Routing in Multihop Wireless Networks

Categories of Multihop Networks:
- Static Wireless Mesh Networks
- Wireless Sensor Networks
- Mobile Ad Hoc Networks
- Intermittently Connected Mobile Networks

Overview of Different Routing Approaches

Wireless Mesh Networks / Wireless Sensor Networks

Static deployments

Main focus: reliability of delivery

- Metrics for reliable routing

ETX - expected #9 transmissions
- OSPF + ETX
- RIP + ETX
- CTP - Collection Tree Protocol (also uses ETX)
- Exploiting the wireless broadcast advantage

Routing between end points taking place through "sets" of nodes

- Anypath Routing
- Opportunistic routing

A generalization of Dijkstra's algorithm can be used for optimal-ETX Anypath routing
Backpressure routing: we use both link metrics for reliability, as well as queue differentials in deciding where to route.

BEP: Backpressure Collection Protocol for WSN

Dynamic packet-by-packet forwarding decisions based on a combination of $\text{ETX}$ and queue differentials

$$w_{ij} = V \cdot \text{ETX}_{ij}$$
MANETs:
- How to develop routes that handle topological changes.
- Route Discovery
- Route Maintenance

Proactive vs. Reactive

Create Routes On-Demand

AODV - Ad hoc On Demand Distance Vector (Reactive)

OLSR - Optimized Link State Routing (Proactive)

Barrage Relay Networking:
- Cooperative MIMO-based approach to MANET operation pioneered by Trellisware
Intermittently connected mobile networks
  - Epidemic routing
  - K-copy routing: Spray & Wait
  - Backpressure with Adaptive Redundancy

EE 649 Stochastic Network Optimization
ETx metric

[Diagram showing ETx metric with some points and lines]

[Diagram showing link quality vs. distance]
Packet Reception Rate

\[ R_2 - R_1 \approx 2 \text{ to } 3 \times R_1 \]

8:1 area ratio for 2x

\[ \text{SNR} > 0 \]

\[ \text{Prob. error (log scale)} \]

\[ \text{SNR (dB)} \]
In many practical deployments, about 90% of "neighbors" are "flaky," i.e., affected by high spatio-temporal variation in link quality. 2 approaches to handle this:

1. Blacklisting: works well only in dense deployments; it can sometimes partition/disconnect the network.

2. ETX-based link metric, which sorts neighbors based on the quality of the link & prefers better neighbors when routing.
Note: Shortest hop routing is a bad idea because it explicitly picks long (likely to be unreliable) links.

Expected # of transmissions to have a successfully delivered packet

\[ \text{ETX}_{ij} = \mathbb{E} \left( \text{# transmission till ACK} \right) = \frac{1}{\prod_{i}^{p_{ij}}} \text{ (more carefully: for i.i.d. trials, smaller the better)} \]
ETX as a metric for anti-jamming.
Compute end-to-end paths that minimize the sum of ETX across the entire path.

Practically, estimated using an exponentially weighted moving average (EWMA).

\[ \text{ETX}_{ij}(t+1) = \alpha \, \text{ETX}_{ij}(t) + \left(1 - \alpha\right) \text{ETX}_{ij}^{\text{inst}}(t+1) \]

\[ \alpha \in (0, 1) \]

# 7 times the last pkt was transmitted before an ACK was received

Typically 0.9-ish.
ETX helps simultaneously for multiple objectives:

1. **Reliability**
2. **Throughput** because of:
   - lower overload per pkt delivered
   - reducing interference to other nodes

3. **Delay**
4. **Energy**
Anypath routing

短路径 ETX 路径：
① → ② → ④
① → ③ → ④

总 ETX = 2 + 2 = 4
= 1/0.5 + 1/0.5

假设我们可以计算出 2 和 3 之间的协调，使得
- 如果 2 收到来自 1 的包，它将转发，否则如果
- 3 收到来自 1 的包，它将转发，那么总 ETX 将是任一路径的 ETX。


\[ D_i = d_{i,j} + D_j \]

\[ d_{i,j} = \frac{1}{p_{i,j}} \]

\[ p_{i,j} = 1 - \prod_{j \in J} (1 - p_{i,j}) \]

In our example:

\[ p_{i,j} = 0.5 \text{ for both, so } p_{i,j} = 0.75 \]

\[ d_{i,j} = 4/3 \]

\[ D_j = \sum_{i \in J} w_{i,j} D_i \]

(Prob. that node \( j \) in the receiver set got it & no other higher priority node got it)
\[ \omega_j = \pi \prod_{k=1}^{j-1} (1 - p_k) \frac{1 - \prod_{j=5}^{\pi} (1 - p_i)}{1 - \pi} \]

\[ \frac{1}{2} \times \frac{2}{3} + \frac{1}{4} \times \frac{2}{3} \]

\[ \frac{3}{4} \times \frac{3}{4} \]

= 2

for the Anypath route

\[ \text{The total anypath ETX} \]

\[ = 4\frac{1}{3} + 2 = 3\frac{1}{3} \]

\[ = 10\frac{1}{3} \leq 4 \]
Realizing the contention:

Approach 1: Sender informs the receiver set of priorities. There is a delay proportional to the priority order where forwarders listen to see if higher priority packets are forwarding. If not, they forward (assuming they got the packet).

Approach 2: Low-overhead 3-way handshake w/ explicit asks in prioritized order & an explicit "go ahead" / RTS message from sender.