Routing in vehicular networks

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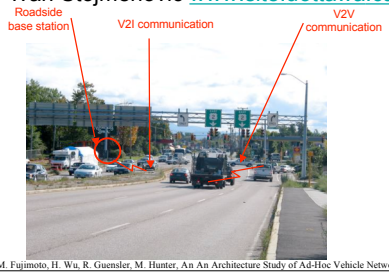

R. M. Fujimoto, H. Wu, R. Guensler, M. Hunter, An An Architecture Study of Ad-Hoc Vehicle Networks

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Routing tasks: assumptions

- Destination (**D**):
  - Fixed (RSU)
  - Mobile but tracked
  - Unknown
- Cars move with/without plans sent to a center
- Destination addressing: IP or geographical
- Source and destination:
  - Always connected
  - May not be always connected

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Bringing Internet to vehicles

- NEMO (Network Mobility) proposed in 2005
- Similar to Mobile IP (maintenance of a tunnel to home agent)
- Currently works for direct link between vehicle and infrastructure
- Extension for multi-hop intermittent access needed
- Based on routing from given car, via V2V to RSUs

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Route discovery with fixed addresses ?

- Flooding to discover destination
- Destination reports to the source
- Source uses discovered path
- Flooding= each receiving node will retransmit ones
- Reliable routes are rapidly changing
- Search must limit number of hops, or
  - be made only within a zone of interest

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Certificate updating

- Sun, Zhao, Su: FCST 2009.
- Certificate request from car to RSU
- Inform RSU where response should be sent
- Geographic routing
- Estimate locations

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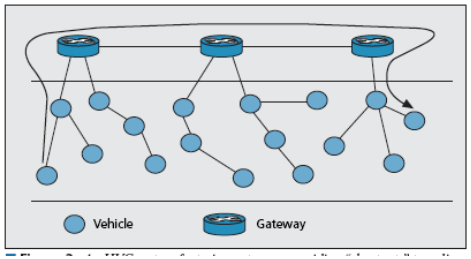
Gateway based routing



Wakikawa and Sahasrabudhe 2005

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Epidemic routing

- Huang, Luo, Li, Li, Li, Shu IEEE TVT 2007
- 4000 taxis in Shanghai
- Assumes known locations of neighbor cars and D
- Two optimizations to flooding:
- Forward packet only to neighbors closer to D
- When a node needs to carry a new packet but has a full buffer, it drops the packet that has the largest number of hops and replaces it with the new one.
- Compatible with DSRC ?

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Connectivity-Aware Routing

- Naumov, Gross IEEE INFOCOM 2007
- Flooding to discover D with shortest delay path, D reports to S along found path
- Adaptive beaconing:
  - fewer neighbors, more frequent beacons
- Data packets carry beacon equivalent reports
- *S routes to D along reported path*
- Intermediate cars may carry the message for a limited time until advancement is possible to another car
- Anchor points added to packets for changing roads
- Message kept around anchor point by delivering to car going toward it

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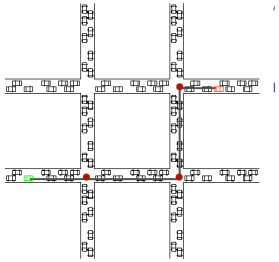
Connectivity aware routing



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Connectivity-Aware Routing

One hop route extension possible when D moves

- New location discovery if not delivered in time, can start at intermediate node, with flooding of half hop count of the original path
- Assuming position of D is known/maintained:
  - use of and maintenance of recorded path
  - introduces communication overheads

▪Requires setting up routing tables bound to become obsolete very soon after their setup.

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Stateless routing

- Assumes position of D is known
- Greedy advance:
  - route towards intersection closest to D, or towards
  - Neighbor/intersection with optimal delay/progress ratio,
  - Assuming delays to intersections are calculated/reported
- Recovery mode (no advance possible)
- Use GFG/GPSR (Bose, Morin, Stojmenovic, Urrutia 1999), adapted for vehicular networks by:
- Dumitrescu, Guo 2005; Lochert et all 2003 and 2005.

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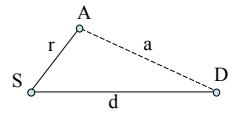
Cost to progress ratio framework

- Progress: measures advance toward destination
- Progress = |SD|-|AD|=d-a
- Select neighbor A that minimizes cost(SA)/progress(A)
- Cost = path length, delay …

Stojmenovic IEEE Network 2006



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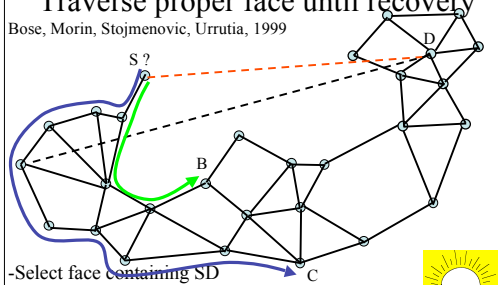
Traverse proper face until recovery

Bose, Morin, Stojmenovic, Urrutia, 1999

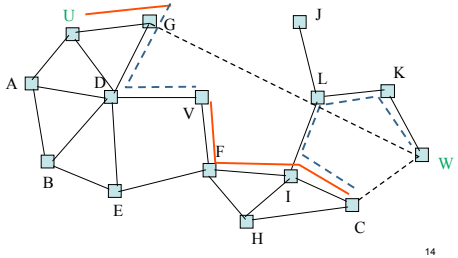


-Select face containing SD

- Follow that face by **left** hand or **right** hand rule

  until recovery (= closer node reached)

Greedy, GFG (greedy-face-greedy)



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Routing with plans of movement

Leontiadis, Mascolo, 2007

NP=nearest point

The time to drive to the NP plus the time for a car to drive from the NP to the destination D is measured for all neighbors.

Message is forwarded to a neighbor having the smallest such measure.

NP to D unpredictable

no guaranteed delivery

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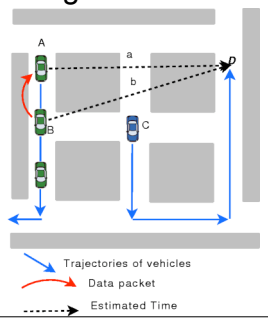
Wrong objective function and forwarding blackholes

Cabrera, Ros, Ruiz 2009
non-monotonic metrics!



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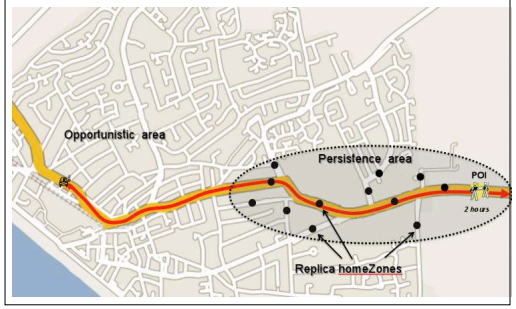
Content based information dissemination



Preserving content

- Leontiadis, Costa, Mascolo 2009
- Preserve content on persistence area before vehicle arrives in opportunistic area
- Route message replica to its home zone

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Delay bounded routing

- Skordylis, Trigoni, ACM Mobihoc 2008 [ST]
- D-greedy algorithm:
- each edge on the shortest path to RSU is allocated a delay budget that is proportional to its length.
- Data muling is used if the allocated delay is sufficient while driving on a road segment;
- otherwise, multi-hop forwarding is used to speed up until the delay is acceptable.
- Multihop forwarding is also used if a vehicle carrying a message moves away from an RSU.

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D-minCost algorithm [ST]

- Preprocessing: computes *delay-constrained, least-cost paths* from the vehicle's location to all access points, and encodes it in the message header.
- If a selected edge has no car available to take over the message at the intersection, *recompute above* to find an alternative edge.
- But a car at an intersection carrying a message, needs to find other car carriers in a timely manner (*no anchors* !?)
- there is no mechanism for recovery when a message cannot progress toward an RSU
- Forwarding may not be available when desired
- Vehicles driving in opposite directions are not utilized

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OPERA

- Opportunistic packet relaying in disconnected vehicular ad hoc networks
- M. Abuelela, S. Olariu, I. Stojmenovic,
  IEEE MASS 2008.
  – Connectivity analysis
  – Routing algorithm between two intersections
  (on a road with traffic in both directions)

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Connectivity analysis

End to end connectivity is not guaranteed on the road

Probability of having a disconnection on the road is

$$\frac{\sum_{i=1}^{m-1}(-1)^{i+1}\binom{m-1}{i}\binom{m+n-i(d+1)-2}{m-2}}{\binom{m+n-2}{n}}.$$

m= number of vehicles

m+n = number of vehicle size spots on the road

d = transmission range (in spot lengths)

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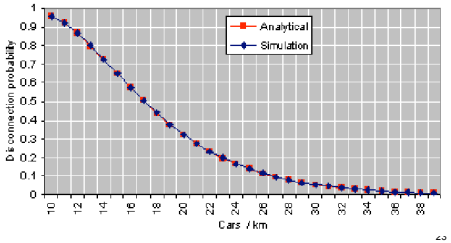
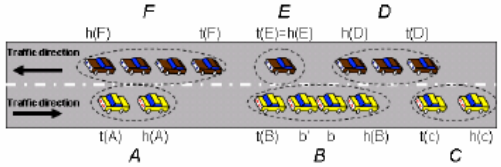
Disconnection probability d=200m



Clusters: heads and tails



Cluster maintenance by DSRC beacons (zero overhead)

Neighbor links are decided by beacons

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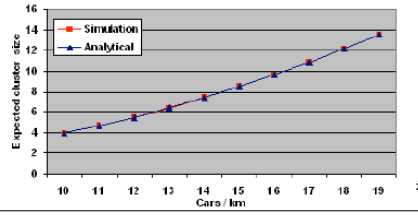
Expected cluster size

$$\frac{m \cdot \binom{m+n-2}{n}}{\binom{m+n-2}{n} + (m-1) \cdot \binom{m+n-d-3}{n}}.$$



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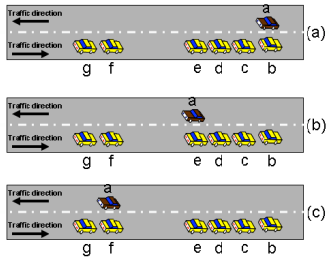
Motivating example



Routing from a to g

No need for:

a→b→c→d→e→a

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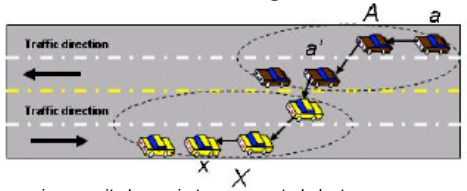
Baseline algorithm



a→x, in opposite lanes, in two connected clusters

Next hop minimizes hop count to x, using local routing table (derived from cluster structures)

Restart baseline from the next node

Step in general algorithm

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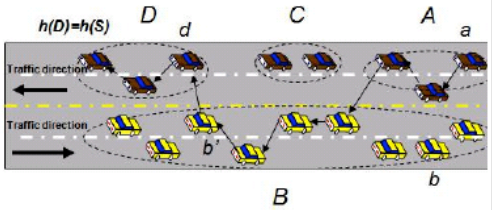
General algorithm



a→x, in two disconnected clusters

Baseline from a to b' (connected to D),

Baseline from b' to h(D) Repeat until delivery

Details: return msg from car in opposite direction if no help

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DV-CAST routing

- Tonguz, Wisitpongphan, Bai, Mudalige, Sadekar INFOCOM08
- Upon receiving a packet:
- Vehicle inside a cluster retransmits with a probability
- Vehicle with a neighbor in opposite direction retransmits, and discards it if moving in same direction as original message source
- cluster head vehicle and disconnected vehicle carries message; retransmits to new neighbor and discard

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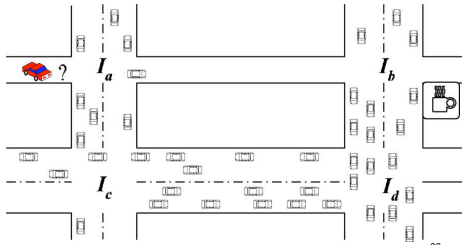
VADD

- Zhao, Cao, IEEE TVT 2008



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VADD overview

- Calculate probabilities for a car arriving at intersection *i* to pass the message to a car at road *j* immediately, based on traffic distribution
- Receive (central) delay matrix for all roads
- Car arriving at intersections selects among neighbors on roads reducing delay, the one with the lowest expected delay (could carry message further)
- Carry and forward between intersections
- Not using cars in opposite directions, no anchor

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Trajectory-based data forwarding

- J. Jeong, S. Guo, Y. Gu, T. He, D.H.C. Du, Trajectory-based data forwarding for light-traffic vehicular ad-hoc networks, IEEE Trans. Parallel and Distributed Systems, to appear.
- Improving VADD
- Input: road map, vehicle arrival rate and speed for each road
- Trajectory movement plan for itself only
- EDD= expected delivery delay to RSU
- Add EDD to beacons to inform neighbors
- Constant speed, few wireless hops at beginning, carrying until next intersection
- Sort roads at intersections by geographically shortest paths (forwarding priority)

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Static node assisted routing

- Ding, Wang, Xiao, ACM VANET 2007
- Beacons (or actual messages) travel between RSUs, and can be carried or transferred to another car
  - (see OPERA or VADD protocol)
- Shortest delay path on RSUs from delay matrix
- LoP (LPP over Progress) routing (Boukhatem, Ivan 2009):
- Select road toward RSU with best LPP/progress
- Beacons could carry recent delay information between RSUs in opposite directions,
  - which can be used for edge selections in LoP routing
  - Position of destination is known

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Routing with real time traffic info

- Nzouonta, Rajgure, Wang. Borcea IEEE TVT 2009
- Route discovery based on 'one-way' broadcasting which may 'jump' over cars on other roads
- Route can be maintained by extending or cutting intersections for mobile source or destination
- Proactive routing: DFS traversal to compute shortest path along intersections, again 'jump' and no carry
- Forwarding optimization: receiver relaying with delay function that depends on forward progress, received power, and transmission area, since receiving short beacon does not mean receiving full message
- Temporary disconnection, store-carry not discussed

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Greedy traffic aware routing

- Jerbi, Senouci, Rasheed, Ghamri-Doudane IEEE TVT 2009
- Decentralized estimation of traffic density:
- Divide roads into grids, average # cars per grid, stand dev (traffic density)
- Select next intersection based on weighted sum of its score distance (reduction ratio of distance to D) and traffic density.
- Note that 'score distance' has lower impact when far from D
- Greedy forwarding between intersections: predict position of neighbors
- Recovery mode: carry-and-forward (if no closer car to the next intersection)

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Static nodes and link selection

- Ghaffari, Ashtiani WCNC 2009
- Static RSUs at intersections
  - estimate delay in arriving next vehicle
- Plus estimated delay between RSUs
- Decides which links/roads are acceptable
- Delivers to first incoming vehicle going in one of acceptable roads.

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Small scale routing

- Wang, Xie, Chatterjee, IEEE TVT 2009
- Connection Based Restricted Forwarding:
- only cars at distance >r from sender retransmit
- Connectionless Geographic Forwarding:
- Forwarding node will choose the next hop as the node progressively closest to the destination among non-congested nodes

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Large Scale routing

- Wang, Xie, Chatterjee, IEEE TVT 2009
- Overlay graph of roads with fast vehicles
- Access graphs connected to Overlays
- Two phase routing: AA, AO, OA, OO
- Access-overlay (AO) nodes are part of path as temporary destinations
- Message is bounced around AO and OA intersections until some node is able to get it to desired road

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Multi-path routing

- Ticket-based Reliable Routing in VANET, MASS09, 609-614.
- Gongjun Yan, Danda B. Rawat, Samy El-Tawab
- Low cost, low delay, high stability paths
- 3 types of control packets probing routing paths satisfying stability, delay and cost requirements
- Tickets for parallel path searches
- *Large scale georouting*

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Topology assist georouting

- Lee, Lee, Gerla WONS 2009
- Greedy advance toward the next intersection, not toward destination
- Targeting neighbor with advance and greatest degree
- Delay function around target for offering forwarding service, with ellipse around it as limit
- Intersection node in recovery mode could be bypassed

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Common issues in VANET routing

- **Cabrera, Ros, Ruiz 2009**
- **Transmission range is not fixed**
- **Solutions:**

1. Receiver-based next hop selection
   1. Receiver-based scheme
   2. Oportunistic neighbor selection (beaconless routing)
2. Active link-status monitoring
   1. Send data to neighbors with high reception probability

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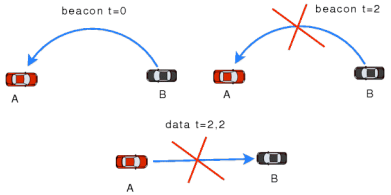
Use of stale information

Beacon messages may get lost



Beacon losses

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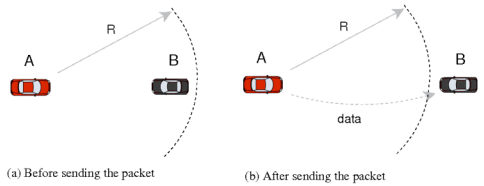
Neighbor disappear within beacon intervals



Mobile vehicles and the outdated position problem

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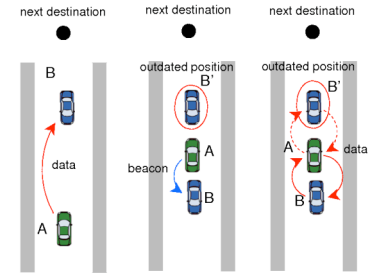
Inconsistency creates loops



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Outdated information problem in DTN-enabled geographic routing protocols

Solutions

Increasing beacon interval or hold-time does not help
Velocity vectors in beacons
Opportunistic neighbor selection

Recommendations

- Use store-carry-forward to deal with partitions
- Avoid beacons as much as possible
- Add useful information to beacons
- Carefully consider forwarding criteria

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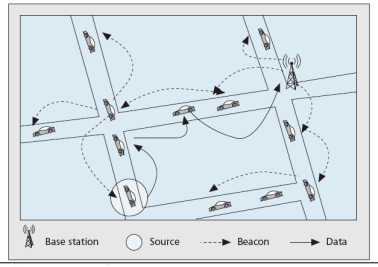
Cross-layer routing: LD-CROP

- Jarupan, Ekici, IEEE ComMag Nov. 2009
- Routing to nearby fixed BS (simul. 3x3 roads)



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Overview: LD-CROP

- Periodic beacons with packet traffic characteristics
  - Initiated by BS
  - Beacons contain street/direction path and path quality (statistics over sliding time window)
  - Forwarded by farthest receiver after defer time delay (=cross-layer) with updated path statistics and appended own location (probably only if at intersection)
- Source routing over smaller delay paths
  - Source vehicle decides the series of streets
- Dynamic data forwarding decisions
  - Neighbors bundle multiple packets, higher priority to forward; smaller waiting time for farther neighbors
  - No discussion on anchor points (when at intersection no car in desired direction exists)
  - No use of vehicles from opposite direction

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Transport layer routing

- Practical Location-based Routing in Vehicular Ad Hoc Networks
- Zhi Li, Yanmin Zhu, and Minglu Li, 2009, MASS09, 900-905.

- GPSR channel to report locations periodically
- Reported location updated by time*speed
- Expected error of estimated location is (time*speed)/2, experimentally
- *Greedy forwarding (closest to destination)*
- Sort packets: nearest first or maximum jump
- Buffer management: residual distance, elapsed time, reject new *(transport layer)*
- *No novelty on the network layer*

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