Vehicular Ad Hoc Networking - Overview

CSI5140

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Outline

Quick Overview
- New possibilities
- VANETs

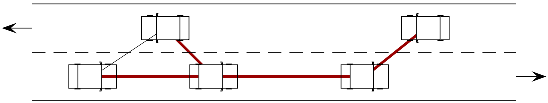
Technological context
- Architecture
- Standards

Research Problems
- Introduction
- Broadcasting (Geocasting)
- Routing
- Traffic optimization
- Bringing Internet into Vehicles
- Mobility Models and Connectivity

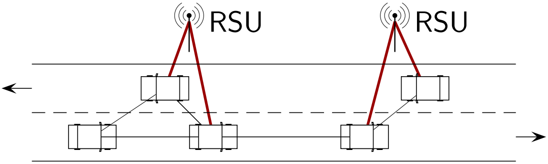
References

New Wireless Communication Capabilities

Vehicle-to-Vehicle (V2V)



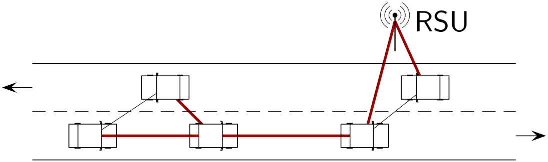
Vehicle-to-Infrastructure (V2I)



Vehicular Ad Hoc Networks

VANETs are Hybrid networks

- Combine V2I and V2V communications

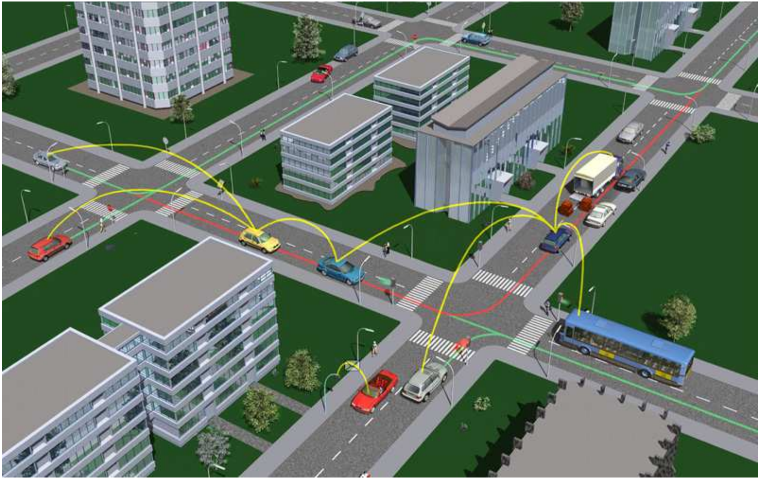


- Allow integration of vehicles and Intelligent Transportation Systems

In a near future, they are expected to..

- improve safety, route selection, geographic notifications..
- allow Internet in vehicles, real-time traffic information, entertainment..

The vision



[car-2-car.org]

Three levels architecture (note: global picture to be moved here, from a few slides later)

In-Vehicle Domain

- On-Board Unit (OBU)
- Application Unit (AU)
- local network/bus to link the OBU with all AUs
- OBU responsible for all shared resources between AUs (including external communications).

Ad Hoc Domain

- Vehicles to Vehicles (OBUs to OBUs)
- Vehicles to Infrastructure (OBUs to RSUs)

Infrastructure Domain

- RSUs to RSUs
- RSUs to Internet
- but also possibly.. vehicles using Wi-Fi Hot Spots or 3G/4G cellular networks (why not?)

Necessity of standards

- Vehicles of all categories and all brands <u>must</u> be able to communicate with each other
- Standardization bodies: ASTM, IEEE, SAE, ISO
- Car manufacturers, consortiums, projects..:

picture from [Olariu & Abuelela, NOTICE slides]

Physical and Mac layers

DSRC standard (Required)

- Dedicated Short-Range Communication
- 5.9GHz (U.S.), 5.8GHz (Japan, Europe)
- 802.11p (MAC & PHY)

Wi-Fi and Others (Optional)

- 802.11 a/b/g for use of classical Hot Spots (e.g. in cities)
- FM, cellular (e.g. UMTS), *etc.* (possibility of full coverage)

Network Layer

New dedicated protocols (VANETs protocols)

- broadcasting (mostly geocasting..)
- routing
- on top of 802.11p

Existing protocols

- IPv6 (+Option Mobile IPv6)
- on top of other radios (801.11 a/b/g, UMTS...) or 802.11p (through encapsulation in dedicated VANETs protocols)

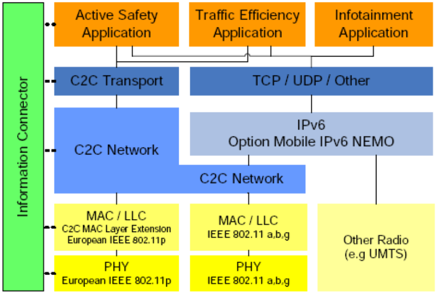
Transport Layer

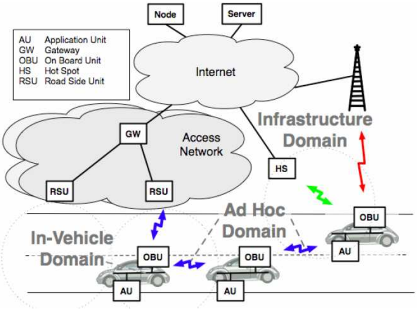
Still under discussion in consortiums..

- dedicated transport protocols?
- TCP/UDP?

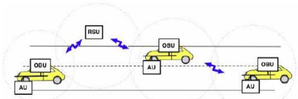
Summarization [pictures from the Car-2-Car Consortium Manifesto]

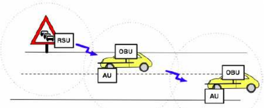
Network overview

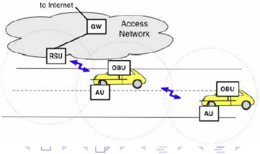




A few basic scenarios







Differents areas

- Broadcasting
  - Geocasting
- Routing
  - towards a given vehicle
  - towards a geographical area
- Traffic optimization
  - centralized (Central server, route request)
  - decentralized (Car to Car traffic data dissemination)
- Bringing Internet into Vehicles
  - Mobile IP
  - NEMO Protocol
- Mobility Models and Connectivity purposes
  - Mobility models
  - Connectivity metrics

Minimum assumptions

Assumptions commonly agreed

- Vehicles are GPS-enabled
- Beaconing (or HELLO) messages:
  - include ID, position and velocity (speed & direction)
  - with period of 300ms (can also be adaptive, *e.g.* [NG07])

Assumptions frequently agreed

- All vehicles are equipped
  (when not the case, referred to as the *market penetration problem*)
- Some geometrical properties of roads (*e.g.* road width neglected, city intersections form square lattices)
- Location service is available to vehicles

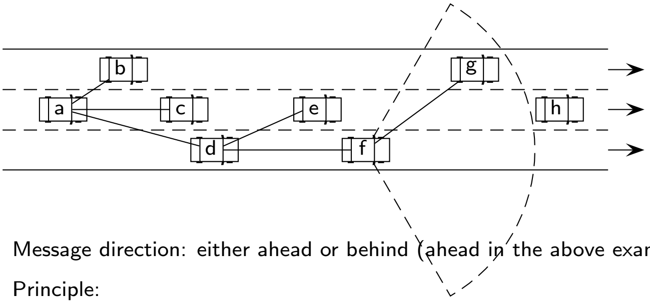
Broadcasting

Motivations

- route discovery (not treated here)
- safety warning
  - accident notifications
  - strong deceleration of traffic flow
  - road hazards (black ice, fallen tree, *etc.*)
- information distribution
  - congestion (makes it possible to choose another path ahead of road)
  - local tourism information
- relevance of information is most often geographically delimited
  - Broadcast $\Rightarrow$ Geocasting

Two GPS-based broadcasting algorithms, Sun *et al.* [SFL+00]

Basic version



- Message direction: either ahead or behind (ahead in the above example)
- Principle:
  - each vehicle knows the positions of its direct neighbors
  - ID of further neighbor (toward message direction) put in the message
  - the further neighbor retransmits

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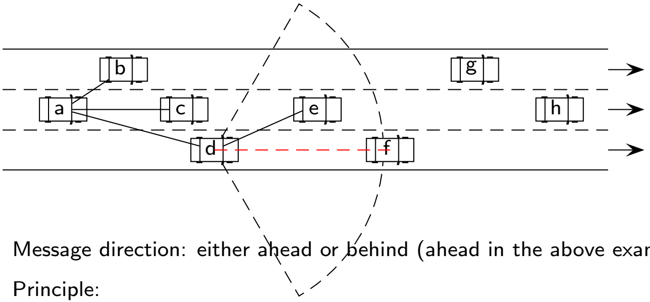

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- Principle:
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  - ID of further neighbor (toward message direction) put in the message
  - the further neighbor retransmits
- A gap may exist between real and known connectivity ($\Longrightarrow$ message loss)

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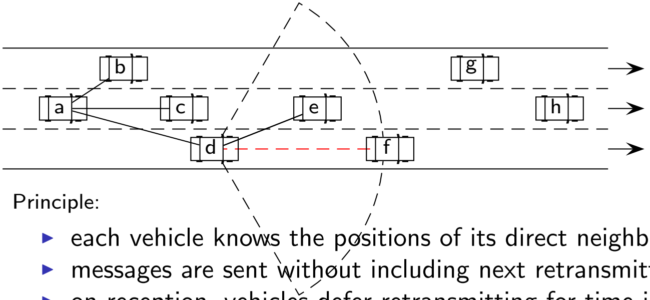
Version with deferred retransmission time:



- Principle:
  - each vehicle knows the positions of its direct neighbors
  - messages are sent without including next retransmitter ID
  - on reception, vehicles defer retransmitting for time inversely proportional to their distance from sender (the further, the sooner).
  - when receiving a copy of the same message, cars notice neighbors that have been covered by it (based on known positions)
  - if no neighbors remain uncovered when deferred time expires, retransmission is canceled

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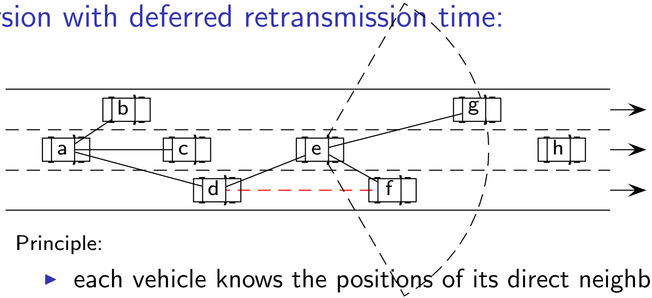

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Cooperative Collision Avoidance, Biswas, Tatchikou, and Dion [BTD06]

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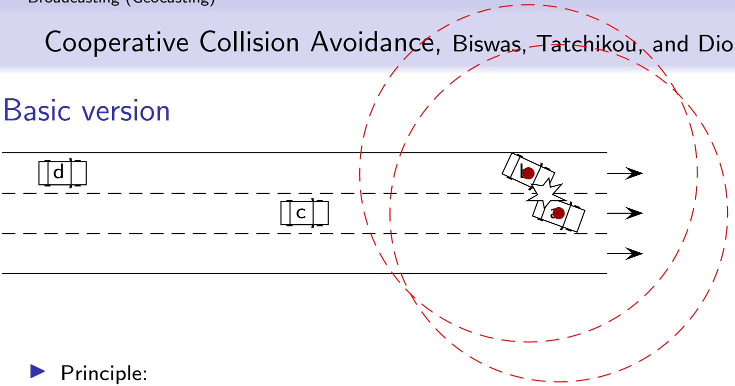

- Principle:
  - If an accident is detected, starts forwarding a warning message at regular intervals
  - Blind flooding, every car retransmits all warnings

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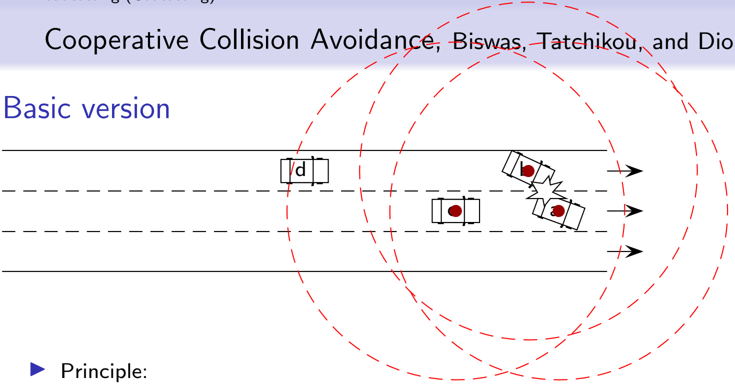

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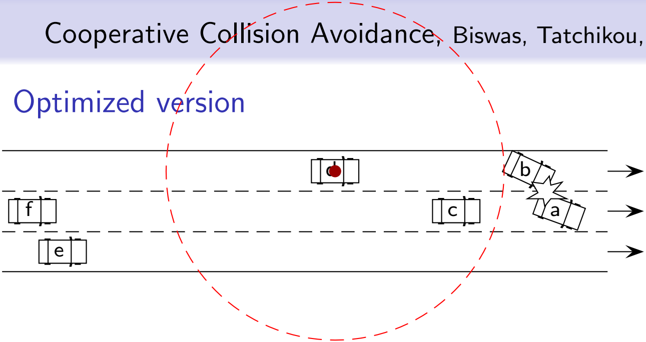

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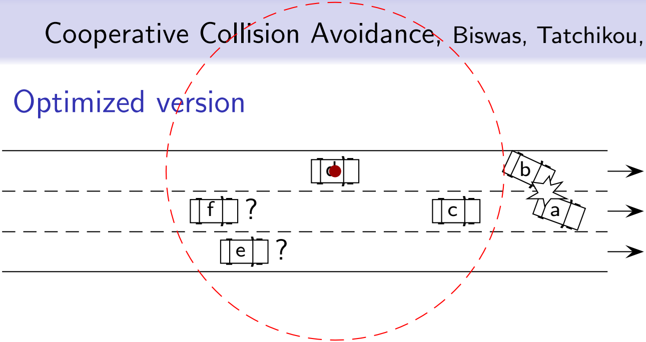

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    e.g. if $random_f < random_e$, then e doesn't retransmit

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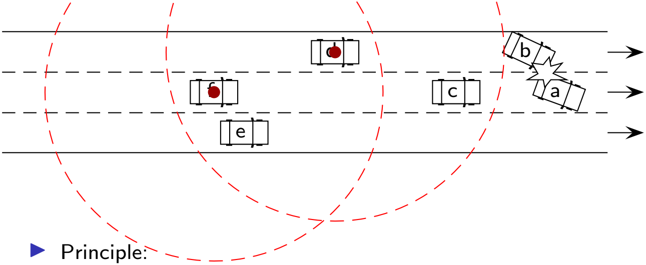

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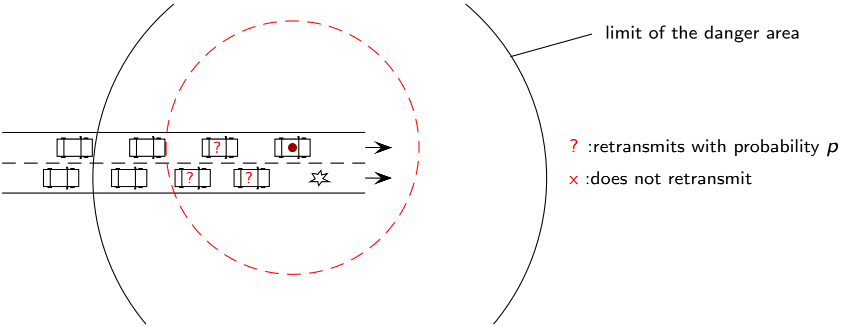
Probability-based warning delivery protocol, Fracchia and Meo [FM08]



- Principle:
  - Every car within the danger area retransmits with probability p
  - Several broadcasting cycles, at regular interval D.

Conclusion

Recurrent drawbacks

- what if temporary partitions (*i.e.*, DTN networks)
- no use of relay nodes outside the danger area to reach disconnected vehicles inside the danger area

Some suggestions

- make use of vehicles in the opposite lane
- make use of infrastructure (RSUs) when available
- optimize broadcasting using Connected Dominating Sets [SSZ02]
- address the DTN nature of VANETs

Routing (Unicast)

Motivations

- Unicast: why addressing only one car?
  - Car tracking (*e.g.* stolen car or friend car)
  - Internet Protocol (enables IP communications)
  - Team synchronization (*e.g.* firemen, policemen, medical staff)
- Road Assumptions:
  - Highway (single- or multi-lane, uni or bi-directional?)
  - City (Square blocs? Roads form regular lattice?)
- Other general assumptions (next slide)

Routing Assumptions

Type of Destination / Location Service?

- A1-Fixed geographic location
- A2-Moving vehicle with known and updated location
- A3-Moving vehicle with unknown location

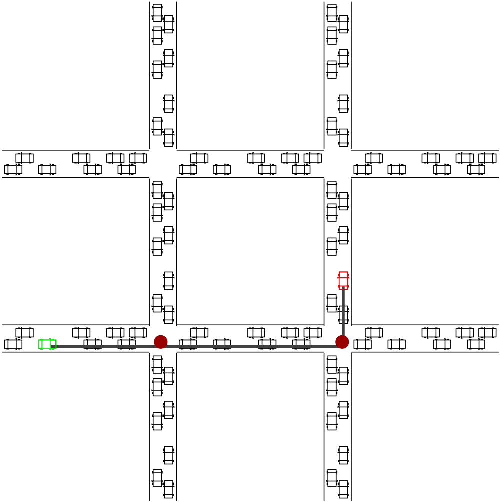
Plan of movement?

- B1-Known (sent to a central server or to vehicles nearby)
- B2-Unknown

Network connectivity?

- C1-Any pair (source, destination) is connected via other cars
- C2-Source and destination may not be instantaneously connected via other cars

City Scenario - Maintainance of a route, Naumov and Gross [NG07]



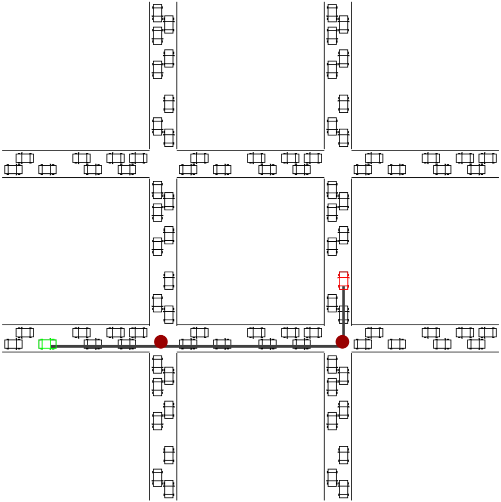
Assumptions

- Moving destination, no location service (A3)
- No plan of movement (B2)
- Source and destination connected, or so. (C1)

Principle

1. Route establishment
   - Flooding for route discovery
   - Intersections recorded as *anchors* in the flooding message
   - Selection of best route at destination
   - Route back to the source

City Scenario - Maintainance of a route, Naumov and Gross [NG07]



Assumptions

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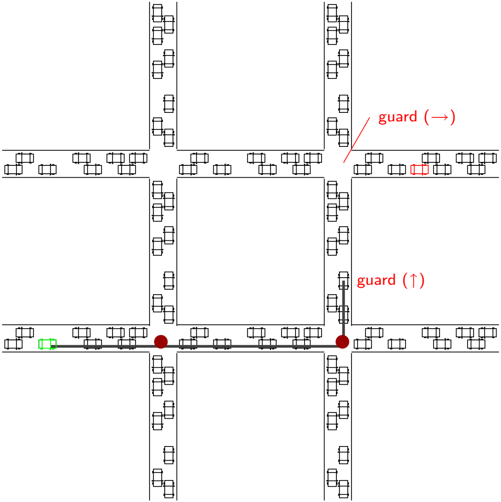
- No plan of movement (B2)
- Source and destination connected, or so. (C1)

Principle

1. Route establishment
2. Normal routing
   - Geocasting toward next anchor
   - Until destination is reached

City Scenario - Maintainance of a route, Naumov and Gross [NG07]



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Principle

1. Route establishment
2. Normal routing
3. Mobility management
   - Guards to guide messages

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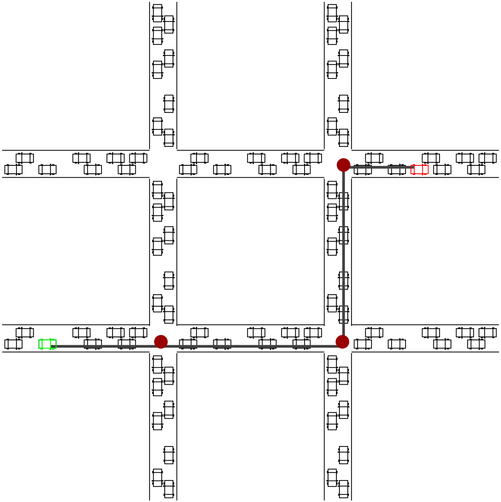

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Principle

1. Route establishment
2. Normal routing
3. Mobility management

Drawback

- This protocol requires the existence of contemporaneous end-to-end connectivity to work (no DTN)

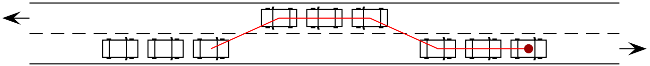
City Scenario - Using plans of movements, Leontiadis and Mascolo [LM07]

Using plans of movements (no picture yet)

- Assumptions:
  - Destination is a fixed point whose location is known (A1)
  - Cars exchange plans of movement with each other (B1)
  - End-to-end connectivity is partially assumed (C1)
- Principle:
  - Neighboring cars exchange their plans of movement
  - Based on them, the source car gives the message custody to the car for which the estimated delivery time t is minimized
  - for each car, t is computed by finding the nearest point (NP) to the destination along the car trajectory, and then by evaluating the time to drive to NP + the time for another car to drive from NP to Destination
- Segment from NP to destination is unpredictable (*e.g.* sparse, closed, or empty roads)
- Limits message speed to vehicle speeds

Highway Scenario - DPP protocol, Little and Agarwal [LA05]

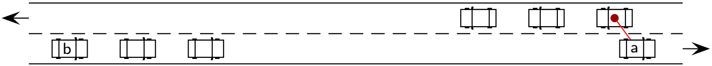
Incoming clusters to bridge connectivity gaps



- Assumption C2 (no end-to-end connectivity assumed)
- Destination is a moving vehicle, located ahead or behind of the source in the same lane (ahead in the above example)
- Principle:
  - opportunistically, incoming clusters are used to bridge consecutive clusters in the same lane

Highway Scenario - Wisitpongphan *et al.* [WBM+07]

Incoming clusters to carry the message



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- Principle:
  - Incoming cluster can carry the message for a while

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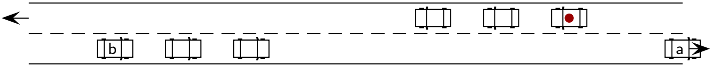

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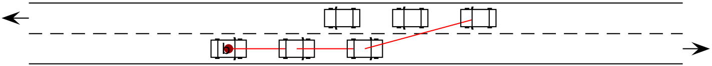

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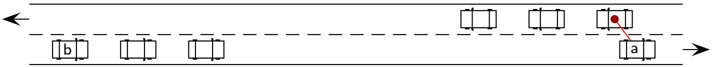
Highway Scenario - Abuelela, Olariu & Stojmenovic [AOS08]

Incoming clusters to carry and route optimally the message



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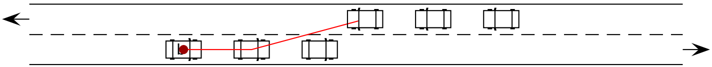


- Assumption C2 (no end-to-end connectivity assumed)
- Destination is a moving vehicle, located ahead or behind of the source in the same lane (ahead in the above example)
- Principle:
  - Incoming cluster can carry the message for a while
  - During carrying time, the message progresses within the cluster
  - Optimal delivery is achieved to the next cluster

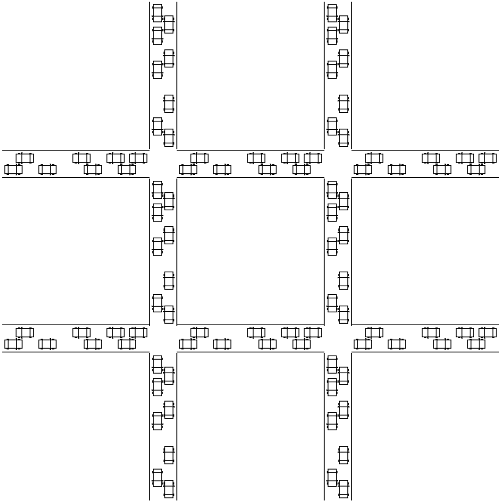
Traffic optimization

Motivations

- Reduce traffic congestion
  - Centralized (with route request)
  - Decentralized (with dissemination)
- Route selection criterions (not treated here)
  - Road quality, Fuel consumption, Road lighting, *etc.*
  - Quality of Travel (as QoS in communication networks)

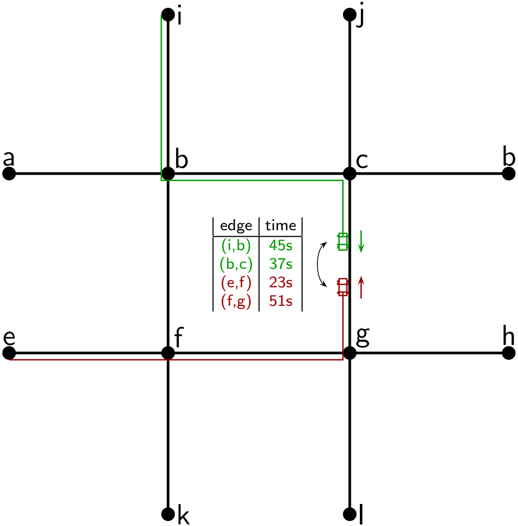
Decentralized Traffic Management Systems

Dissemination of Traffic Information



Decentralized Traffic Management Systems

Dissemination of Traffic Information



Ohara, Nojima, and Ishibuchi [ONI07]

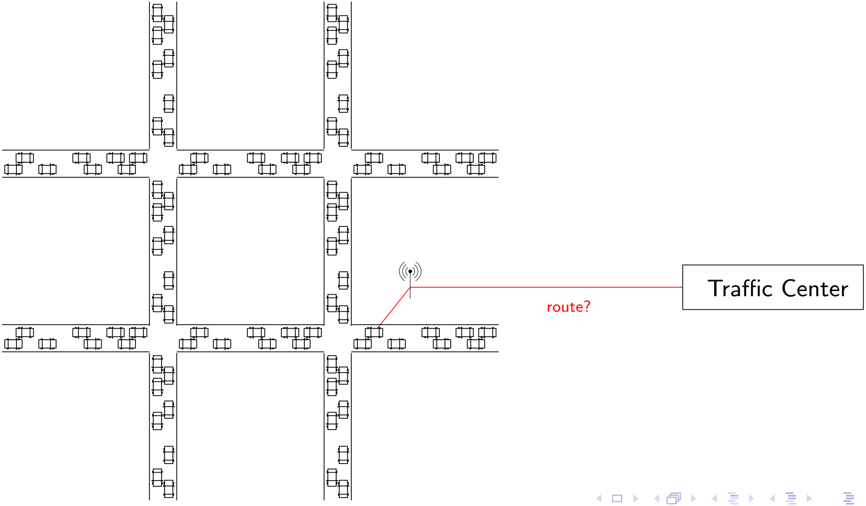
- Edge weight initialized with trunk lengths
- Cars measure travel time for passed trunks
- Cars exchange (and confront) measured time
- Averages done (ponderation with freshness) $\Rightarrow$ Real-time traffic information available to in-car navigation devices
- hard to avoid the flash crowd effect !

Some other papers

- Similar schemes can be found in [SFUH04] and [STK$^+$06]

Centralized Traffic Regulation Systems

Shortest path in time-varying weighted graph



Centralized Traffic Regulation Systems

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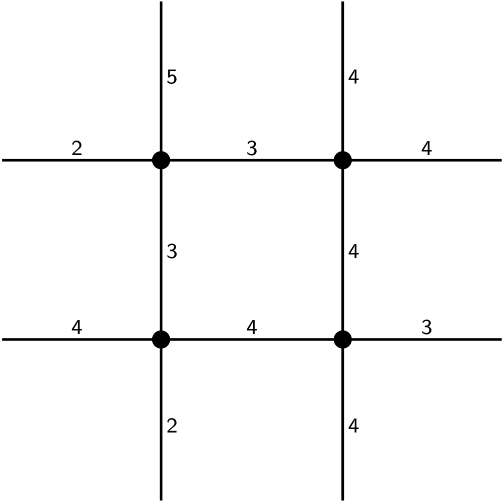


Existing algorithms

- (static) Dijkstra algorithm ([Dij59])
- (static) A* algorithm ([HNR68])
- (dynamic) A* algorithm (Chabini & Lan [CL02])
- (others, dynamic) [ZM93, CH66, Cha98]

Computation of future weights

- Decisions influence future weights
- Congestion prediction (historic, events, *etc.*)
- Fine-grain time (or flash crowd effect!)

Complete frameworks

- Harvesting protocols (real-time statistics)
- Routing (for route request / route answer)
- Central processing: algorithms, cache, forecast..
- example: Traffcon (Collins & Muntean [CM08])

Bringing Internet into Vehicles

Motivations

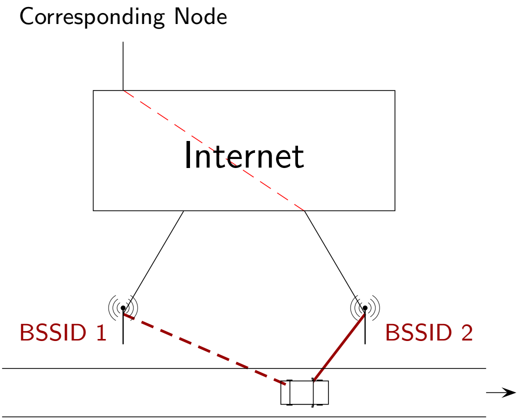
- Several motivations:
  - Traffic Information Server on the web
  - Integrated phone, VoIP,..
  - Entertainment for passengers
  - Real-time information everywhere
  - Meteo alerts
  - *etc.*

Active research areas

- IP Mobile, Network Mobility (NEMO)
- Nested-NEMO, route optimization for NEMO
- Spanning tree maintainance from RSUs to Vehicles (not treated here)

Mobile IP

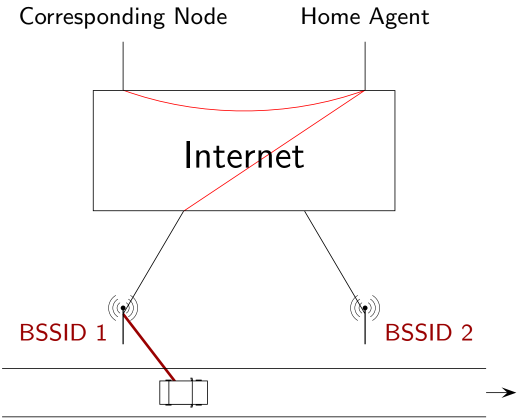
Without Mobile IP



Change of IP address $\Longrightarrow$ disconnection with Corresponding Node

Mobile IP

Using Mobile IP



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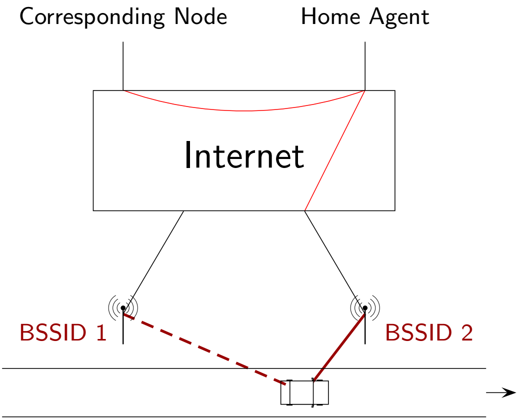


Change of IP address OK, seamless for Corresponding Node

Drawbacks

- What if several IP devices in a car?
- No multihop in the Ad Hoc Domain (distance 1 needed to RSU)

NEMO (Network Mobility) [RFC3963]

Principle

- extension of Mobile IP
- nodes are networks (i.e. addresses $\Longrightarrow$ range of addresses)
- OBU manages the local network inside the car, then addresses are mapped to public and stable addresses by the Home Agent

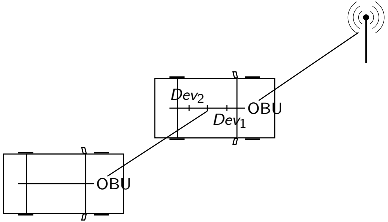
Does it solve the problems?

- multiple IP devices in vehicles, yes
- multi-hops Internet access in Ad Hoc Domain, not enough

Nested NEMO (1)

Principle

- NEMO^n
- attach a vehicle to another vehicle as if it was an inner IP device



- works, but may lead to sub-optimal routing paths such as

  Car n ⟶ Car n-1 ⟶ ...Car 1 ⟶ Home Agent 1... ⟶ Home Agent n-1 ⟶ Home Agent n ⟶ CN

  when a car communicates with a distant node on the Internet, through n-1 other cars

Nested NEMO (2)

Route optimization (VANEMO)

- Use NEMO in Infrastructure Domain and VANET routing protocols in Ad Hoc Domain
- Make it work together
- Work in progress.. [BFA07, BSC+07, MED06, WMK+05]

Mobility Models and Connectivity

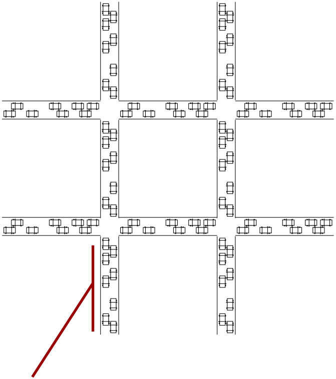
Motivations

- Better understanding of VANETs deepest nature
- $\Rightarrow$ Better design of protocols

Fundamental characteristics of VANETs

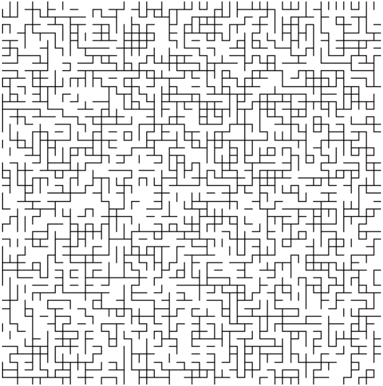
- Highly constrained mobility
- Unlimited size and population
- Almost no chance to meet a node several times
- Not always connected, specific connectivity

Lattice Percolation Theory (used in [SHW+08])



Let p_{ct} be the probability for one trunk to be connected

Question:
what density d_{car} to have the entire network connected?



Lattice Percolation Theory says:
$p_{ct} > 0.5 \implies \forall v_1, v_2, p_{path}(v_1, v_2) \approx 1$

Critical density: d_{car} such that $p_{ct} > 0.5$
$\Rightarrow$ depends on the mobility model considered..

Impact of the model (studied in [FH08])

Mobility Model Classes

- stochastic models (random paths, random speeds)
- traffic stream models (macroscopic, hydrodynamic phenomenon)
- car-following models (behaviour depends on surrounding vehicles)
- [+]flows-interaction models (several flows: intersections, insertion ramps, *etc.*)

Connectivity Metrics

1. Link durations (how stable)
2. Nodal degrees (how dense)
3. Cluster number (how fragmented)
4. Normalized cluster size (distribution of cluster sizes)
5. Clustering coefficient (connectivity index within clusters)

Conclusions:

$\Longrightarrow$ more realism implies worse connectivity

$\Longrightarrow$ most existing results are optimistic

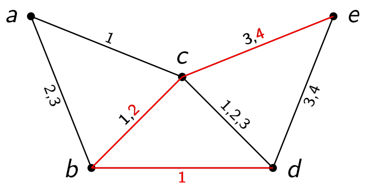
Note: Non-DTN Metrics.

DTN Connectivity

Expression of DTN-Metrics

- path → journey (path over time)
  - sequence of edges associated with increasing dates
  - non-symmetrical !
  - *shortest vs. fastest vs. foremost journeys*
- cluster → over-time-connected component:
  $\forall v_1, v_2 \in otcComp, \exists \mathcal{J}_{(v_1,v_2)} \subseteq \mathcal{G}$

DTN Network/Evolving Graph



$$\mathcal{J}_{(d,e)} = \{(d,b,1),(b,c,2),(c,e,4)\} \subseteq \mathcal{G}$$

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