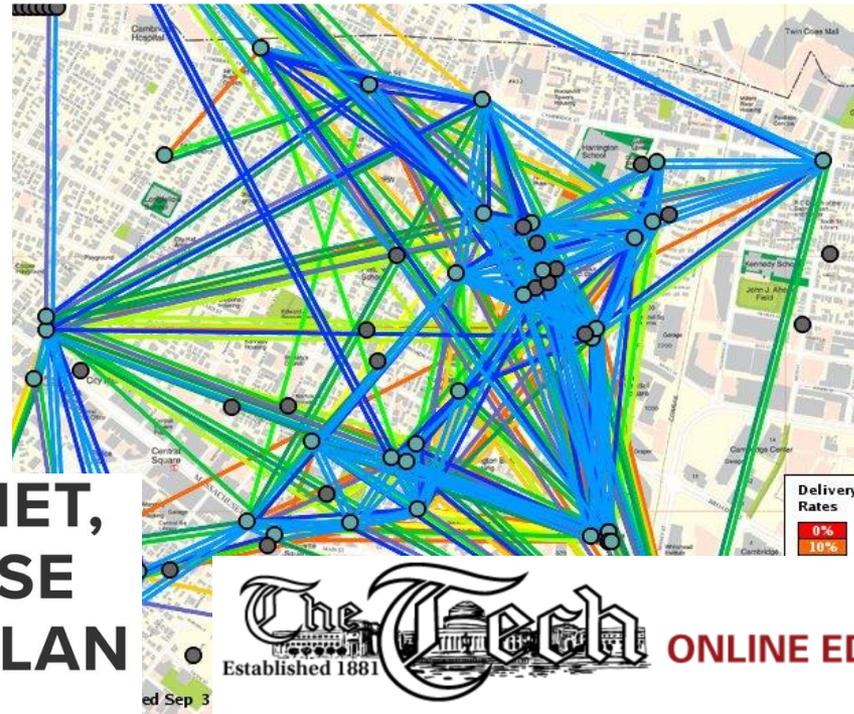
Posted by: @merakisimon

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### Cisco Acquires Enterprise Wi-Fi Startup Meraki For \$1.2 Billion In Cash

Josh Constine @joshconstine / 6:36 pm EST • November 18, 2012



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Volume 125 >> Issue 65 : Wednesday, February 1, 2006

PDF of This Issue

### MIT and City Collaborate To Provide Free

SS

Thibault  
NEWS EDITOR

MIT researchers may provide Cambridge with a free, city-wide, wireless internet service as early as next year. The project will rely on a mesh networking technology that allows individual computers to become nodes, projecting the reach of the network beyond its original antennas.

One of the project's goals is to provide internet access to Cantabrigians who live in public housing, said Cambridge City Officer Mary P. Hart, though the resulting infrastructure will have a far wider benefit for city residents.

MIT's chief information officer, John '68, vice president for Information Services and Technology, said he expects the maximum speed of the network to be 54 megabits per second. The speed users experience will decline as more people access the network.

Although the level of internet service will not be known until the antennas are tested, users should be able to use a browser and send e-mail, though they might not be able to send large pictures or view streaming video.

# Single Path Routing

Represent the wireless network as a graph

- Two nodes have an edge if they can communicate (i.e., are within radio range)
- Each edge is labeled with a weight (where a smaller weight indicates a preferred edge)

Run shortest path algorithm on the graph (e.g., Dijkstra)

- Produce the minimum weight path between every pair of nodes

How do you pick the edge weights?

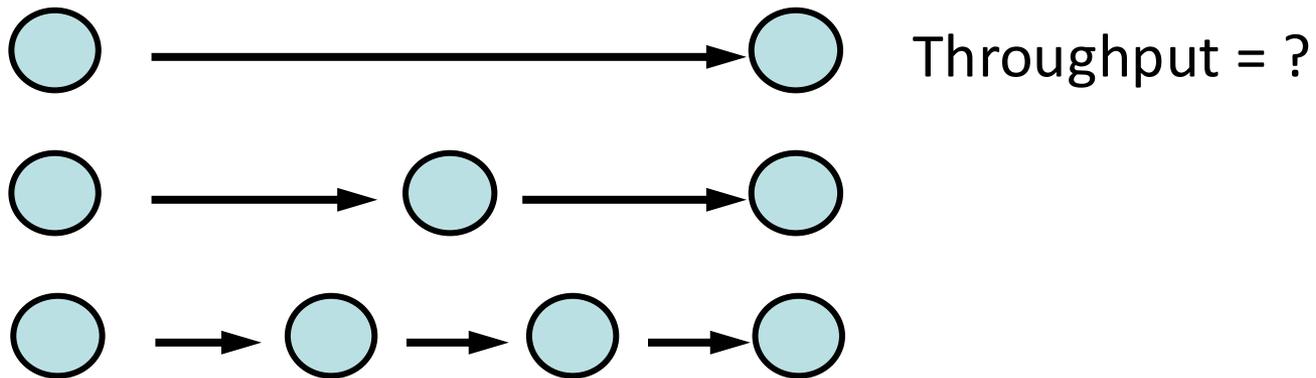
- i.e., what metric should shortest path minimize?

## Approach 1:

Assign all edges the same weight → Minimize number of hops

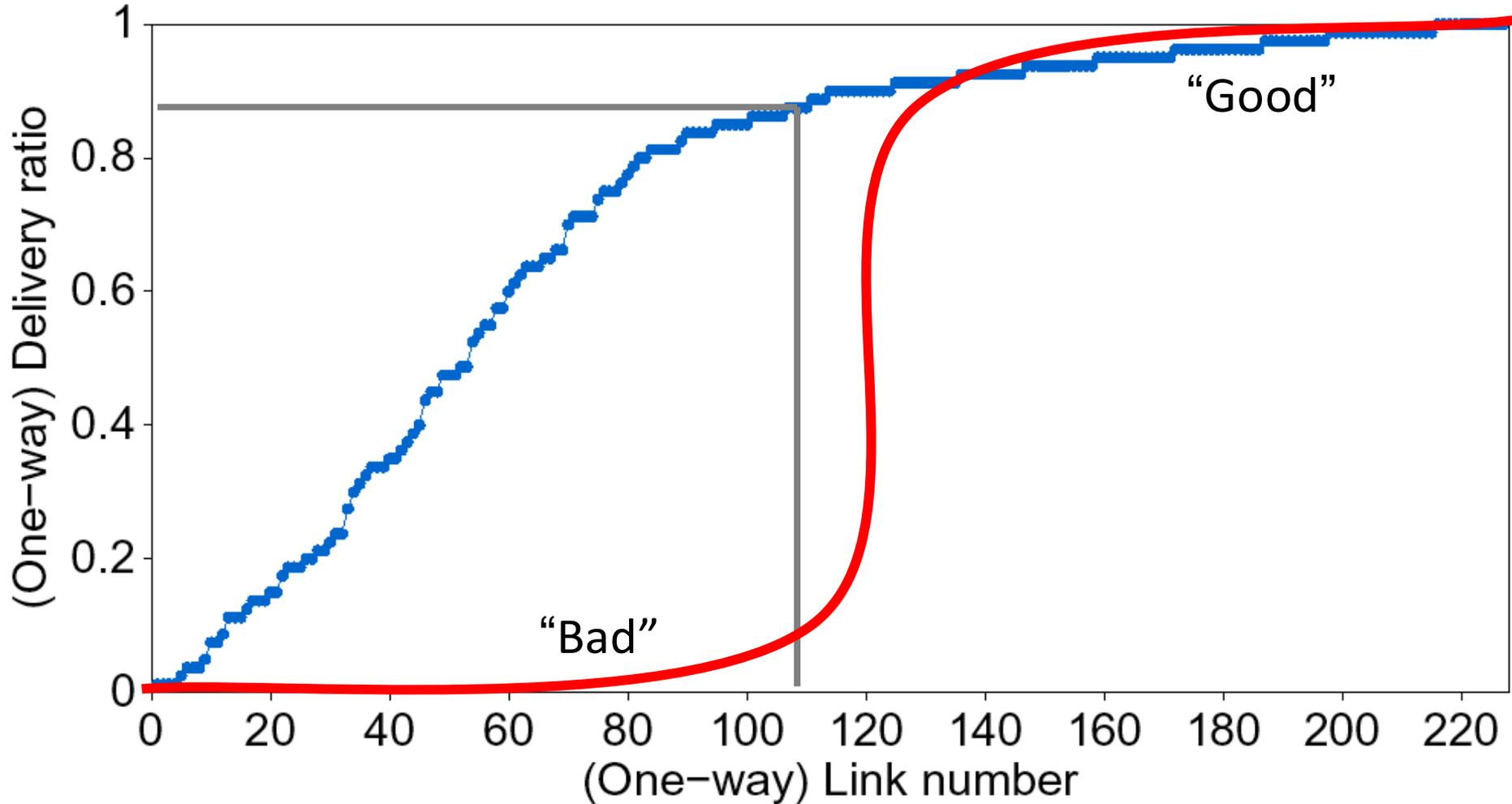
Reasoning:

- Links in route share radio spectrum
- Extra hops reduce throughput



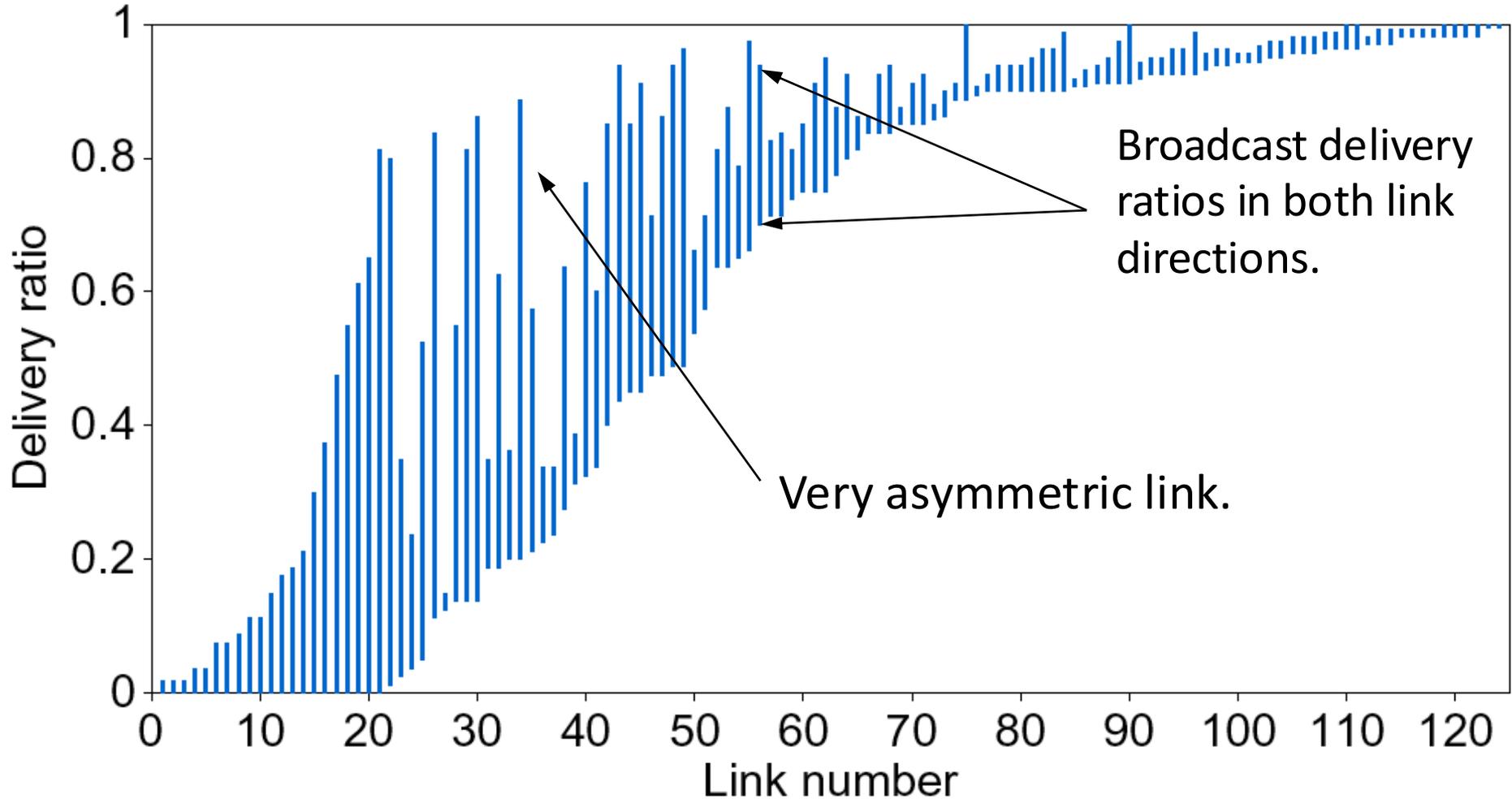
# Challenge: many links are lossy

## One-hop broadcast delivery ratios



Smooth link distribution complicates link classification.

# Challenge: links are lossy and asymmetric

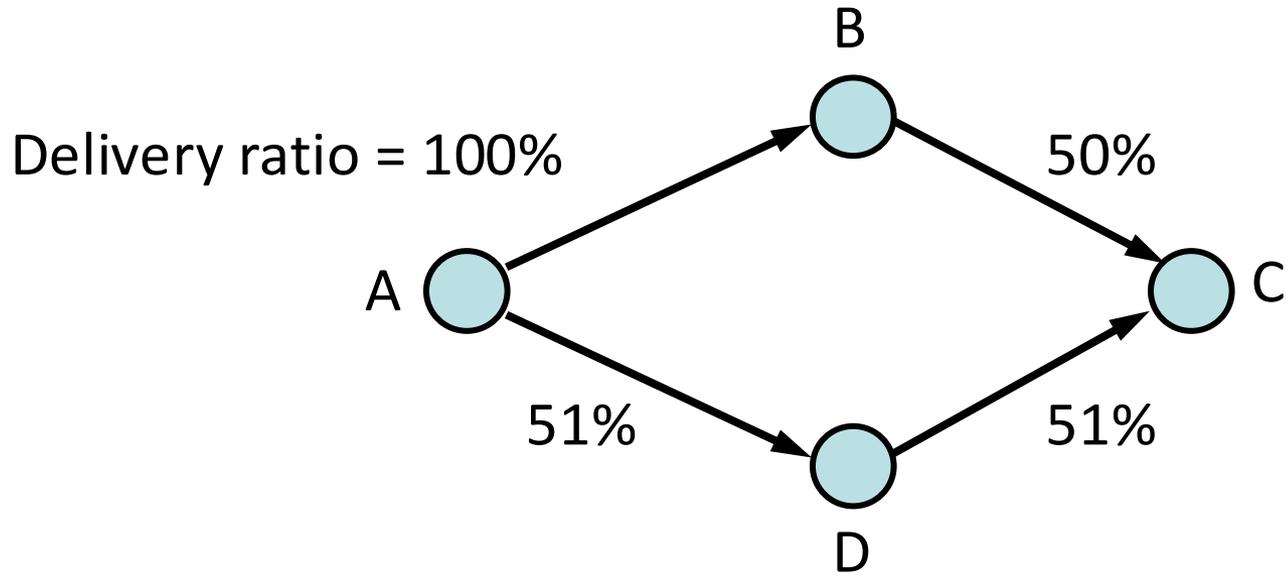


Different links have different loss rates

Further, the loss rate may be different in each direction

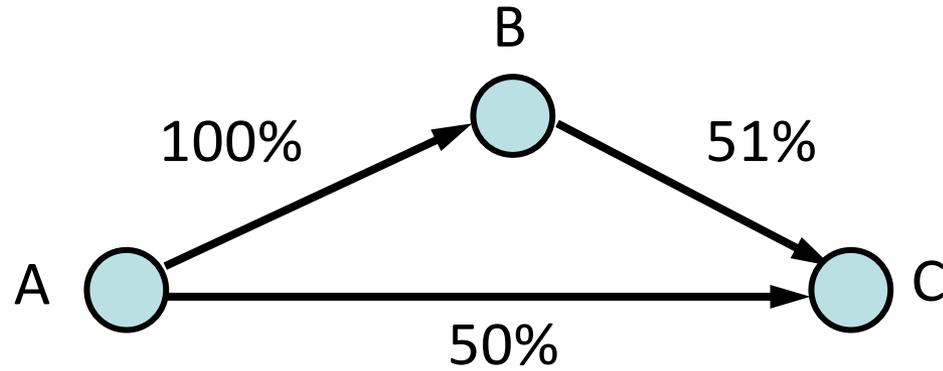
## Approach 2:

Maximize bottleneck throughput



## Approach #3:

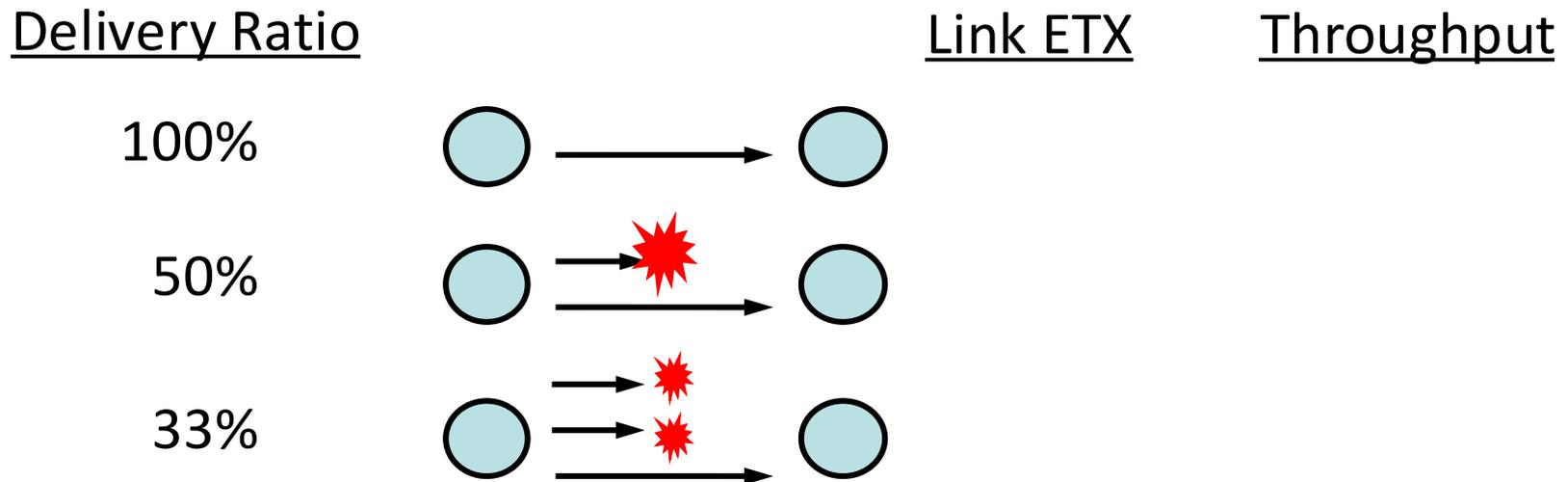
Maximize end-to-end delivery ratio



# Approach #4: Wireless routing metric: ETX

Minimize total transmissions per packet  
(ETX, 'Expected Transmission Count')

Link throughput  $\approx 1 / \text{Link ETX}$



# Calculating Link ETX

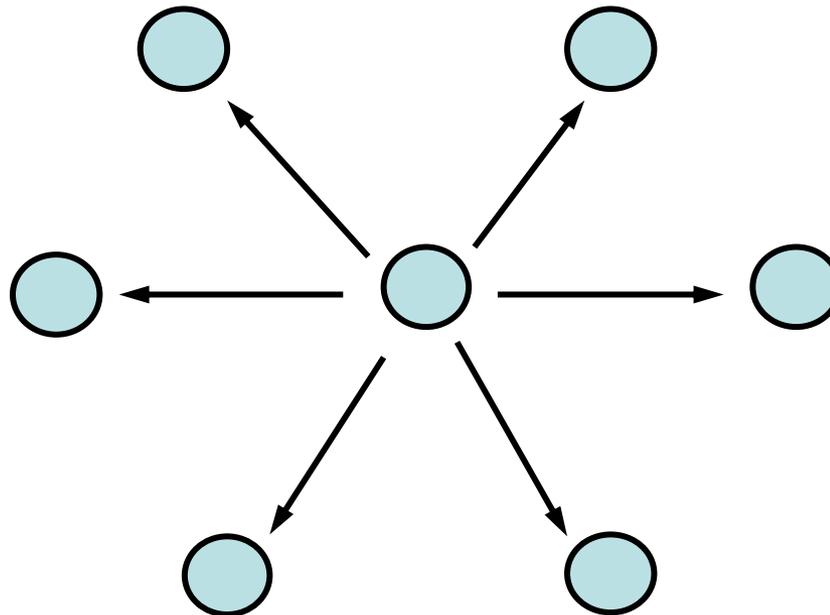
- Assuming 802.11 link-layer acknowledgments (ACKs) and retransmissions:
- $P(\text{TX success}) = P(\text{Data success}) \times P(\text{ACK success})$
- $\text{Link ETX} = 1 / P(\text{TX success})$   
 $= 1 / [ P(\text{Data success}) \times P(\text{ACK success}) ]$
- Estimating link ETX:
  - $P(\text{Data success}) \approx$  measured fwd delivery ratio  $r_{\text{fwd}}$
  - $P(\text{ACK success}) \approx$  measured rev delivery ratio  $r_{\text{rev}}$
  - $\text{Link ETX} \approx 1 / (r_{\text{fwd}} \times r_{\text{rev}})$

# How can we measure delivery ratios?

- Each node broadcasts small link probes once per second
- Nodes remember probes received over past 10 seconds
- Reverse delivery ratios estimated as

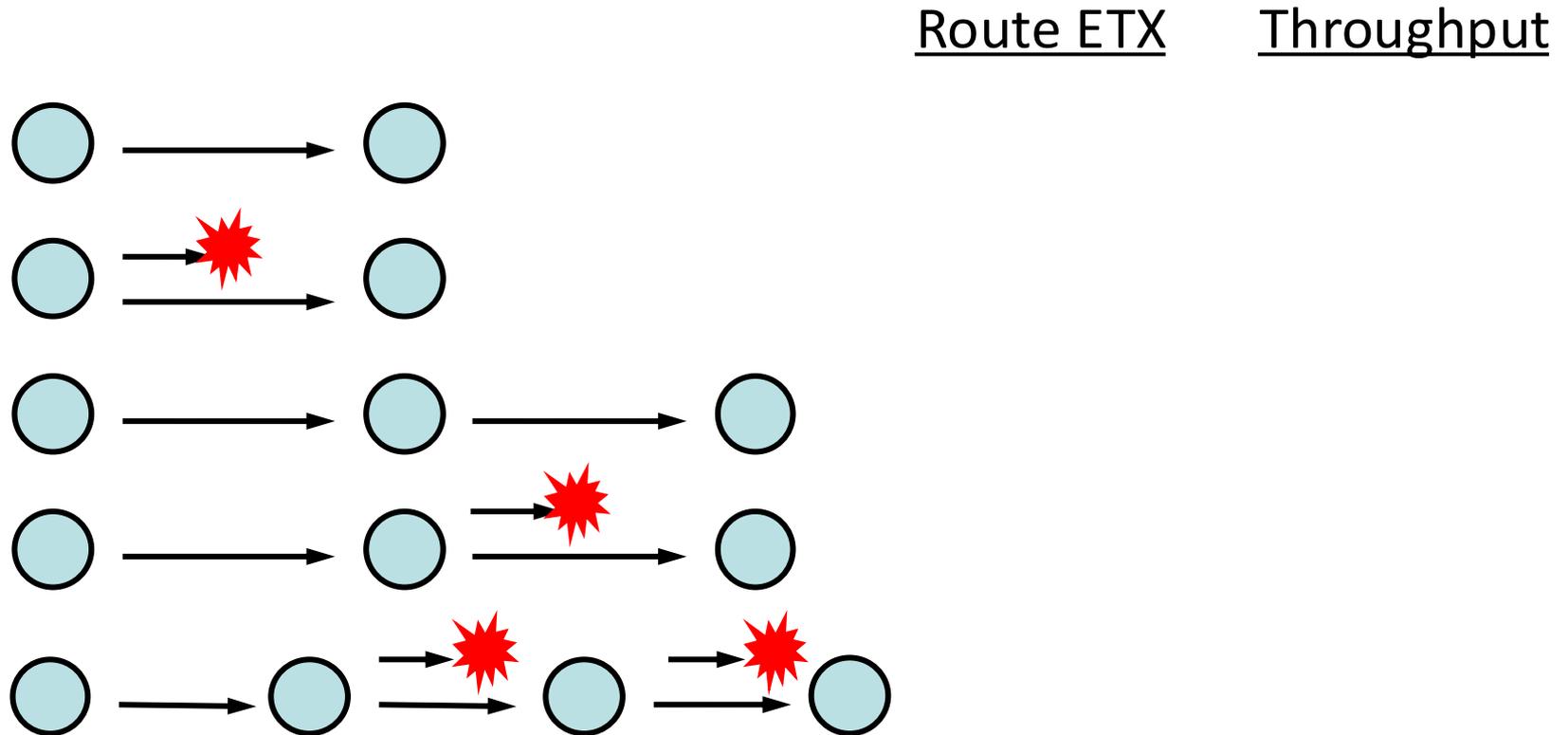
$$r_{\text{rev}} \approx \text{pkts received} / \text{pkts sent}$$

- Forward delivery ratios obtained from neighbors (piggybacked on probes)



# Route ETX

Route ETX = Sum of link ETXs

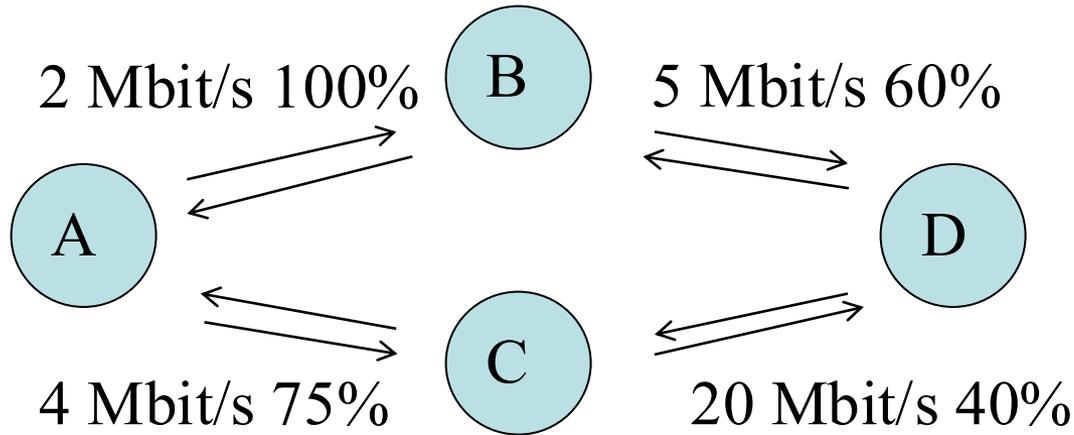


# ETX Pros?

# ETX Caveats

# How Can We Account to Different Bitrates?

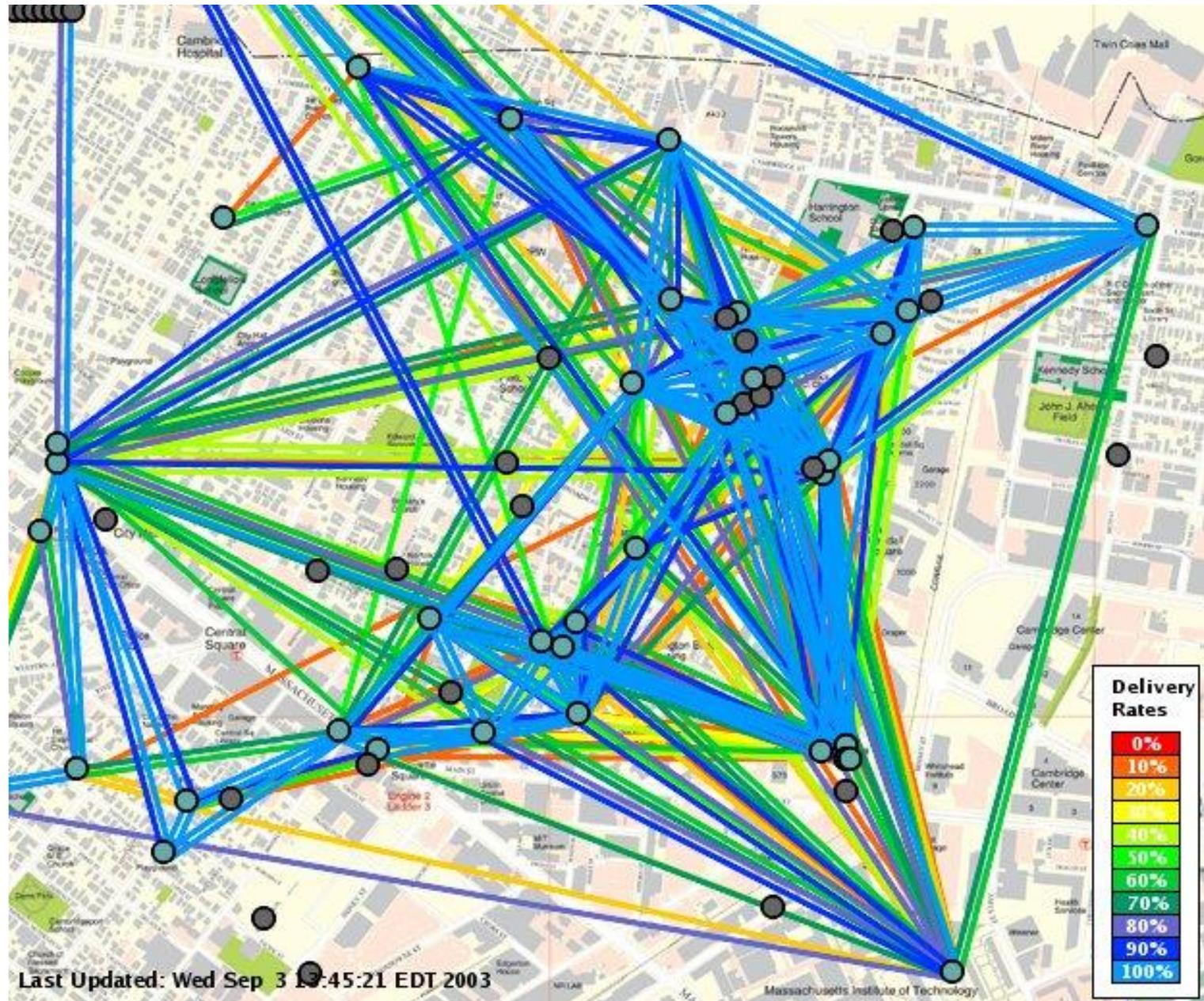
(and different delivery ratios)



# Caveats?

- Bitrate and delivery ratio are related
  - If Tx at higher rate, bitrate is lower
  - In fact, this problem led to the original rise of “information theory”
  - CS/EE -> rate adaptation based on “SNR”:  
signal-to-noise ratio
- Use multiple channels at the same time:  
each at different bitrate

# MIT Roofnet



# Where are mesh networks used today?

- Defense
- Electric car meters
- Home networks (e.g., Google WiFi, TP-link, etc.)
- Some satellite constellations (Iridium)
  - Will likely be replaced by LEO

# Objectives of the Three Lectures Series

Learn the fundamentals, applications, and implications of  
**IoT connectivity technologies**

1. What is the overall IoT system architecture? ✓
2. What are the various classes of connectivity technologies? And how do we choose the “right” technology for a given application? ✓
3. What are various routing architectures for wireless networks & IoT systems? ✓
4. How does energy impact IoT device design? And how do batteryless IoT systems work? ✓

**next lecture**