Vehicular Ad Hoc Networking - Overview

CSI5140

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Outline

Quick Overview

New Wireless Communication Capabilities

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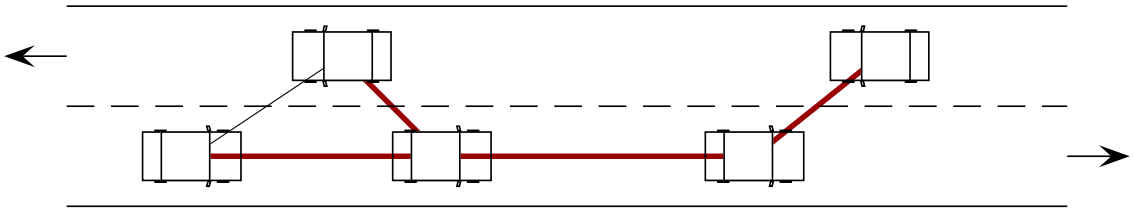
Vehicle-to-Vehicle (V2V)



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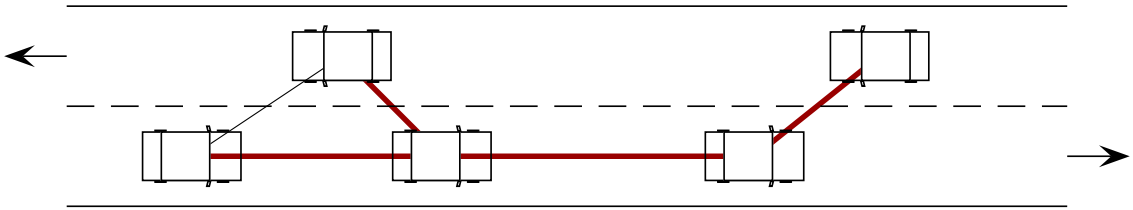
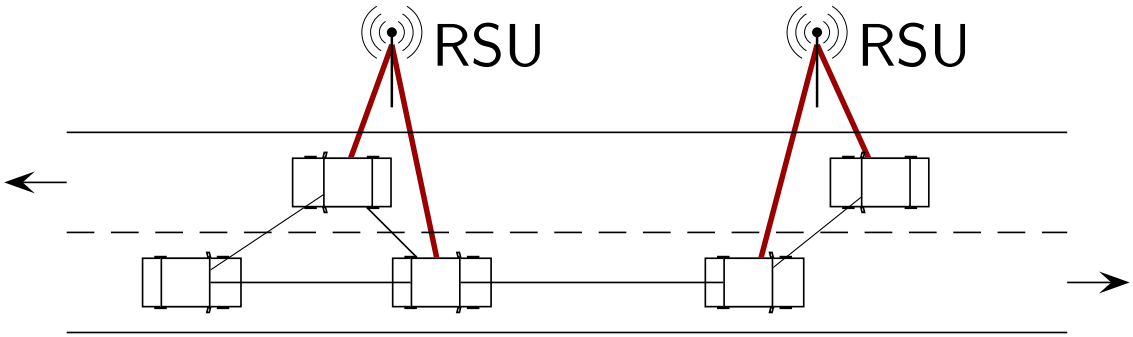


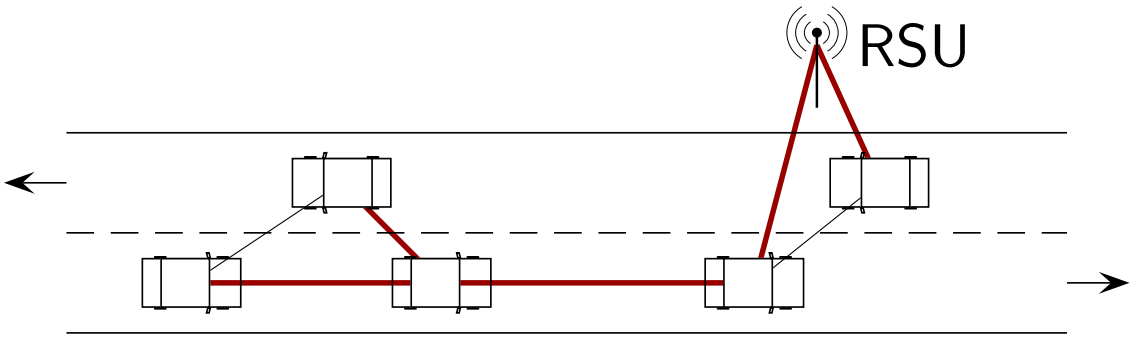
Vehicle-to-Infrastructure (V2I)



Vehicular Ad Hoc Networks

VANETs are Hybrid networks

- Combine V2I and V2V communications

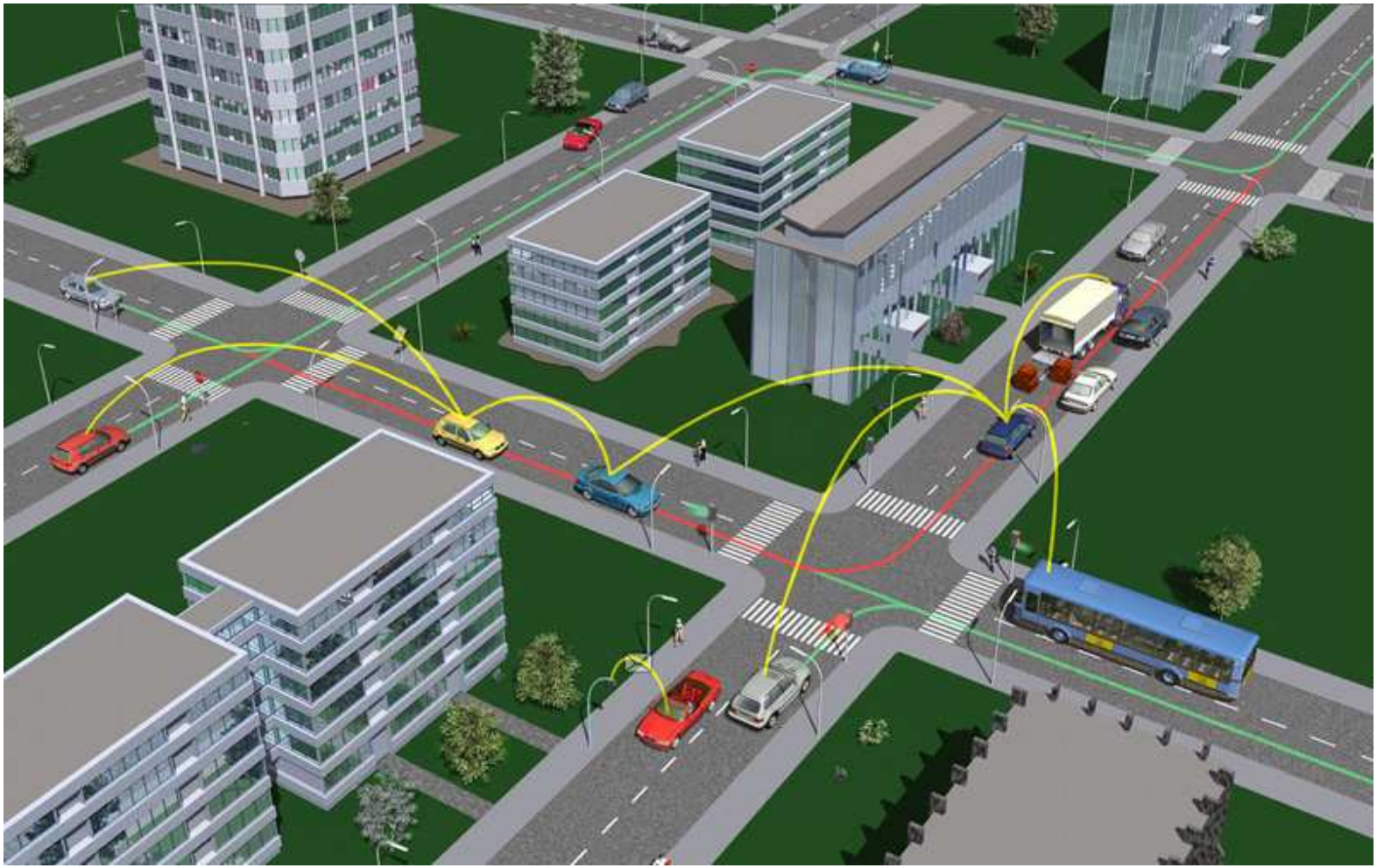


- Allow integration of vehicles and Intelligent Transportation Systems

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]

Architecture and Protocols

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).

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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 must 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

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

Wi-Fi and Others

- 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)

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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)

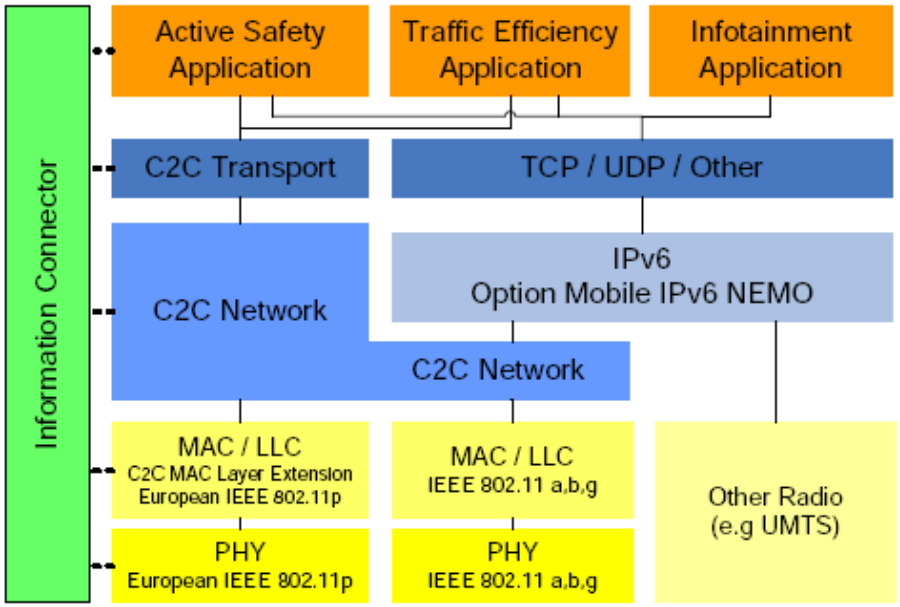
Transport Layer

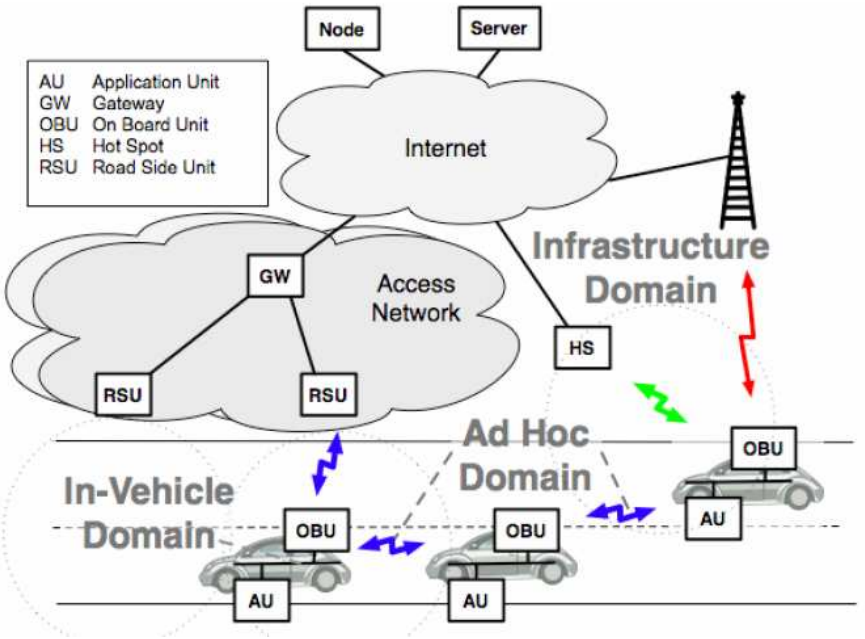
Still under discussion in consortiums..

- dedicated transport protocols?
- TCP/UDP?

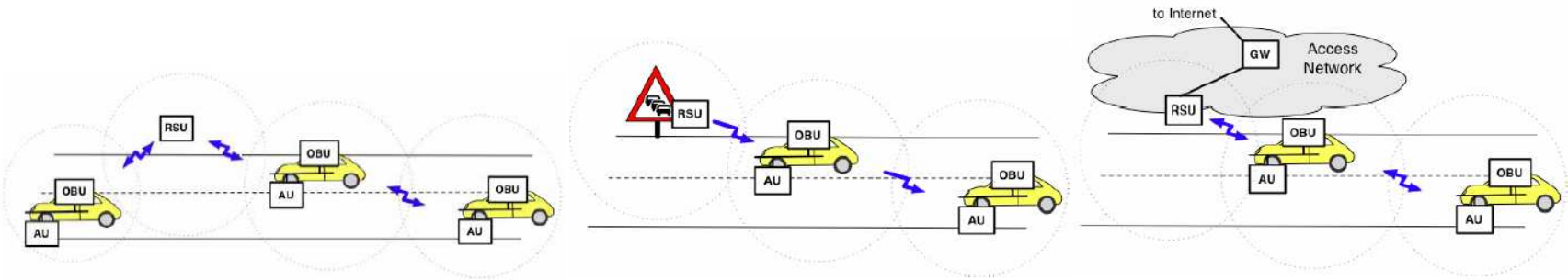
Summarization [pictures from the Car-2-Car Consortium Manifesto]

Network overview





A few basic scenarios



A few research problems

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

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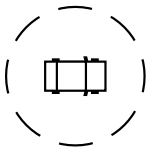

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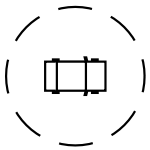

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- Location service is available to vehicles

Broadcasting

Motivations

- route discovery (not treated here)
- safety warning
  - accident notifications
  - strong deceleration of traffic flow
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  - local tourism information
- relevance of information is most often geographically delimited
  - Broadcast $\Rightarrow$ Geocasting

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

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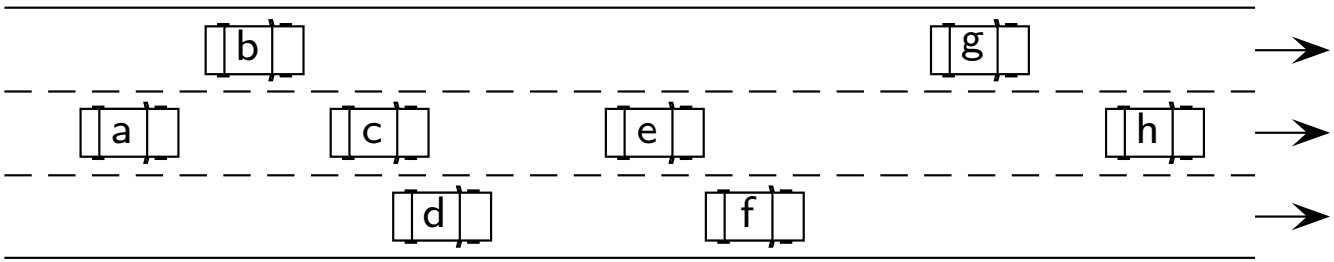

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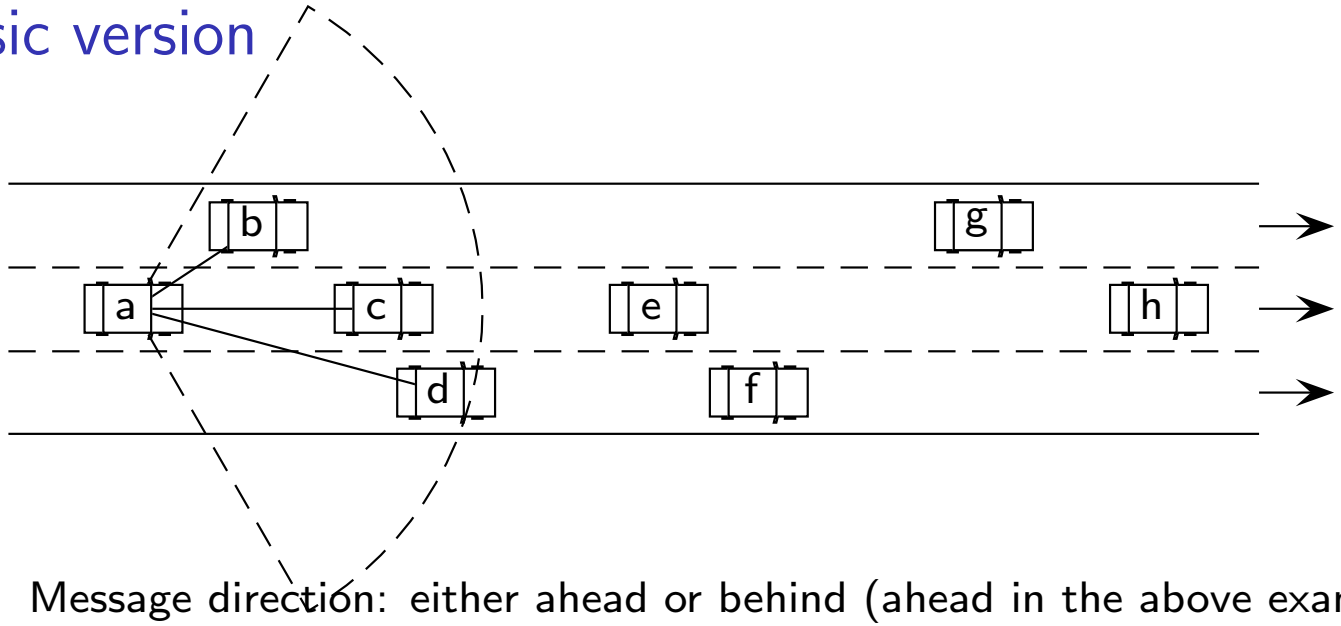

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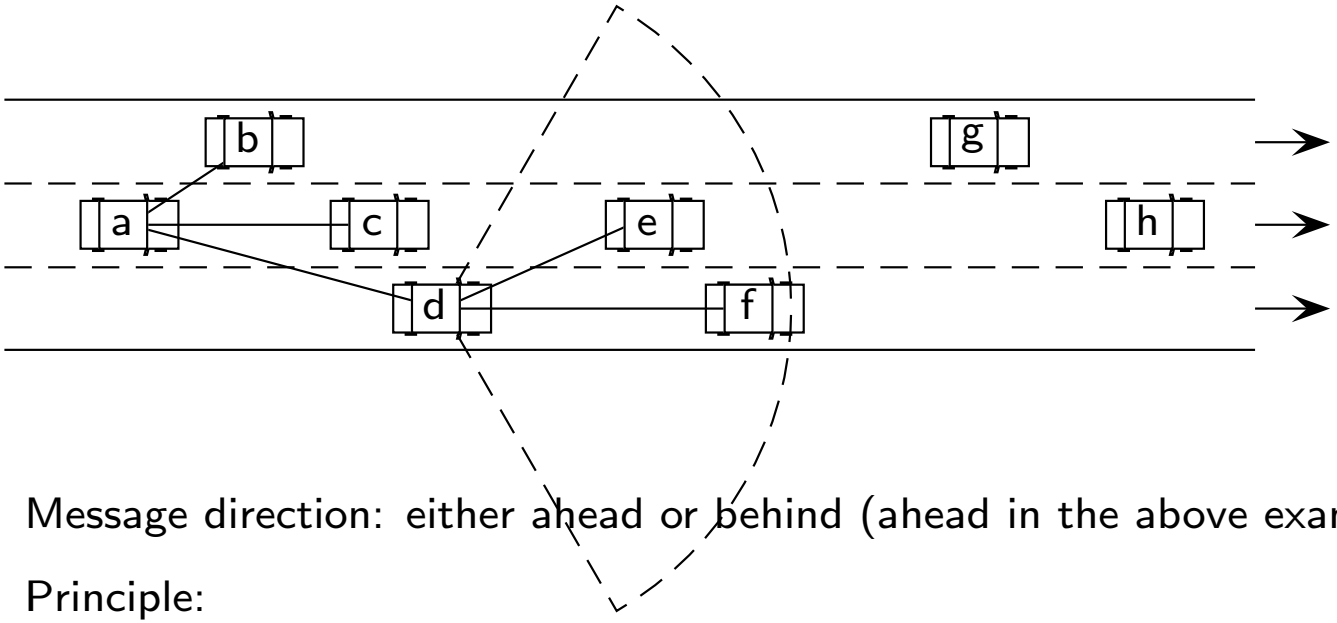

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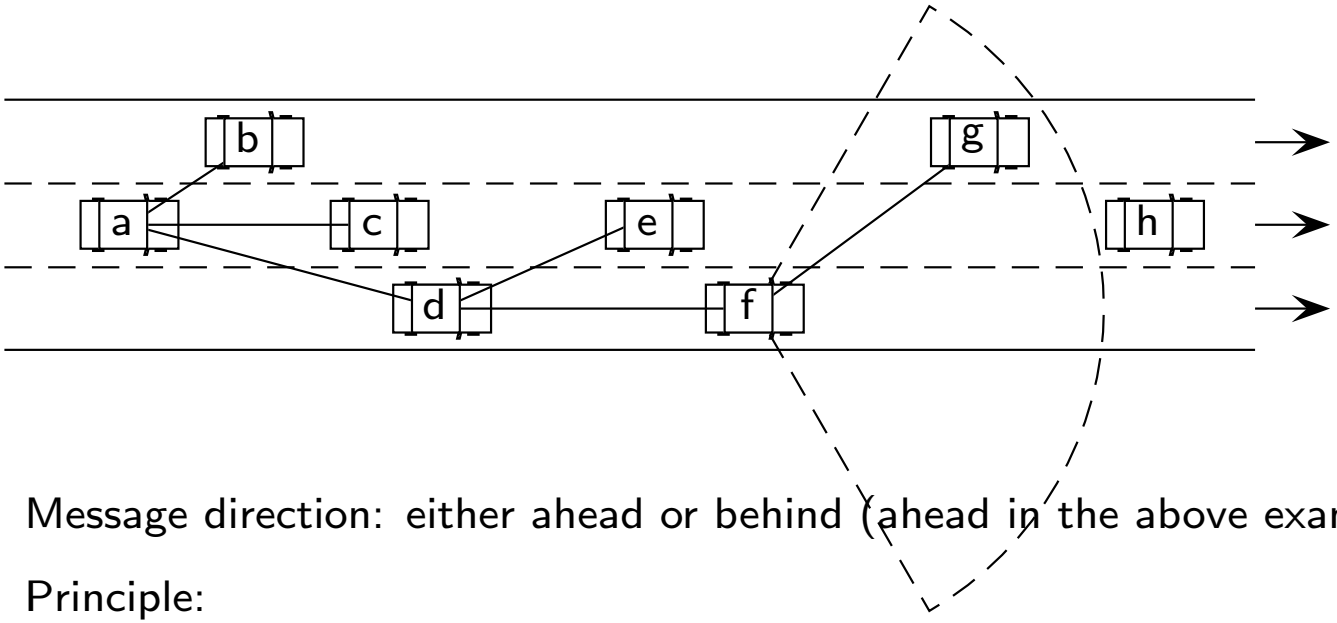

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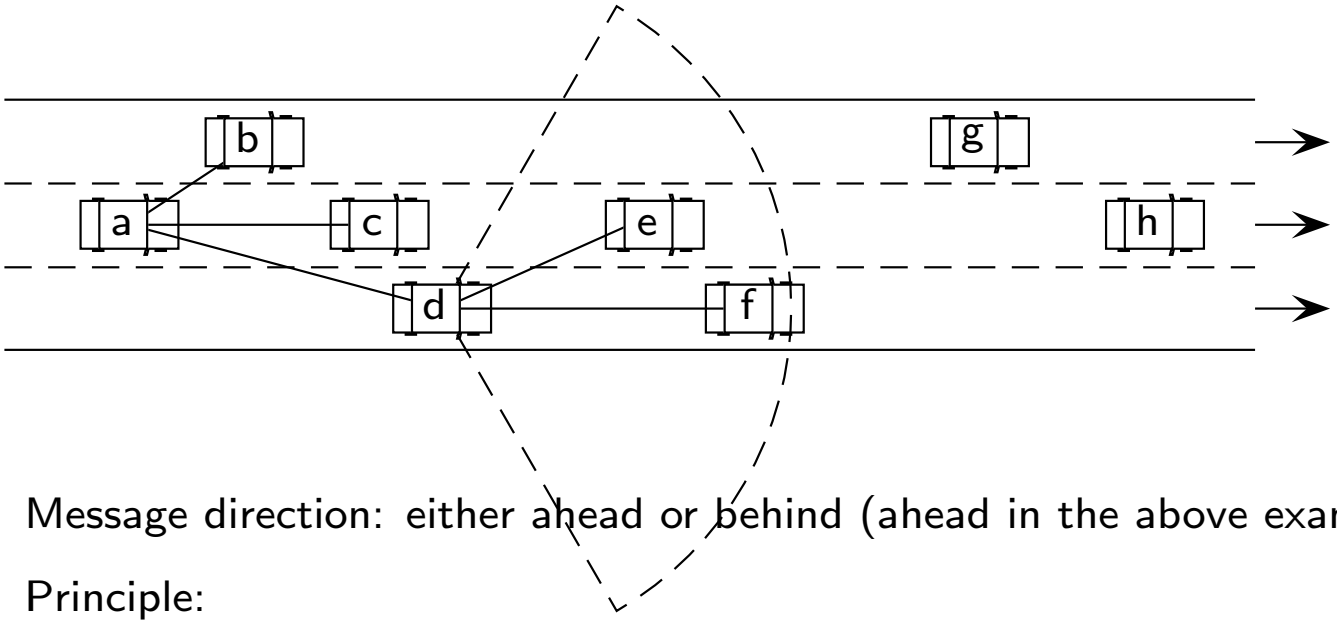

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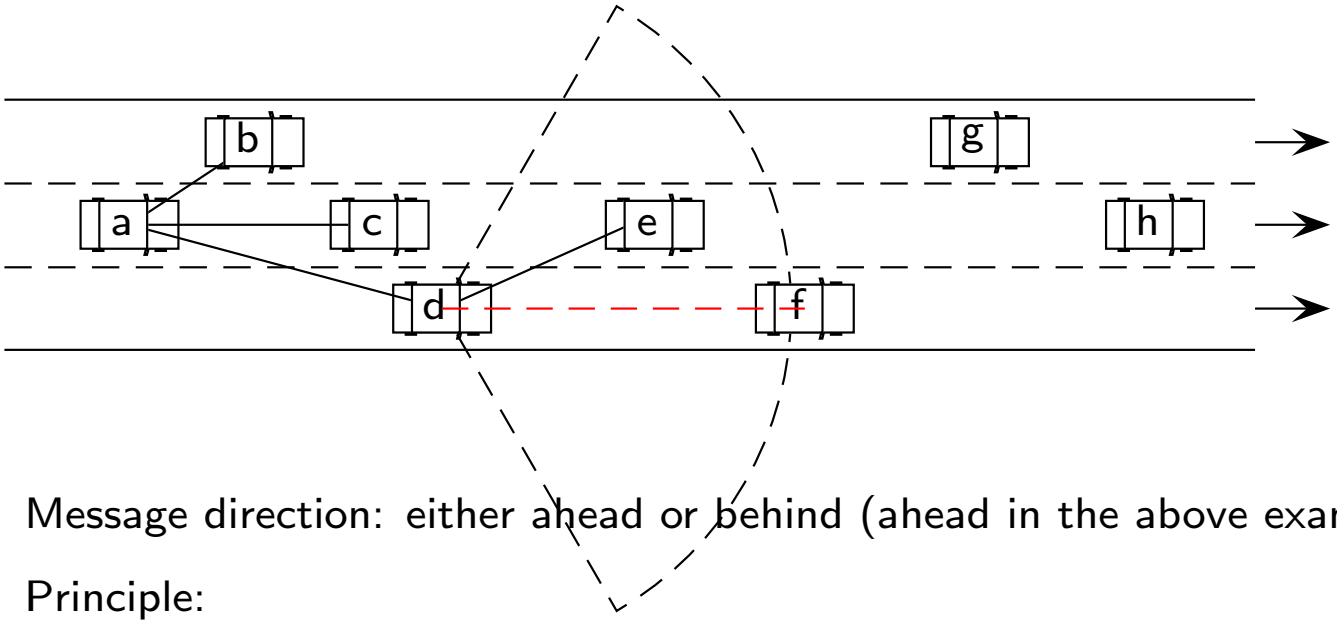

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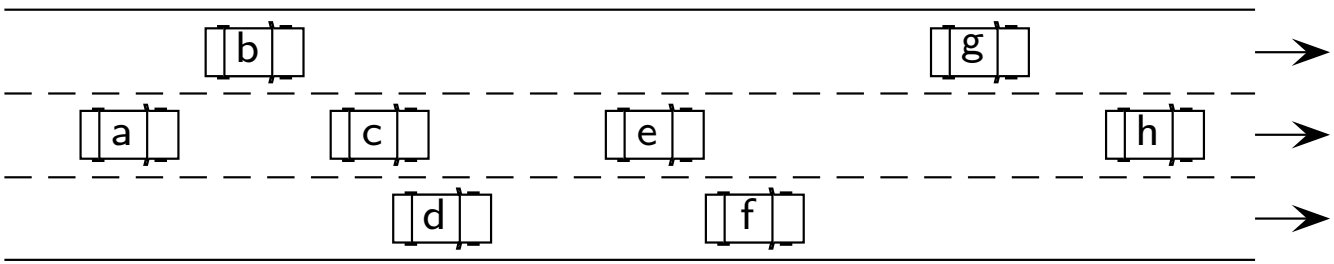

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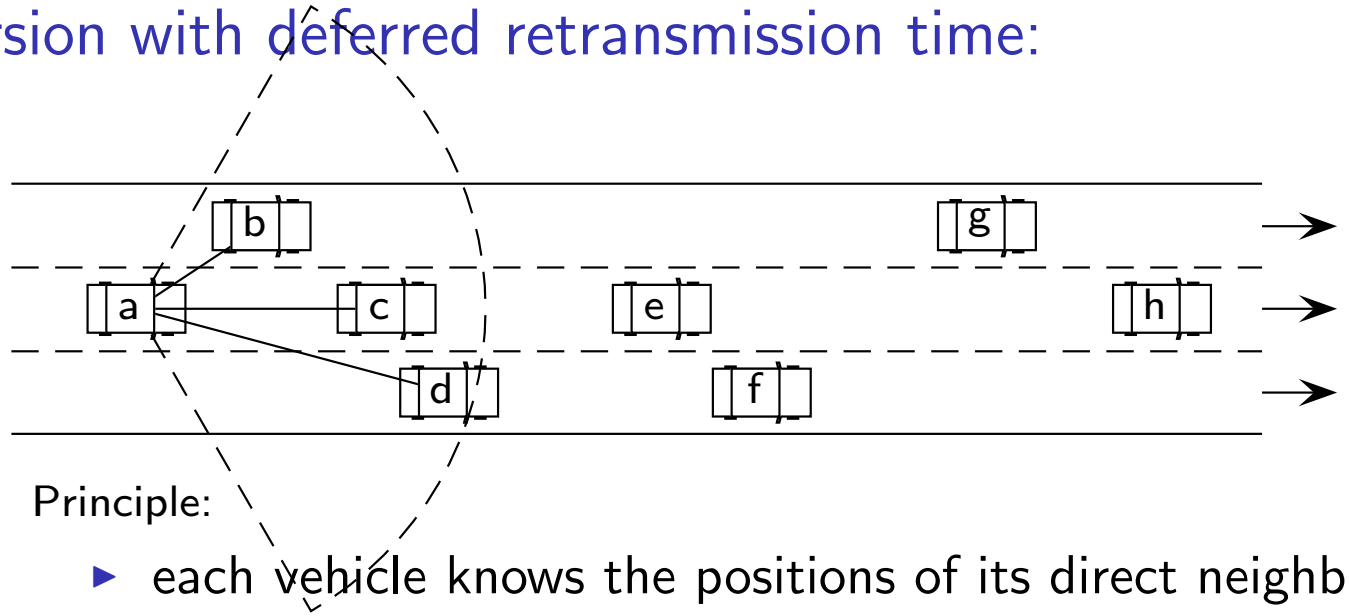

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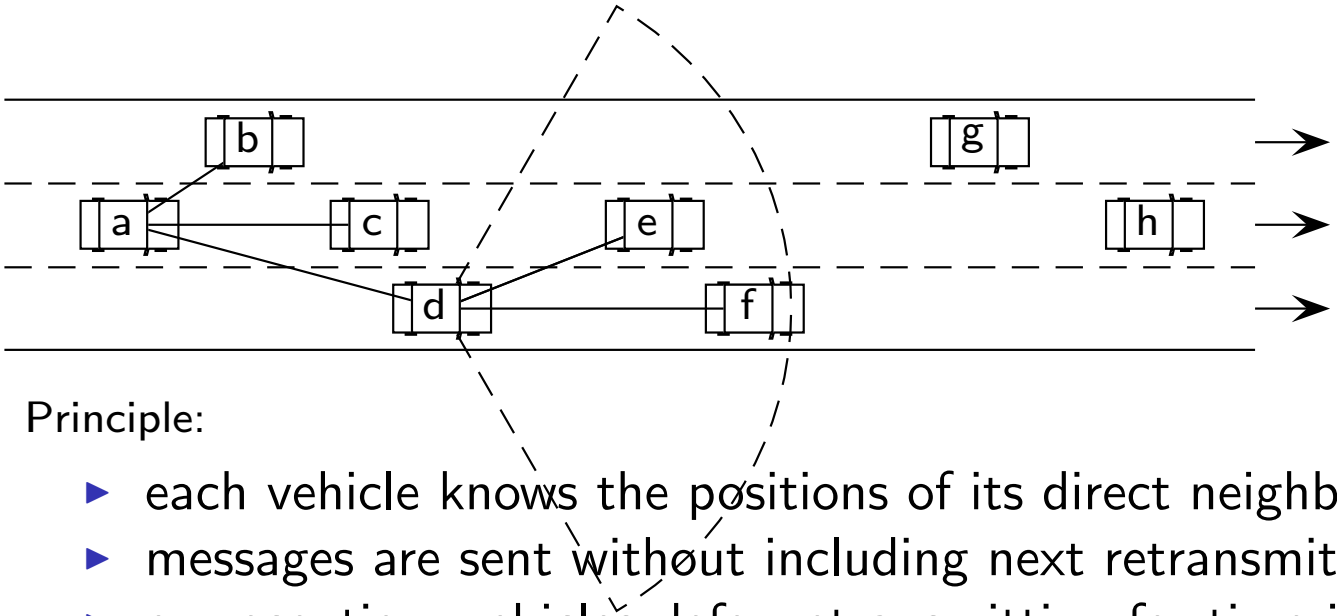

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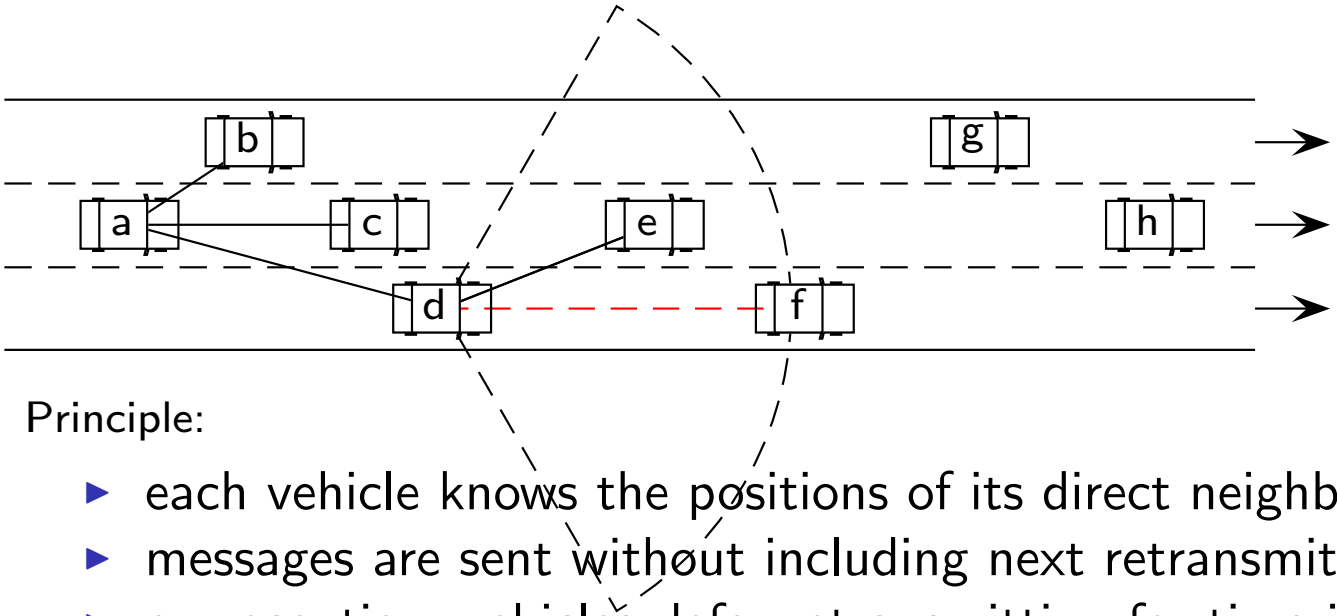

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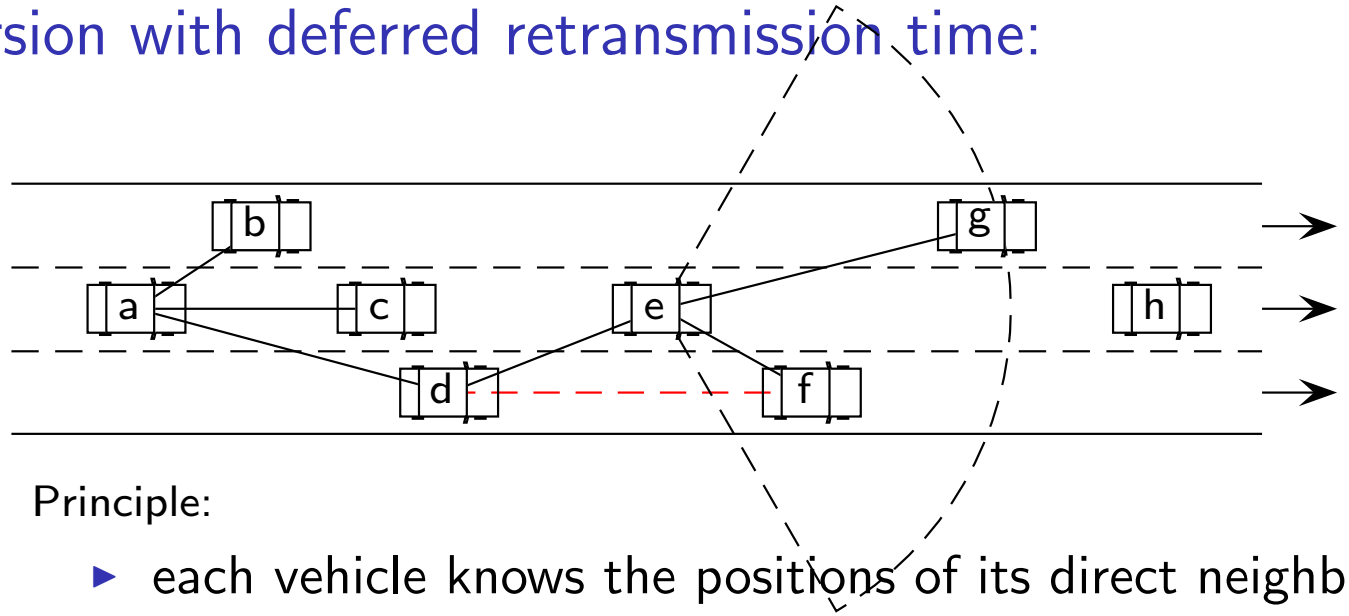

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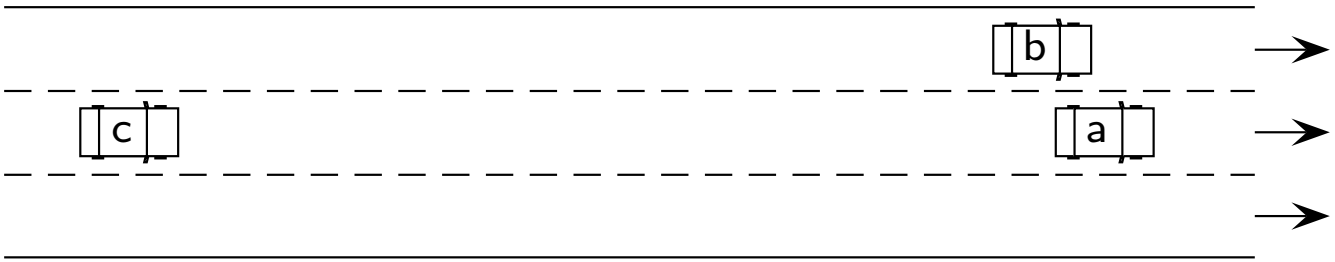

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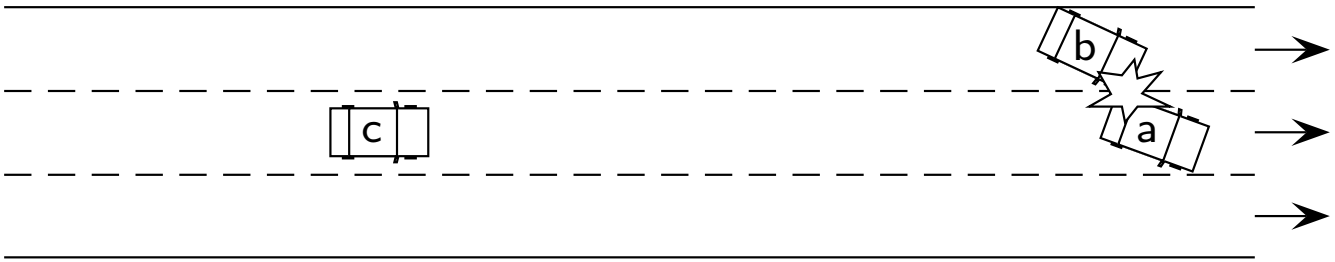

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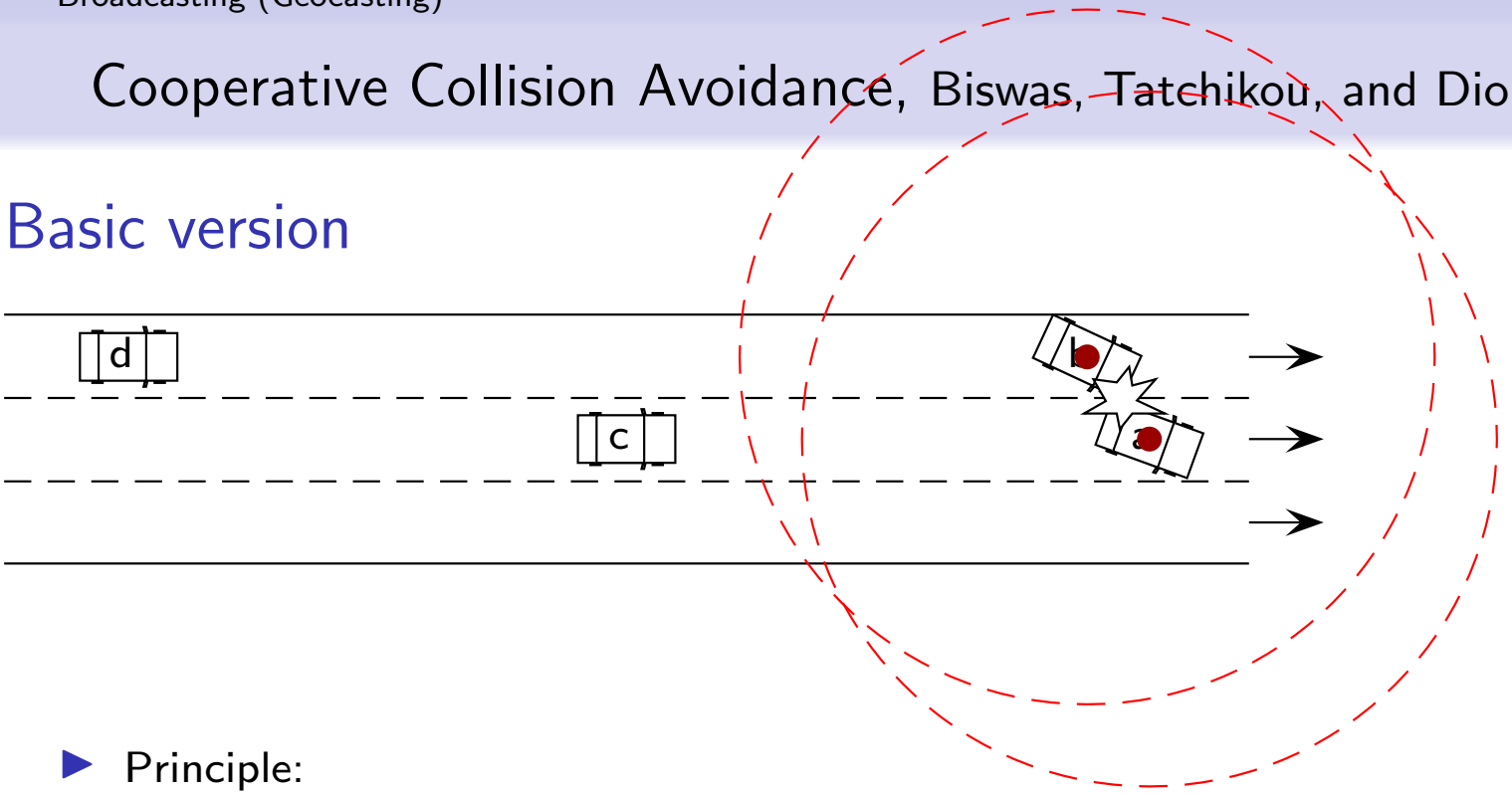

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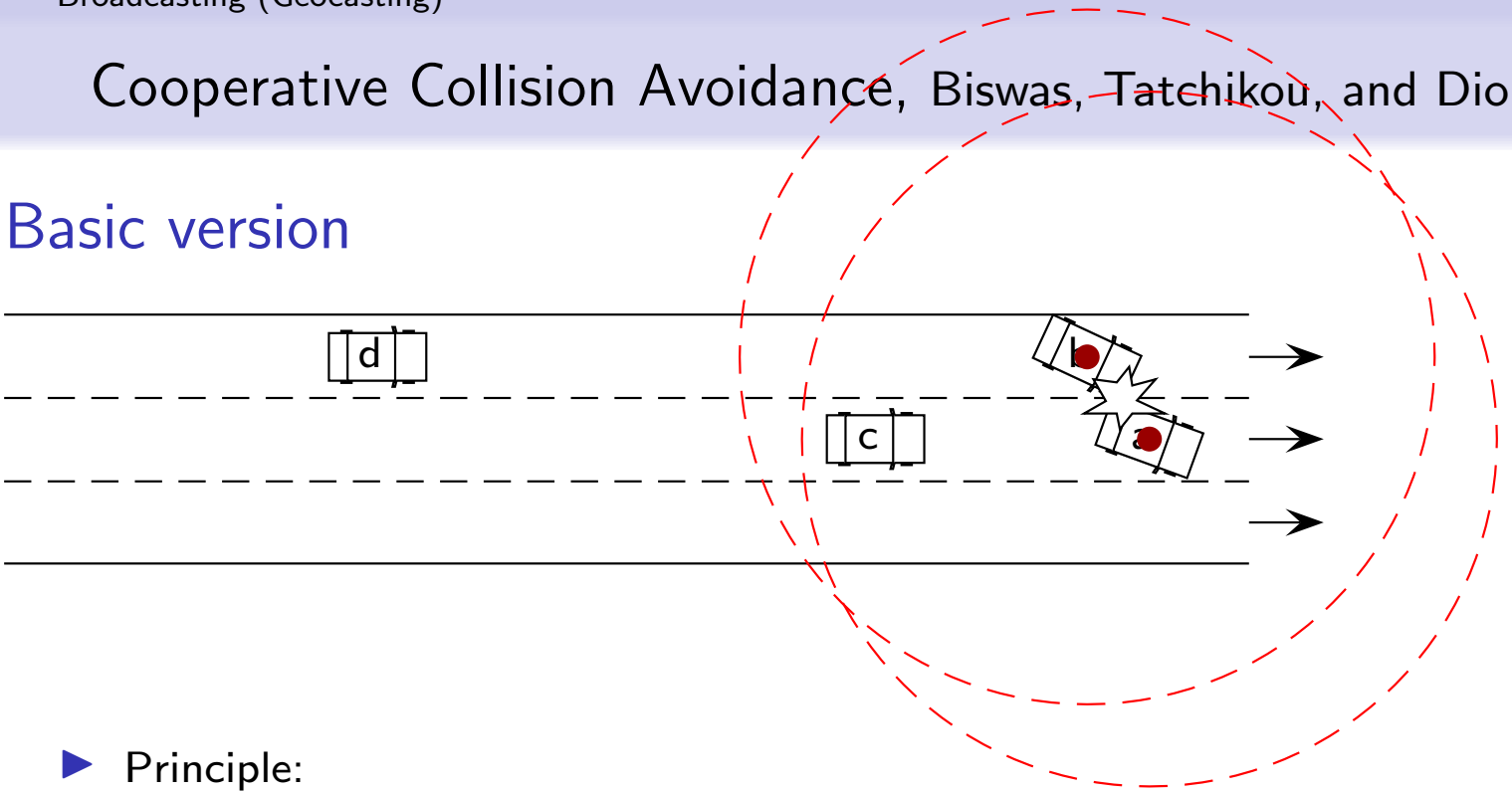

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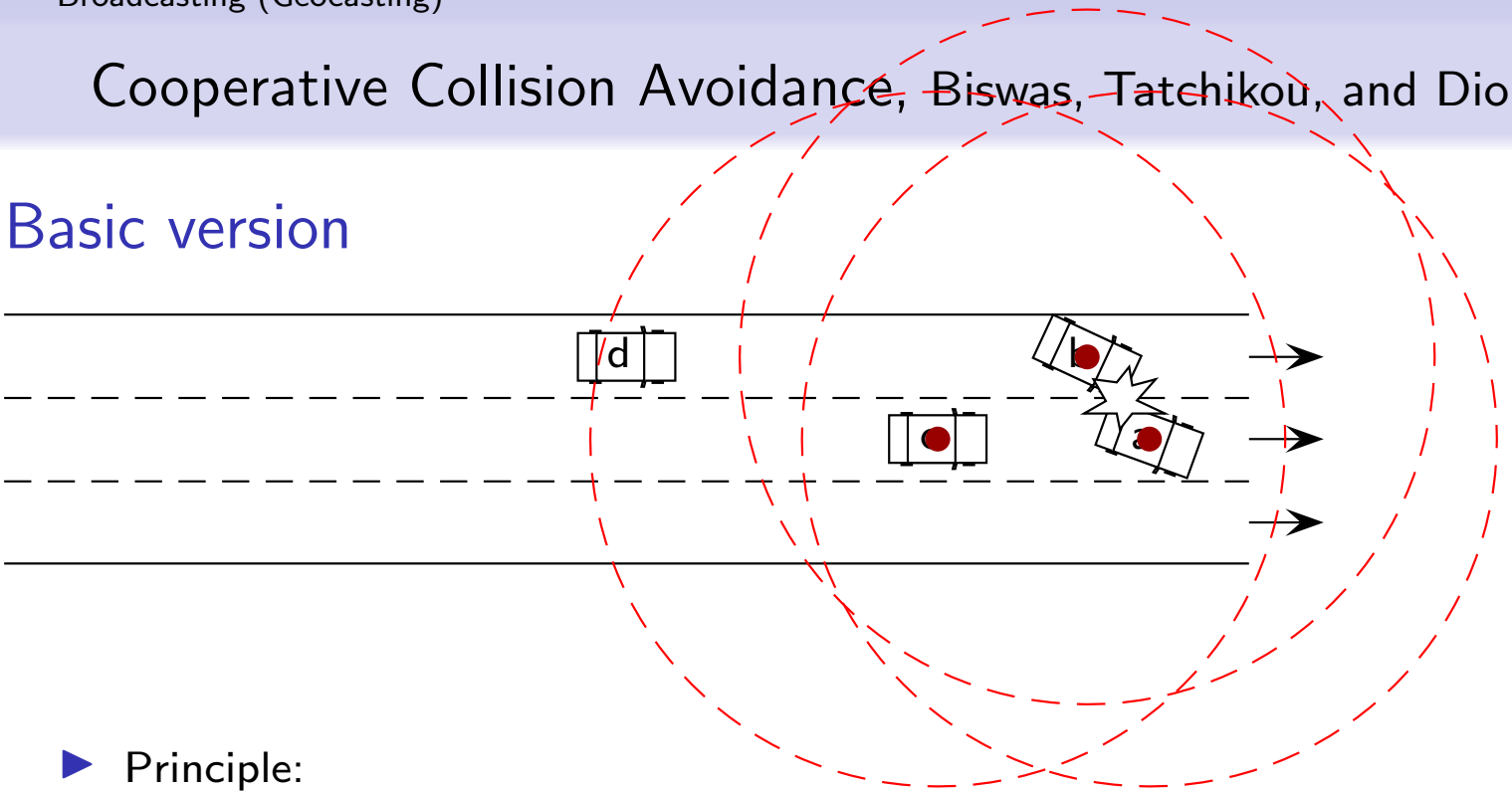

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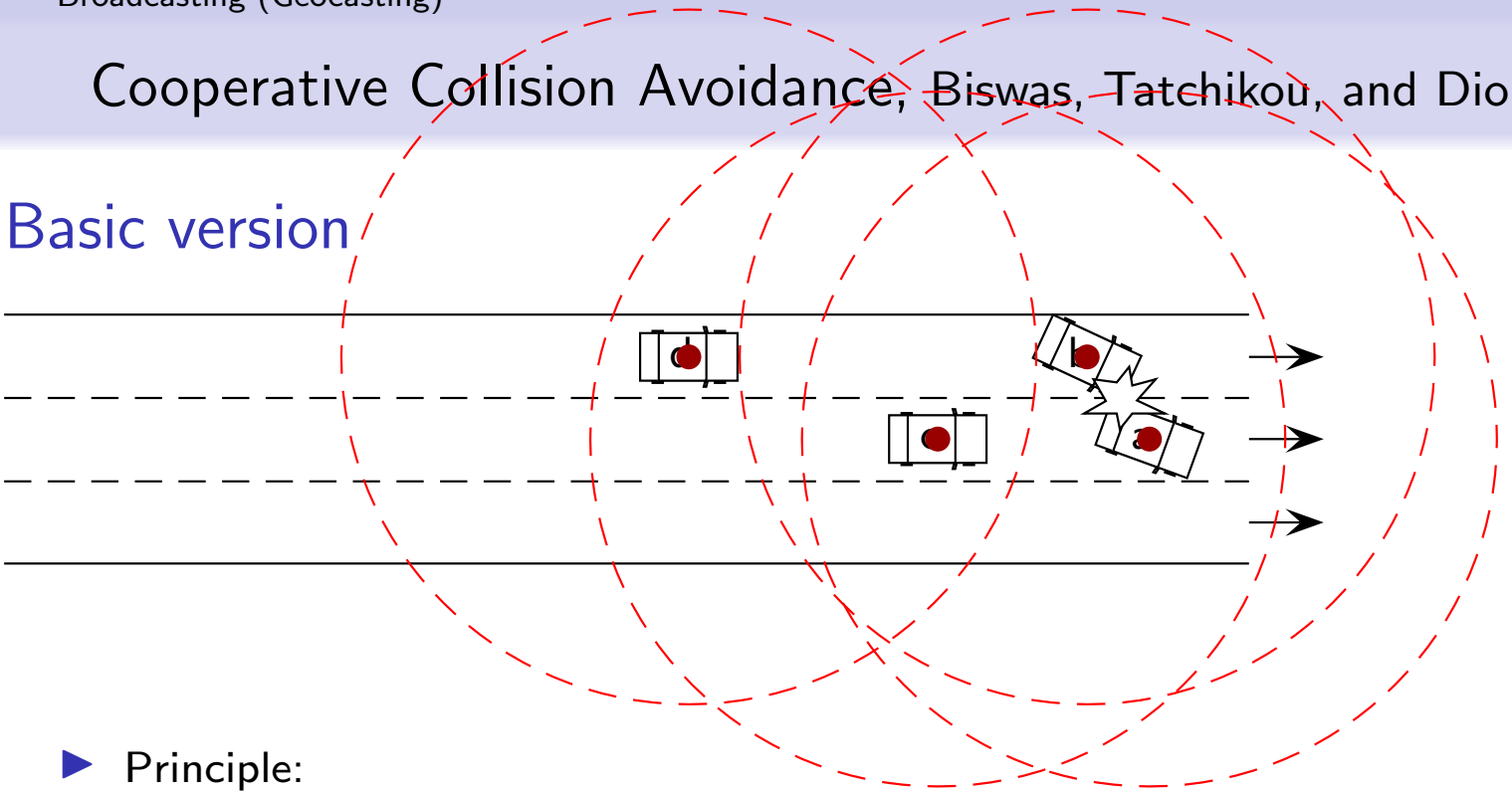

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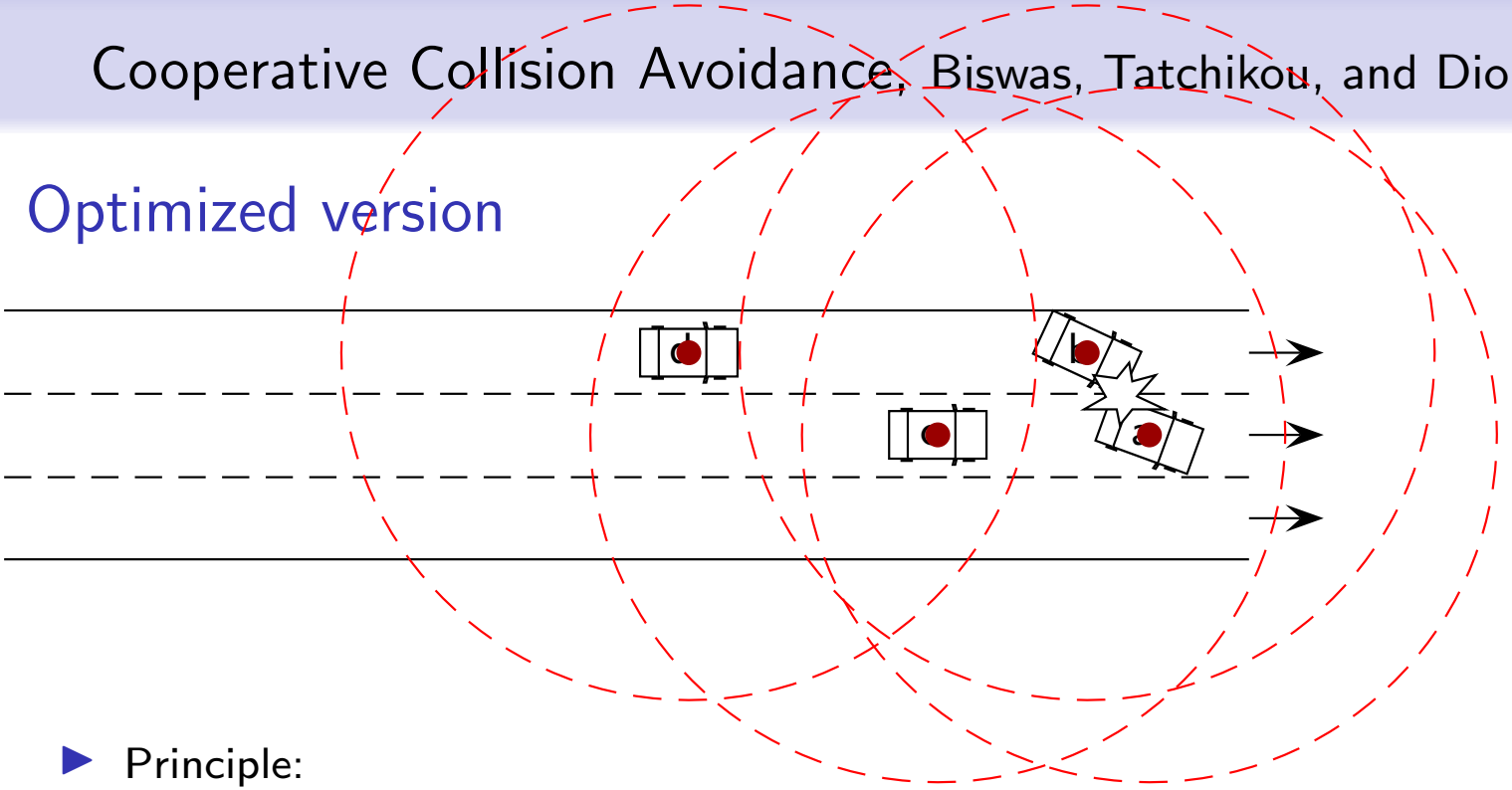

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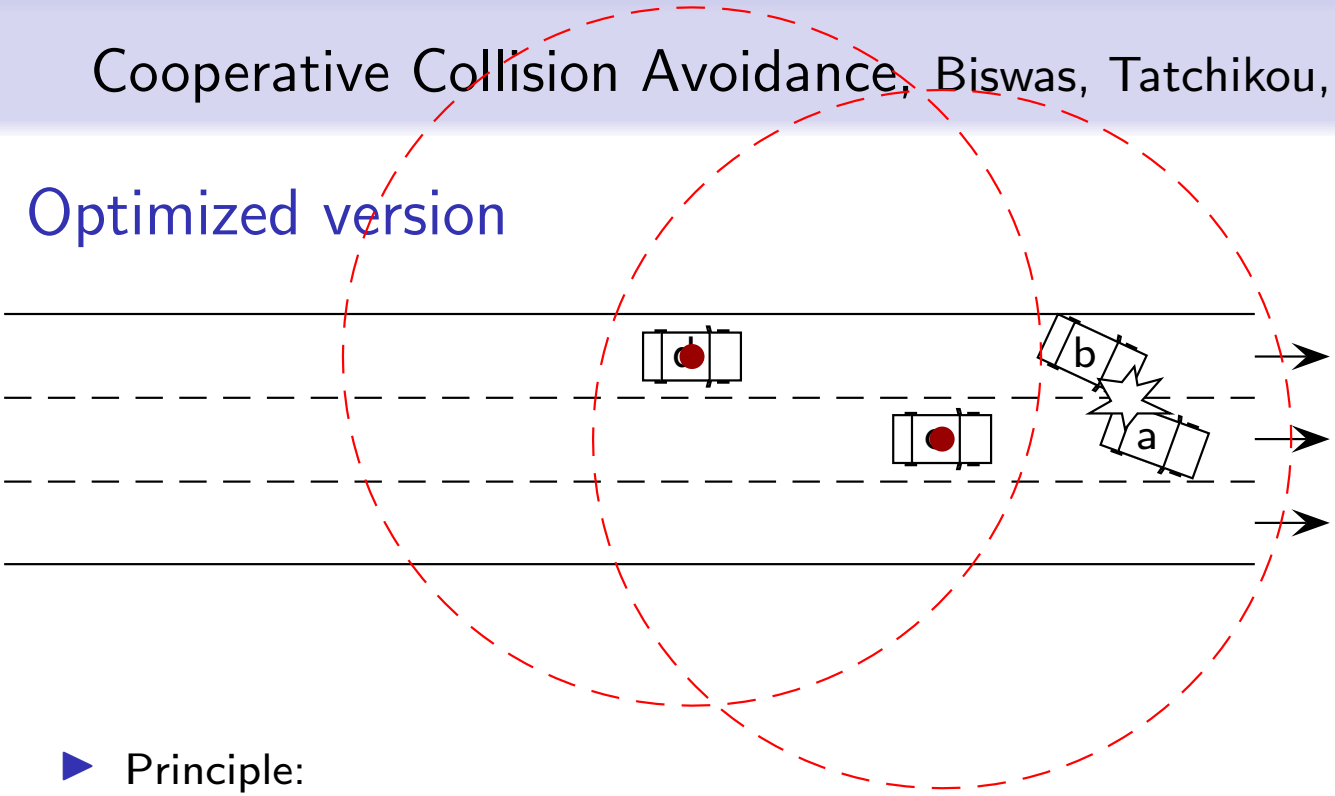

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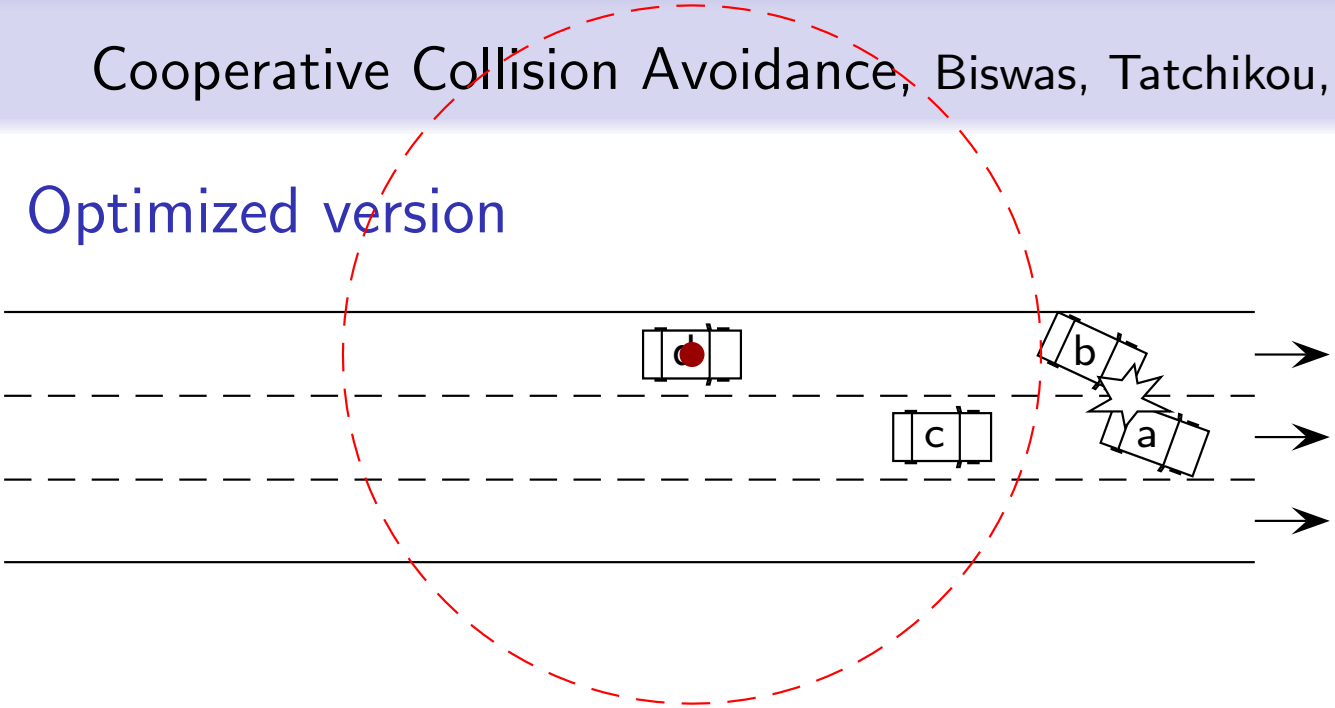

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Cooperative Collision Avoidance, Biswas, Tatchikou, and Dion [BTD06]

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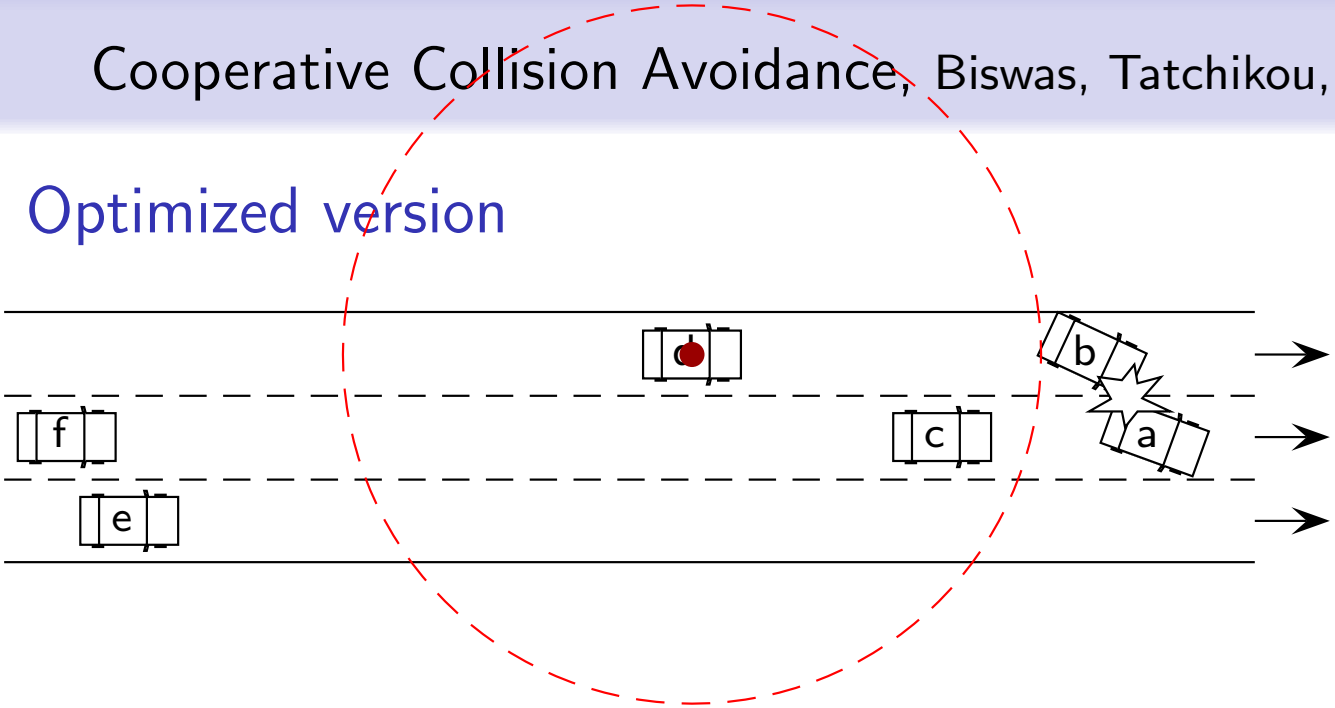

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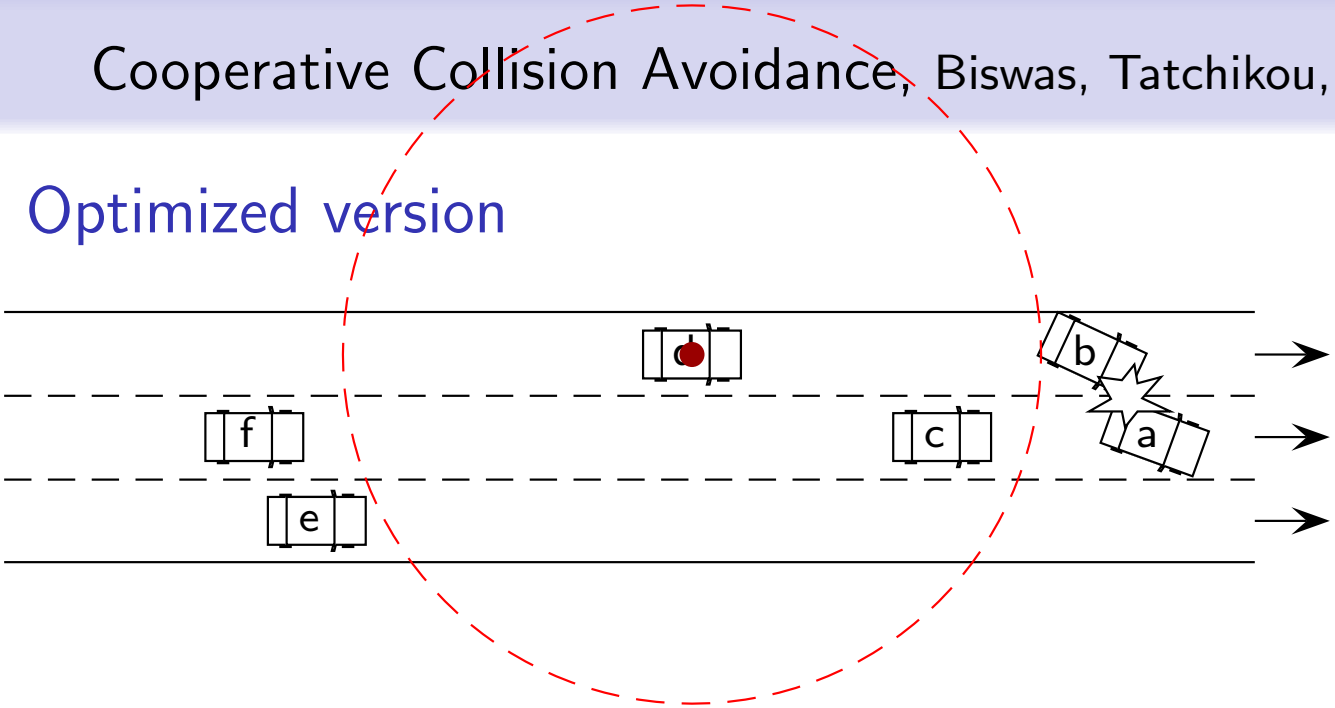

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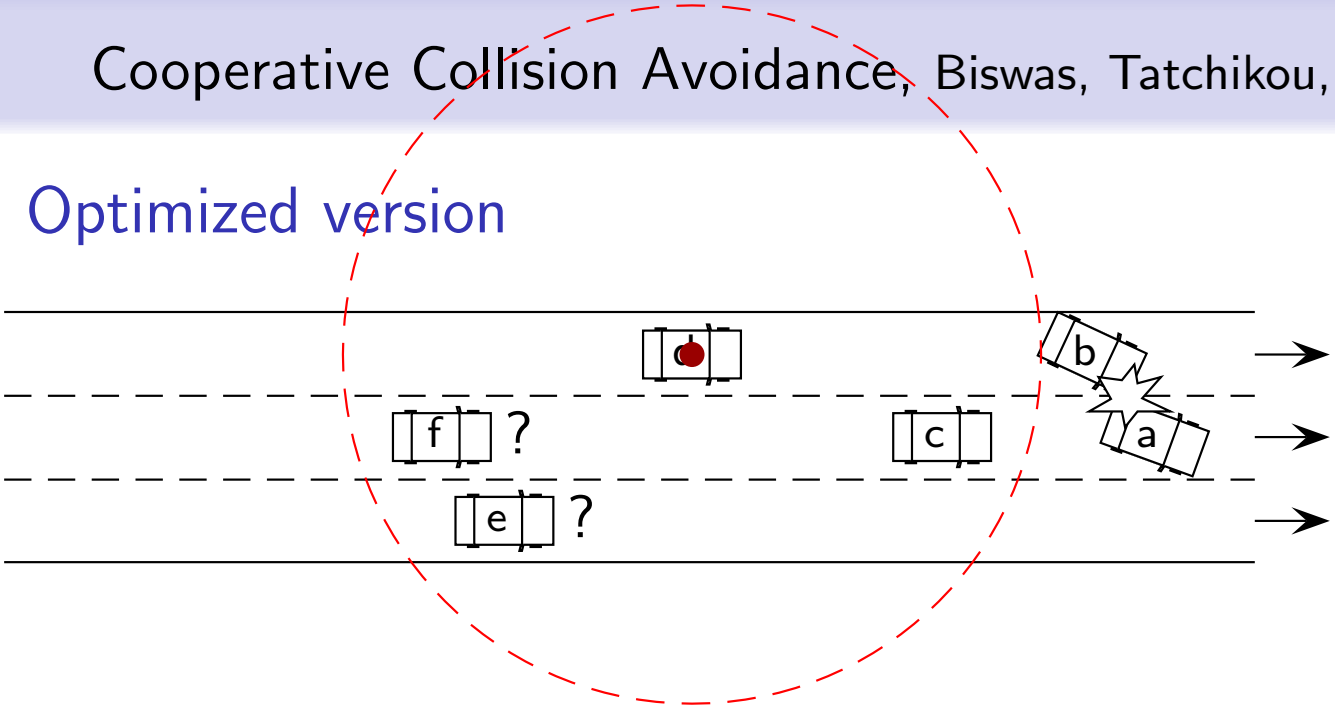

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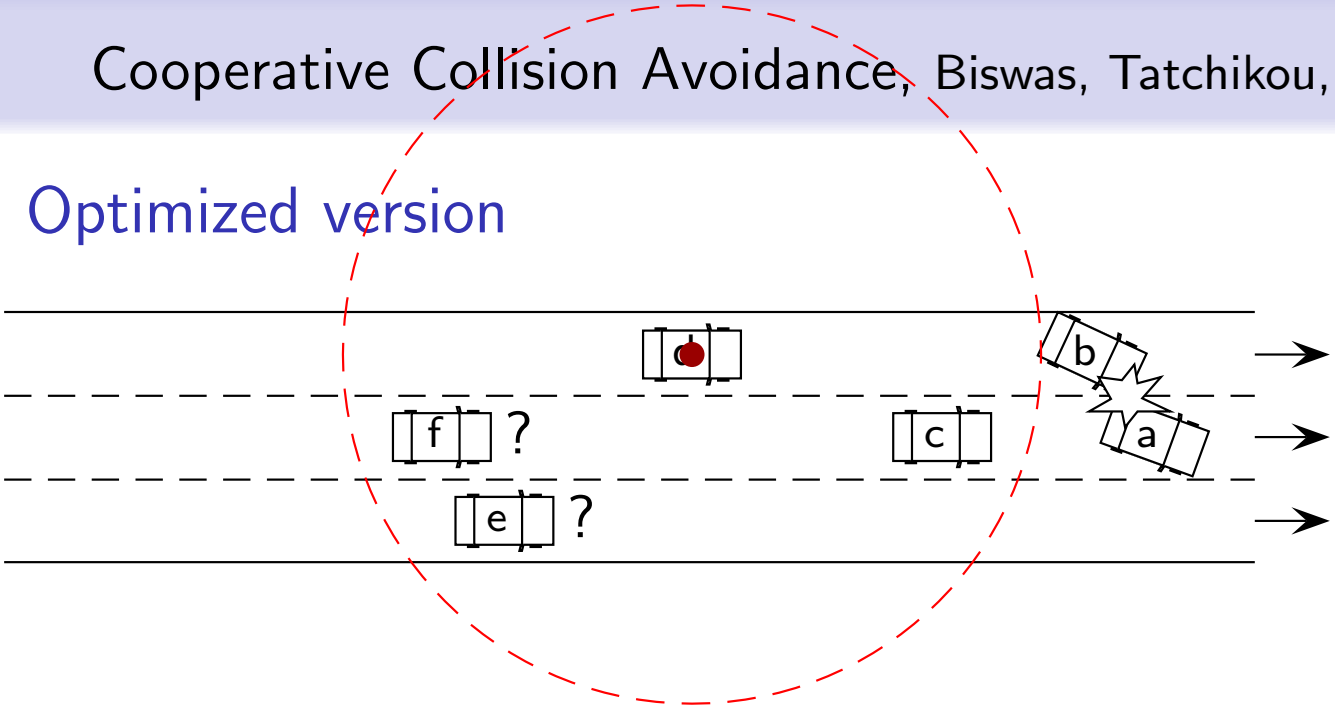

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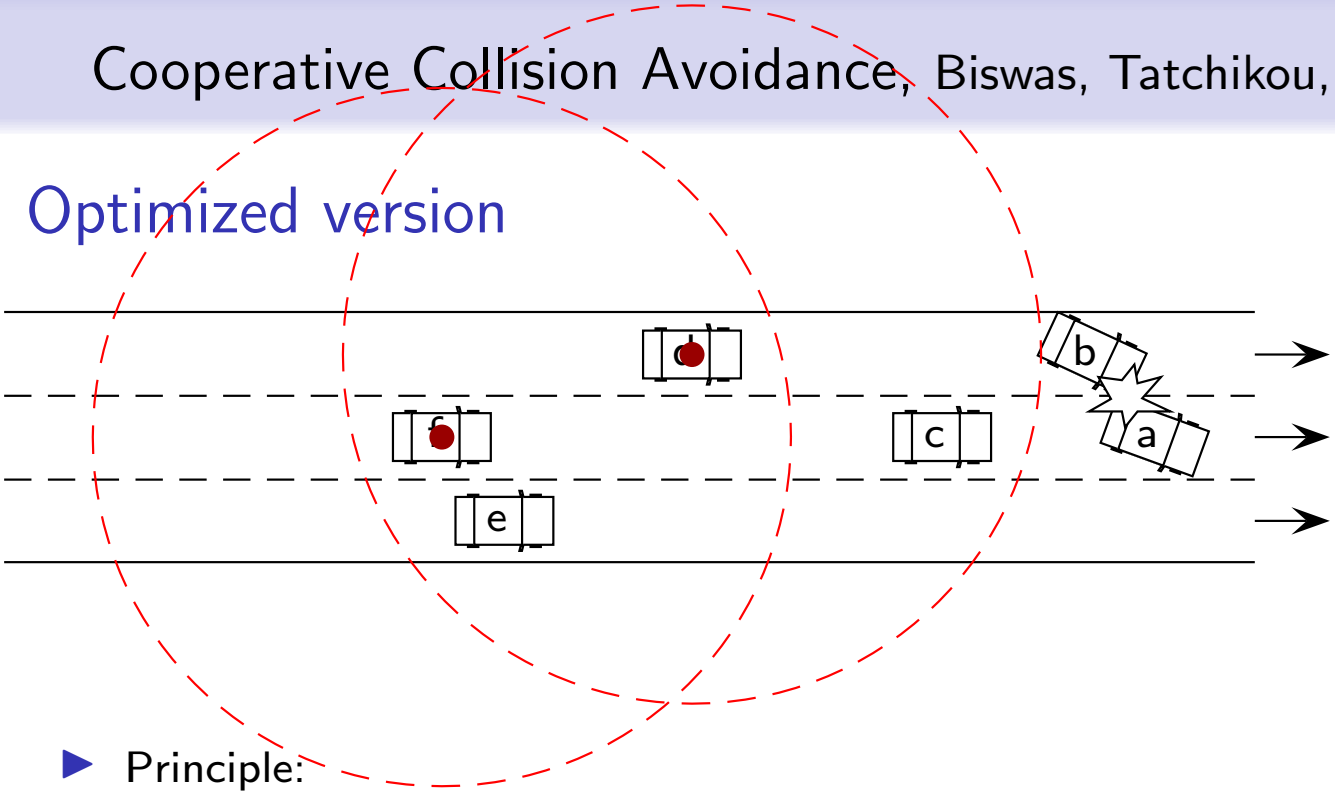

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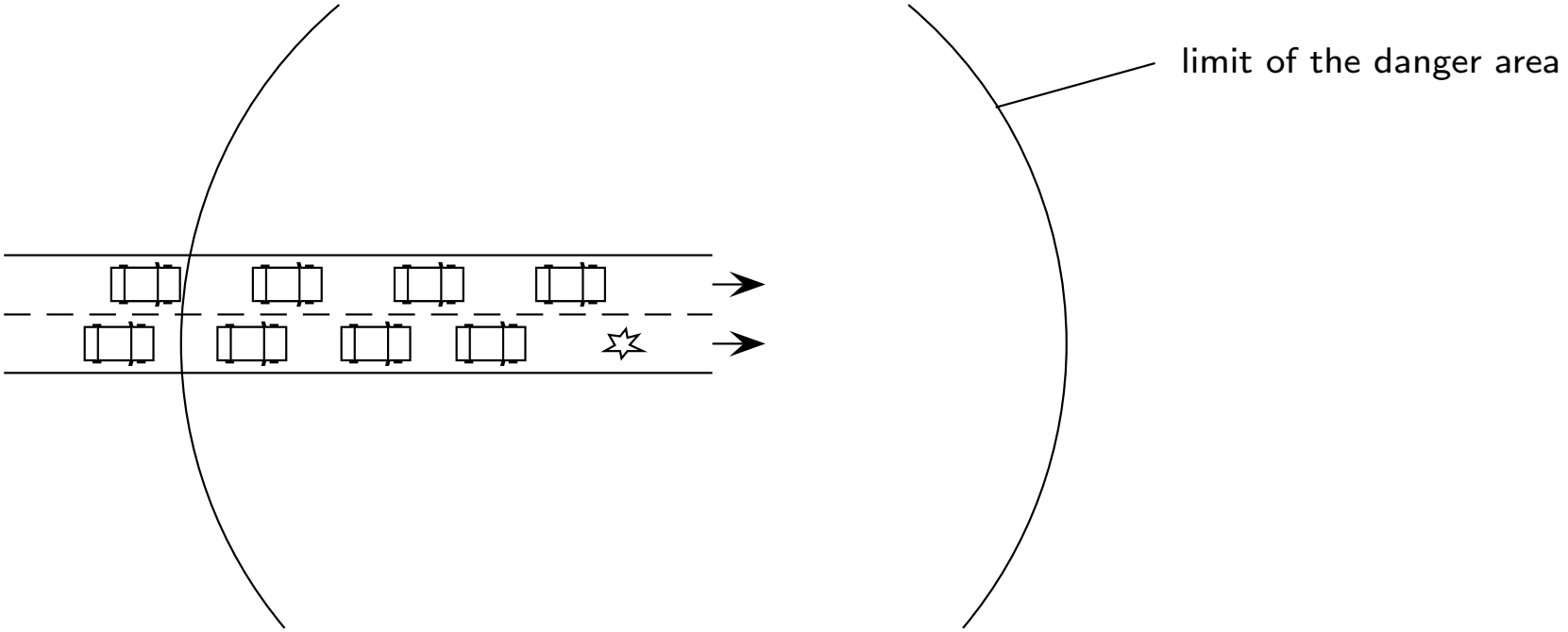

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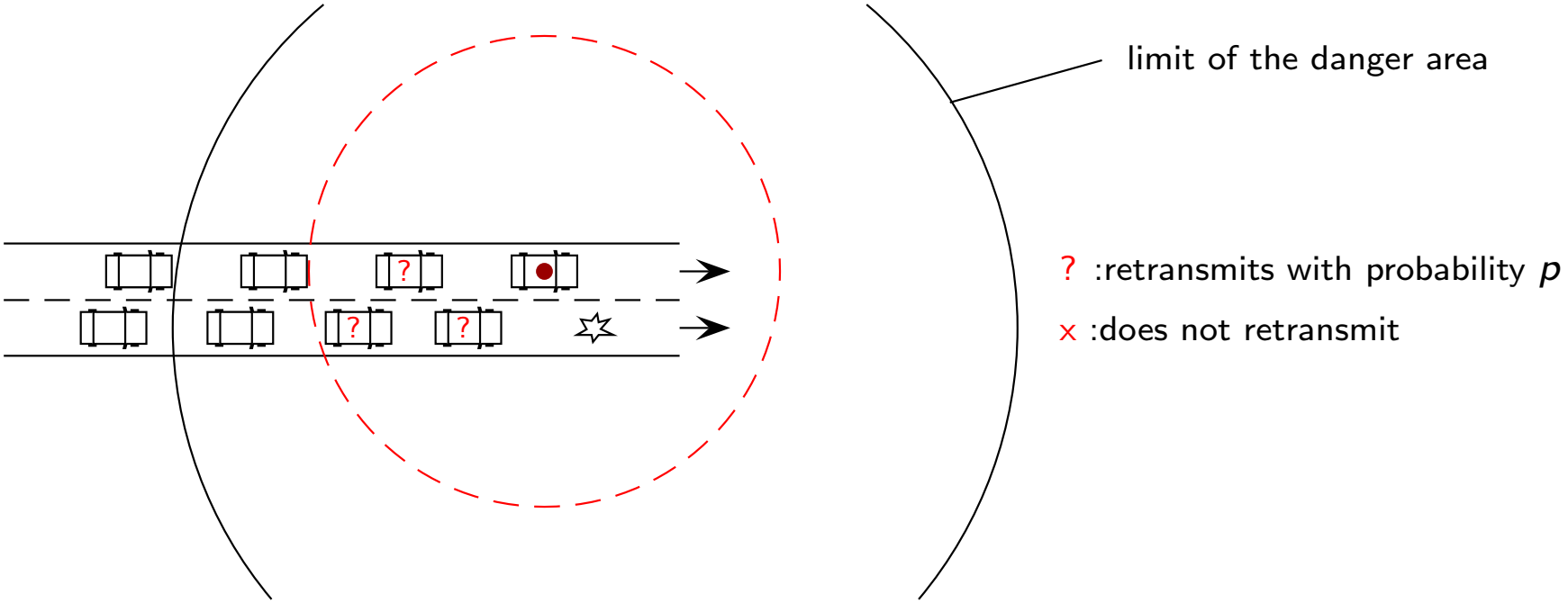

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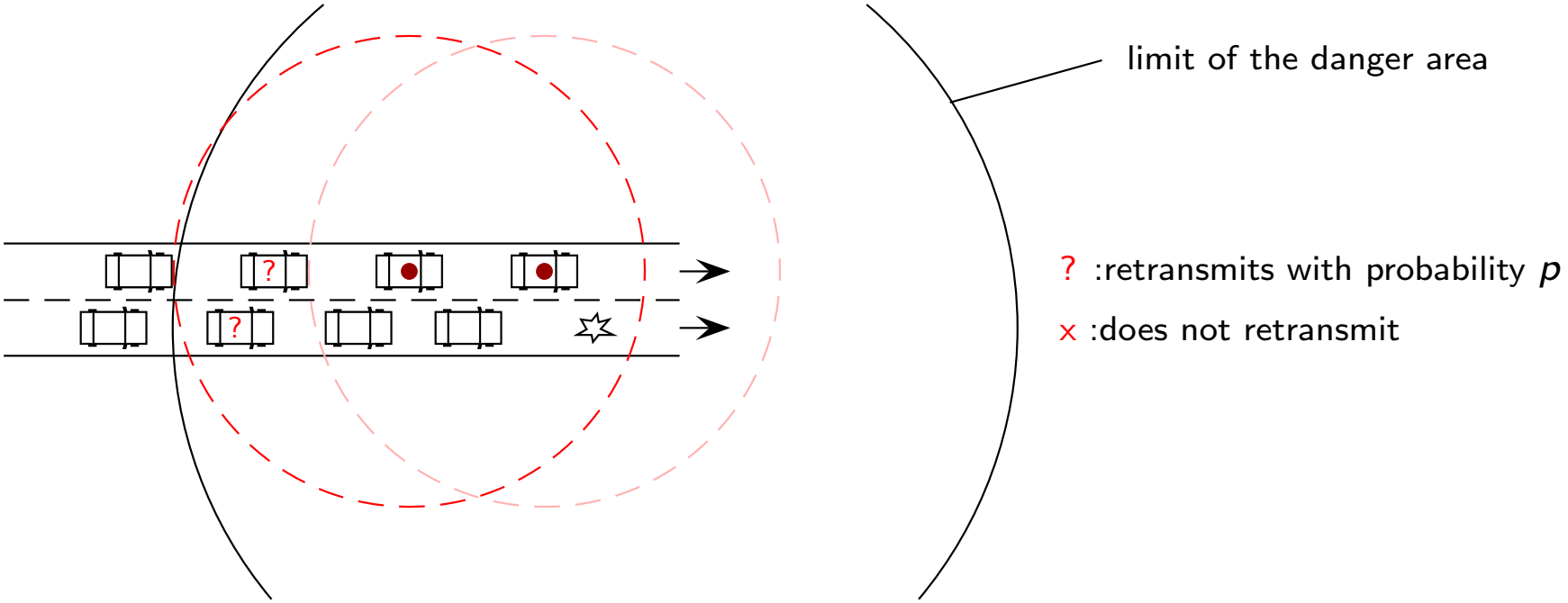

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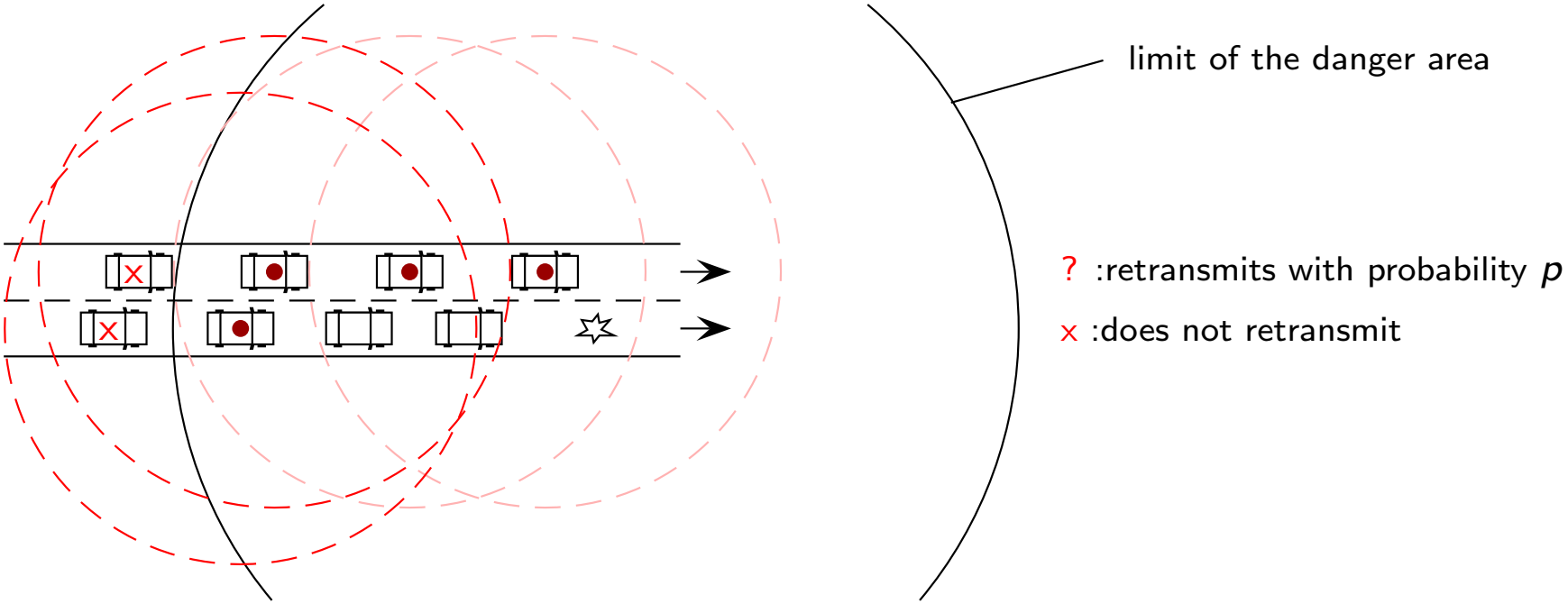

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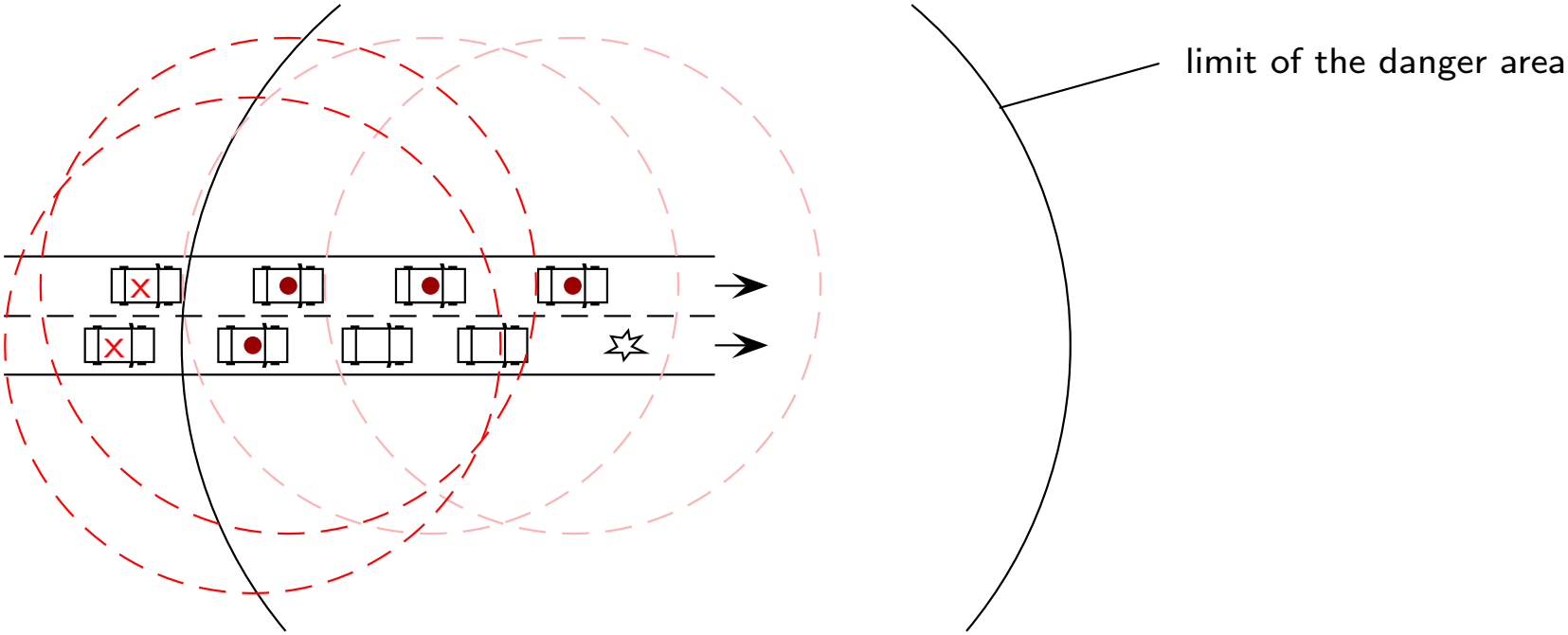

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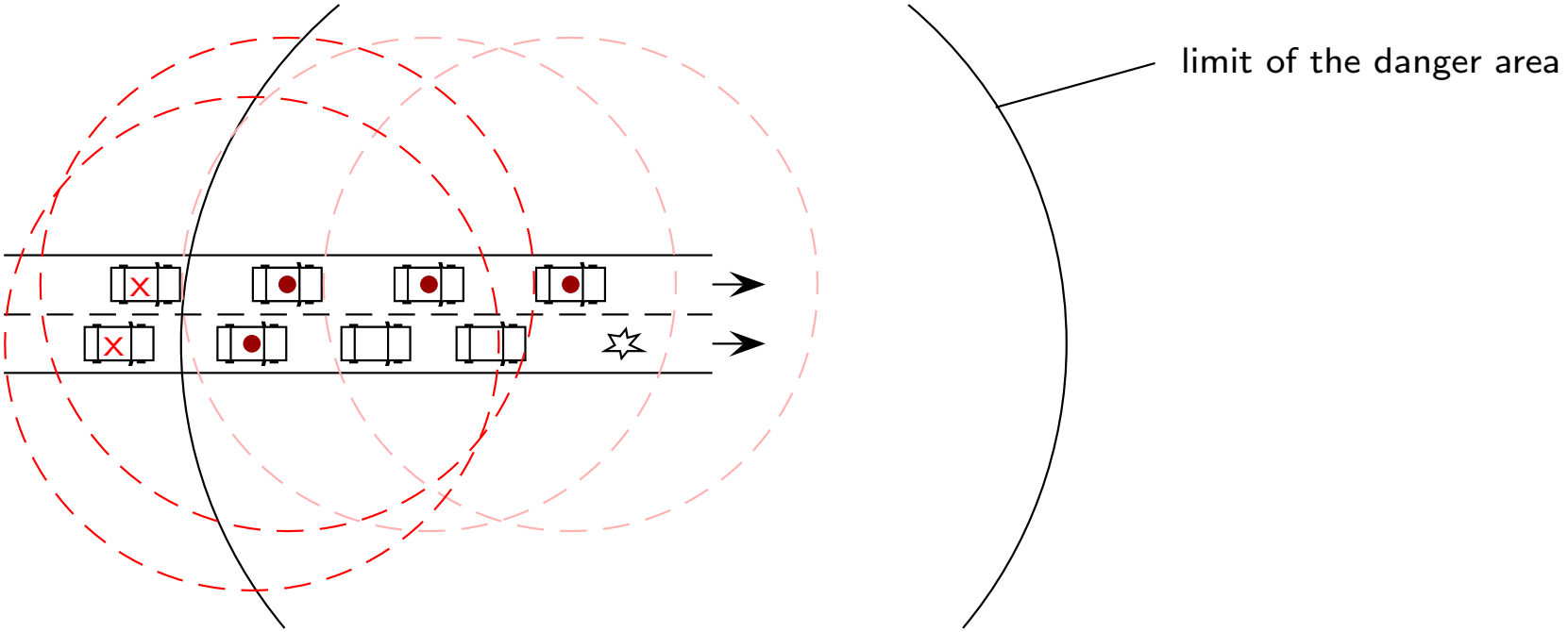

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  - probabilities $\Rightarrow$ no guarantee !

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

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- Other general assumptions (next slide)

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- A1-Fixed geographic location
- A2-Moving vehicle with known and updated location
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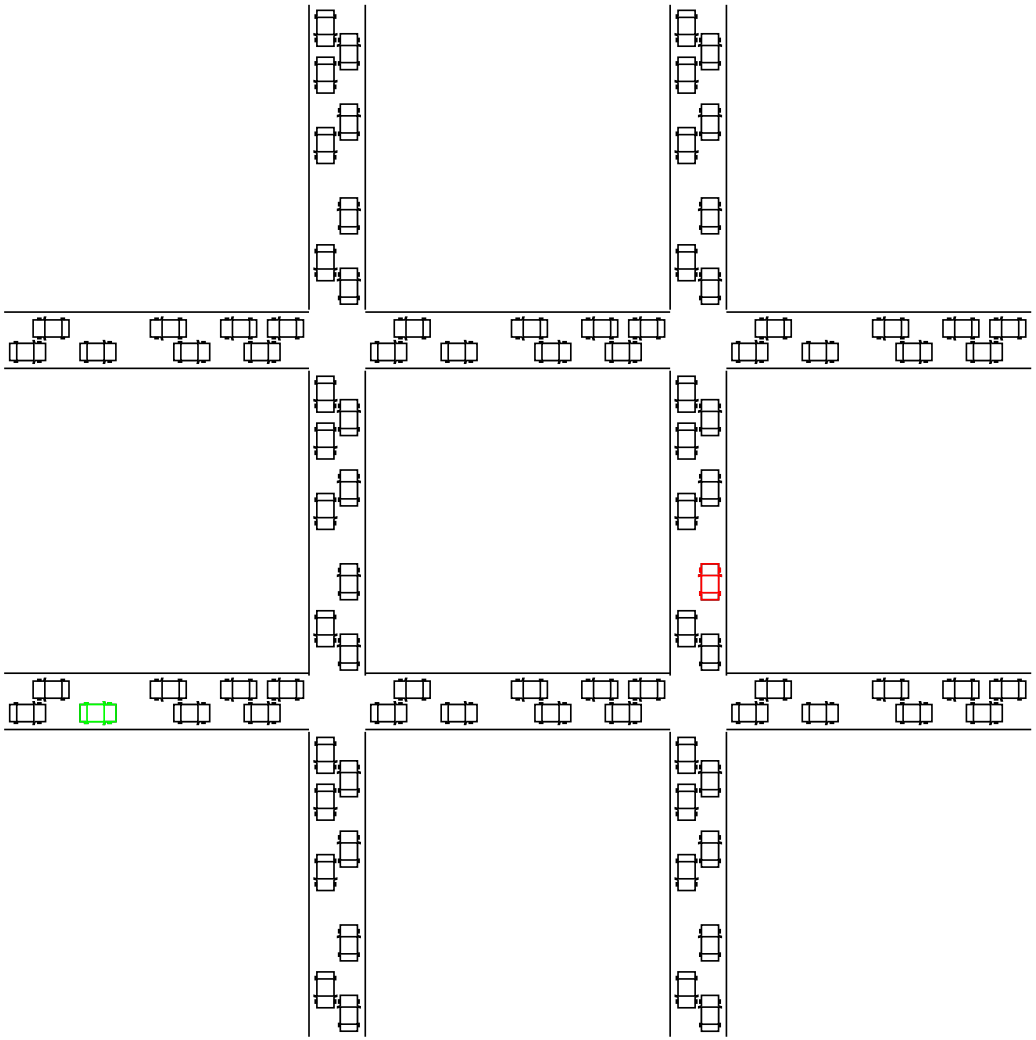
Network connectivity?

- 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]



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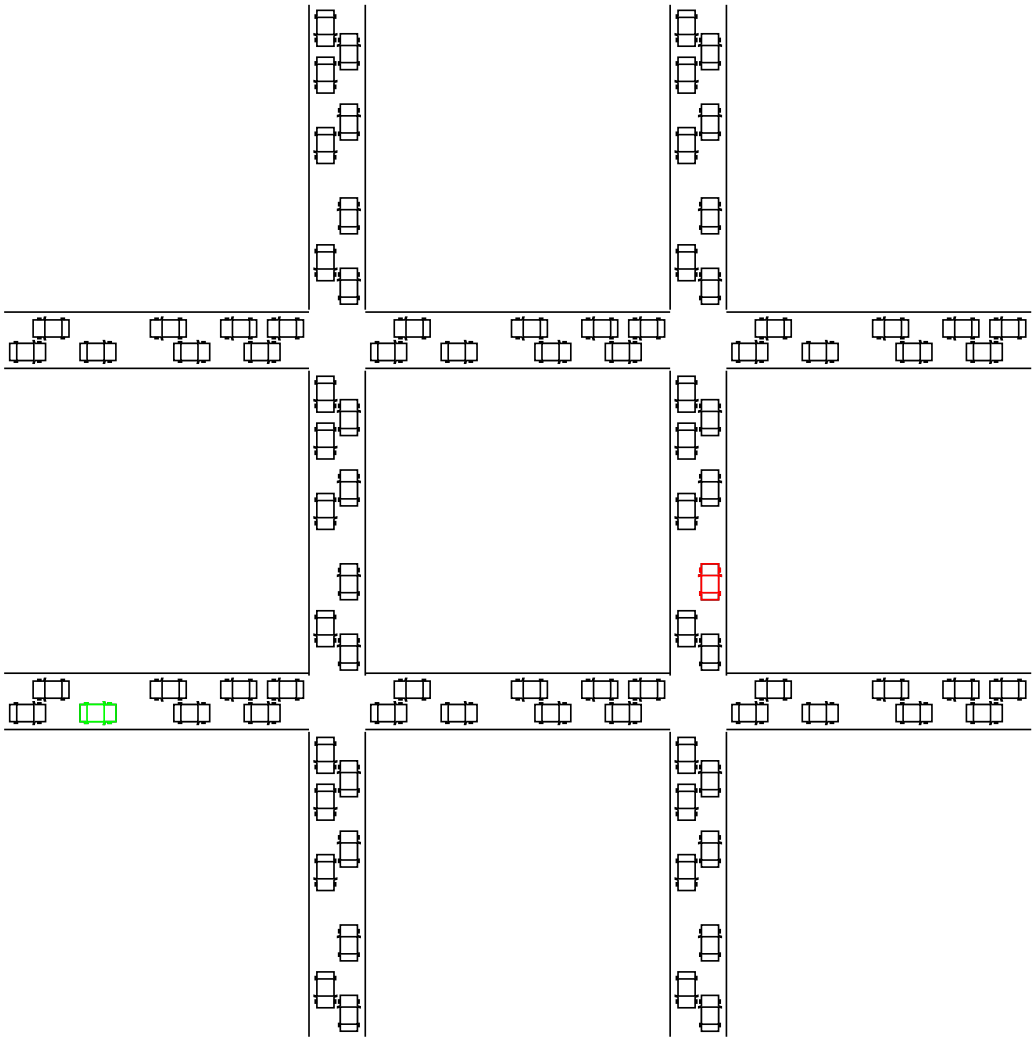

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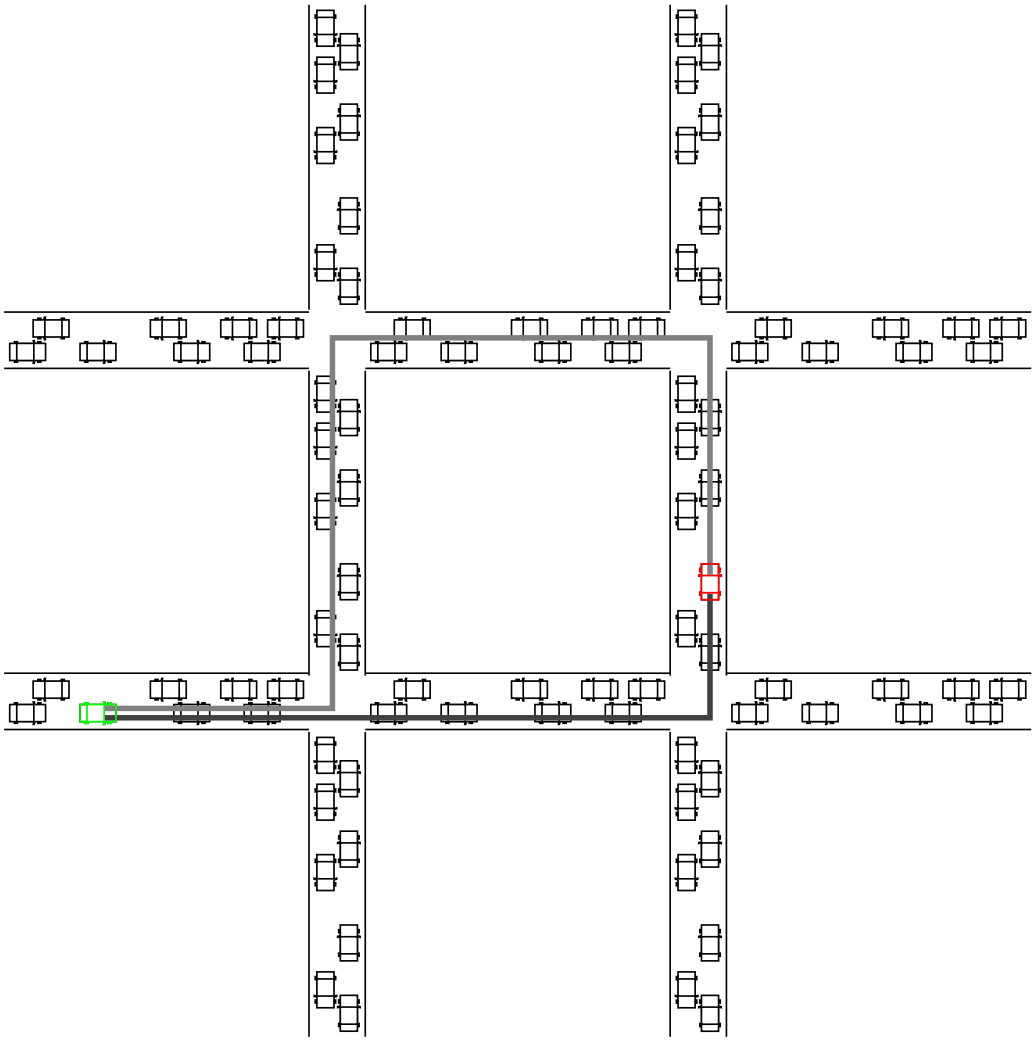

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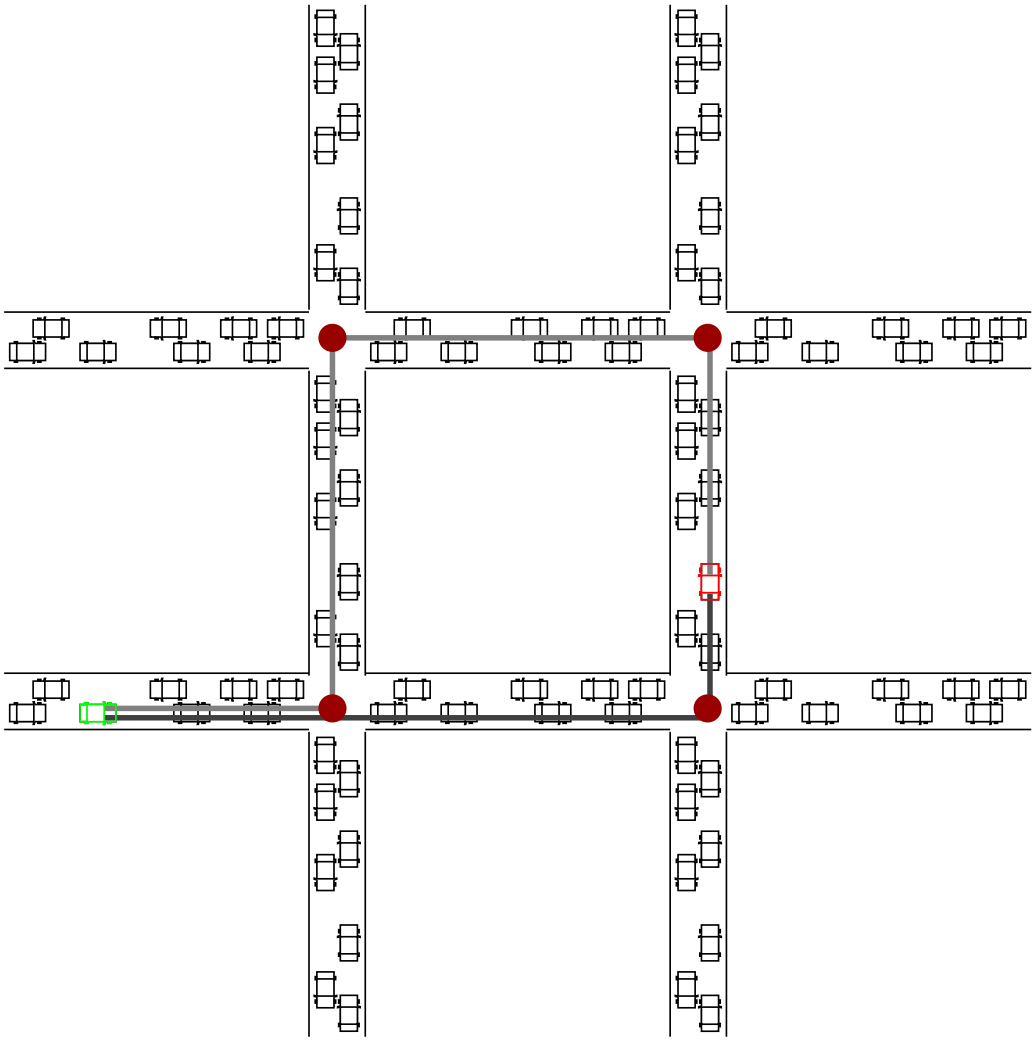

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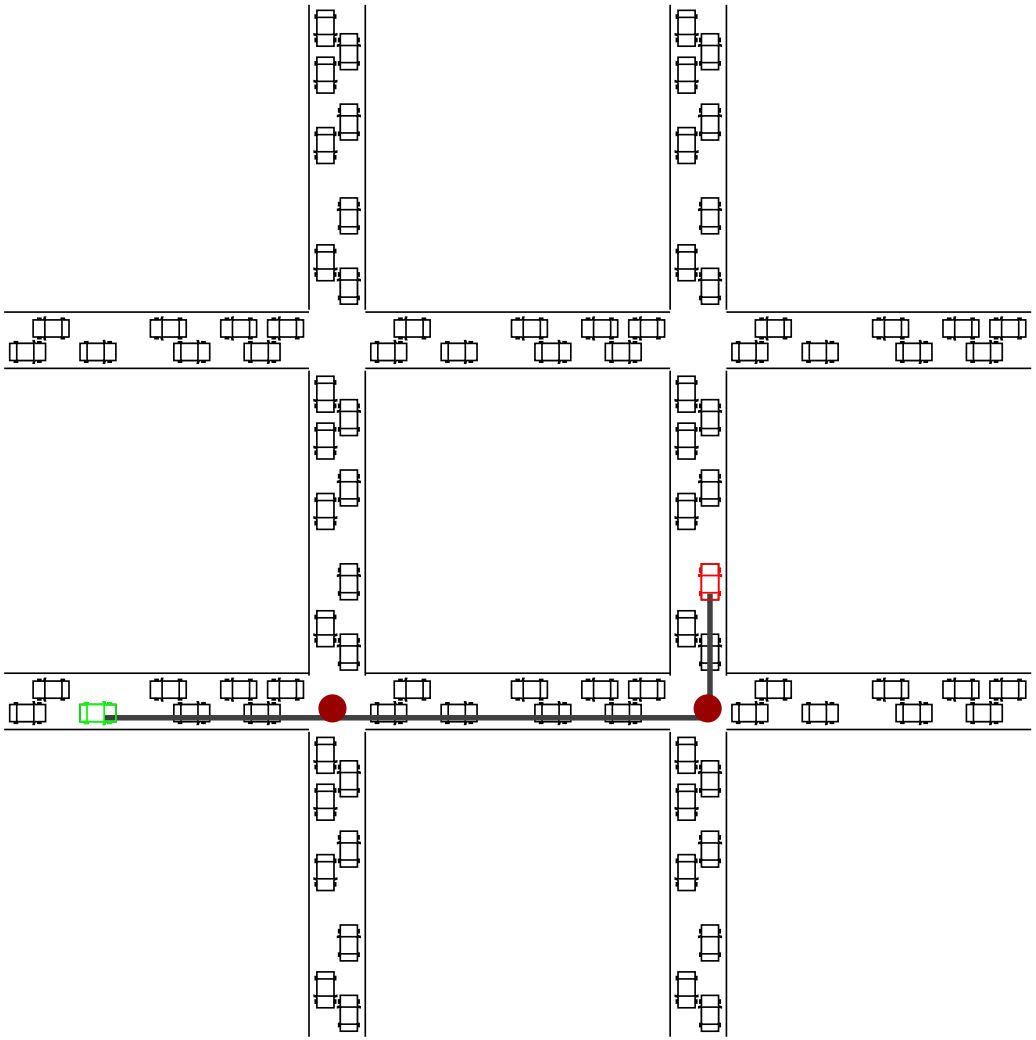

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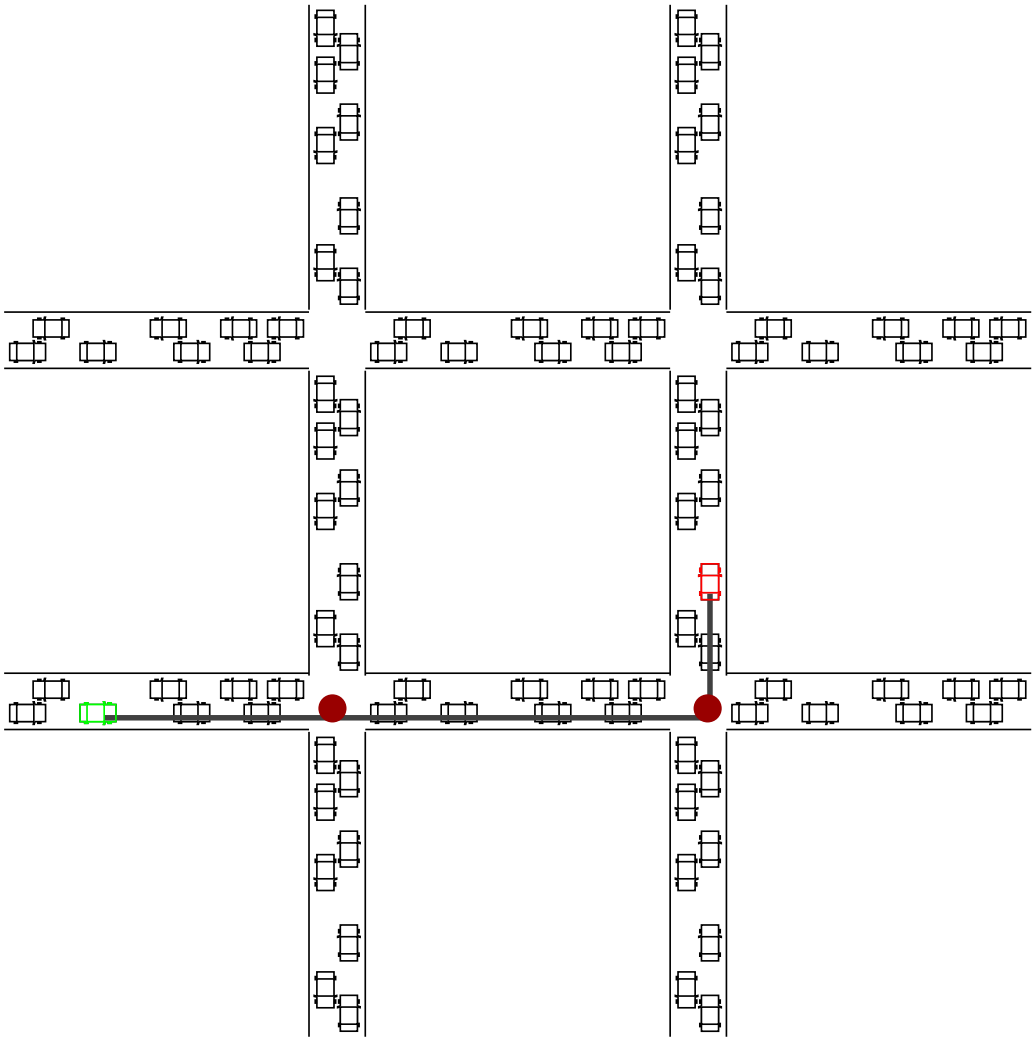

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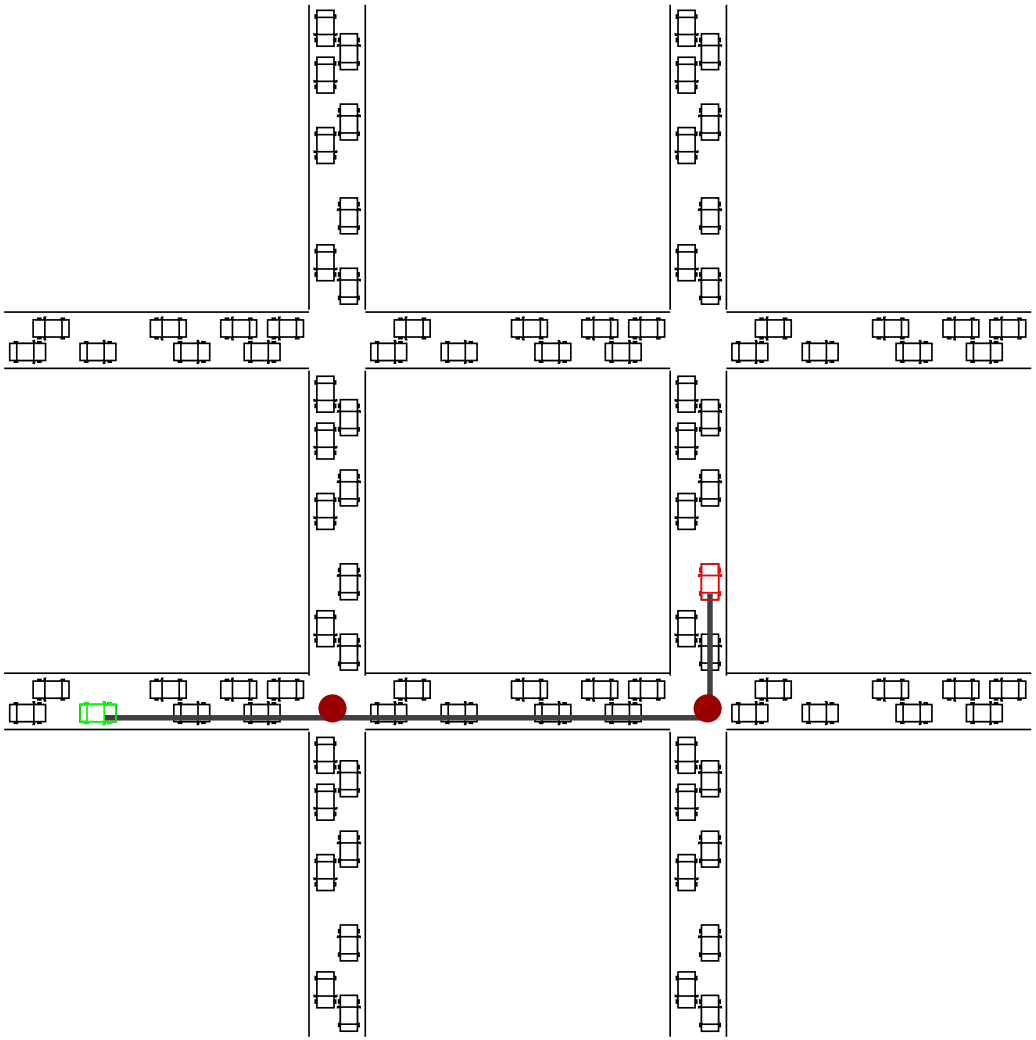

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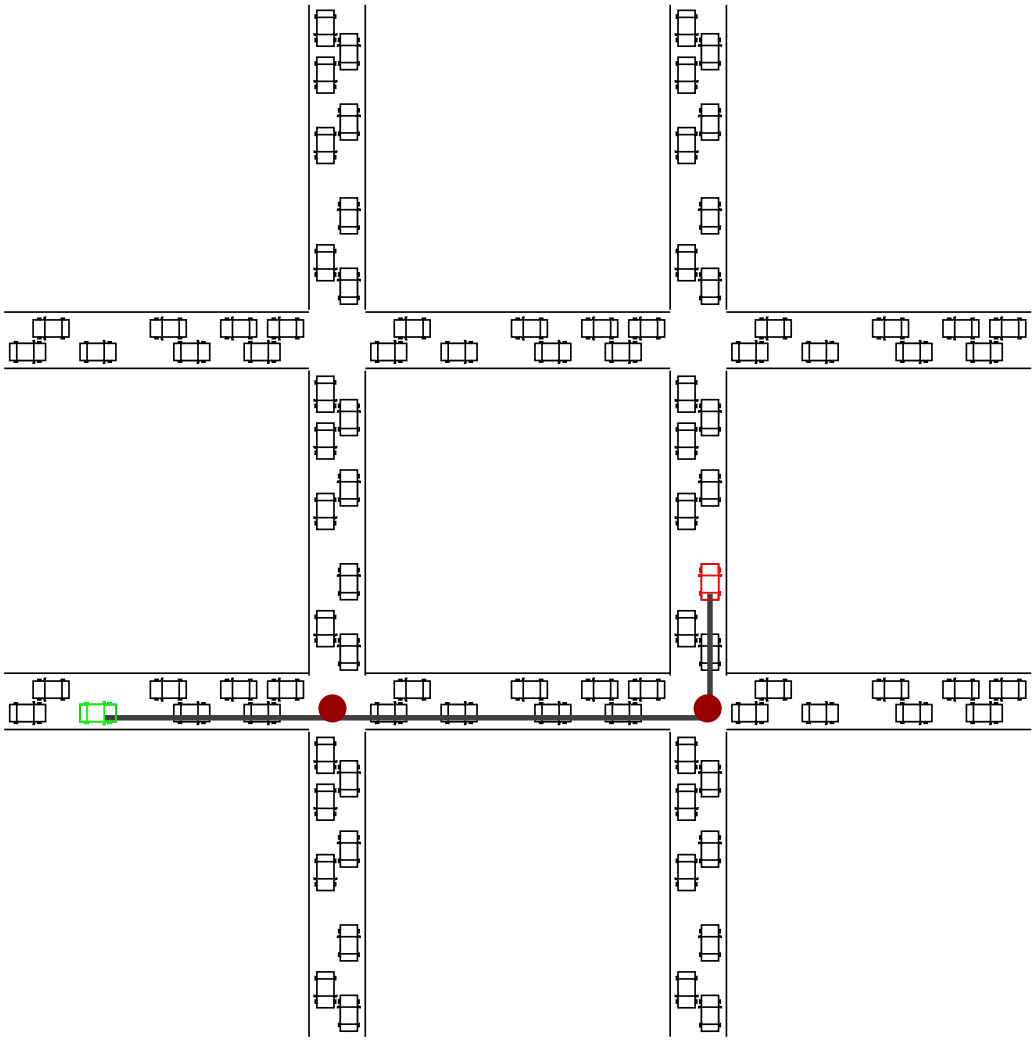

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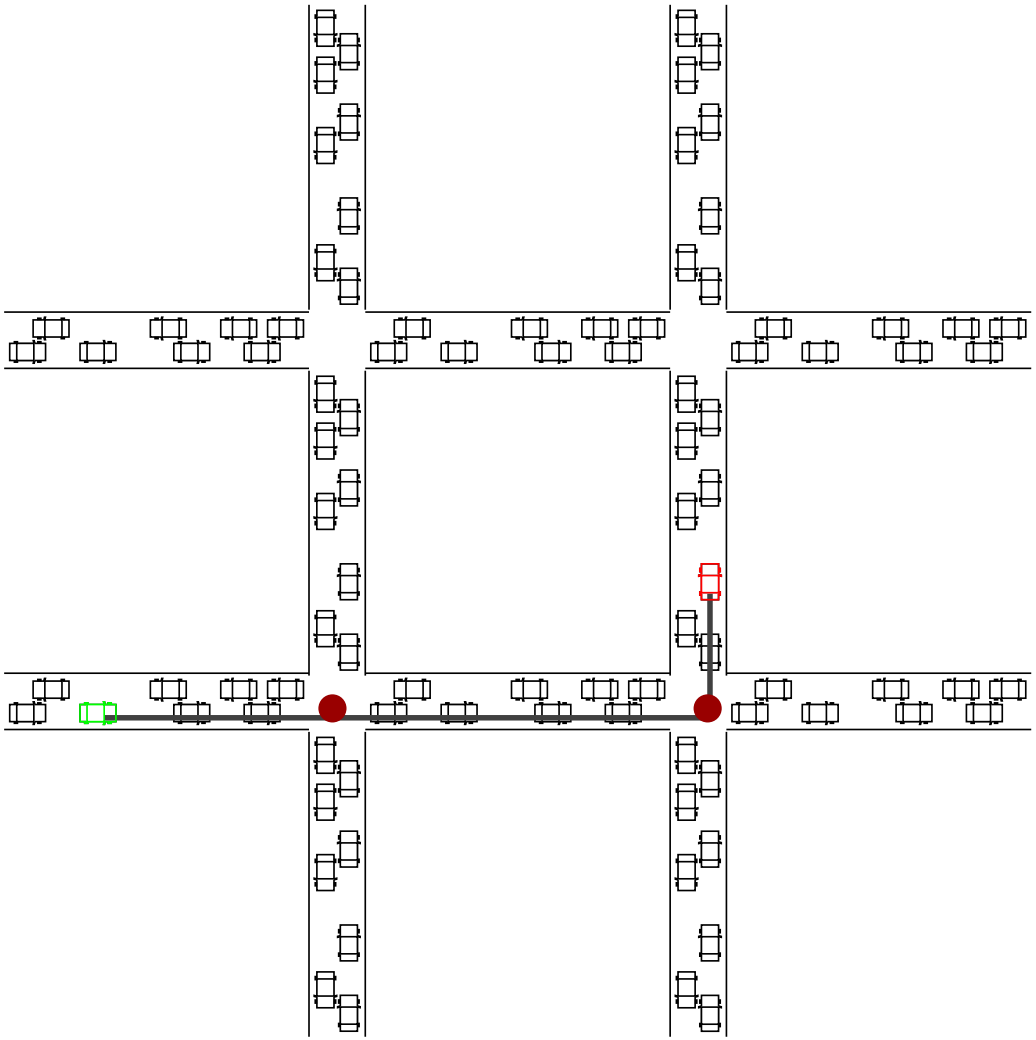

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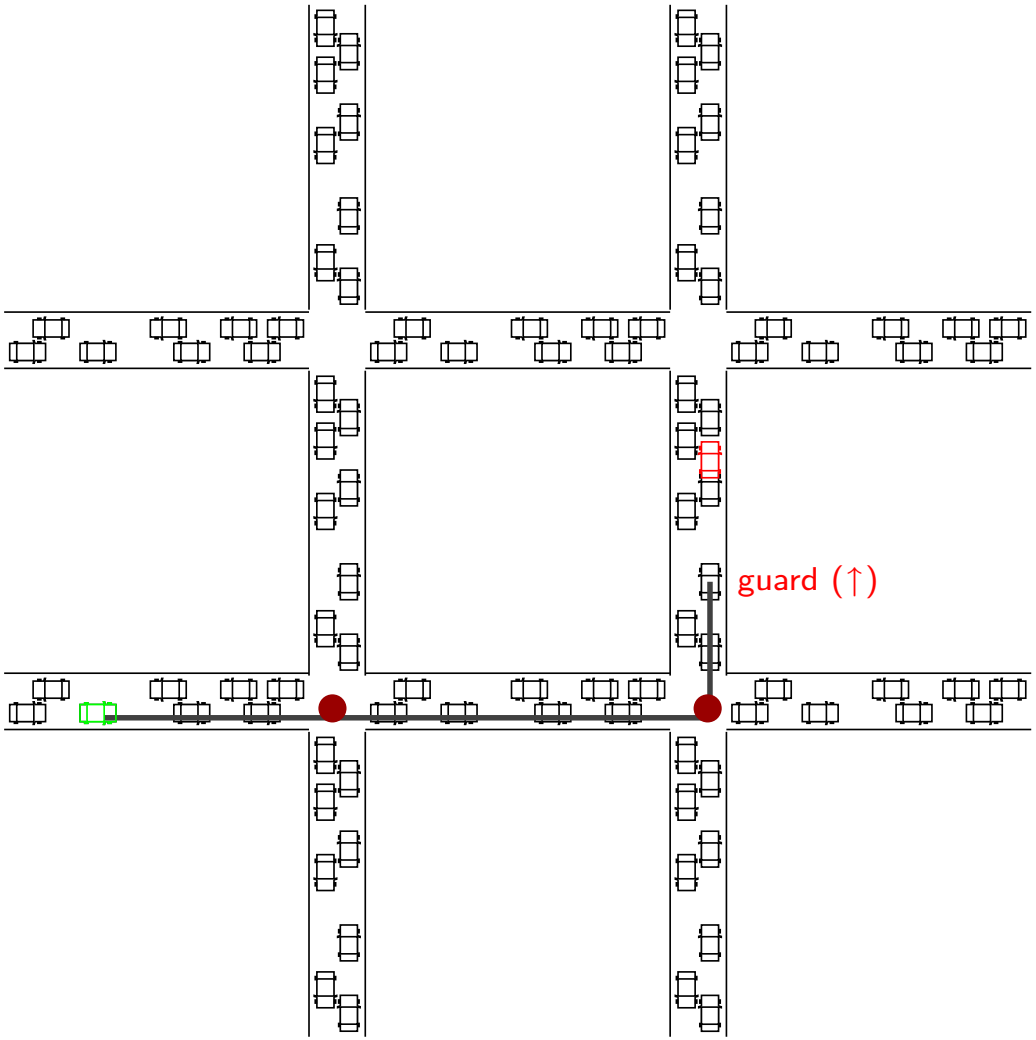

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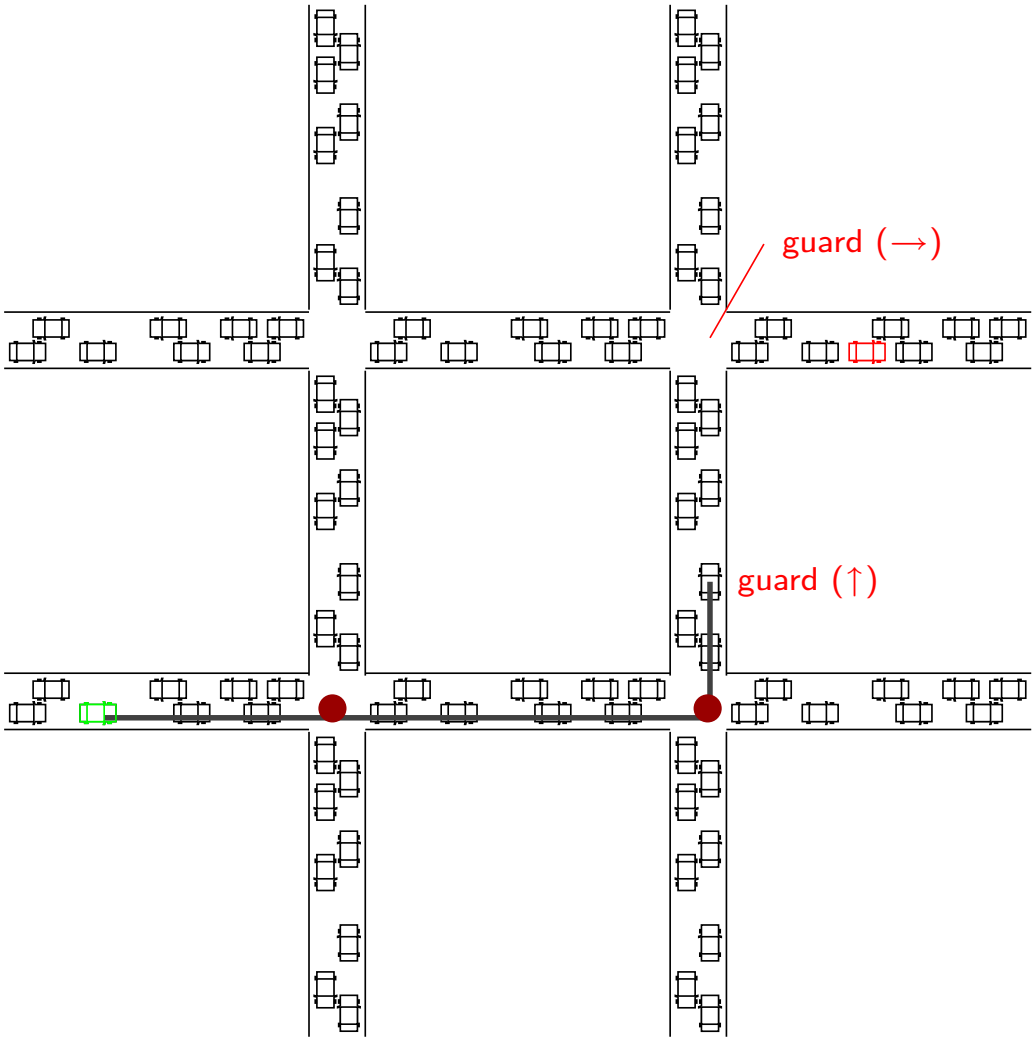

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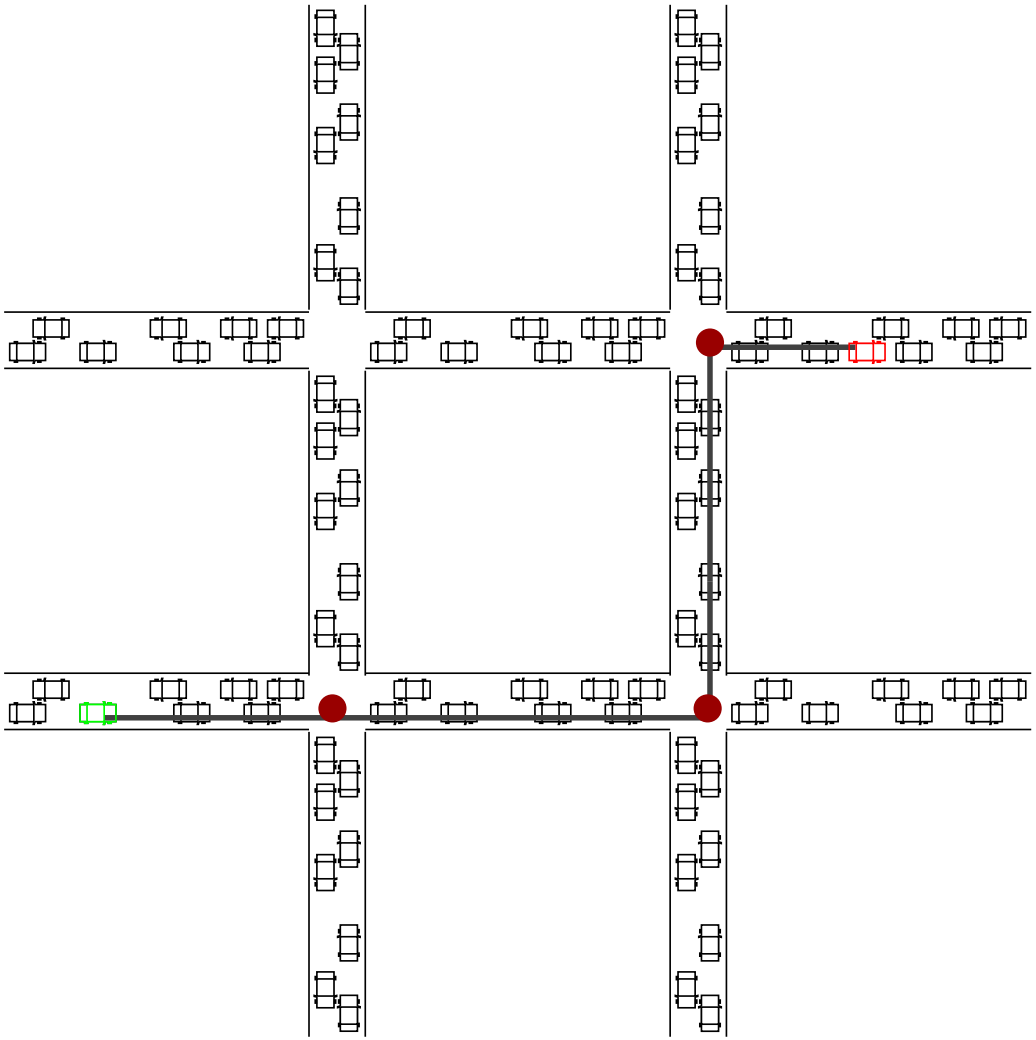

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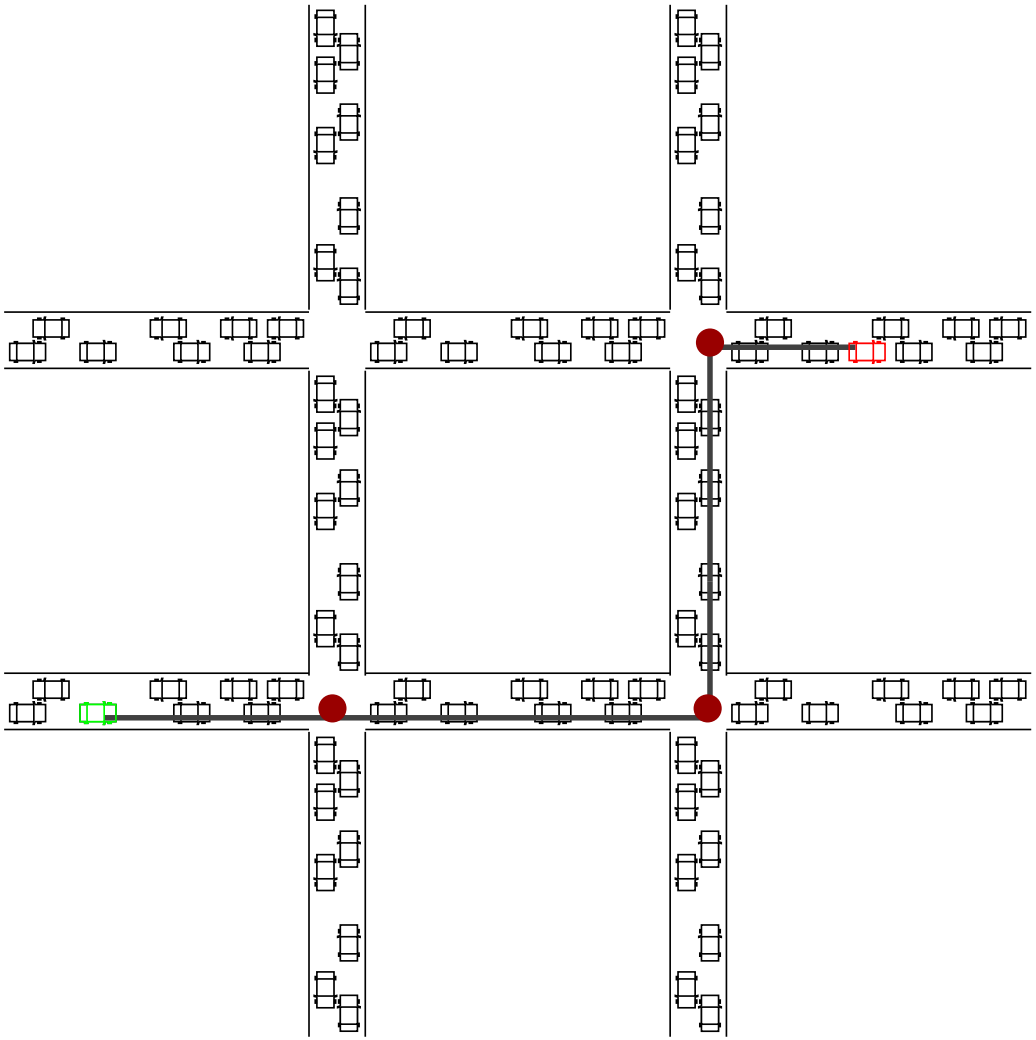

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Drawback

- 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)
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- Limits message speed to vehicle speeds

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

Incoming clusters to bridge connectivity gaps

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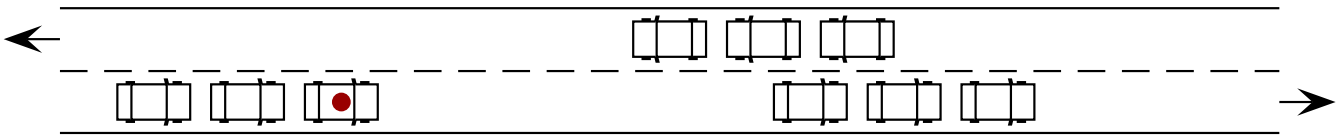

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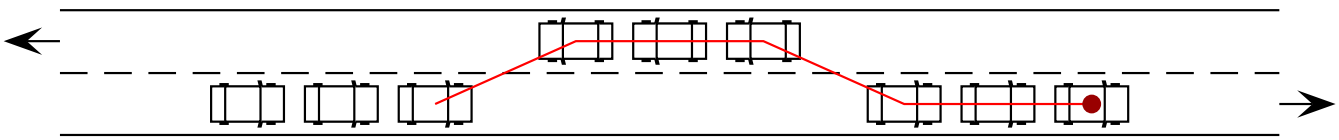

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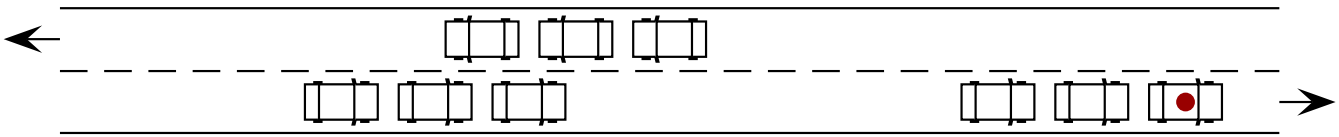

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Highway Scenario - Wisitpongphan *et al.* [WBM+07]

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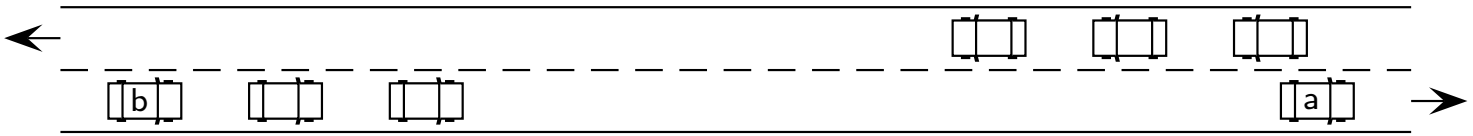

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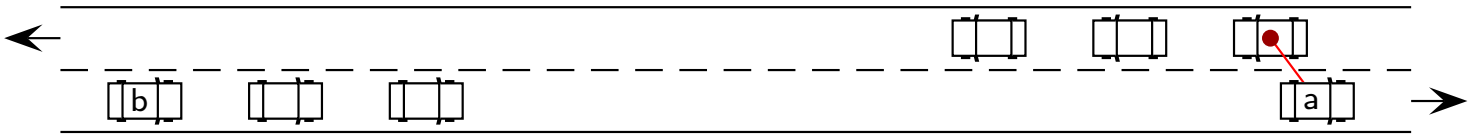

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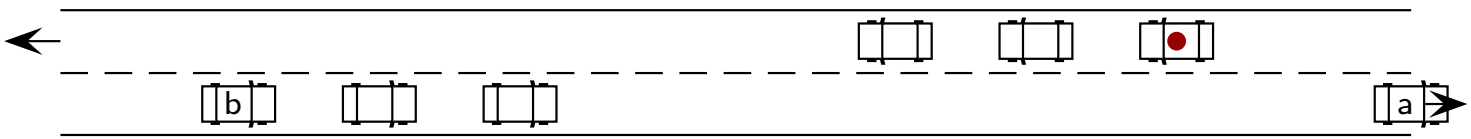

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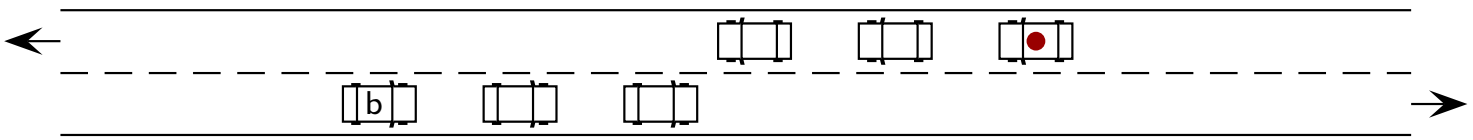

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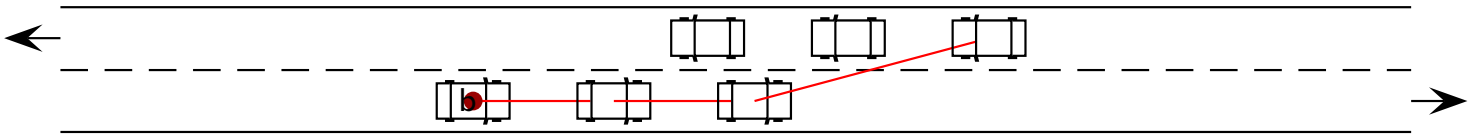

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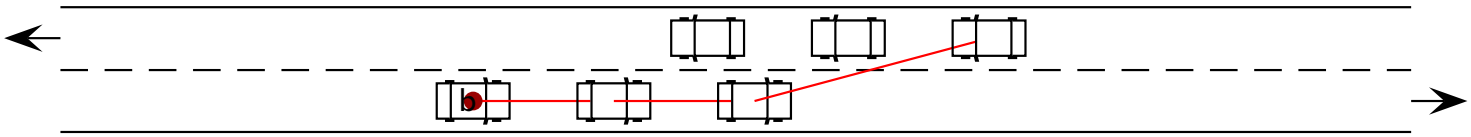

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Highway Scenario - Abuelela, Olariu & Stojmenovic [AOS08]

Incoming clusters to carry and route optimally the message

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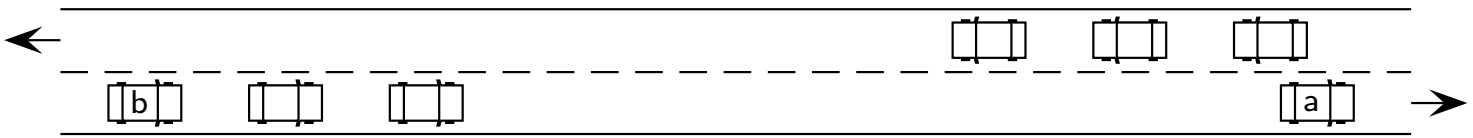

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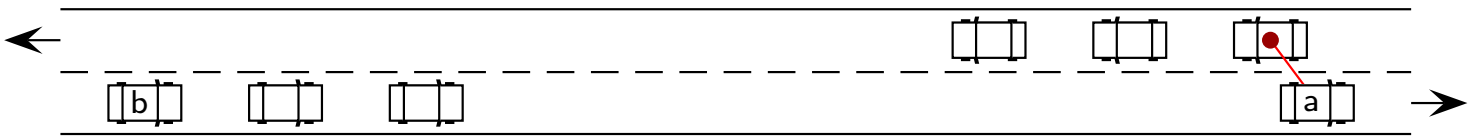

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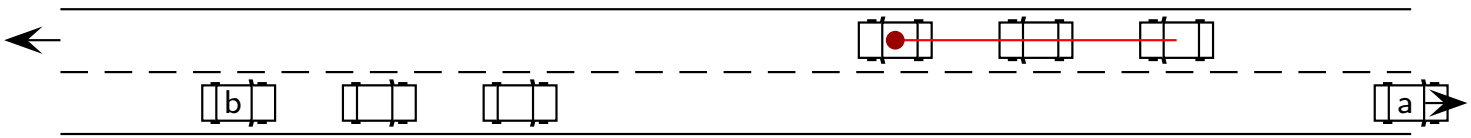

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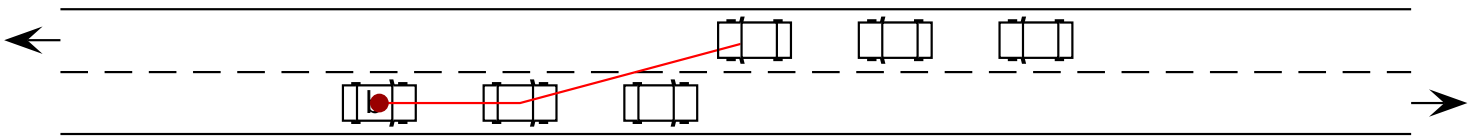

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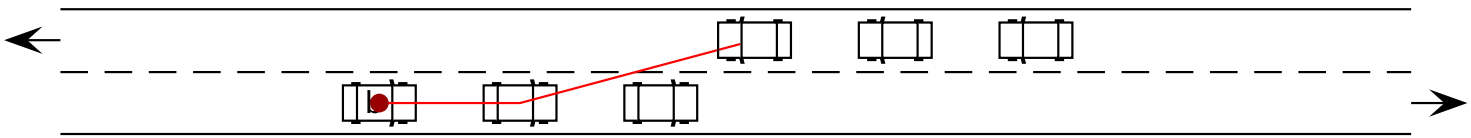

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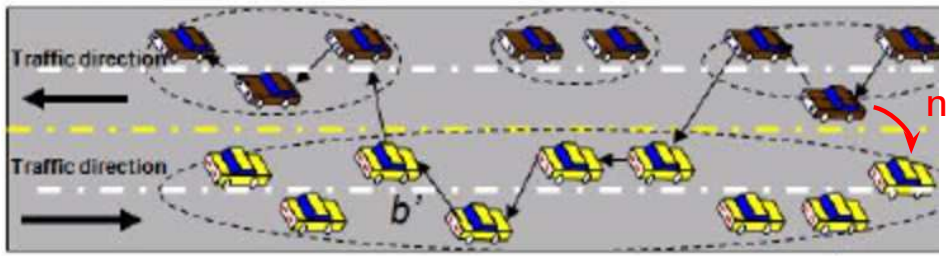

not used because not optimal.

Traffic optimization

Motivations

- Reduce traffic congestion

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  - Centralized (with route request)
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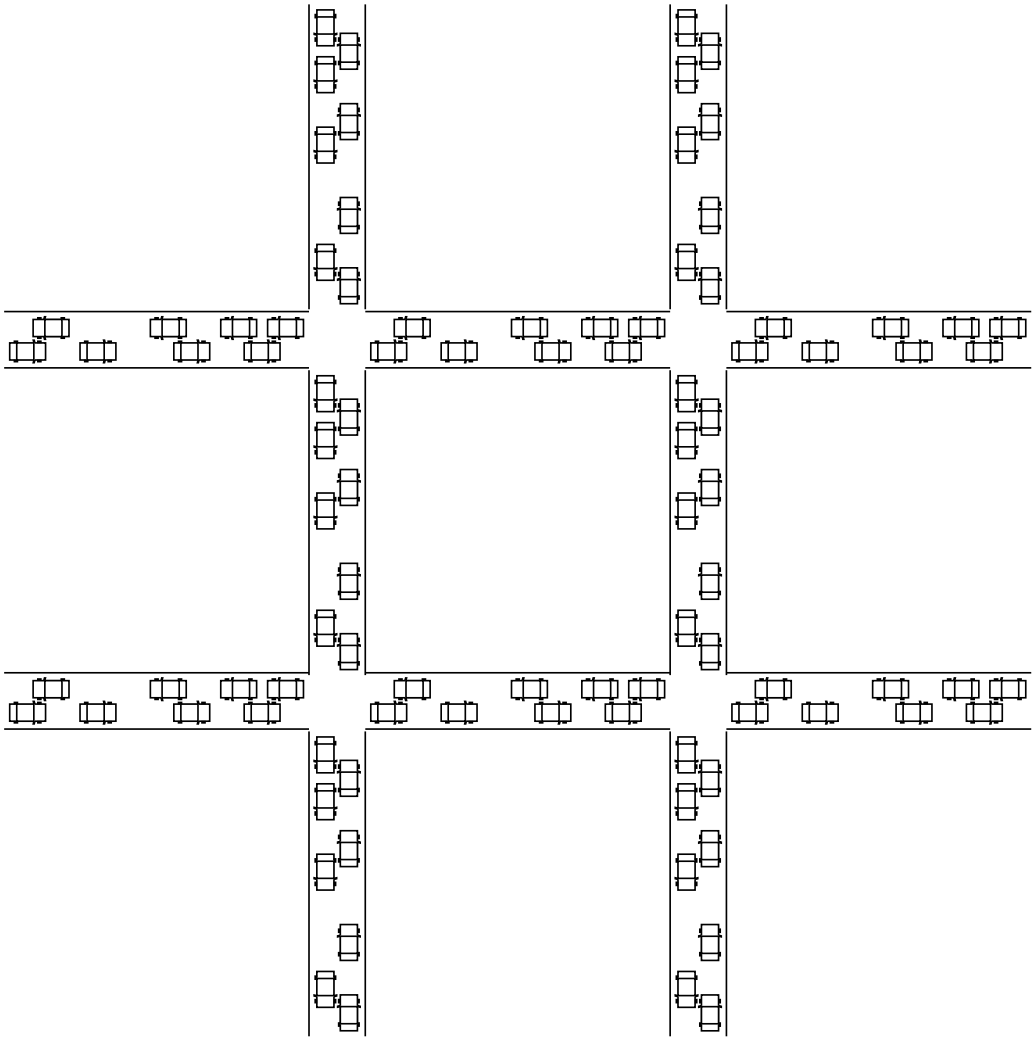
  - Quality of Travel (as QoS in communication networks)

Decentralized Traffic Management Systems

Dissemination of Traffic Information



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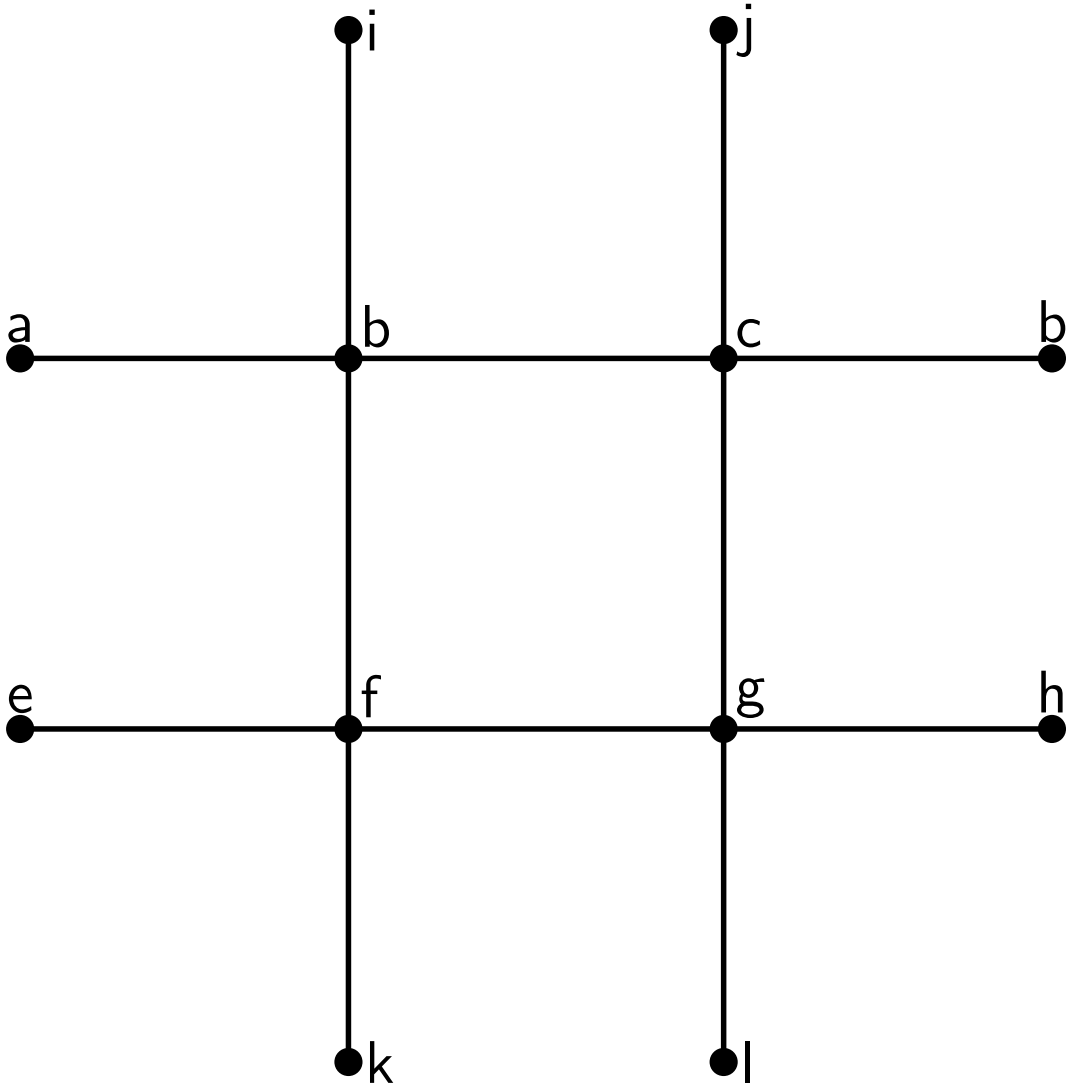

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- Edge weight initialized with trunk lengths

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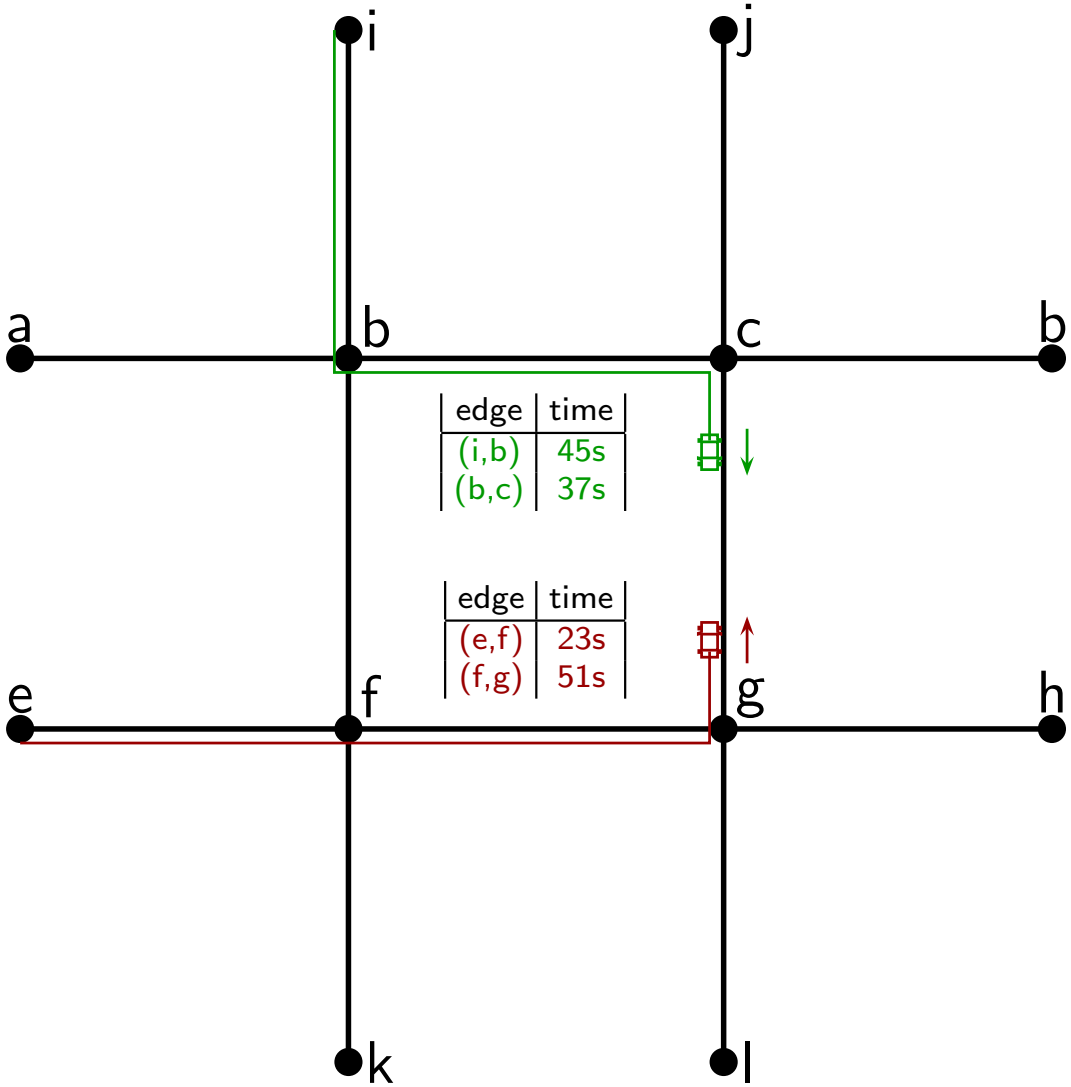

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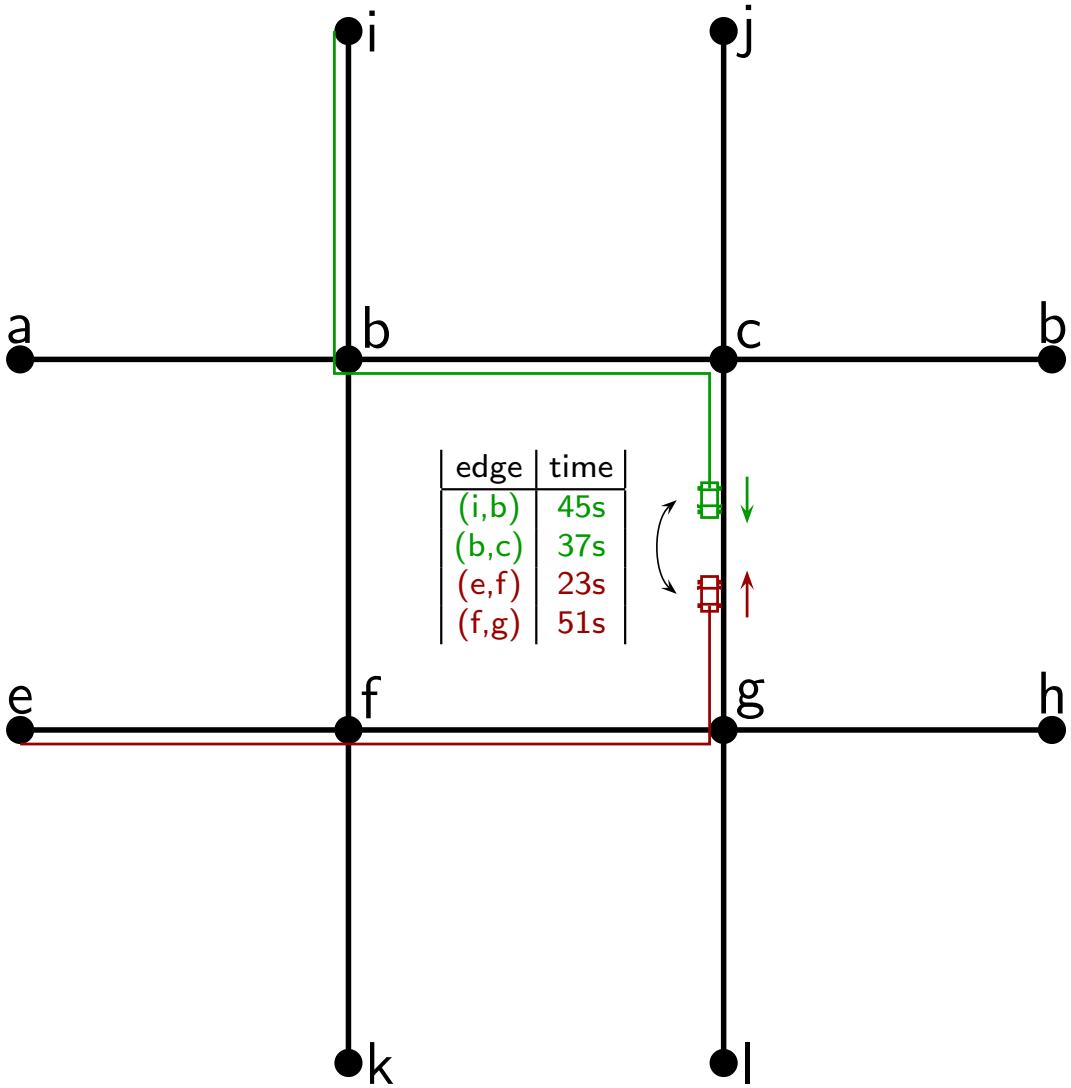

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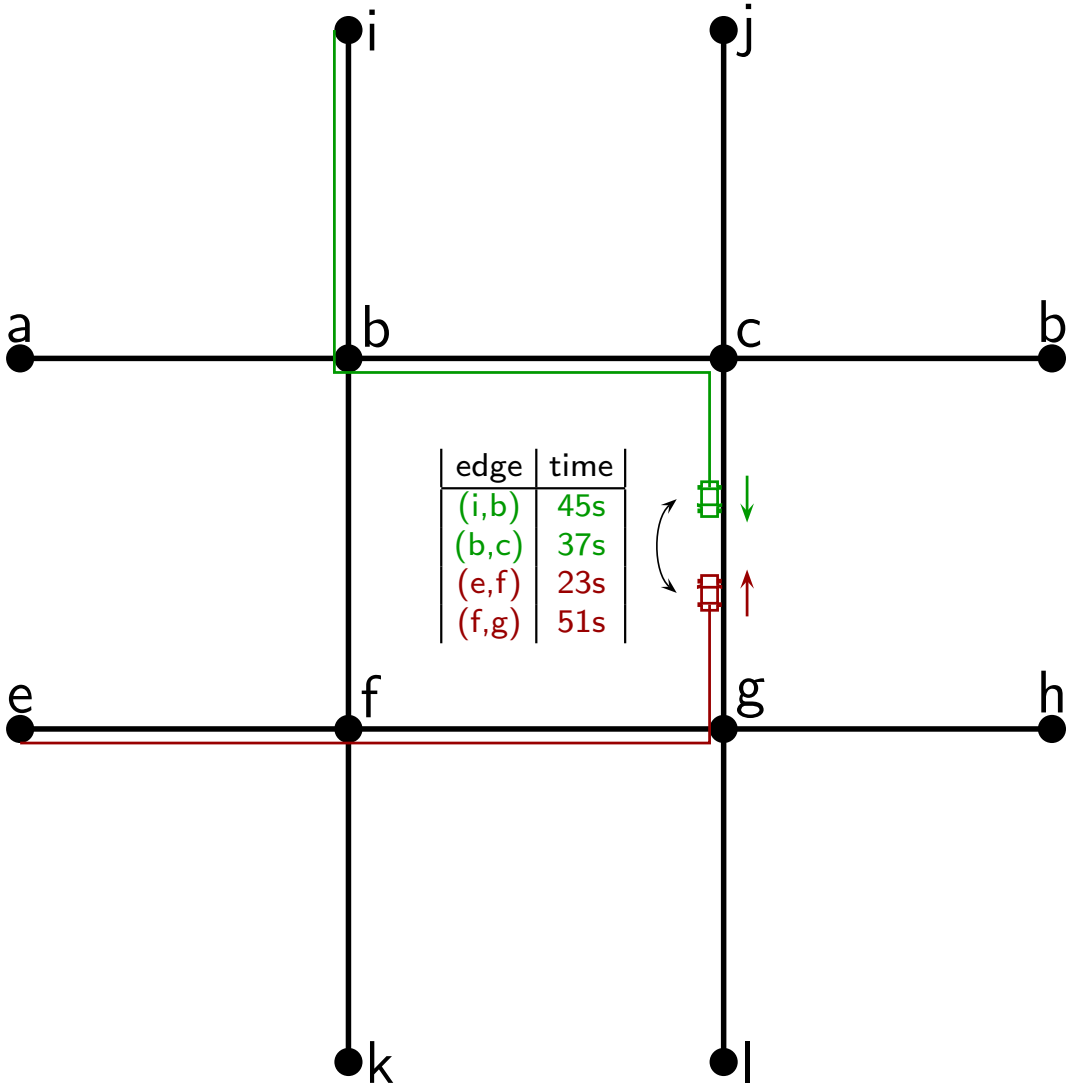

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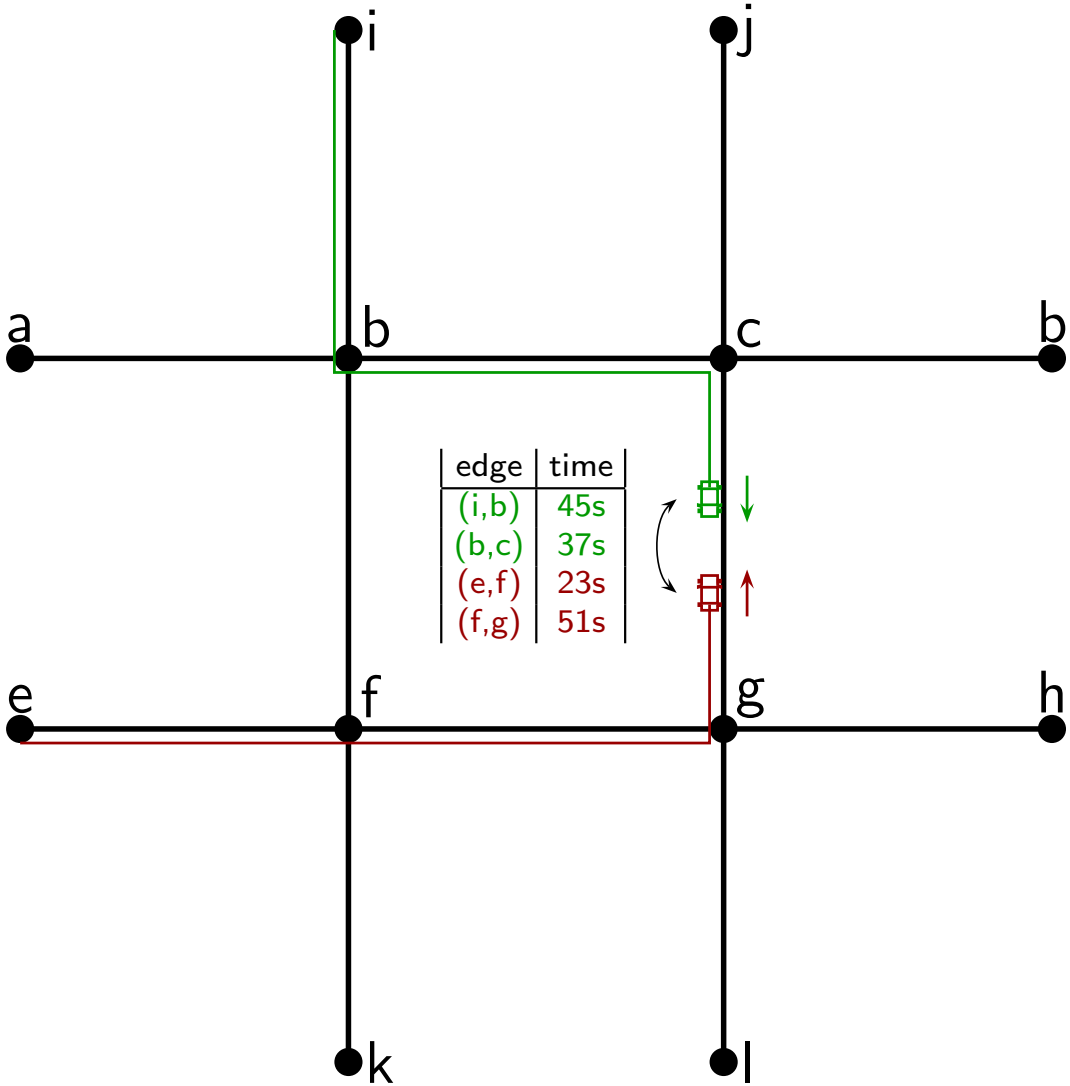

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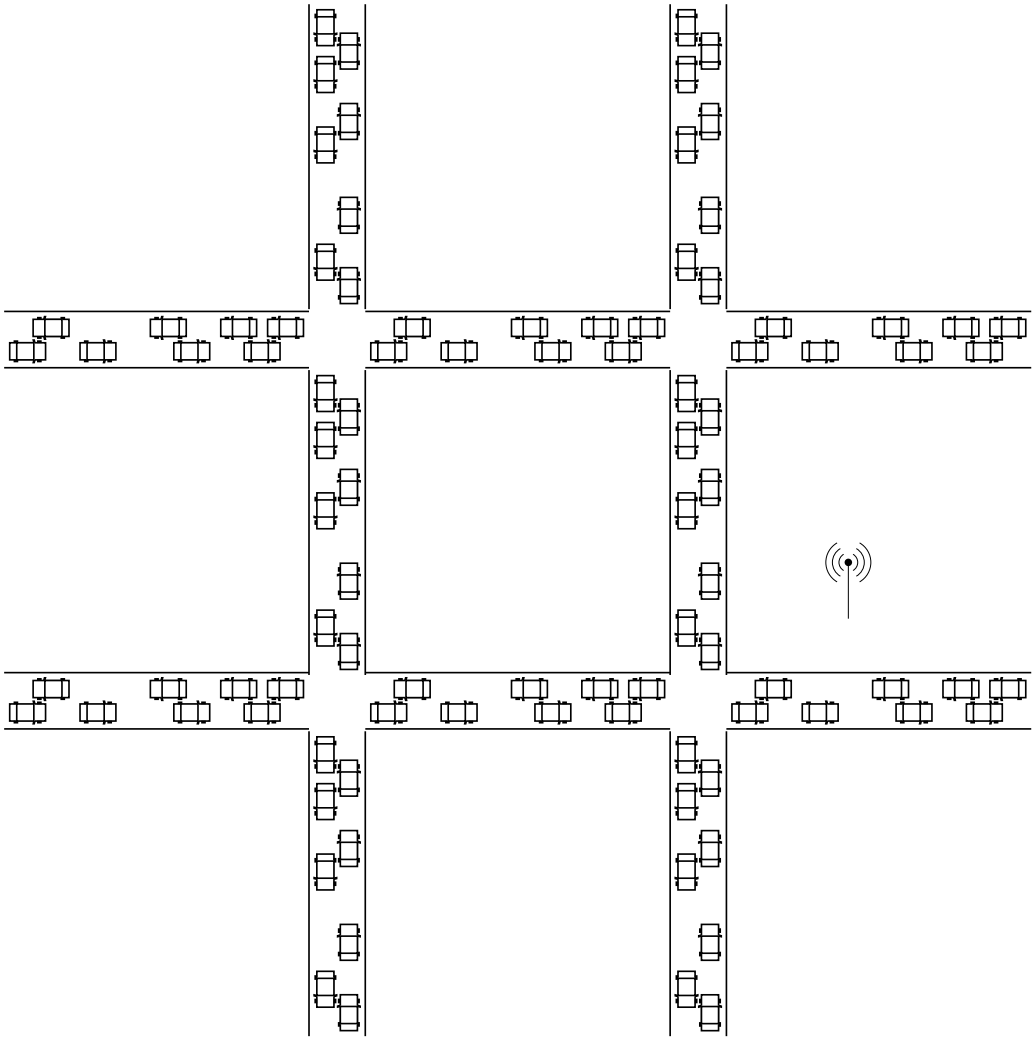
Some other papers

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

Centralized Traffic Regulation Systems

Shortest path in time-varying weighted graph



Traffic Center

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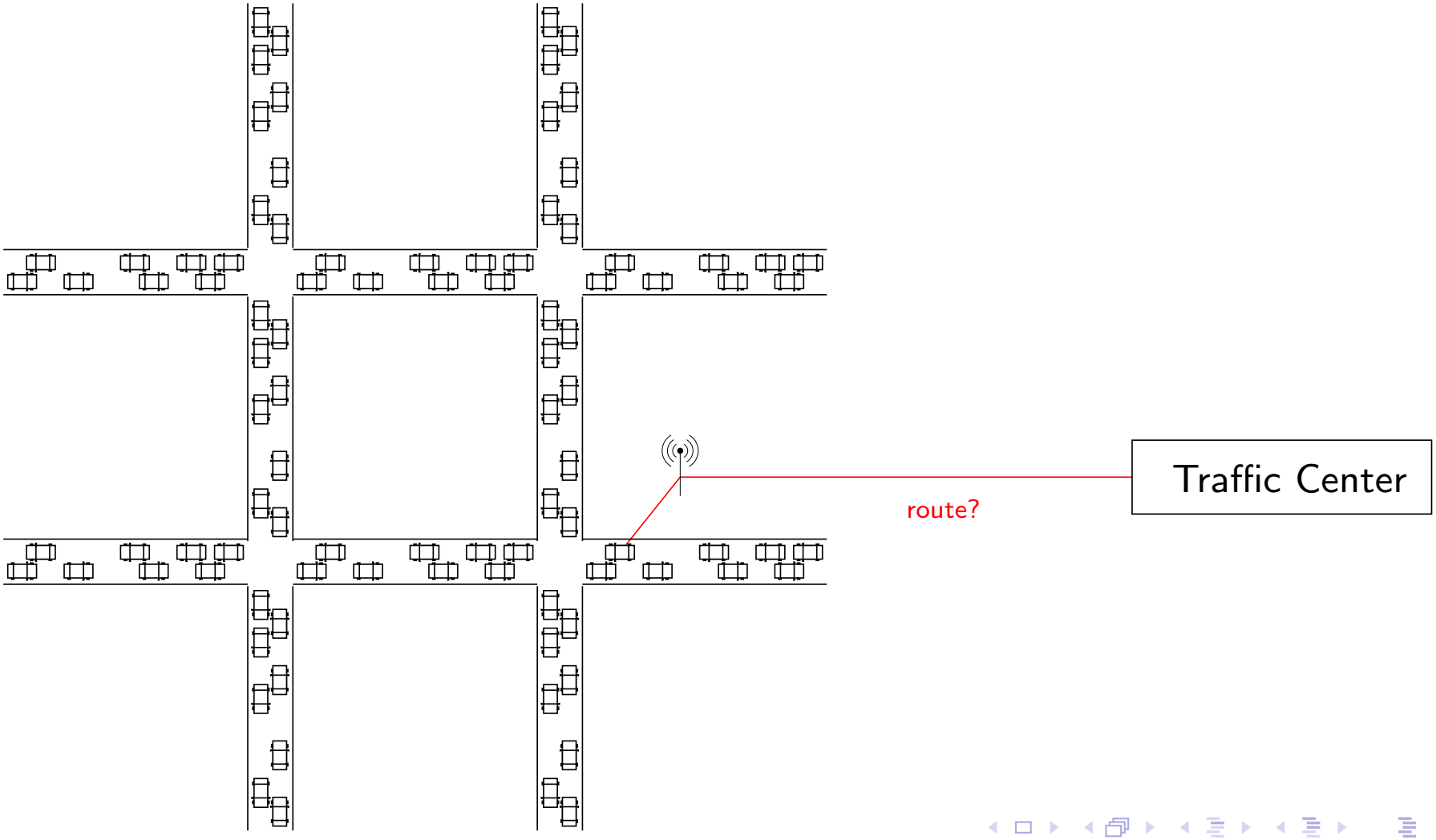

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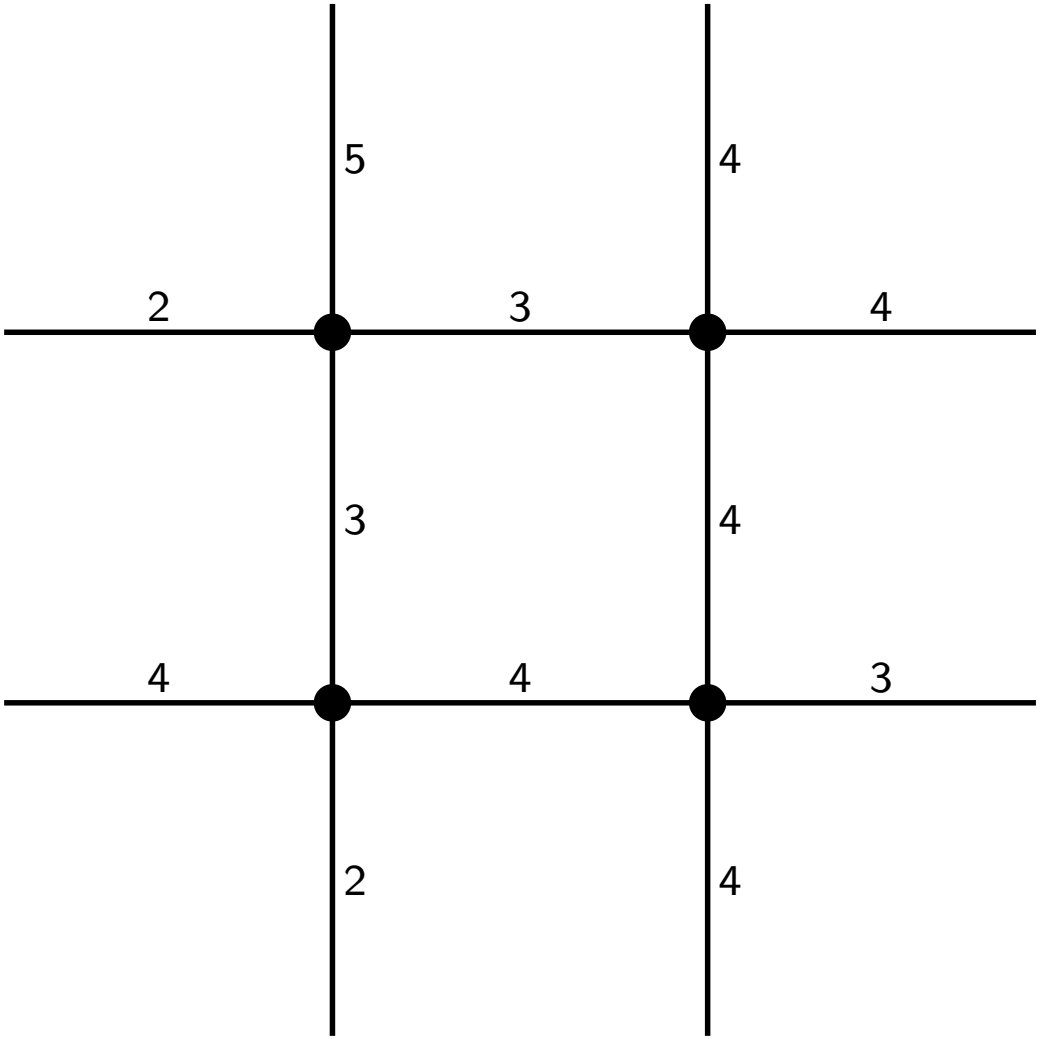

Existing algorithms

- (static) Dijkstra algorithm ([Dij59])
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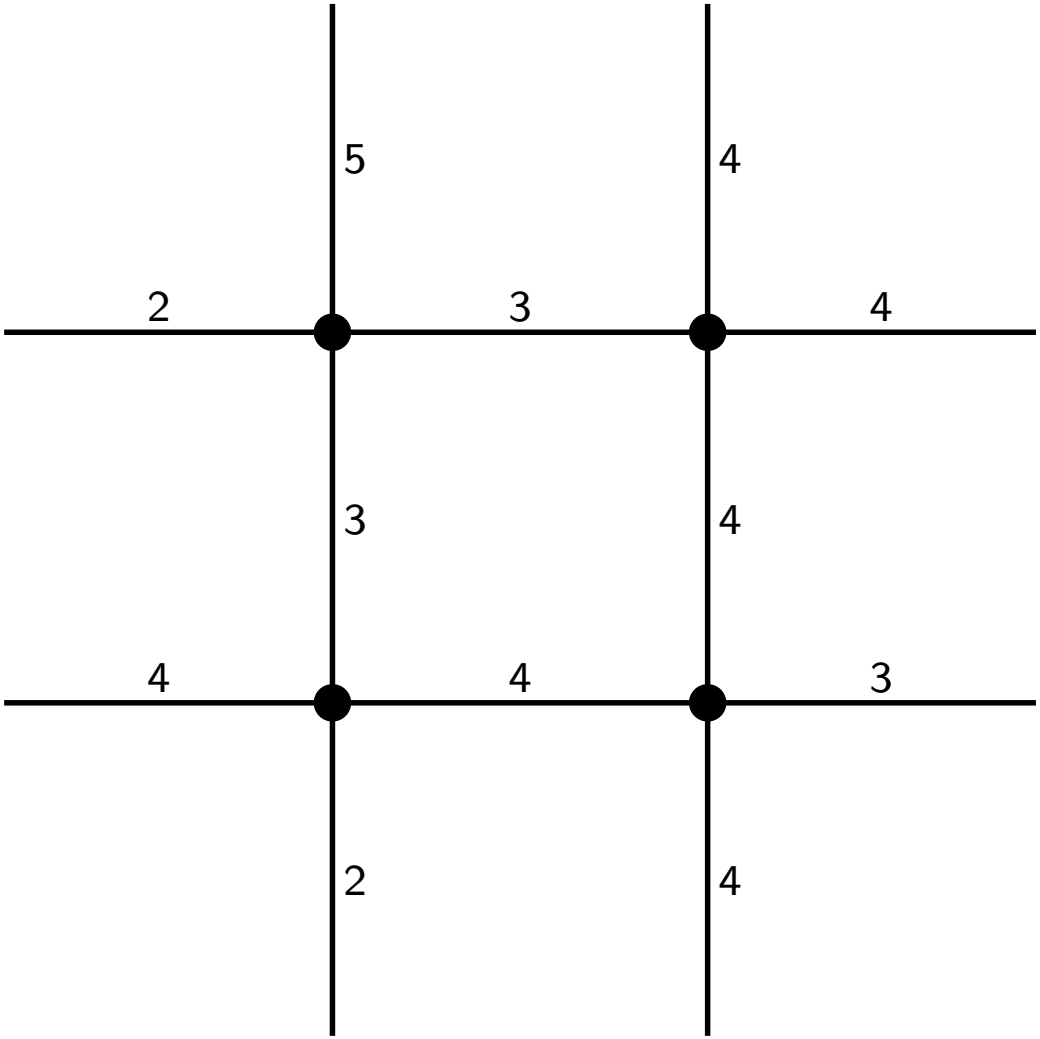

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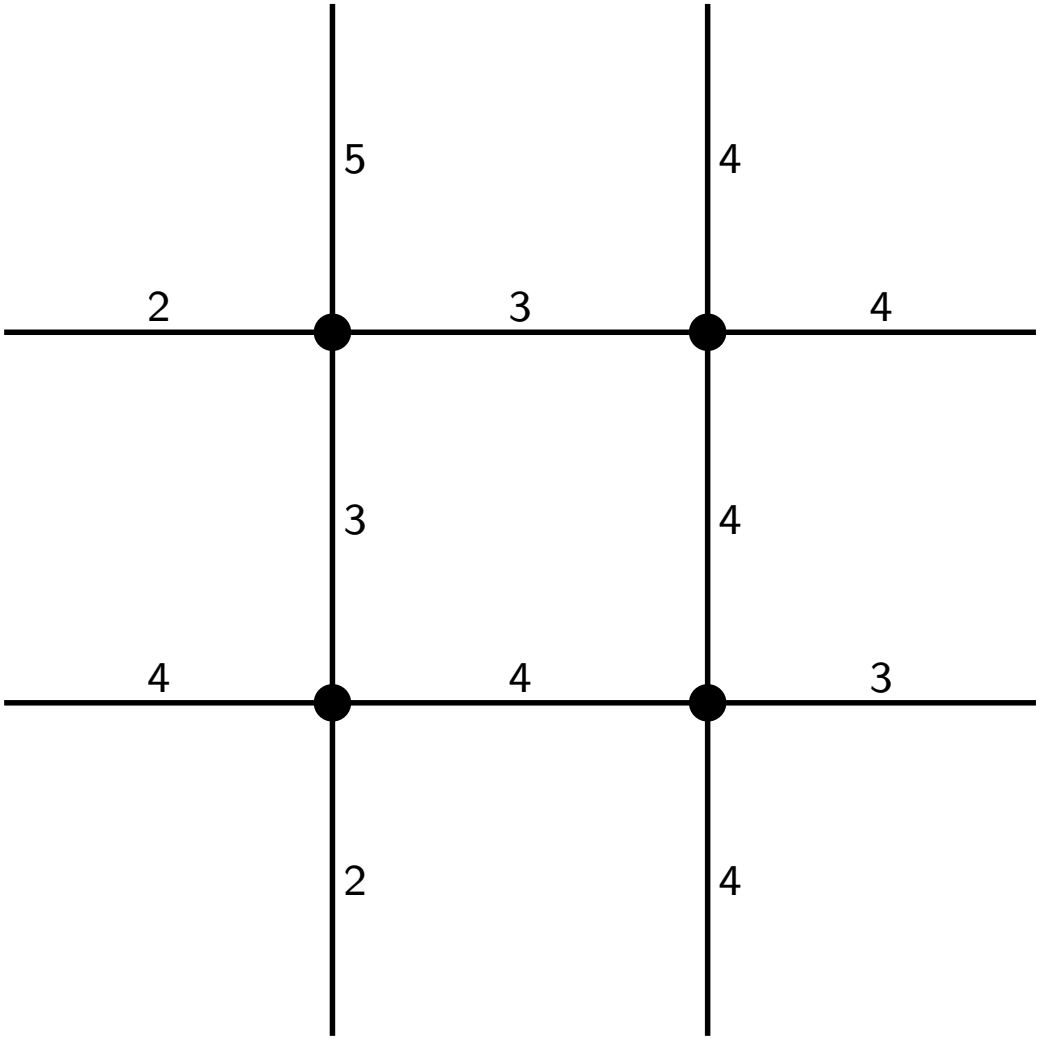

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Complete frameworks

- 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

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Motivations

- Several motivations:

Bringing Internet into Vehicles

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  - Traffic Information Server on the web

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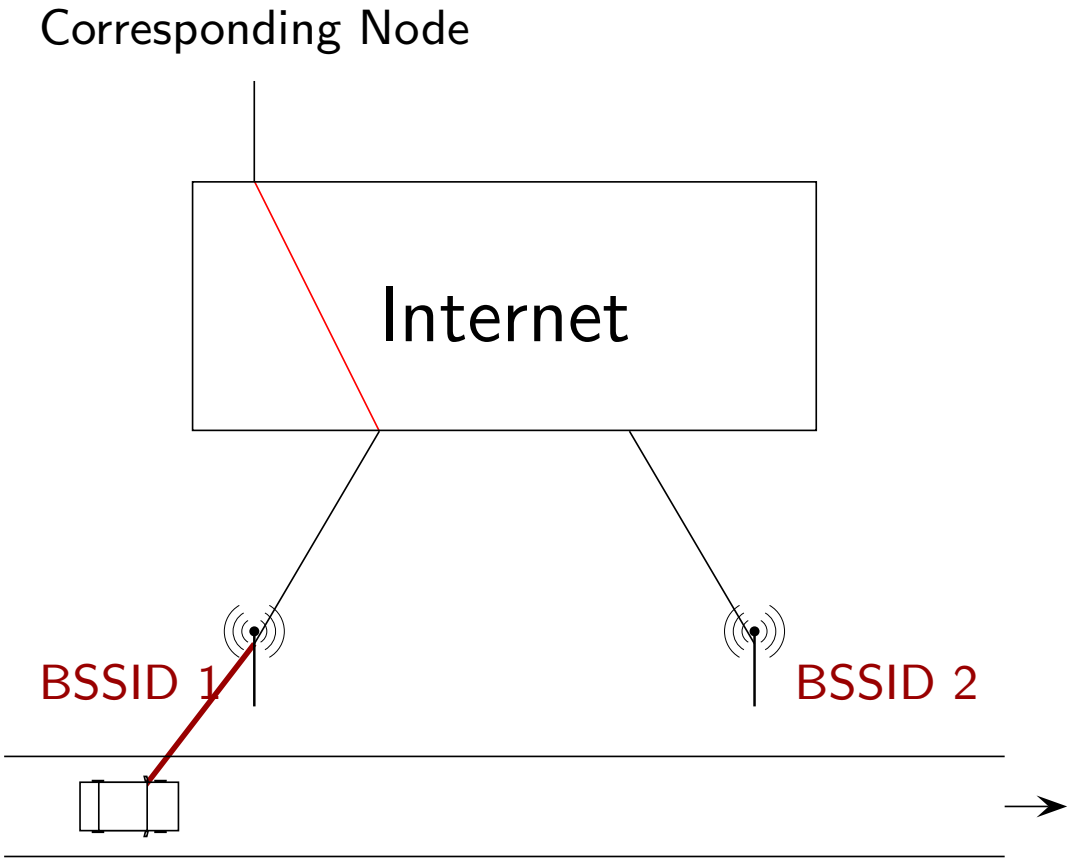
Active research areas

- 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



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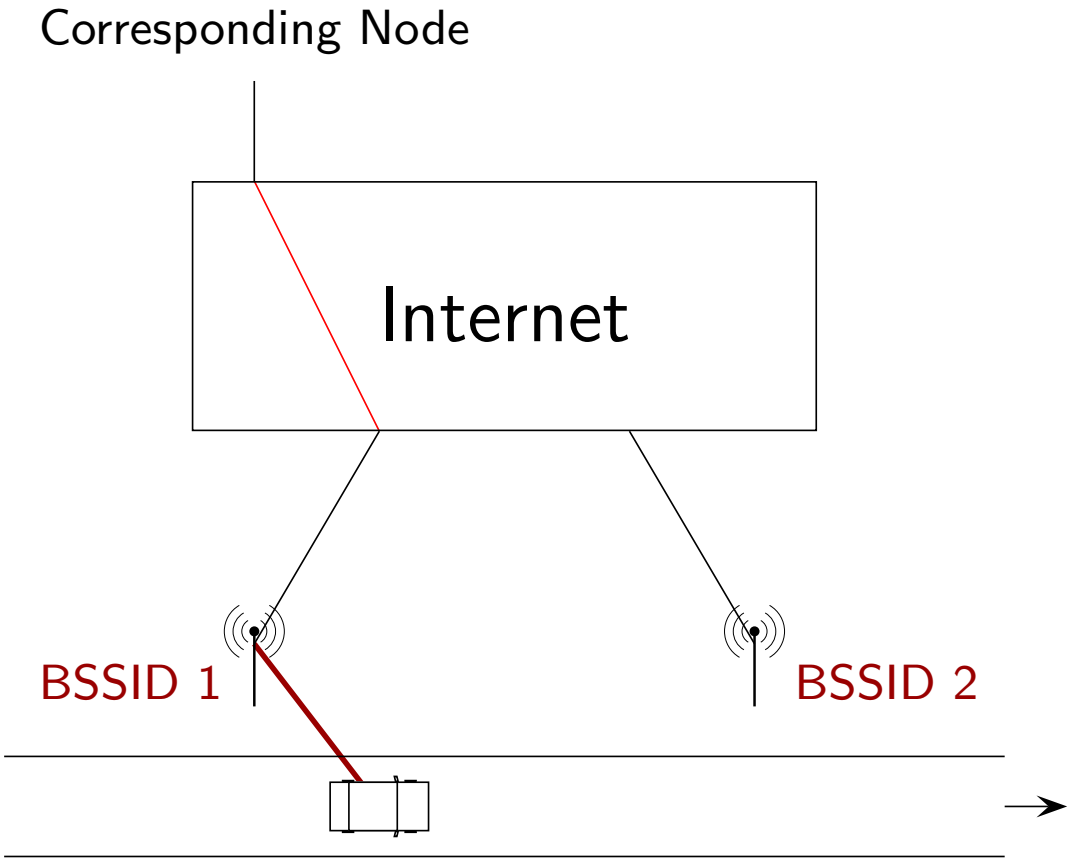

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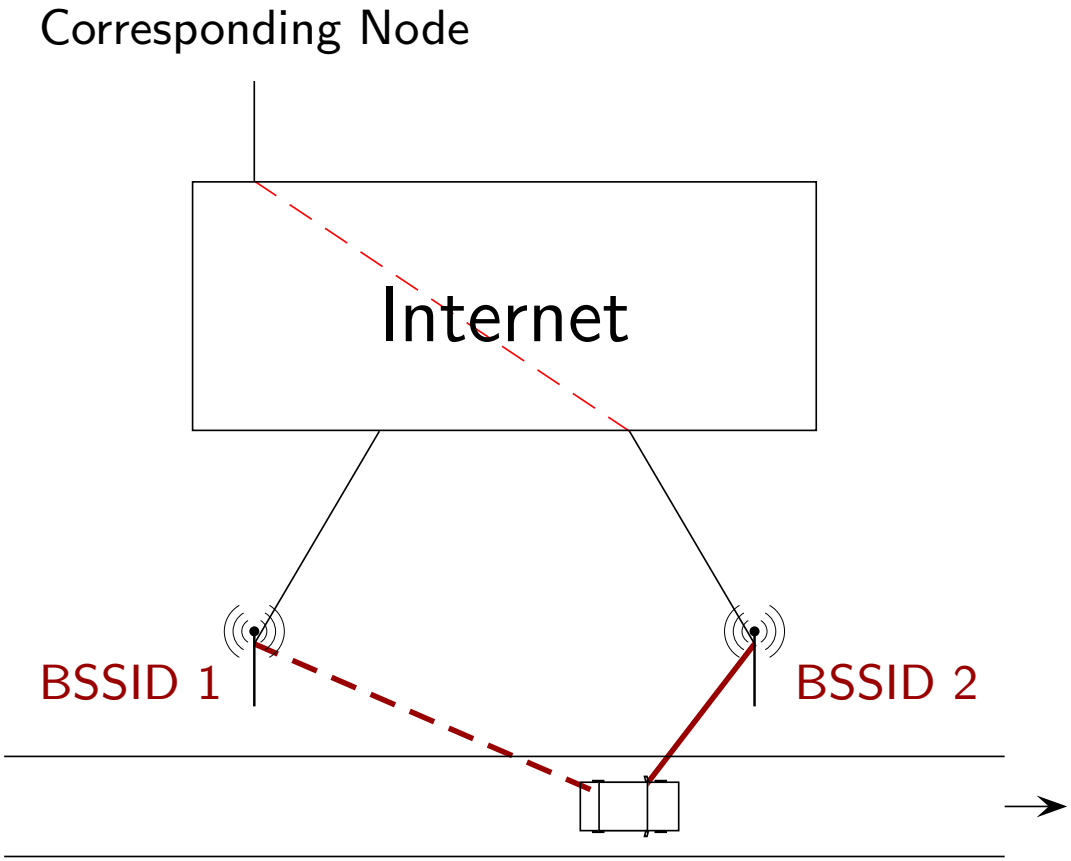
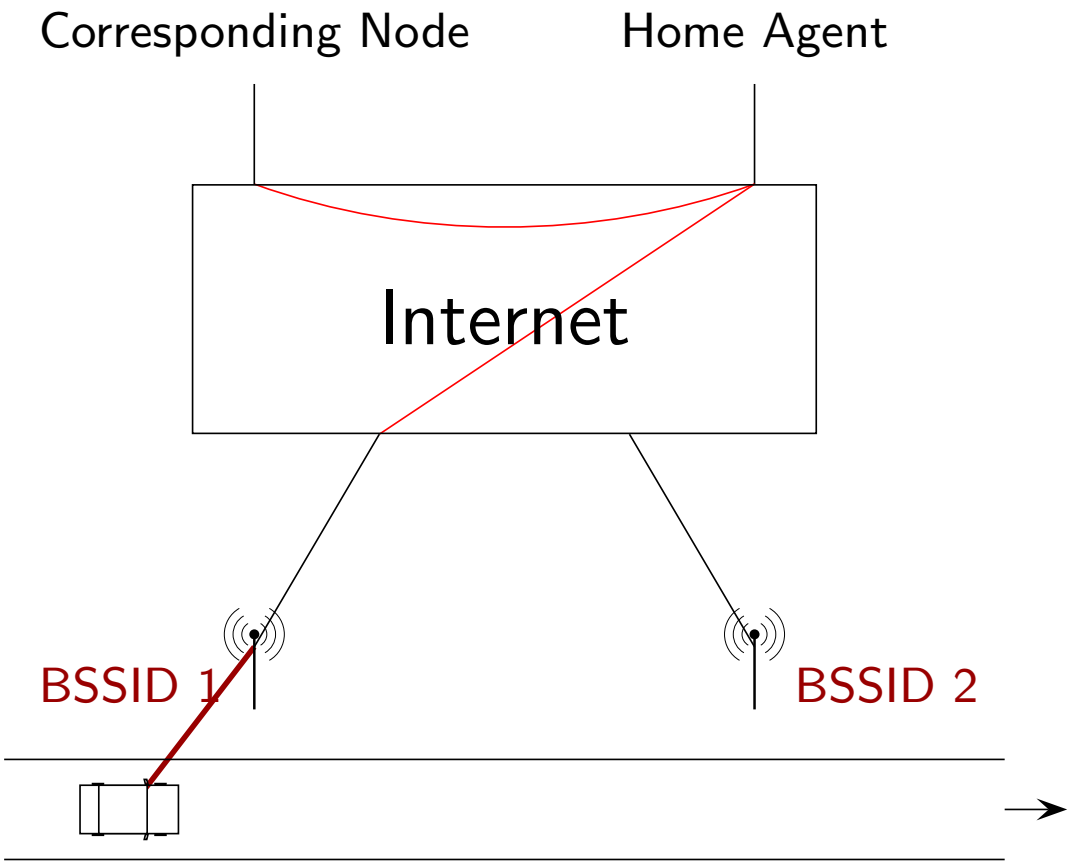


Change of IP address $\Longrightarrow$ disconnection with Corresponding Node

Mobile IP

Using Mobile IP



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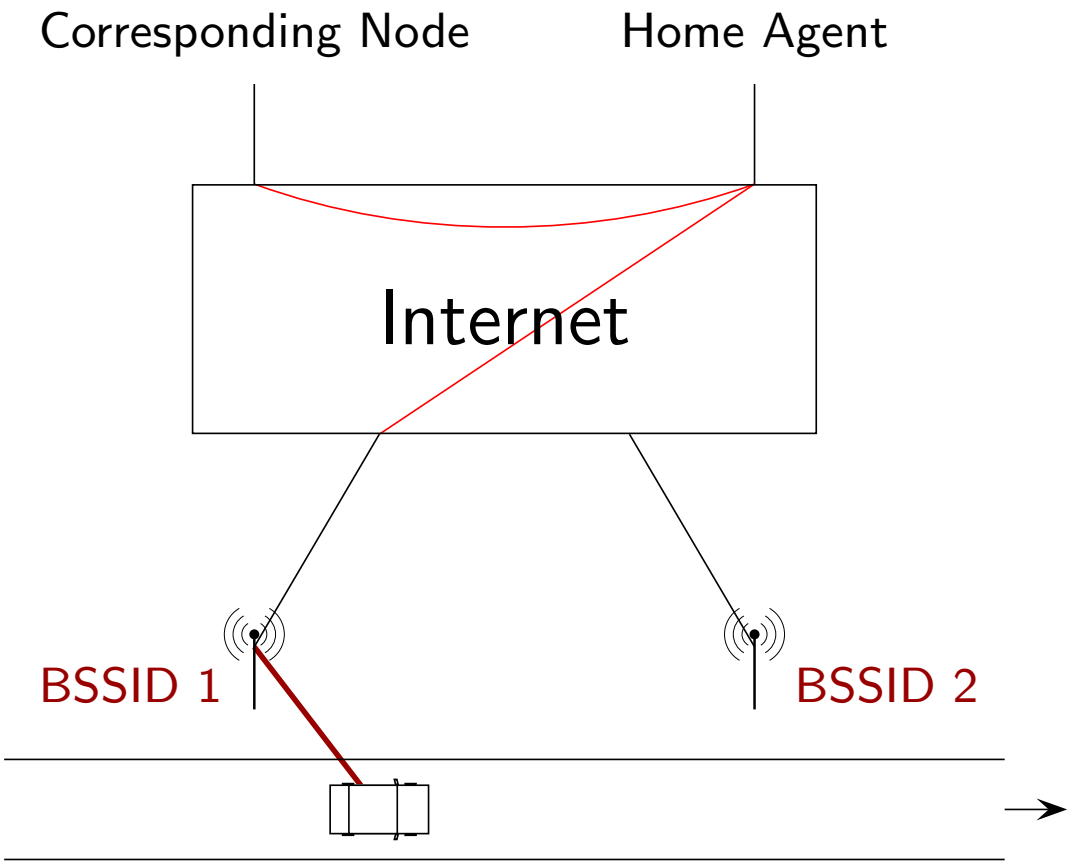

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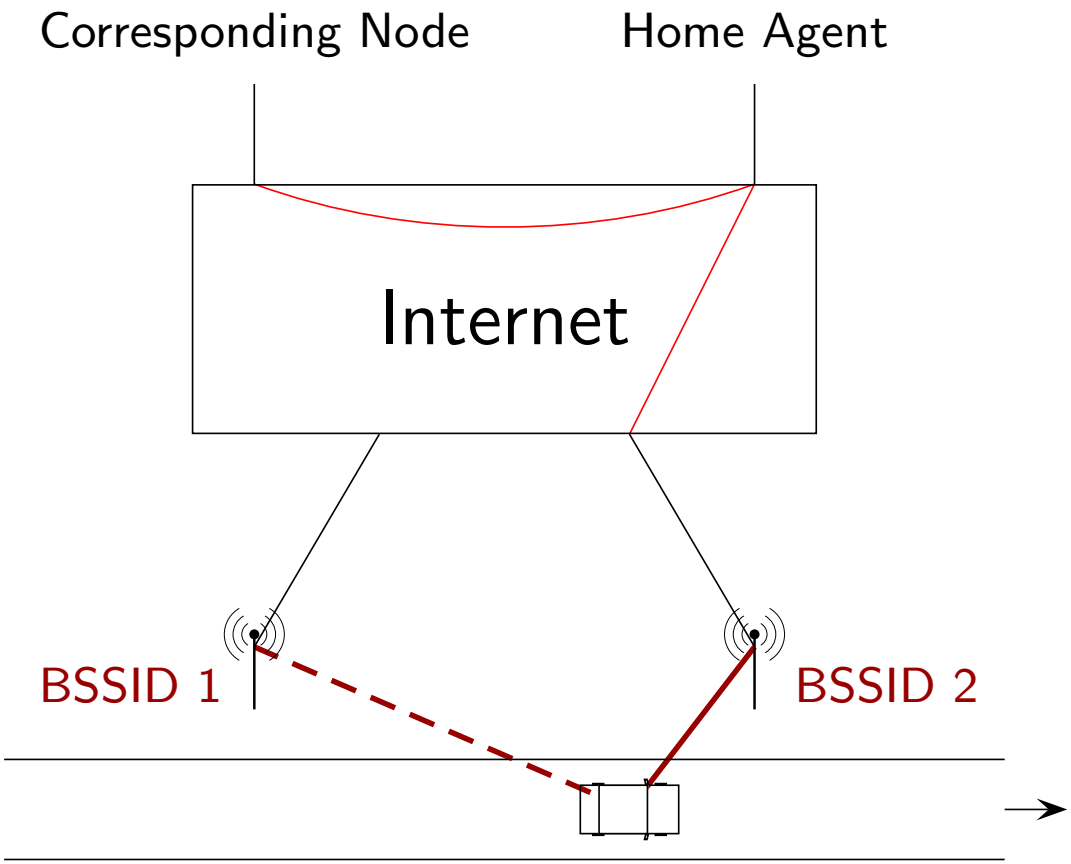

Change of IP address OK, seamless for Corresponding Node

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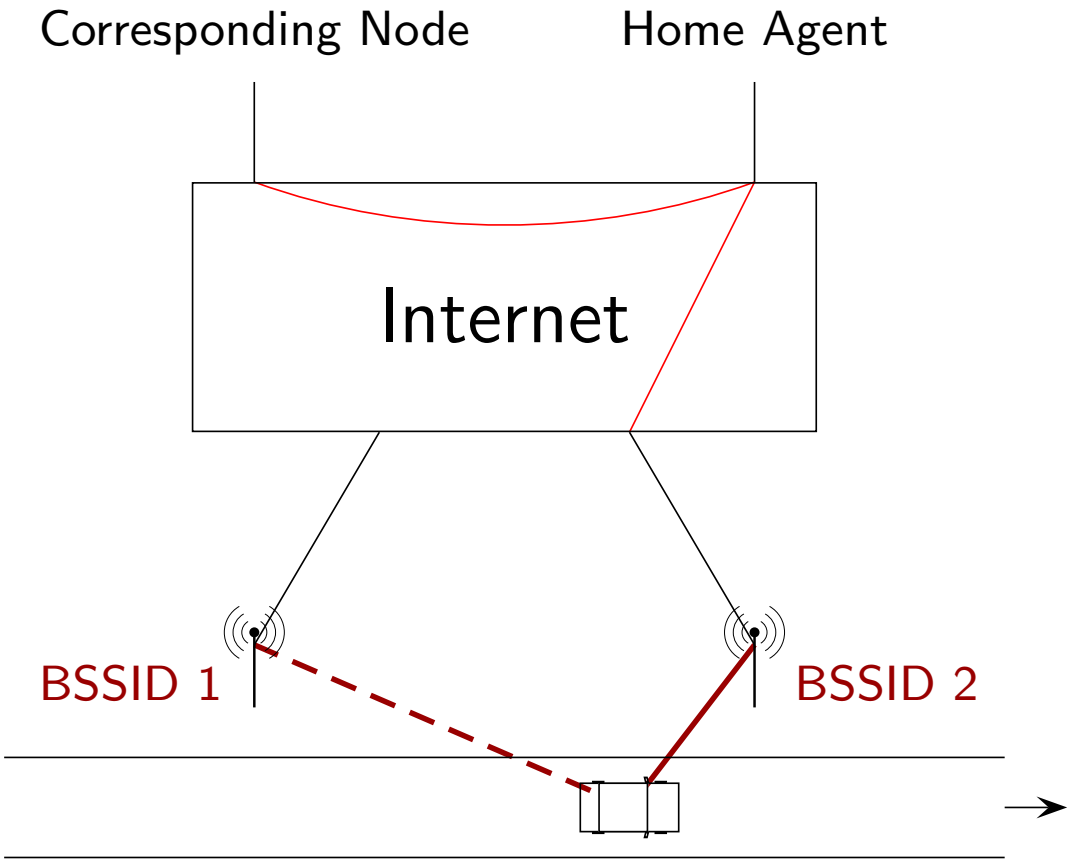


Drawbacks

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

Change of IP address OK, seamless for Corresponding Node

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

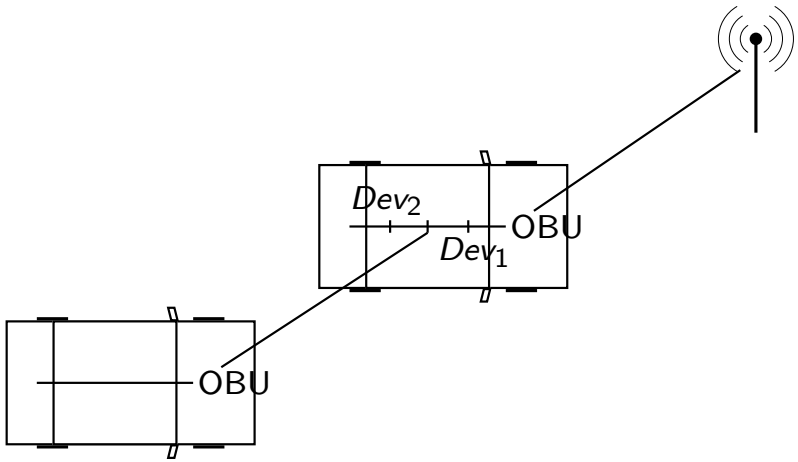
Does it solve the problems?

- 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



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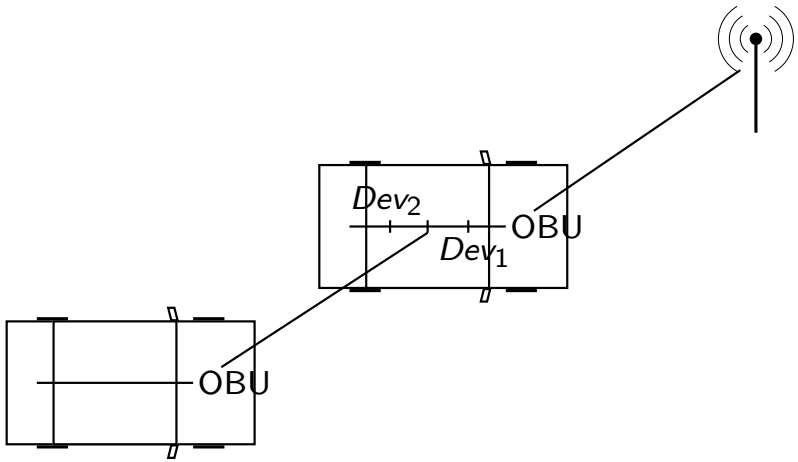

- works, but may lead to sub-optimal routing paths such as

  Car n $\longrightarrow$ Car n-1 $\longrightarrow$ ...Car 1 $\longrightarrow$ Home Agent 1... $\longrightarrow$ Home Agent n-1 $\longrightarrow$ Home Agent n $\longrightarrow$ 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

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- Better understanding of VANETs deepest nature

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Fundamental characteristics of VANETs

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- Unlimited size and population
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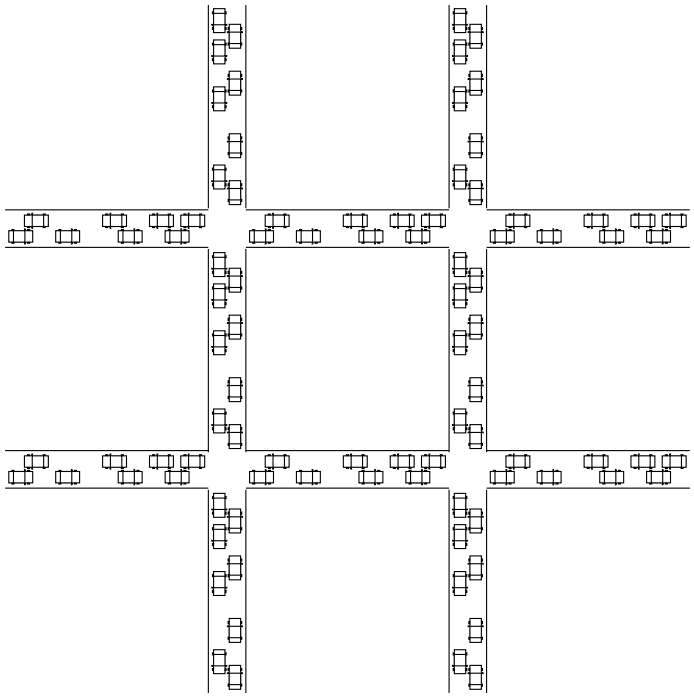
- Not always connected, specific connectivity

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



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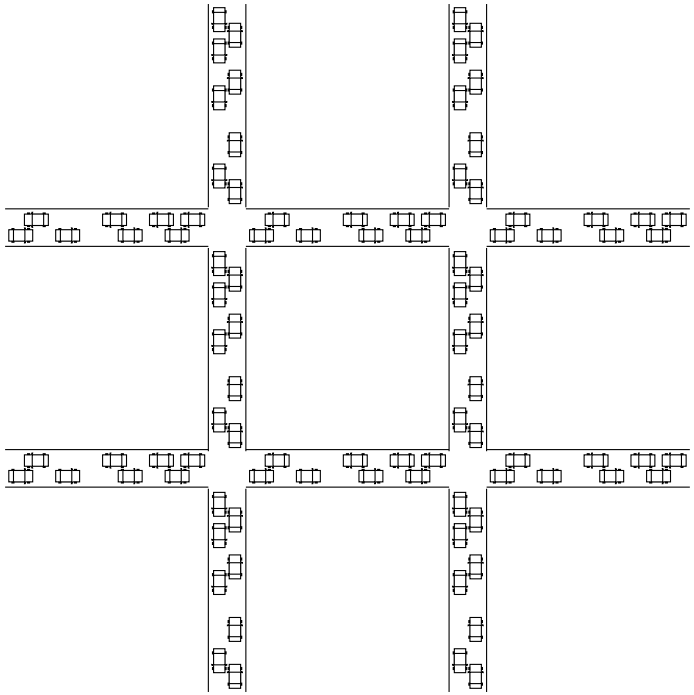
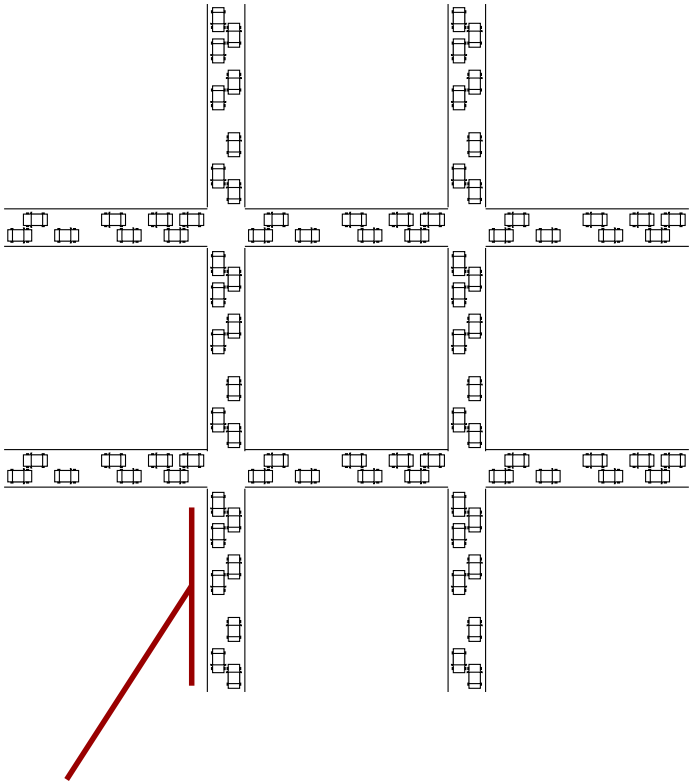


Question:
what density d_{car} to have the entire network connected?

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



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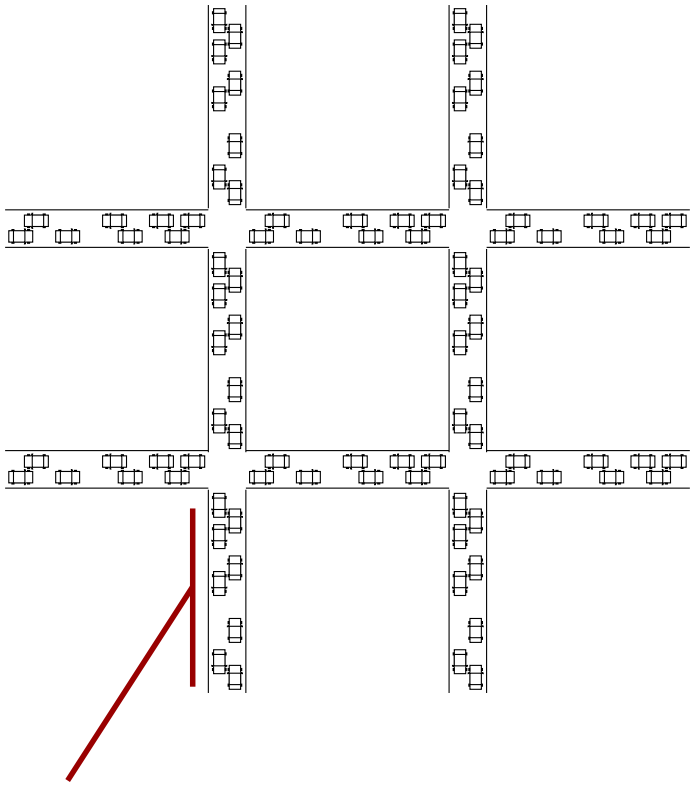

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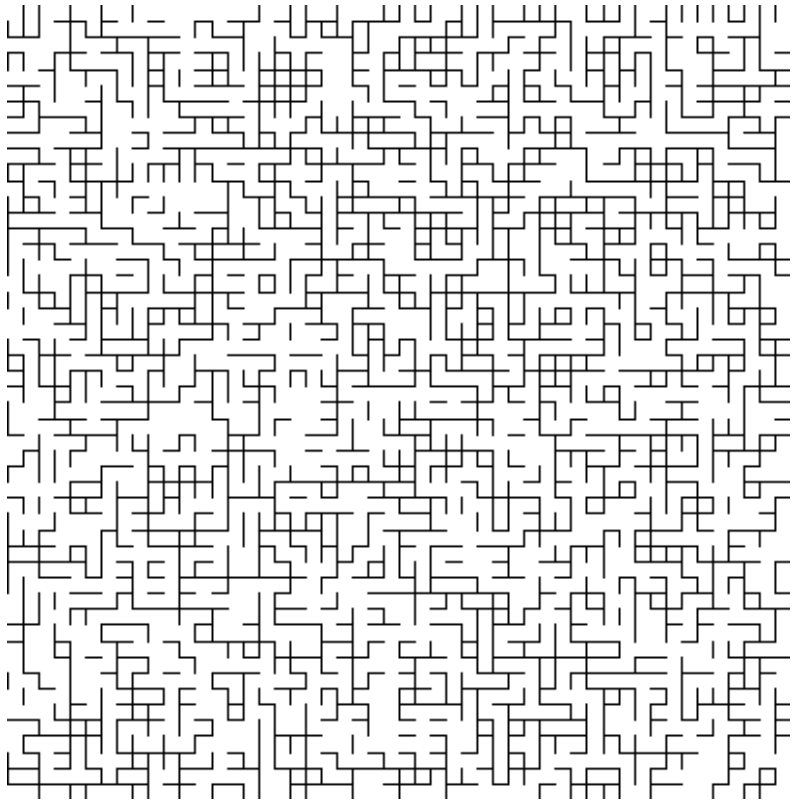

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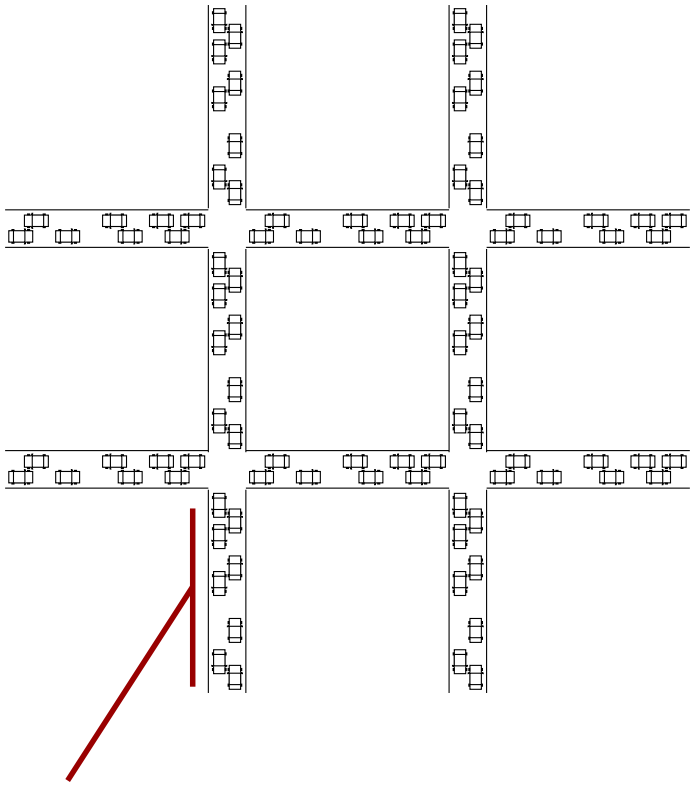

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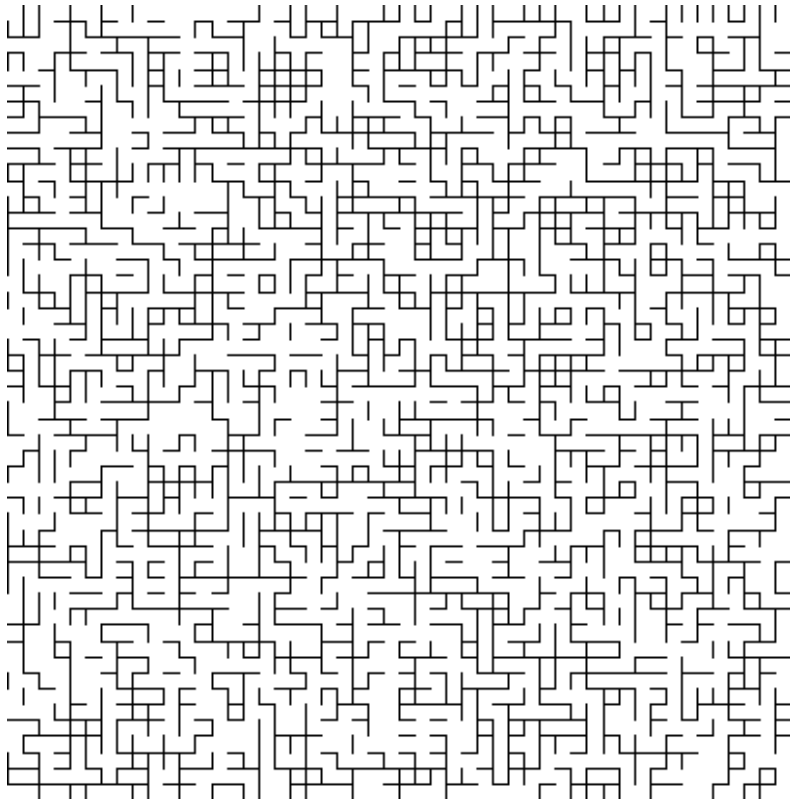

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Critical density: d_{car} such that $p_{ct} > 0.5$
$\Rightarrow$ depends on the mobility model considered..

Impact of the model (studied in [FH08])

Mobility Model Classes

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Note: Non-DTN Metrics.

DTN Connectivity

DTN Network

Expression of DTN-Metrics

- path $\longrightarrow$ journey (path over time)

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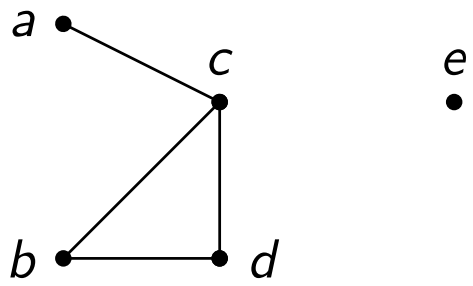
DTN Network



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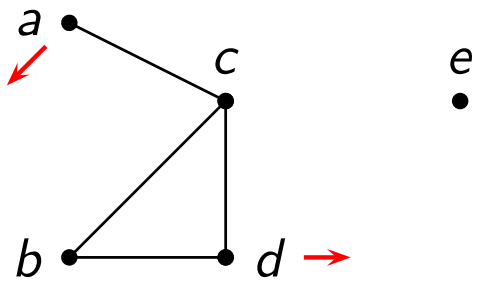

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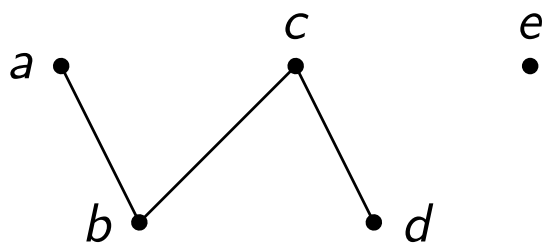

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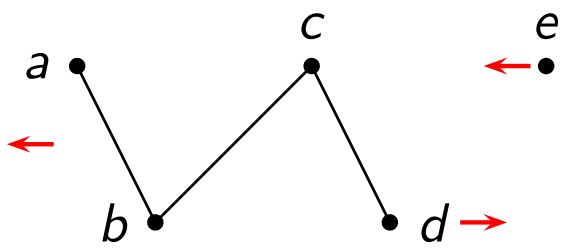

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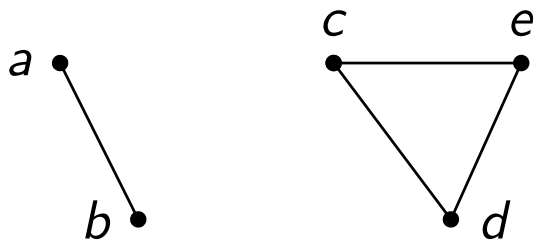

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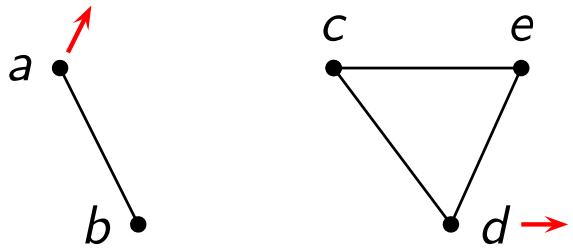

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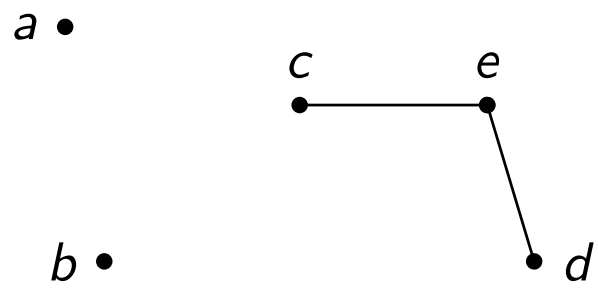

DTN Connectivity

DTN Network/Evolving Graph

Expression of DTN-Metrics

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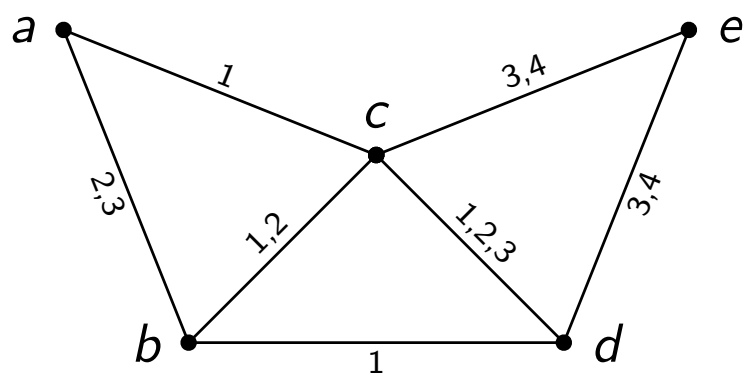
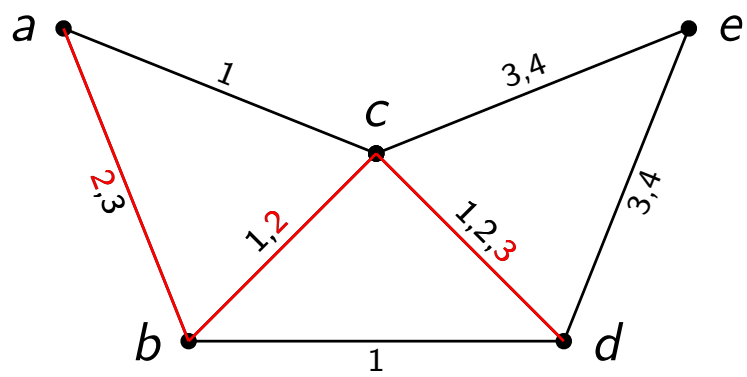


DTN Connectivity

DTN Network/Evolving Graph

Expression of DTN-Metrics

- path $\longrightarrow$ journey (path over time)
  - sequence of edges associated with increasing dates



$$\mathcal{J}_{(a,d)} = \{(a,b,2),(b,c,2),(c,d,3)\} \subseteq \mathcal{G}$$

DTN Connectivity

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- path $\longrightarrow$ journey (path over time)
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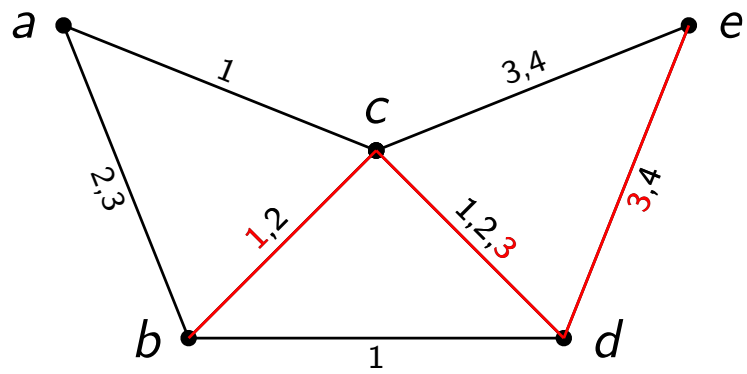
  - non-symmetrical !

DTN Network/Evolving Graph



$$\mathcal{J}_{(b,e)} = \{(b,c,1),(c,d,3),(d,e,3)\} \subseteq \mathcal{G}$$

DTN Connectivity

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  - *shortest vs. fastest vs. foremost journeys*

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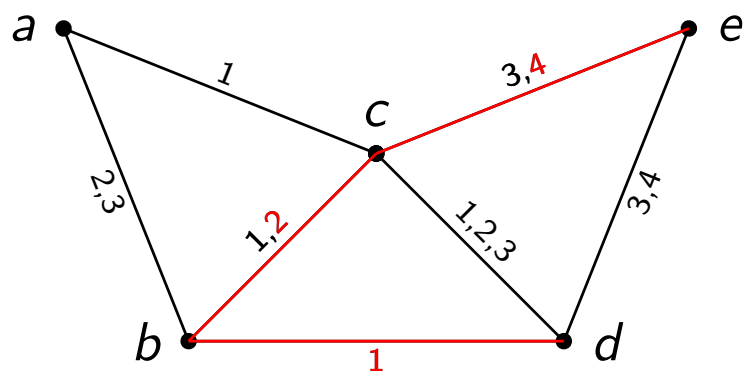

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- path $\longrightarrow$ journey (path over time)
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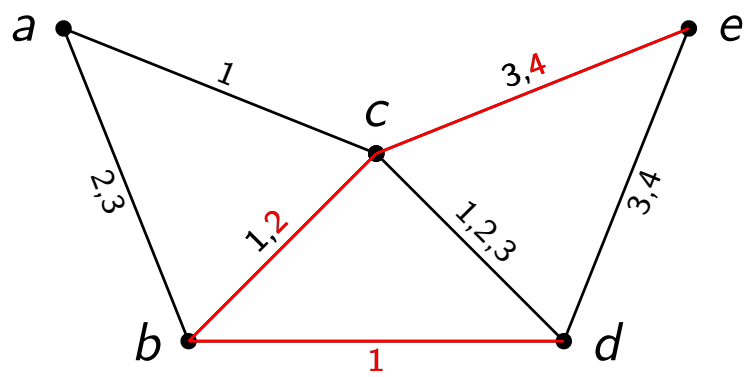
  - *shortest vs. fastest vs. foremost journeys*
- cluster $\longrightarrow$ over-time-connected component:
  $\forall v_1, v_2 \in otcComp, \exists \mathcal{J}_{(v_1,v_2)} \subseteq \mathcal{G}$



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