Opportunistic Routing

Biswas, Morris, paper
slides adapted from Biswas
Multi-hop wireless networks

- dense 802.11b-based mesh, all sorts of loss rates
- goal – efficiency, high-throughput
Traditional view

- identify route, forward over links
  - approach used by AODV, DSR (numerous other wireless routing protocols)
- use link level retransmissions
We know

Every packet broadcast
No such thing as a link
ExOR: exploits this insight

- figure out which nodes rx’d broadcast
- node closest to destination forwards
ExOR Assumptions

- many receivers receive every broadcast
- gradual distance-vs-reception distance degradation
- uncorrelated receiver losses
Multiple Receivers per Transmission

- broadcast tests on rooftop network
  - source sends packets at max rate
  - receivers record delivery ratios
- omni-directional antennas
- multiple nodes in “radio range”
Gradual Distance vs. Reception Tradeoff

- wide spread of ranges, delivery ratios
- transmissions may “get lucky” and travel long distances
Receiver losses uncorrelated

- example broadcast trace:

  Receiver 1 (38%):  

  Receiver 2 (40%):  

  Receiver 3 (74%):  

  Receiver 4 (12%):  

- two 50% links don’t lose same 50% of packets
- losses not due to common interference source
Extremely Opportunistic Routing (ExOR) design goals

- ensure only one receiver forwards packet
- receiver “closest” to destination should forward
- constraints:
  - lost agreement messages may be common
  - control overheads
How ExOR might provide more throughput

- → traditional path
- traditional routing compromises to choose hops long enough to make good progress but short enough for low loss rate
- with ExOR each transmission has greater chance of being received, forwarded
- takes advantage of transmissions that reach unexpectedly far, or fall unexpectedly short
How ExOR might provide more throughput

- independent losses
- traditional routing: \( \frac{1}{0.25} + 1 = 5 \) transmissions
- ExOR: \( \frac{1}{1 - (1 - 0.25)^4} + 1 = 2.5 \) transmissions
ExOR protocol challenges

- how often should ExOR run?
  - per packet expensive
  - use batches
- who should participate in forwarding?
  - too many participants $\Rightarrow$ large overhead
- when should participant forward?
  - avoid simultaneous transmission
- what should each participant forward?
  - avoid duplicate transmission
- when does process complete?
  - identify convergence of algorithm
Who should participate?

- source chooses participants (forwarder list) using ETX-like metric
  - only considers forward delivery rate
- source runs simulation and selects best set of nodes
- a background process collects ETX information via periodic link-state flooding
ETX

ETX – expected number transmissions

Min ETX routing

Loss percentages

ETX = 2.28
ETX = 1.17
ETX = 2.85
ETX = 0
ETX = 1.43
When should each participant forward?

- forwarders prioritized by ETX-like metric to destination
- receiving nodes buffer successfully received packets till end of batch
- highest priority forwarder transmits from its buffer when batch ends
  - these transmissions comprise batch fragment
- remaining forwarders transmit in prioritized order
- question: how does forwarder know turn to transmit
  - assume other higher priority nodes send for five packet durations if not hearing anything from them
What should each participant forward?

- packets it receives not yet received by higher priority forwarders
- each packet includes copy of sender’s batch map, contains sender’s best guess of highest priority node to have received each packet in batch
- question: how does node know set of packets received by higher priority nodes?
  - batch map
When does process complete?

- if node’s batch map indicates over 90% of batch received by higher priority nodes, node sends nothing when turn comes
- when destination’s turn comes to send, it transmits 10 copies of batch map (no data)
- question: how is remaining 10% data delivered?
  - traditional routing
Who received packet?

- standard unicast 802.11 frame with ACK:

  src | dest | payload | ack

- ExOR frame with slotted ACKs:

  src | cand₁ | cand₂ | cand₃ | payload | ack₁ | ack₂ | ack₃

- slotting prevents collisions (802.11 ACKs are synchronous)
  - 2% overhead per candidate, assuming 1500 byte frames
Slotted ACK example

- packet to be forwarded by node C
  - but if ACKs are lost, causes confusion
Agreeing on best candidate

A: sends frame with (D,C,B) as candidate set
D: broadcasts ACK "D" in first slot (not rx’ed by C,A)
C: broadcasts ACK "C" in second slot (not rx’ed by A,D)
B: broadcasts ACK "D" in third slot

Node D now responsible for forwarding packet
Transmission timeline for ExOR transfer

- N24 not able to listen to N5
- N8 does not send
- N17 might have missed some batch-maps

- higher nodes have lower ETX metrics to N24
Preliminary concept evaluation

Strengths
- ExOR nimble
- Efficient in total number of packet transmissions

Weaknesses
- Requires (partial) link-state graph
- Candidate selection tricky
- Requires changes to MAC
65 Roofnet node pairs
Experimental evaluation

- 65 node pairs

Phase 1 – collect link state
- nodes broadcast 1500 byte packets 60 times, measure delivery probabilities
- disseminate results
- calculate ETX’s

Phase 2
- each pair transfers one MB file
  - traditional, ExOR
- batch size 100 pkts
ExOR: throughput comparison

- Median throughputs: 240 Kbits/sec for ExOR, 121 Kbits/sec for Traditional
25 Highest throughput pairs

For single hop pairs ExOR reduces probability source resends packets, because of destination’s 10 batch-map packets
ExOR uses links in parallel

Traditional routing
3 forwarders
4 links

ExOR
7 forwarders
18 links
Batch size

- ExOr header grows with the batch size
- large batches work well for low-throughput pairs due to redundant batch map transmissions
- small batches work well for high throughput pairs due to lower header overhead
Drawbacks

- static, known topology
- ETX measurement costly
  - measure link states of all possible links
- small scale
  - tens of nodes
- dense network
  - only rooftop networks?
- file download application
  - no voice, maybe not web (no reliable guarantee)
Course summary

- where have we been?
- where is networking world going?
Where have we been?

Signaling
- telephone network
- ATM
- Internet: RSVP
- hard-state versus soft-state
Where have we been?

Design Principles

- separation of control/data (signaling, SDN)
- randomization (CSMA-CD, router synch, RED, load balancing, BitTorrent)
- indirection (multicast, mobile IP, $i^3$)
- multiplexing: packet level (WFQ, priority), burst level, call level, routing in telephone net)
Where have we been?

Routers
- input queue scheduling

Traffic engineering and routing
- shortest path routing
- LP and duality
Where have we been?

Congestion control and resource allocation
- optimization-based congestion control
- controller design
- TCP fluids
- TCP fixed point analysis

Wireless networking
- what makes wireless different
- broadcast nature
- path loss, shadowing, fading
- interference
- diversity
Topics not covered in course

- network economics, net neutrality
  - not enough time
- sensor networks (D. Ganesan)
- data center networks
  - was hot, starting to cool
  - driving SDN
- management/measurements
  - not enough time
- on-line social networks
  - (communication) networking topic?
Where are we headed: a biased view

- content-centric networking
  - CCN, idlICN
- new types of networks:
  - sensor nets, body nets, home nets, mesh nets
- integration of new wireless technologies
  - cooperation, spectrum scavenging
- security
  - harnessing randomness from the environment
One particular problem
ALN/Network Interactions

- network control
  - routing, congestion control, call admission
- add an overlay
- and another
  - CDN, P2P, ICN, …
Overlayed controllers

- network control
  - routing, congestion control, call admission
- add an overlay
- and another
- or an application
  - video streaming, VoIP

Result?
- controller mismatch?
- well-tuned machine?
Issues

- what are interactions?
- architecture for synergy?
- interfaces?
- network out of the loop?
Remember the class goals:

- fundamental material
- material with long half life
- material you will use 10 years from now

Remember that you learned it here!
The end!