Vehicular Ad Hoc Networks Intro and Data Dissemination

Stefano Basagni, NU, Boston, MA, U.S.A.
(featuring also slides from I. Stojmenovic)

Vehicular Ad Hoc Networks

- VANETs, for short
- Wireless networks of vehicles that are
  - Distributed
  - Self organized
  - Potentially highly mobile
- An incarnation of Mobile Ad Hoc Networks
  - MANETs
  - Node mobility is restricted by road and traffic regulation

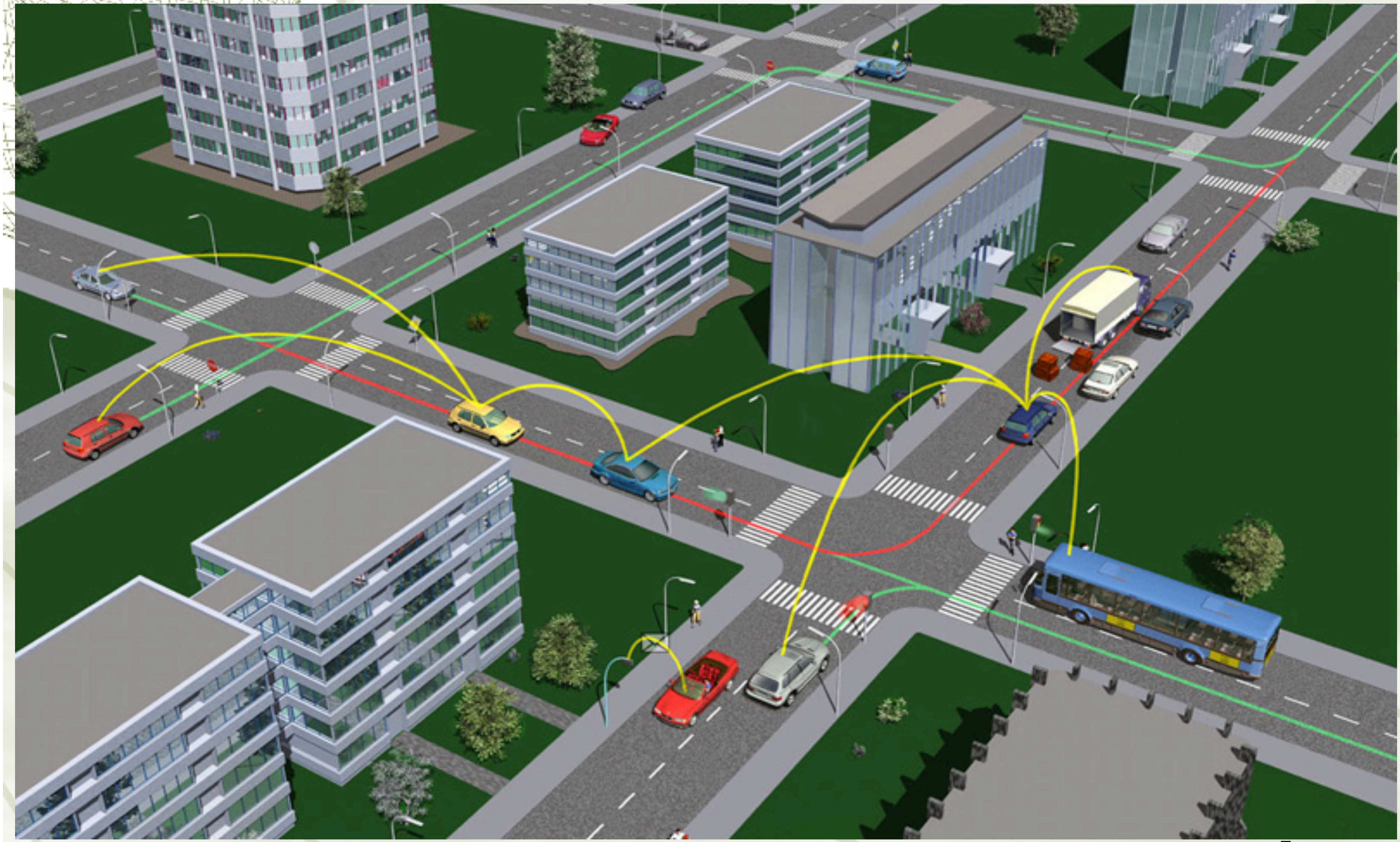
Vehicular Ad Hoc Networks, 2

- With respect to MANETs
  - Restriction by road direction, traffic and traffic regulation
  - Higher dynamics
  - Intermitted connectivity
- However …
  - Movements can be more predictable
    - Roads and speed bounds are usually known
  - Energy is less of a problem

VANETs and ITS

- VANETs are the core of the **Intelligent Transportation Systems** (ITS)
- ITS goals:
  - Safety goals
  - Better transportation services
  - Improved traffic management
- ITS is an integrated, flexible, scalable architecture

The ITS vision



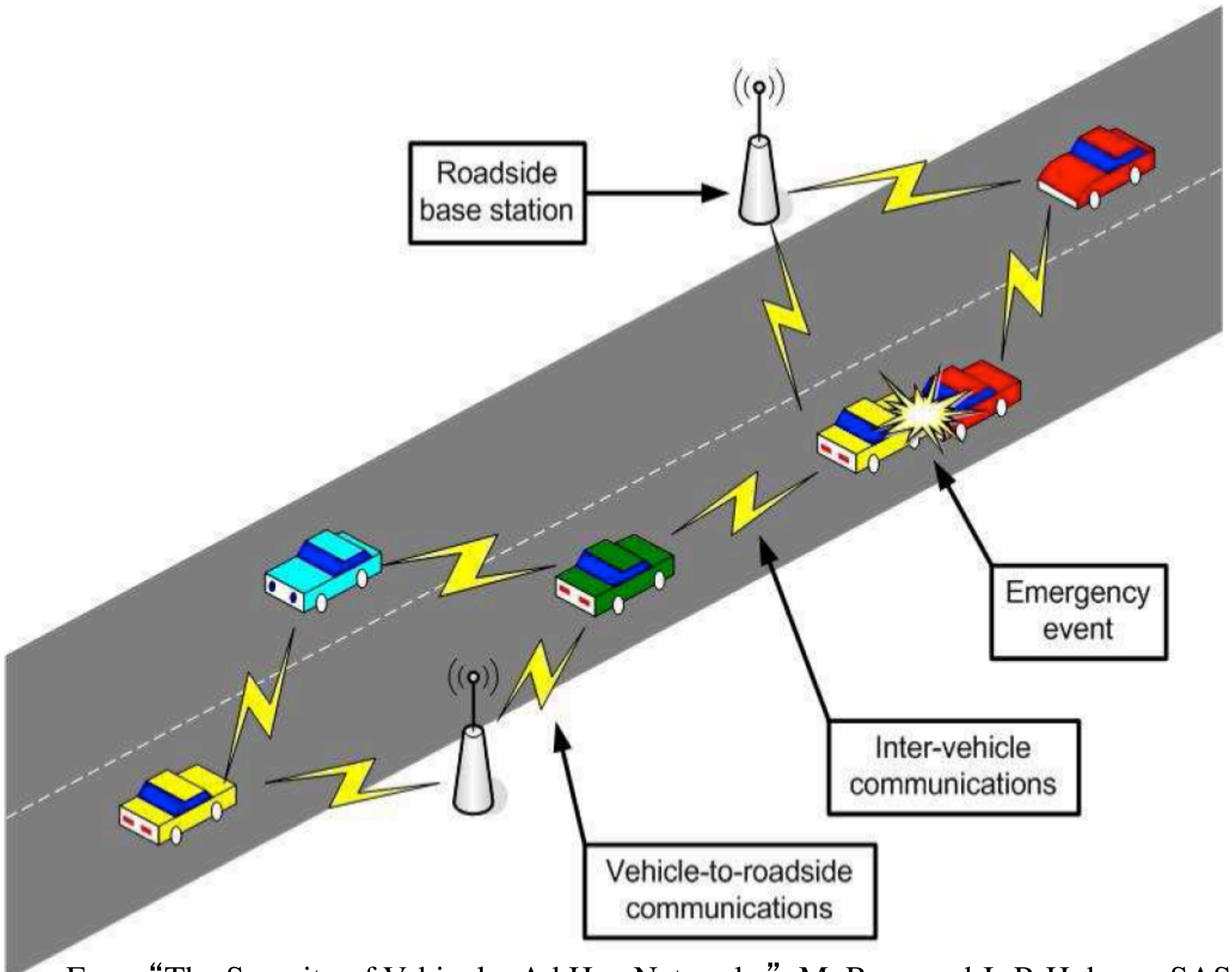
www.car-2-car.org

Protocols for VANETs

- Higher level taxonomy
  - Infrastructure based
    - General: 3 or 4 G communication systems, cellular
    - Dedicated: Road Side Units (RSUs)
    - Communications are V2I: Vehicle to Infrastructure
  - Infrastructure-less
    - No RSU deployment/connection to existing network
    - Vehicles communicate among themselves
- The more likely scenario: Hybrid

VANET

V2V / V2I Architecture



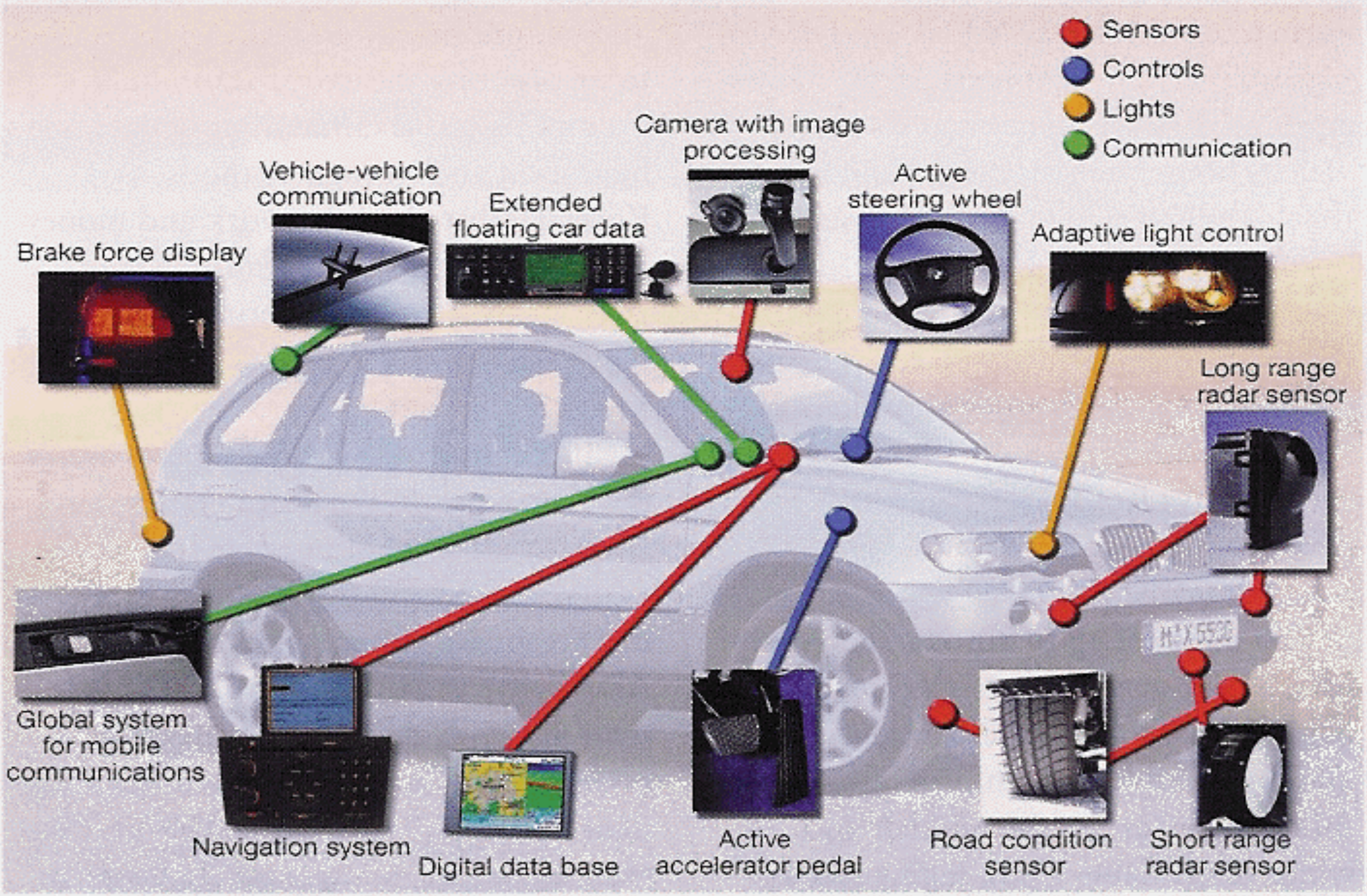
From "The Security of Vehicular Ad Hoc Networks", M. Raya and J.-P. Hubaux, SASN 2005

Assumptions: Embedded hardware

- Central processing unit to run protocols
- Wireless transceiver and GPS receiver
- Sensors to measure various parameters
- Input/output interface for human-vehicle interaction

- Realistically, only a few vehicles are equipped initially; however …

Smart vehicles are upon us



Sensor systems and components

Advantage of V2V over V2I

- Supports time critical safety (collision avoidance)
- Abrupt events can be broadcast via V2V
- Informing of nearby business activity
- Stores can deliver ads from their RSUs and V2V
- Can provide localized service
- No infrastructure cost, no user fees

Advantage of V2I over V2V

- Provision of Internet applications
- Global traffic coordination and prediction
  - collect info at control centers and data fusion
- Diversity of applications (via Internet access)
- Reliability and technical simplicity
- Possible QoS
- Wider coverage
- Professional maintenance

Sample Applications

- Inform vehicles about a congested area (V2V)
- Finding a parking lot, a gas station, a restaurant (V2I)
- Receiving traffic flow updates (V2V)
- Crash warnings (V2V)
- Cooperavive adaptive cruise control (V2V)
- Speed limit warnings (V2I)
- Animal warnings (V2I)
- Map updates (V2I)

App taxonomy

- Based on traffic safety
- Traffic safety applications
  - Inform the driver of safety messages urgently
  - Based on monitoring vehicles and road conditions
  - Vehicles cooperate with each other swapping msgs
- Non-traffic safety applications
  - Provide drivers (and passengers) with with info on traffic efficiency and entertainment
    - Include business ads
  - Enable also cooperative driving

Communication Standards

- DSRC = Dedicated Short-Range Communication
- IEEE 802.11p
  - Approved amendment to the IEEE 802.11 standard to add WAVE: Wireless Access to Vehicular Environments
- 5.850-5.925 GHz (one of the ISM)
- 7 channels (one dedicated to safety)
- 6-27 Mbps
- Up to a 1000m transmission range

Network access - DSRC

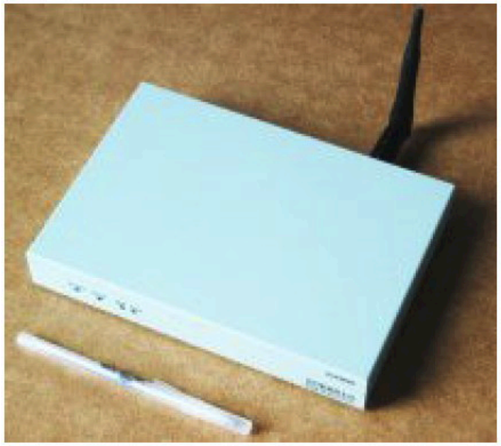
- Regular periodic beacons to learn neighbors
- GPS provides location
- Not slotted, no delay and bandwidth guarantees
- Bit Error rate of DSRC can be very high
- High mobility causes fast fading conditions
- Geographic addressing not supported at MAC layer
- Acknowledgements and reliability must then be handled at network layer

Developing ITS applications

- Most existing applications do not use V2V
- NCTU Taiwan (Jason Yi-Bing Lin)
- Handheld device added to vehicle
- Internet access
- Mobile entertainment
- Fleet-social networking
- Map updates
- Drive-through payment/notification
- Appointment confirmation/changes

Initiatives

- Car Manufacturers
  - GM-CMU - http://gm.web.cmu.edu/
  - MIT CarTel, Berkeley PATH, PSU CITrans, etc.
- Europe
  - Fleetnet in Germany: Ten smart cars and RSUs
    - Contention based forwarding
  - Network-On-Wheels (Germany)
    - Communication and data security for standardization
    - Hybrid sender-oriented and receiver-oriented protocols
  - Car 2 Car Communication Consortium - http://www.car-2-car.org/
- Governments of USA and Japan support developing DSRC and deploying RSUs
- Japan
  - Advanced Safety Vehicles, V2I and V2V, e.g., alert drivers of incoming vehicles at blind intersections
  - Japan Automotive Research Institute: Standardization, improved direct communication (e.g., between vehicles sandwiched by trucks)



USA

- CarTel at MITEmbedded computer, GPS unit, WiFi card, sensors (3D accelerometer), camera: Ten taxies in Boston; simple carry and forward protocols
- DieselNet at UMass: 35 buses: DTN routing
- UCLA CVeT: 50 cars on campus, V2V Internet, content sharing (P2P with VANET), sensors to monitor environment and opportunistically diffuse summaries of sensed data
- GM DSRC fleet: 3 vehicles, DSRC measurements

China initiatives

- ShanghaiGrid at SJTU: Over 10,000 taxies and buses for V2I and V2V
- Real time vehicle tracking, traffic and environment sensing
- Opportunistic data forwarding
  - (e.g., epidemic routing: All cars closer to destination RSU will retransmit)
- Realistic mobility model study

Mobility models

- *Macroscopic modeling*: Traffic density, traffic flows, initial vehicle distribution
- *Microscopic modeling*: Location, velocity, acceleration of each vehicle
- Car following models:
  - Stimulus response, safe distance, psychophysical, cell based, optimum velocity, trajectory based
- Multi-lane traffic modeling:
  - lane change criteria: Minimize braking, incentive, safety restrictions

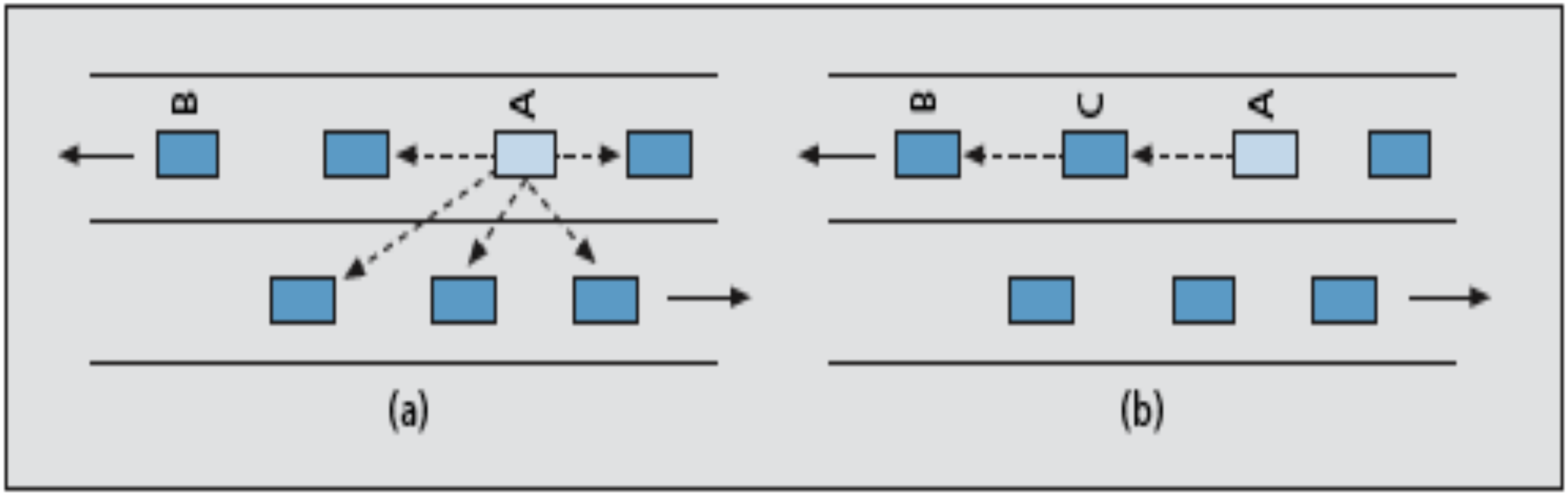
Mobility simulators

- 3 commercial, allowing to vary number of lanes, road shape, ramps, acceleration lanes, traffic lights and signs, etc.:
  - TSIS-CORSIM, PARAMICS, VISSIM
- Non-commercial:
  - SmartAHS (UC Berkeley)
  - Microscopic Traffic Applet (Volkswagen)
  - VanetMobiSim (Eurecom)
  - SUMO (Germany)

Integrated simulators

- Network simulators: NS-2, OMNET++, SWANS
- VANET simulators need interaction between mobility and network modules (input from mobility trace file needs to be modified)
- TraNS (NS-2+SUMO), Veins (OMNET++ + SUMO), NCTUns, VGSIM (SWANS + mobility)

Single-hop and multi-hop inter-vehicle communications



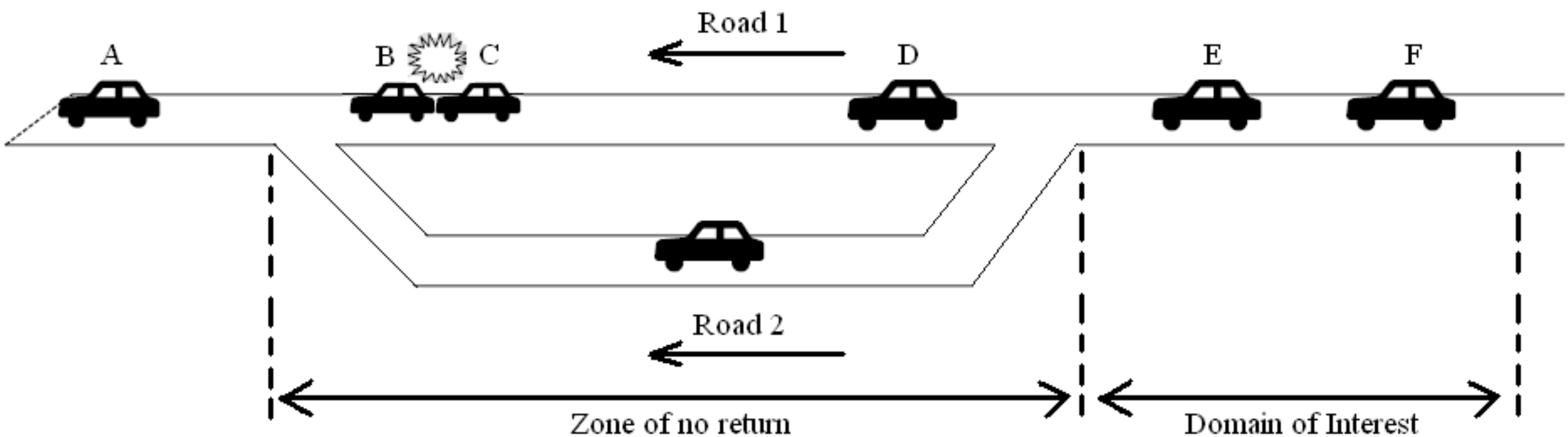
Diffusion

- = transmitting regular content beacons
- Application collects data from neighboring vehicles, aggregates and stores data
- Current table is transmitted to neighbors at regular intervals, updating their tables
- Nadeem et al., 2004
- Wischhof, Ebner, Rohling, 2005

Delivering Road Conditions to Drivers

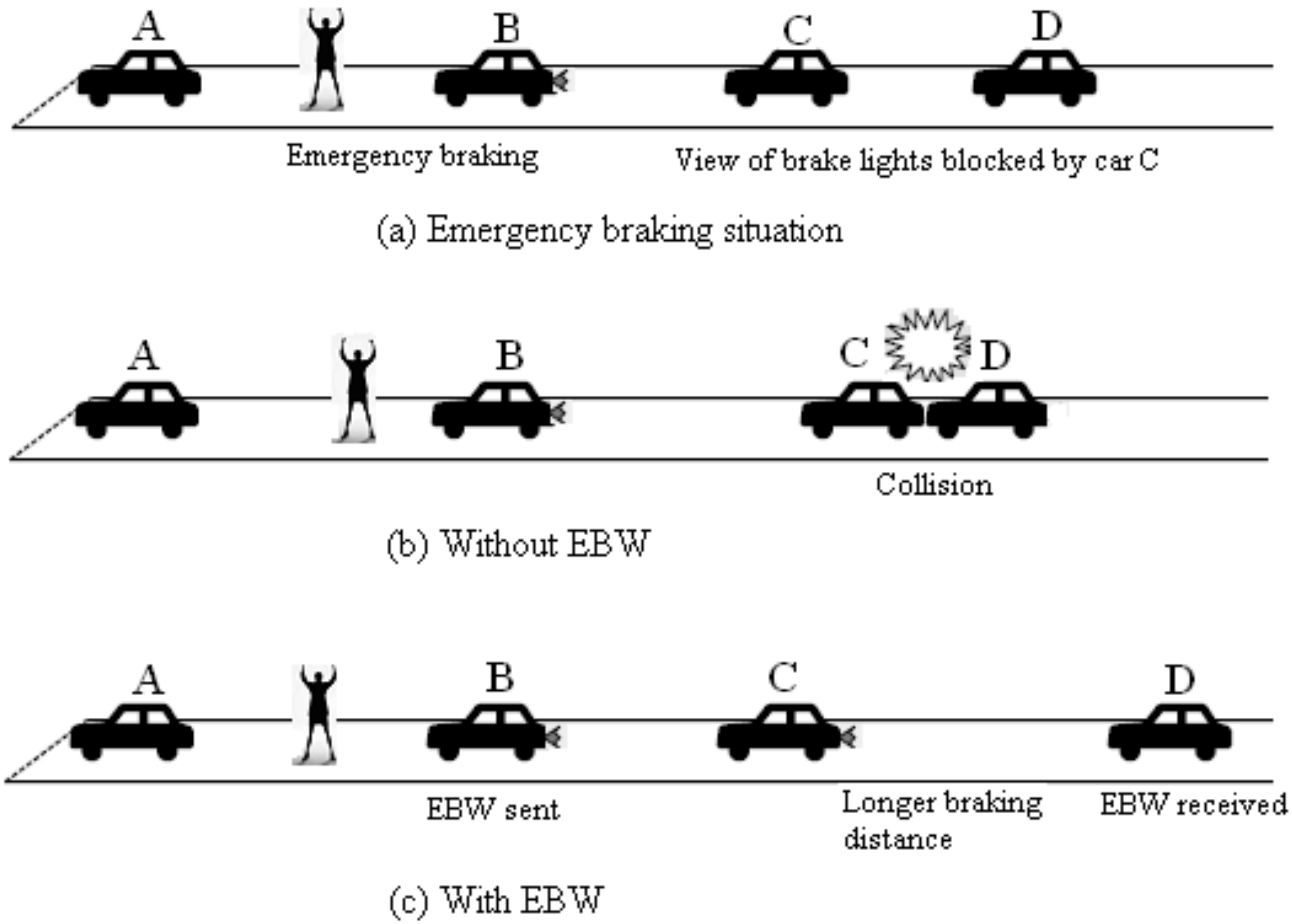
- **Broadcasting** = data dissemination
  - for warning delivery
  - from one node to all other nodes in the network
- **Geocasting** involves
  - broadcasting of information to all vehicles on a road segment or in a given geographic area
  - suppressing multiple warnings for the same event
  - determining boundaries for spreading warnings

Example: Traffic jam scenario



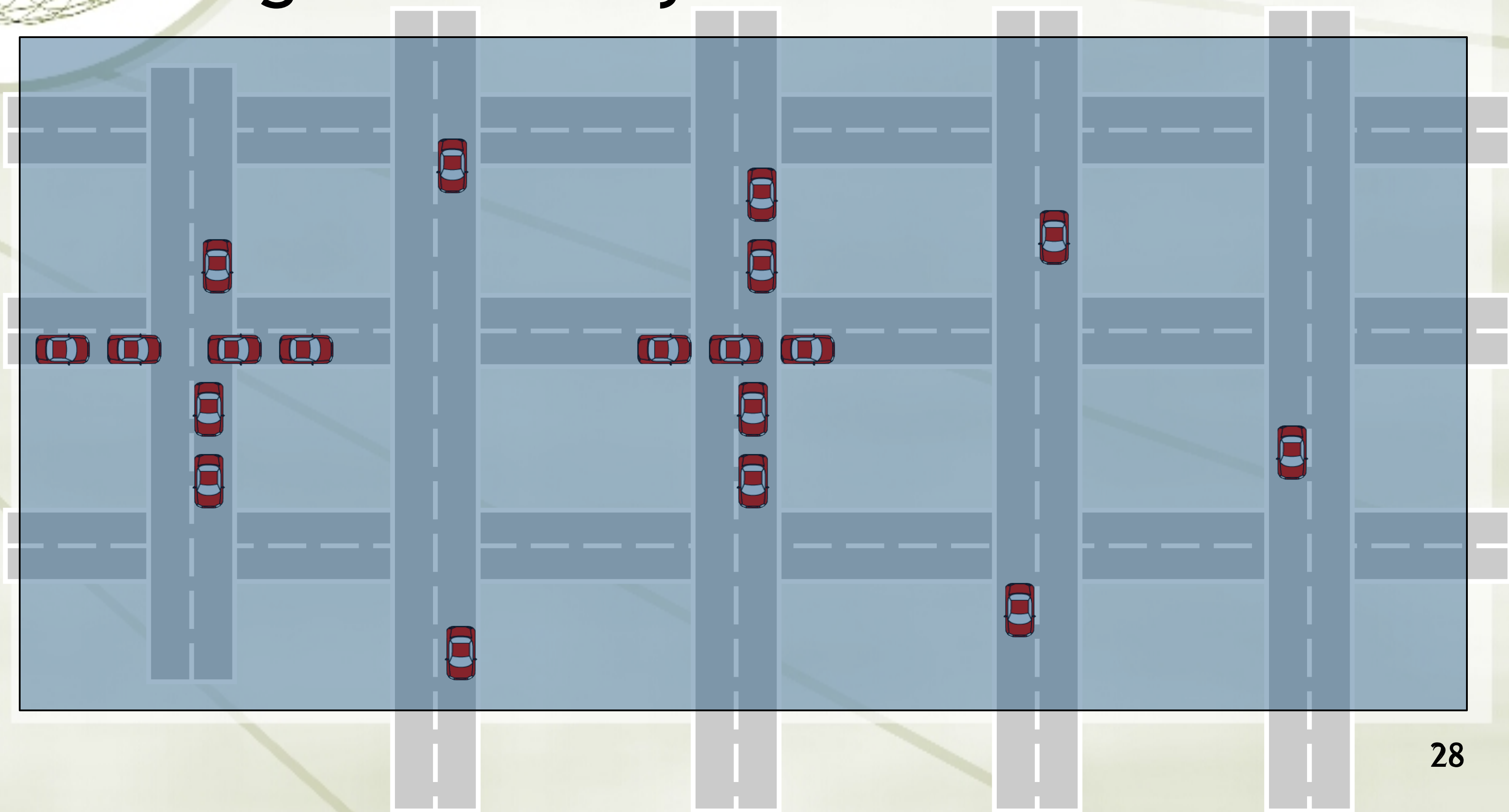
source not in geocasting region

Warning delivery



Problem Statement

- How to reach all vehicles in the selected area, with low message overhead and with high reliability?



Issues

- Low packet reception rate
- 2D road structure
- Intermittent connectivity
- Density changes
- DTN hyper flooding, transmit message on new encounter, causes collisions when a new node arrives at intersection with many cars
- Reliability vs. delay
- Excess messaging may be counterproductive due to collisions

Protocols: Routing

- *Routing*: One-to-one communications
  - Used for apps requiring one or two way communication from vehicle to RSU or to another vehicle
  - Can be facilitated by RSU
  - Destination can be:
  - A fixed geographic location
  - A moving car
    - Address is known and updated
  - Moving destination with no known address

Protocols: Routing, 2

- *Routing* protocols usually solve three issues

1. Finding the destination, if unknown
2. Providing *small scale* routing
   - i.e., between two road intersection
3. Providing *large scale* routing
   - For larger areas

- Applications like finding a parking spot require integration of the IP stack with vehicular routing

Protocols: Geocasting+

- *Geocasting*: One-to-all in a specific location
- An instance of *broadcasting*: One-to-all nodes in the networks
  - Also called flooding
- Geocasting also involves
  - Suppressing multiple repetitive warnings for the same event
  - Determining the boundaries for spreading warnings
- It is initiated by a vehicle or by a RSU

Road dimensions

- Highway with no intersections: 1D
- Segment among two intersections: 1D
- More general: 2D scenario, with intersection, change of lanes, roundabouts, etc.
- Ideally: Protocols should be adaptive
- Some solutions works only in 1D

Neighbor knowledge

- Some protocols make forwarding decisions without any knowledge of current neighbors
  - e.g., geographic greedy forwarding
- Some other times, knowledge of neighbors is necessary
  - additional required info include: Location, speed, directions, etc.
- DSRC with periodic beaconing provides for neighbor knowledge

Acknowledgments

- Used to confirm that a message has been received
- Some protocols do not use acks
- Some do:
  - Beacon acks: Acks to messages are added to the beacons
  - Independent acks
  - Passive acks
  - Reception estimation: Based on inter-vehicle distance

Starting forwarder selection

- Vehicles are normally *idle*
- A vehicle transitions to *active* state when
  - each time a message is received
  - only the first time a message is received
    - e.g., flooding
  - when an ack is missing
  - emergence of a new neighbor

Connectivity

- VANETs tend to disconnect
  - especially when the traffic is intense
- Some protocols assume that the networks is connected all the times
  - Their performance usually drops when the network disconnects
- Possible solutions to disconnection
  - Store-carry-forward as in DTNs
- Intermittent connectivity scenarios = when the protocol handles disconnections

Urgency

- How urgent is a message?
- How fast should it be delivered?
- A requirement of safety applications
  - accident report to incoming vehicles
    - more urgent than reporting the accident to centers
- Sometimes reliability is more important
  - deliver is more important of when
  - time critical vs. reliability oriented

Message content

- Different message types
- Two categories:
  - full messages (receiver oriented)
  - forwarder attached (sender oriented)
- Full messages
  - containing payload, indication about source and destination, locations, speed
- Forwarder attached messages
  - Include ID of dedicated forwarder to ensure quick and reliable message delivery

Sender oriented (dedicated forwarder): 1D

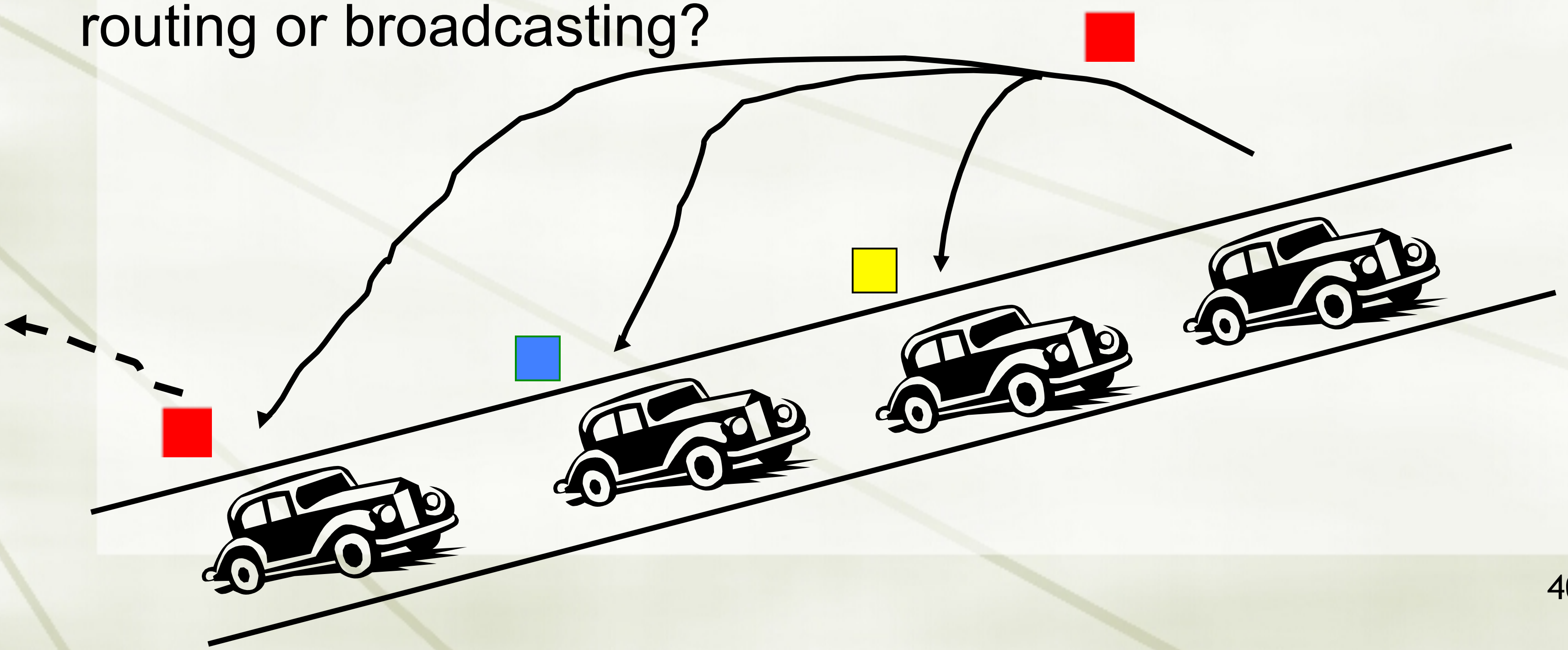
Sun, Feng, Lai, Yamada, Okada 2000

-Learn neighboring cars on the same highway and direction

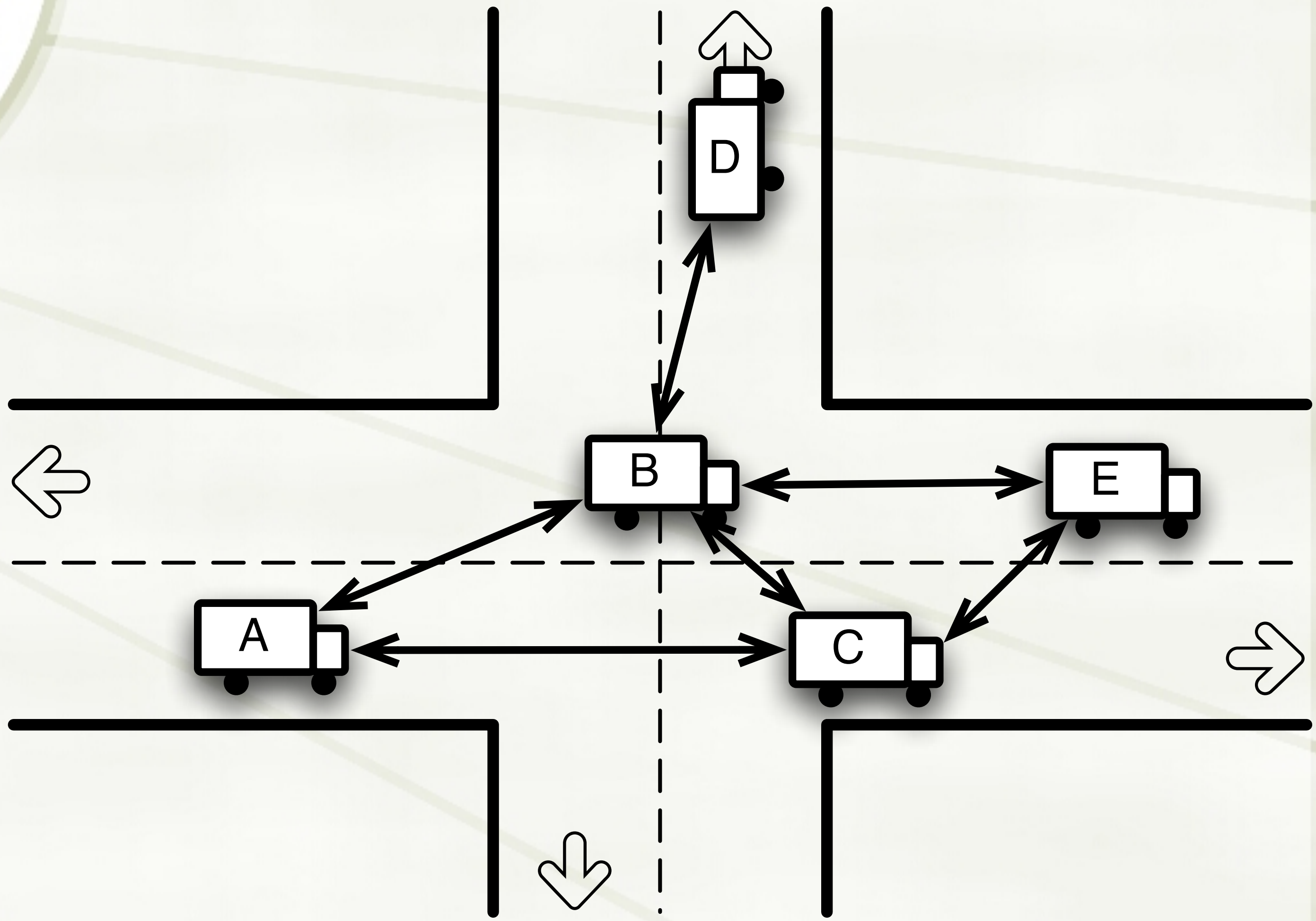
-include ID of furthest neighbor in the transmitted message

-furthest neighbor retransmits

routing or broadcasting?



Dedicated forwarder in 2D?



Receiver oriented: 1D

Sun, Feng, Lai, Yamada, Okada 2000

Briesemeister, Schaefers, Hommel 2000

-Include LOCATION with the message

-defer time inversely proportional to distance from vehicle

- discard neighbors covered by any of transmissions

-retransmit at end of defer time if any of neighbors is not covered

Opportunistic broadcast

- M. Li, W. Lo, K. Zeng, OppCast: Opportunistic Broadcast of Warning Messages in VANETs with Unreliable Links, IEEE MASS 2009, 534-543.
- 1D broadcasting
- Furthest node from sender retransmits for fast progress
- Node closest to the middle between two senders retransmits for increased reliability
- [SFLYO] does not attempt to deliver to nodes between forwarders
- How to decide closest to middle?
- How to stop this algorithm? Ack?

Probabilistic flooding

- [FM08] Fracchia, Meo "Analysis and Design of Warning Delivery Service in Inter-vehicular Networks," *IEEE Transactions on Mobile Computing*, 2008
- Vehicle, after receiving warning message, decides, with probability *p*, to act as relay and forwards the message
- Few broadcasting cycles, start at regular intervals
  - every D seconds (parameter based)
- The question of which car initiates a broadcast cycle remains unresolved in [FM08].
- The analysis assumes
  - *constant density* along the safety area and
  - *one-dimensional car distribution*, which allows any car to decide its speed independently

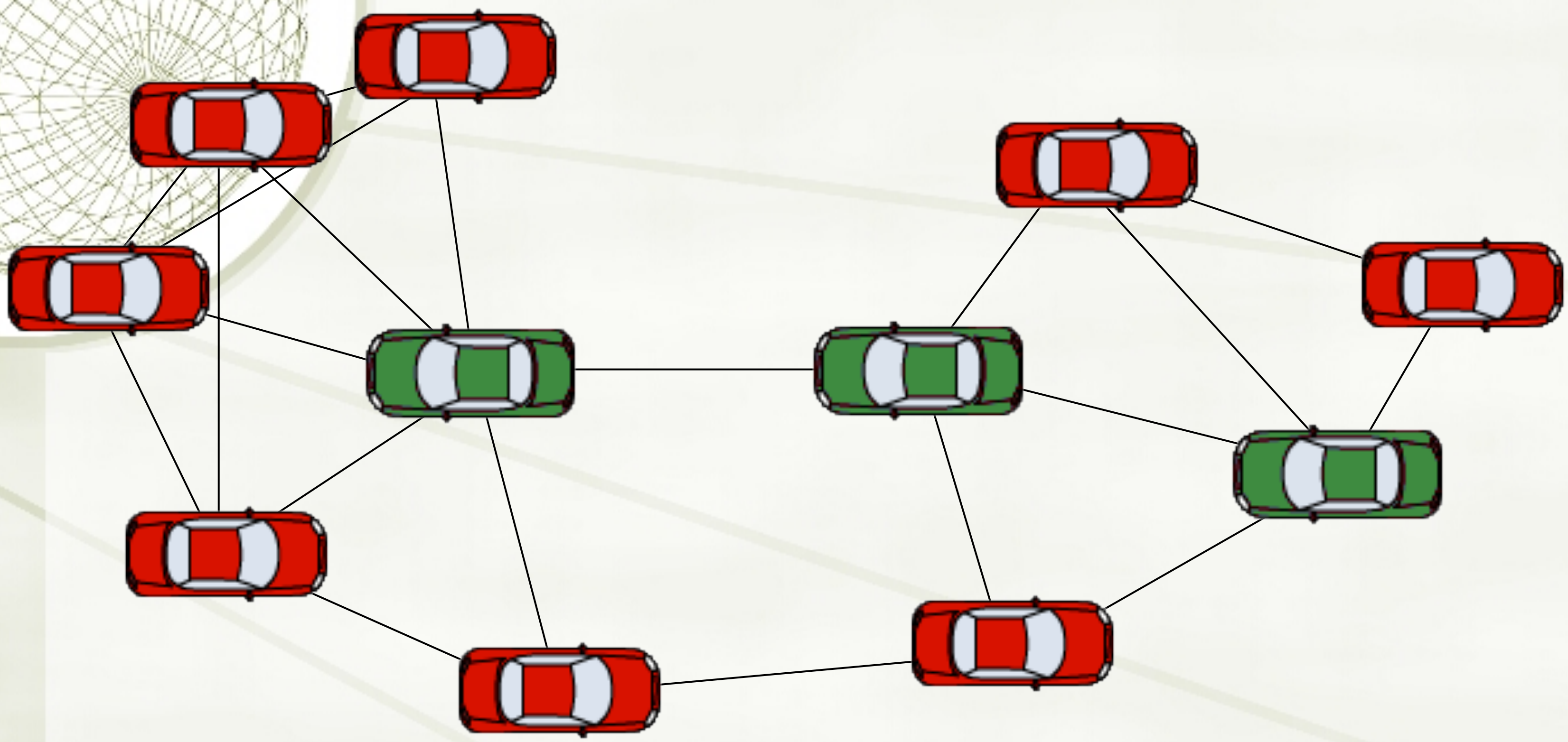
Drawbacks of existing geocasting

- Do not resolve any *temporary disconnection* from the source node. They all assume that vehicles belong to the same connected cluster, except:
- [FM08]: Forced additional static flood repeat time parameter with retransmission at sole initiating node in each cycle. It also fails because:
  - there is no dynamic mechanism to restart flooding upon discovery of new neighbors
  - additional flooding may not be necessary
  - Probability *p* does not adjust quickly to the local network density

Parameterless reliable broadcasting

- Ross, Ruiz, Stojmenovic, IEEE Transactions on Mobile Computing, January 2012
- Beacons used by cars to decide whether or not they belong to a connected dominating set (CDS)
- Vehicles in CDS use shorter waiting period before possible retransmissions
- Identifiers of circulated broadcast messages are added to beacons as *piggybacked acknowledgements*

Connected Dominating Sets: **CDS**



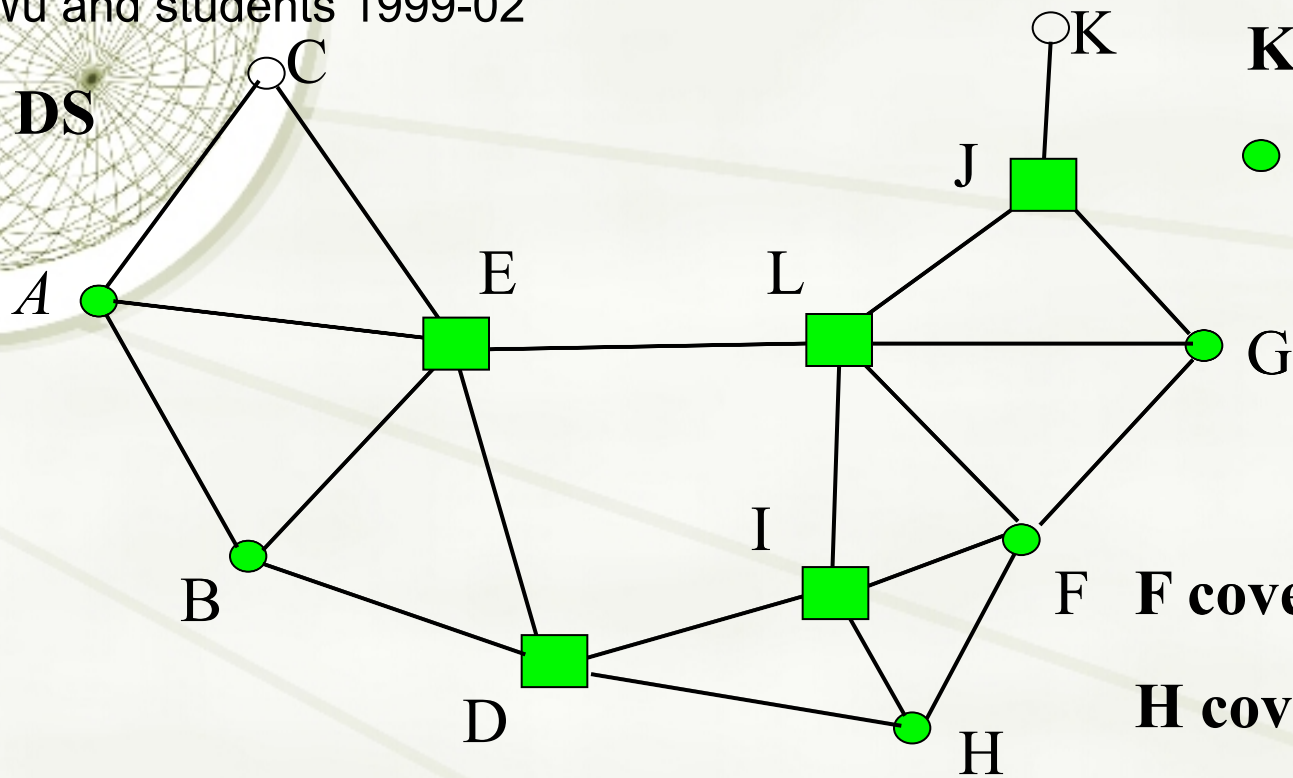
Each node either in *dominating set* or has a neighbor from dominating set

Flooding reduced if only nodes in ***connected dominating set*** nodes retransmit

Dominating sets by *covering*

Jie Wu and students 1999-02

■ **DS**



Keys A<B<C<….

● **covered**

F covered by I and L

H covered by I

○ **Not intermediate** (no two unconnected neighbors)

F covered by I, L, … ← I, L, … connected and any neighbor of F is neighbor of one of I, L,.. and key(F) < min (key(I), key(L),…)

Compatibility with DSRC ?

- Solution requires piggybacking list of received broadcast to periodic beacons
- Not possible or limited with DSRC standard
- Alternative: PBSM
  - (Parameterless Broadcasting from Static to Mobile)
  - Khan, Stojmenovic, Zaguia, 2008 (2-hop variant)
- No acknowledgments in beacons
- High message reception failure rate causes lack of intelligence in retransmission decisions
- Low reliability and/or high delay even with extensive retransmissions

Some Conclusions

- Intelligent Transportations Systems call for new vehicles, capable of communicating
  - among themselves
  - with/through the system infrastructures
- VANETs provide an answer for the core of ITSs
- There are many challenges, several solutions
- Still very many open problems

- Info: basagni@ece.neu.edu, petrioli@di.uniroma1.it