Wireless Networks
Lecture 15:
Mesh and Ad Hoc Networks

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Overview

- Ad hoc networking concept
- Proactive versus reactive routing
- Proactive, table based routing: DSDV
- Reactive routing DSR
- Geographic routing: GPSR
- Other routing solutions
- Vehicular networks
- Wireless link metrics

Greedy Perimeter Stateless Routing (GPSR)

- Use *positions* of neighboring nodes and packet destination to forward packets
  - No connectivity or global topology is assumed – no forwarding or path information anywhere!
  - Nodes are assumed to know their location
  - Need some address-to-location look up
- Two forwarding techniques is used
  - *Greedy forwarding*, if possible
  - *Perimeter forwarding*, otherwise

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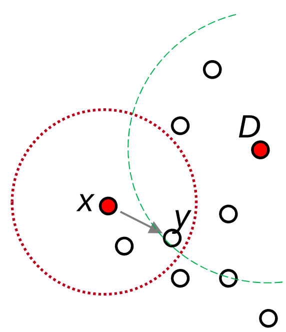
3

GPSR – Greedy forwarding

- A sender/forwarder *x* chooses to forward to a neighbor *y* such that $\{d_{xy} + d_{yD}\}$ is minimum



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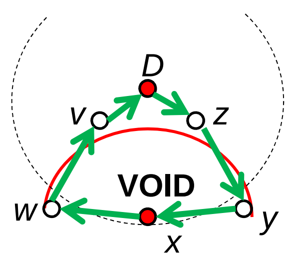
4

GPSR – Perimeter forwarding

- What happens if a node does not have a neighbor that is closer to the destination
- Right Hand Rule: you forward the packet to your first neighbor clockwise around yourself
  - traverse an interior region in *clockwise* edge order



These sequence of edges traversed is termed as *PERIMETER*

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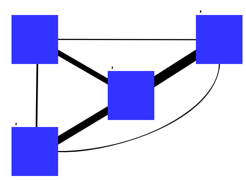
Link Metric

- Routing protocols for wired networks tend to use very simple link metrics
  - » Hop count (all links have cost of 1) or simple integers
  - » Performance of wired links is predictable!
- Wireless links can be very different and their performance can be unpredictable
  - » Hop count is a bad idea – why?
- Some links are so bad they are not really links
- Solution: Require a minimum PDR to qualify as a link
  - » PDR = Packet Delivery Rate
- Is that a sufficient solution?



Factors Influencing "Link Quality"

- Signal strength and quality: affects the bit rate used for packets
  - » Bit rate affects the transmit time of packets
- Number of retransmissions needed to deliver packets
  - » Retransmissions delay packets and use up more bandwidth
- Interference from nearby nodes
  - » Interference limits the transmission opportunities a node has, i.e., it can take longer to get channel access
  - » Some links may also face more hidden and exposed terminal problems

ETX: Minimize Number of Transmissions

- Measure each link's packet delivery probability with broadcast probes
  - » Must also measure the reverse link – ACKs must be received too for a transmission to be successful!

  P(delivery) = 1 / (d_f * d_r)
- The link ETX is the average number of transmissions needed to deliver a packet

  Link ETX = 1 / P(delivery) = d_f * d_r
- Route ETX = sum of link ETX
  - » Pessimistic: not all links interfere with each other
- ETX only considers some factors: bit rate, short probes under-estimate loss rate, traffic load, hidden terminals, …

ETX: Sanity Checks

- ETX of perfect 1-hop path: 1
- ETX of 50% delivery 1-hop path: 2
- ETX of perfect 3-hop path: 3

- So, e.g., a 50% loss path is better than a perfect 3-hop path!
  - » A PDR threshold would probably fail here…

ETT: Expected Transmission Time

- The bit rate used for transmission can have a very big impact on performance
  - » E.g., 802.11a rates range from 6 to 54 Mbps
- ETT – expected *transmission time*

  ETT = ETX / Link rate

  = 1 / (P(delivery) * Bit Rate)
- Accounts for all major factors
  - » Traffic load and resulting competition for transmission time is still a factor
  - » Must update metric periodically

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Vehicular “Ad Hoc” Networks

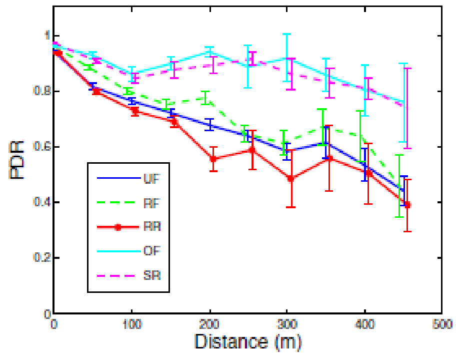
- Inter-vehicular communication
  - Emergency and military contexts
  - Everyday applications: Accident prevention, in-vehicle ‘Internet’, entertainment, …
- Very different from other ‘ad-hoc’ networks
  - Rapidly changing topology due to road and traffic conditions
  - Non-homogenous distribution of nodes
  - Constrained mobility and signal reception (obstacles?)
  - Diverse and rapidly changing physical environments
- How different from DTNs?

Background - IEEE 802.11p Standard

- IEEE 802.11p-based Dedicated Short Range Communication standard for vehicular environments
- OFDM modulation as the IEEE 802.11a/g
  - » Except carrier frequency bandwidth (5.9 GHz band)
  - » Channel bandwidth (change 20 MHz to 10 MHz)
- OFDM is an effective wireless communication scheme for non-mobile environments
  - » Both the symbols and their sub-channels are orthogonal
    - Zero ISI and zero ICI
  - » But both properties might be affected by Doppler spread/shift and fading environment

The PDR Gray-zone Phenomenon

- "Intermediate reception" with links that are bad but usable prevails
  - » True at all distances but gets worse as distance increases
  - » There is no region with a perfect reception rage
- Open Field and Suburban Roads works best
  - » Not surprising
- Rural Roads is harshest environment
  - » Remote houses, trees, cross traffic, ..



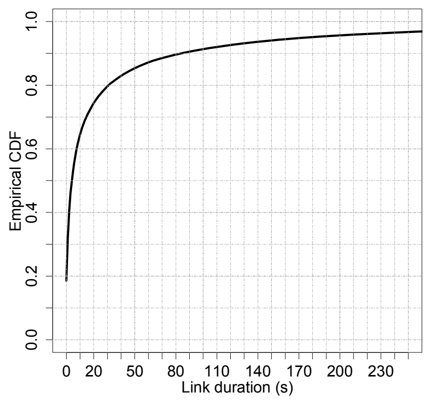
(a) PDR vs. Separation Distance

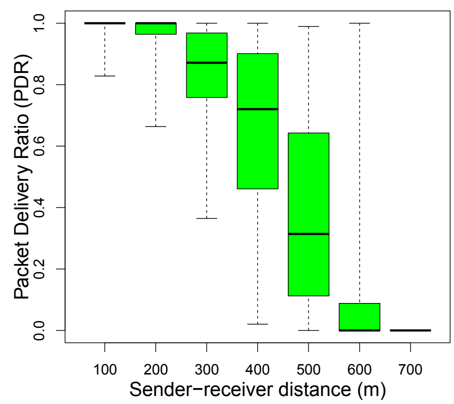
Experiment Settings

- Urban Freeway (UF)
  - » a large number of walls, tunnels and overhead bridges, as well as heavy vehicle traffic are present
- Rural Freeway (RF)
  - » The number of walls, tunnels and vehicle traffic are slightly less than its UF counterpart
- Rural Road (RR)
  - » The traffic was heavy on these routes because they lead toward a vehicle testing facility.
- Suburban Road (SR)
- controlled Open Field (OF)
  - » no buildings and other vehicles.

Dynamic Topology and Links

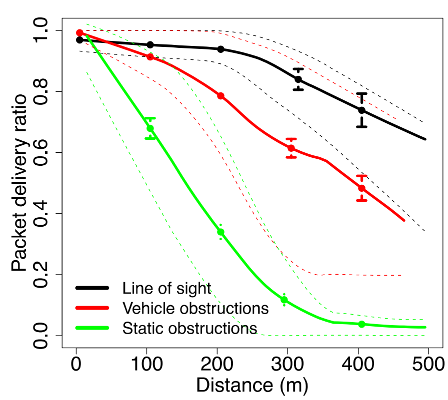
- Causes: high mobility, obstacles (multipath, shadowing)
- Effects: links have short life spans and partial connectivity





Spatial heterogeneity

- Transmission “range” is depends strongly on LOS conditions
- Line of sight blockages affect connectivity
  - » Terrain, buildings
  - » Other vehicles
- Node density varies according to location
- Pure geographic protocols assume connectivity uniformity



Idea

- Think of communication as connecting geographic areas instead of specific vehicles

1. Forwarding based on node diversity: Each area may have many antennas distributed across vehicles
2. Routing also uses spatial connectivity: topology graph is based on geographic areas instead of specific vehicles

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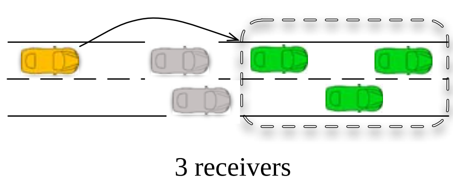
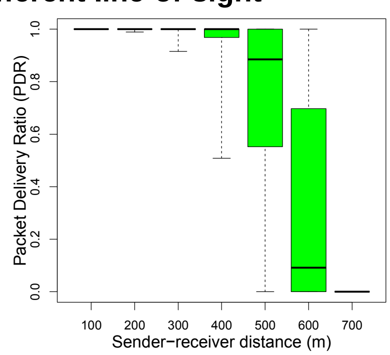
19

Exploiting Node Diversity

- Different vehicles experience different channels
  - » Multipath diversity due to physical separation
  - » Shadowing diversity due to different line-of-sight conditions





- DAZL – Density-Aware Zone-based forwarding

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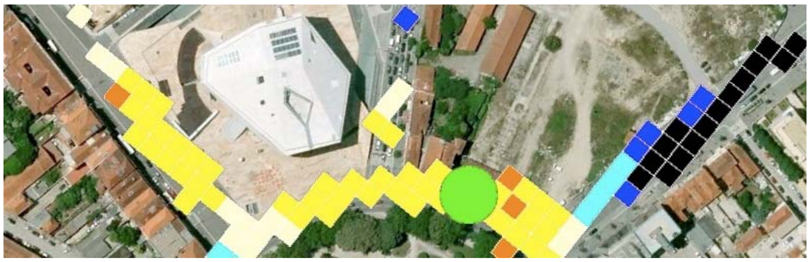
20

Spatial Connectivity Heuristic

- Collect spatially-indexed connectivity data
- Create map of delivery probability between areas



- LASP – Look-Ahead Spatial Protocol

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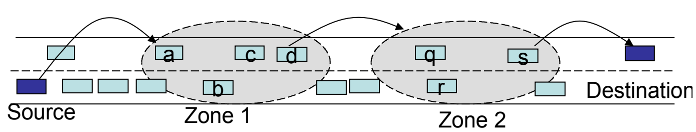
21

DAZL Forwarding

- Forwarding only
- Packets addressed to a geographic forwarding zone
  - » Reliability from node diversity
- Forwarder coordination and prioritization
  - » Minimizes congestion, maximizes distance traveled



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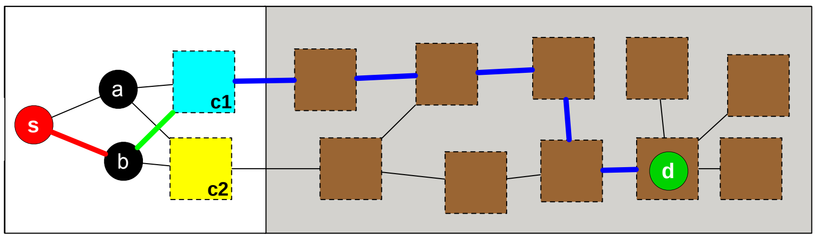
22

How about Routing?
Use a Spatial Connectivity Graph

- Each node in the graph represents a geographic area
  - » Accounts for all vehicles in the area that can be used by zone-based forwarding algorithm
- Can use traditional routing protocols to find path
- Graph can use historical data or recent measurements

Real-time graph | Historical spatial look-ahead graph



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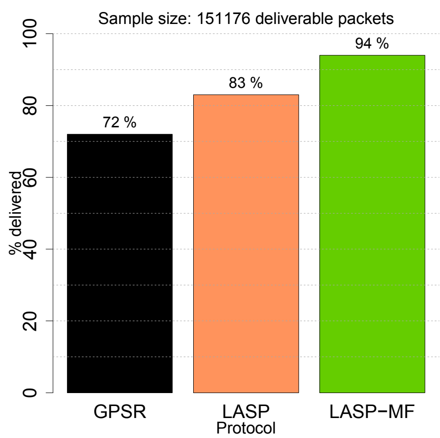
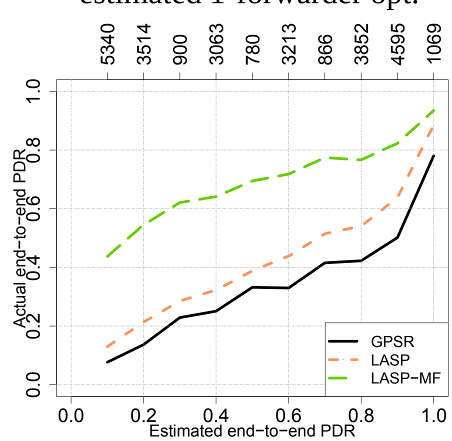
Experimental evaluation

PDR of deliverable packets



End-to-end PDR vs estimated 1-forwarder opt.



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Summary

- Ad hoc networks face many challenges
  - » Bad links, interference, mobility, …
  - » Makes routing very challenging
- Many proposals!
  - » Proactive routing: variants of “wired” routing protocols
  - » Reactive routing: only establish a path when it is needed
  - » Geographic routing: forwarding based on a node’s location – no need for access to network topology
  - » Many variants and extensions
- Vehicular networks are especially challenging
  - » High speed mobility, very unstable links and topologies
  - » Active area of research