Exam Scores: (out of 100)

3 in 80-90 range
3 in 70-80 range
2 in 60-70 range

most got all of Q1 right
most got much of Q4 right
(graph coloring)

The coloring produced by GVDO may be optimal, but is not guaranteed to be optimal.

GVDO yields 4 colors

$$\underset{2}{\omega(G)} \le \chi(G) \le \underset{6}{\Delta_{max}(G)+1}$$

Q2 & Q3 no one got
either completely right,
most ~~to~~ got both wrong,
some got part of one right...

Phy - Link

Have asked TA to post an
individual (not to be done in pairs,
extra credit not to be discussed!)
assignment: asking you to
solve & write up Q2 & Q3
by hand AND also ~~turn~~
~~in~~ code & turn in programs
that solve them numerically.

+10 to your midterm
score.

See the posted assignment for exact details, but roughly:

Q2 — BS interference pblm

input textfile → CODE → output textfile

(CODE: Matlab / Python / C)

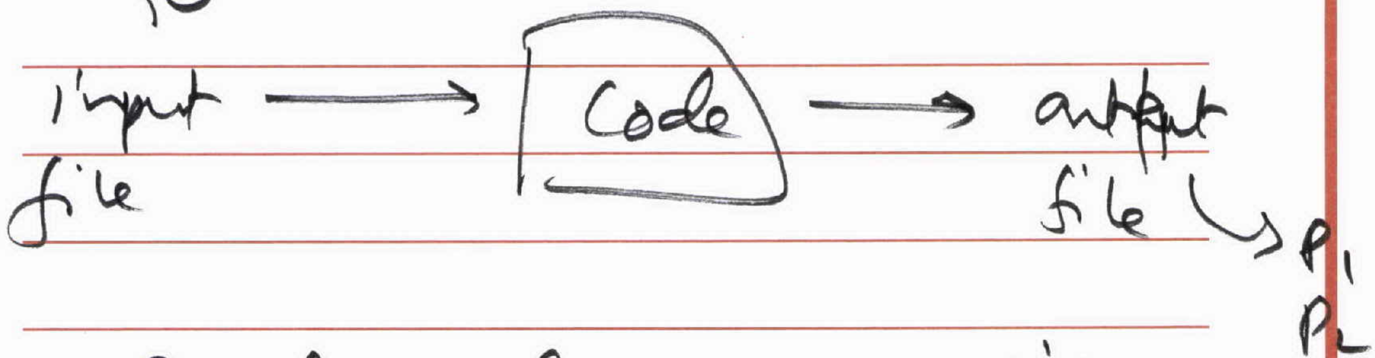
input file specifies:

- P
- R
- d_0
- K
- T
- N
- σ^2
- p

output file:

- d_A ← distance w/ no fading to ensure SINR > T
- d_B ← distance w/ fading to ensure $Pr(SINR < T) < p$

Q3



2 channels w/ arbitrary pmf for $\frac{n1}{S1}$ & $\frac{n2}{S2}$

Input file
- 2 lines
- 2 lines
- + 1 line for total power

pmf: values it can take on
corresponding prob.

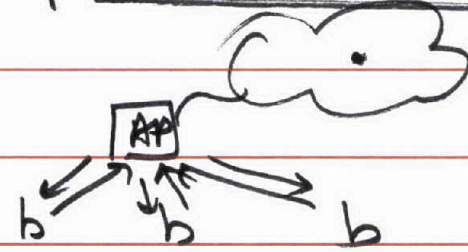
Ch 1
1 3 7
0.2 0.6 0.2

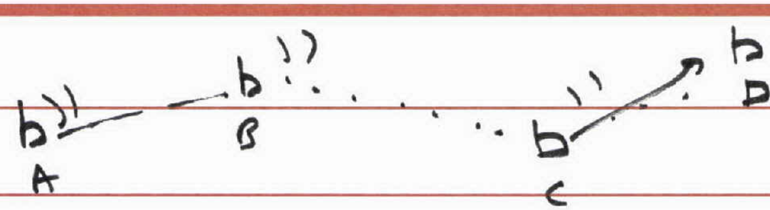
Ch2
0.5 4 10 20
0.3 0.4 0.1 0.2

10

Phy
↓
Link / MAC
↓
Network Layer.

Multi-hop Wireless Networks



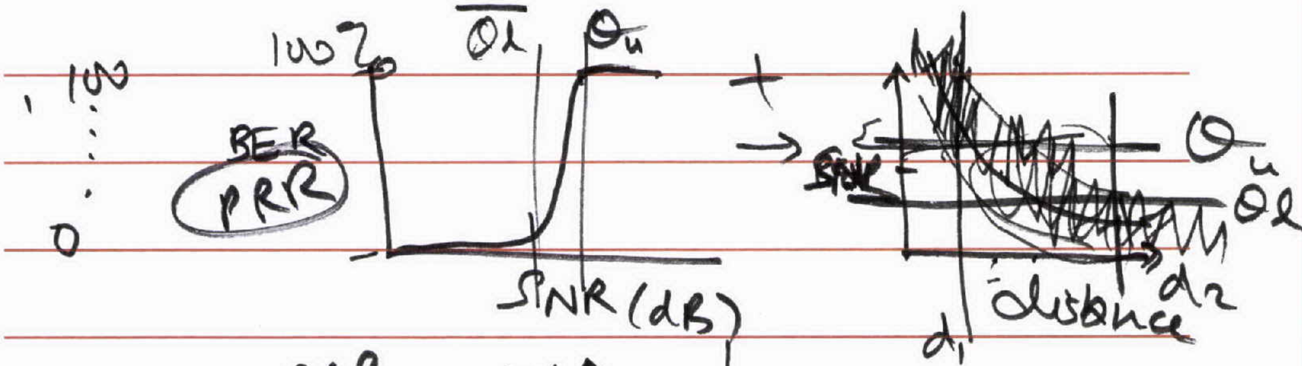


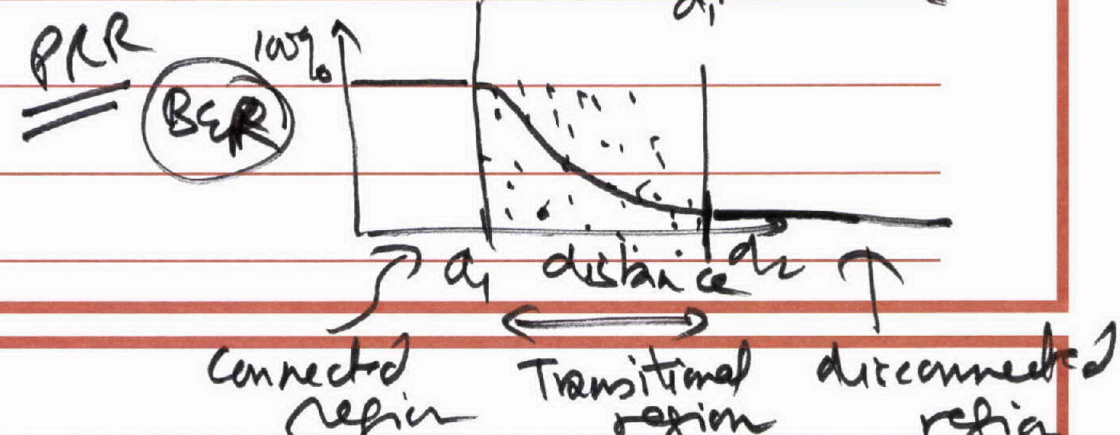
Key dimension for classifying these is amount of mobility & the density of the network.

MULTIHOP WIRELESS NETWORK

- STATIC NETWORKS
  - WIRELESS SENSOR NETWORK / IoT LOW POWER NETWORK
  - MESH NETWORK (STATIC) FOR WIRELESS ACCESS
- MOBILE AD-HOC NETWORKS
  - nodes are mobile & always/ most of the time the network graph is connected. (DENSE)
- INTERMITTENTLY CONNECTED MOBILE NETWORK
  - nodes are mobile, & may not be always / often in range of other nodes (SPARSE)

Routing in Multihop Wireless Networks





Link Metric of interest at higher layers:

Packet Reception Rate (PRR)

(packet delivery Rate

→ % of pkts transmitted on the link that are successfully received.

Given a modulation scheme / coding scheme & packet size BER → PRR

To summarize: if we focus on PRR,

for $d < d_1$: PRR~100%
connected region

for $d > d_2$: PRR ~ 0%
disconnected region

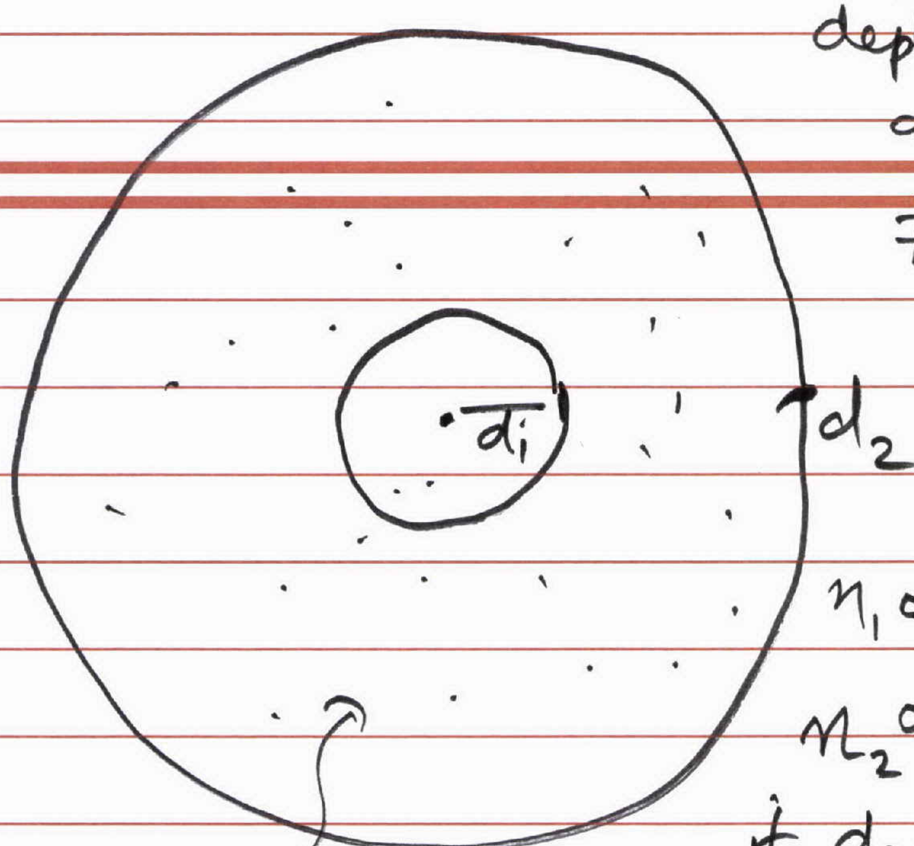
for $d_1 < d < d_2$
PRR shows
high variance
due to fading
If the env. has slow fading
the PRR in this range can
be very high or low &
stay that way. In
fast fading env. it may
fluctuate over time.

In typical radios, e.g. IEEE 802.15.4-based radios (used in WirelessHart, Linear Technologies),

$$\frac{d_2}{d_1} \sim 2-3$$

If nodes are deployed uniformly at random:

# of nodes in ~~an area~~ a region is proportional to its area.



$n_1 \propto \pi d_1^2$

$n_2 \propto \pi(d_2^2 - d_1^2)$

if $d_2 = 3 d_1$

$n_2 = 8 \cdot n_1$

transitional region (unreliable neighbors)

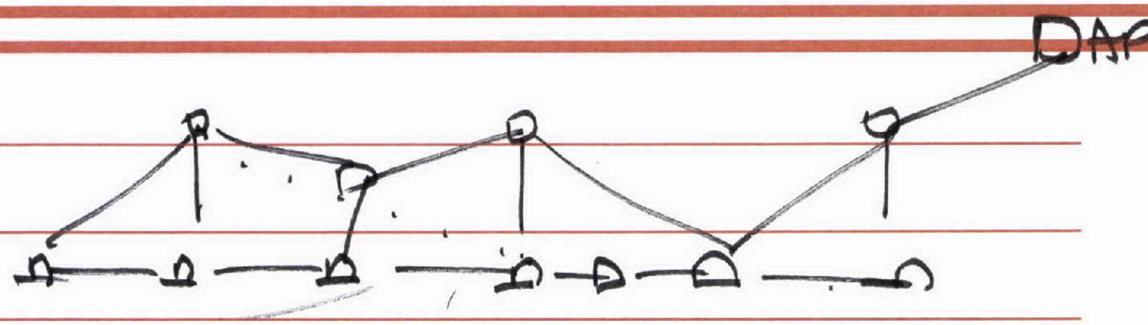
$\Rightarrow$ 88% of nbrs are unreliable!

To have a high reliability network

1. "Filter out" all nbrs not in the connected region

Black listing

Deterministic Topology construction at Deployment time

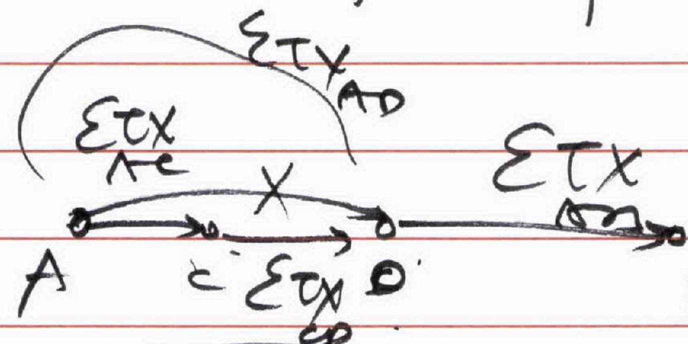


Pro: reliable by construction

Con: requires high density. could result in partitions

2. metric-based routing:

preferentially route through higher quality links.



minimize (hop count): A - D - B

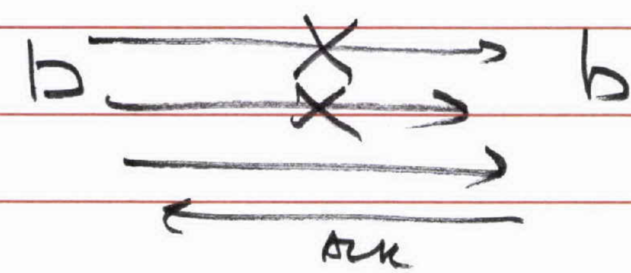
minimize (metric X): A - C - D - B

(metric)

ETX - expected # of transmissions per successful reception.

↓

1 to ∞



Empirically, ETX has been found to be a very useful & efficient metric.

One reason for this is that ETX captures multiple objectives:

① it favors high PRR links, resulting in higher reliability.

(If we assume i.i.d pkt losses over time:

mathematical

$$ETX = \frac{1}{PRR_{\text{fwd data}} \cdot PRR_{\text{reverse Ack pkts}}}$$

(PRR reverse Ack pkts ≈ 1 → can be ignored for small Ack pkts)

Expected value of Geometric r.v. w/ (prob. of success = $PRR_{fwd} \cdot PRR_{ack}$)

$$= \frac{1}{PRR_f \cdot PRR_{ack}}$$

(2) ETX is correlated w/ lower energy usage

(3) ETX is correlated w/ lower in-network interference (reduces inter-link interference) increasing network throughput

(4) ETX is correlated w/ lower link latency → Improves network delay.

Practical estimation of ETX:
based on empirical counting of retransmission averaged over the past w/ a exponentially decaying weight.

EWMA — exponentially weighted moving average

$$\text{estimated}\ \widehat{ETX}(n+1) = \alpha \cdot \widehat{ETX}(n) + (1-\alpha) \cdot ETX_{\text{current/instantaneous}}$$

$\alpha \in [0, 1]$

typically ~ 80%.

If α is large — we have more weight to past measurements can help smooth instantaneous noisy measurement. If too large, it's not dynamic/responsive to changing conditions

Can combine w/ L3 distance vector/link state protocol to compute shortest end-to-end paths that minimize $\sum_{e \in \text{Path}} ETX_e$

cost