CIS373 - Pervasive Computing
VANETs

Erik Fredericks // frederer@gvsu.edu

Adapted from materials provided by Xiang Cao

Emergence of Vehicular Networks

In 1999, US' FCC allocated 5.850-5.925 GHz band to promote safe and efficient highways

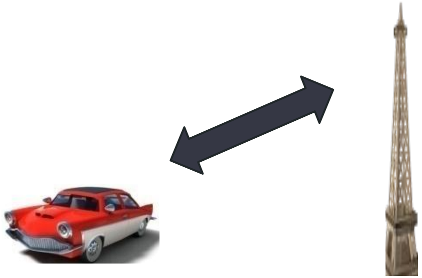
- Intended for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication
- EU's Car2Car Consortium has prototypes in March 2006
  - http://www.car-to-car.org/
- Radio standard for Dedicated Short-Range Communications (DSRC)
- Based on an extension of 802.11

Desirable system properties

- Data collection and distribution in a **local** environment
- **Low** information delivery **latency**
- **Cheap** deployment and communication
- **Secure and privacy preserving**

Probable solutions

- Cellular ? **Service fees** ❌
- Satellite ? **High latency** ❌
- Vehicular Networks ?



What is a vehicular network?

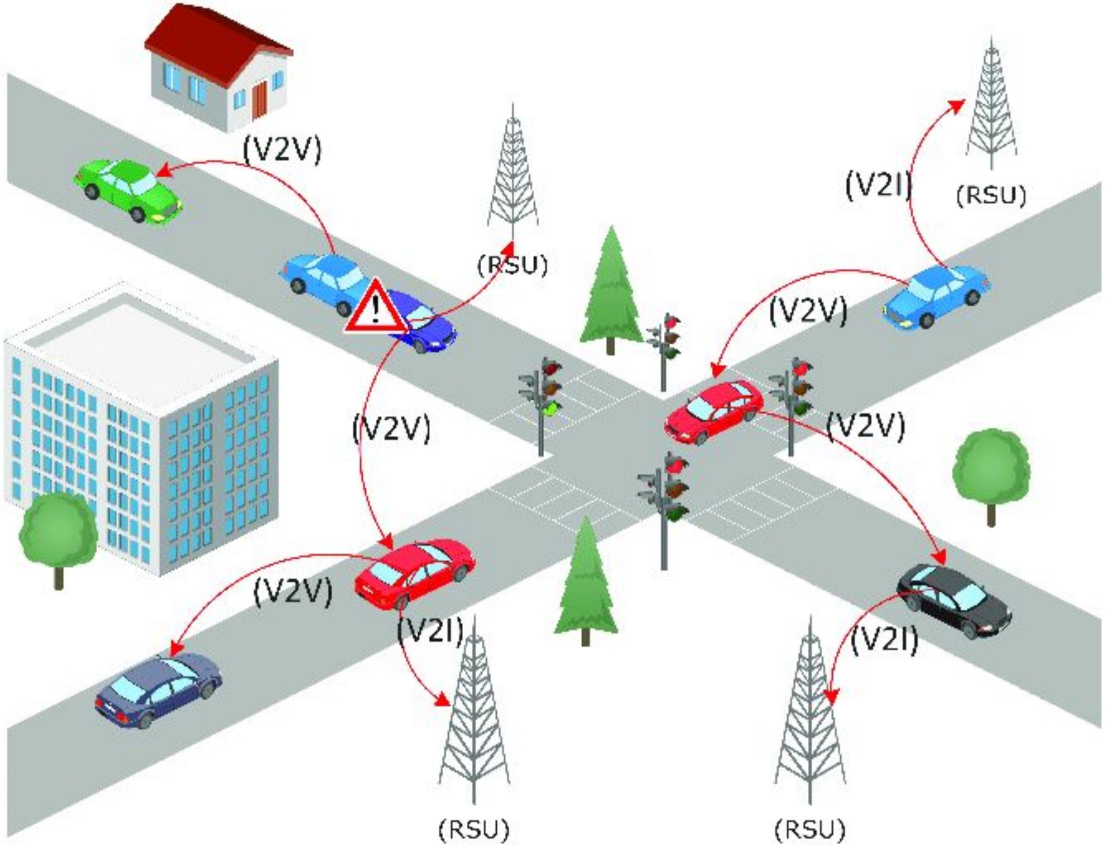
https://www.youtube.com/watch?v=PVwKUGj1d0E
https://www.youtube.com/watch?v=14fOqMBn9aw

Vehicular ad-hoc network (VANET)

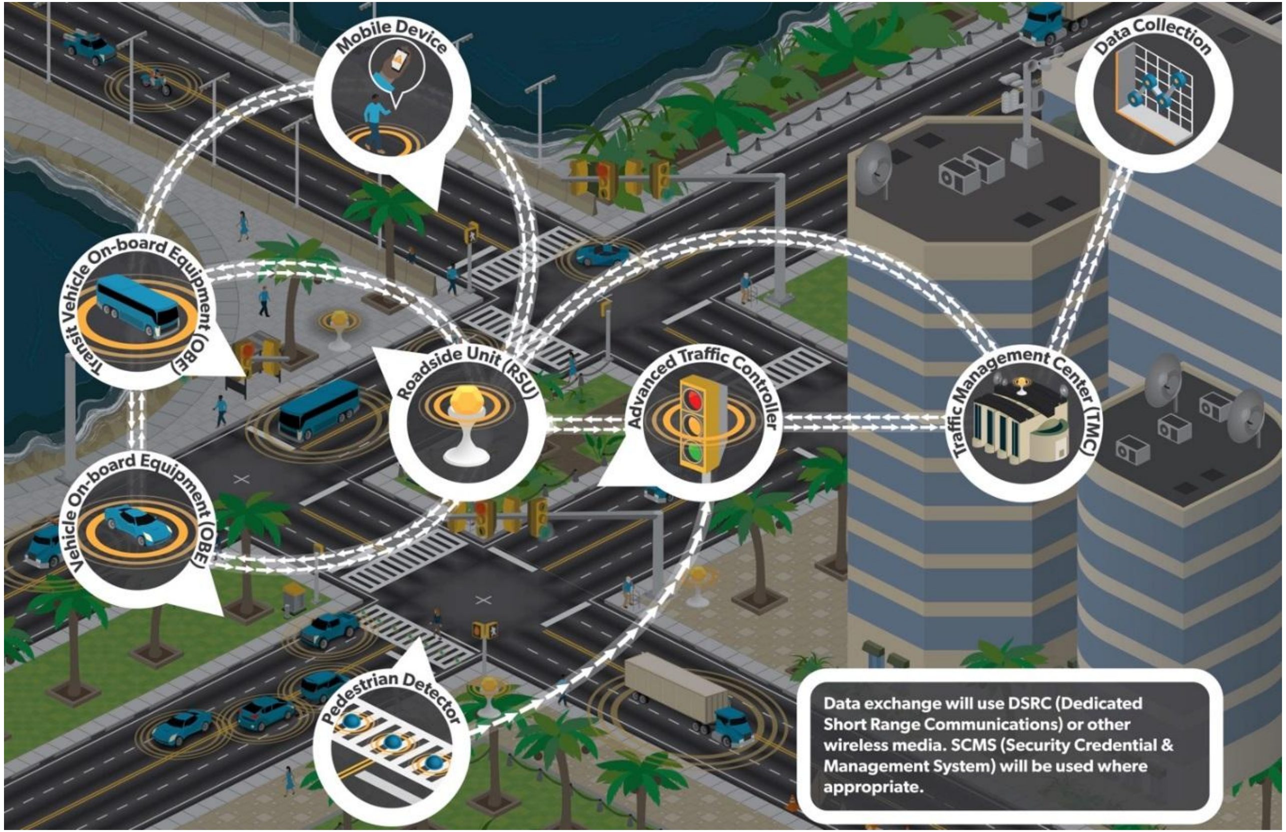
- Vehicles are equipped with sensing, computing and wireless devices

- Vehicles talk to roadside infrastructure (V2I) and other vehicles (V2V)

- Has all the desirable properties from the last slide



Connected Vehicles



Who is working on vehicular networks?

Automobile Industry

DaimlerChrysler, GM, BMW, Toyota, VW, Nissan, Ford

US DOT

Projects

- Vehicle to Infrastructure test-bed, SFO
- PATH, CarTel, DieselNet (USA)
- FleetNet, NOW, CarTalk2000 (Europe)

But … why VANETs? Safety!

In US:

- Motor vehicle crashes are costly and increasing
- Human toll: **32,675** people died in 2014
- **$836 billion dollars a year** to society
- A leading cause of death for 4 to 34 year olds
- U.S. falling behind other European countries and Japan

← NEWS ARCHIVE

NHTSA Estimates Traffic Fatalities Declined 4.4% in the First Nine Months of 2024

Marks 10 straight quarters of declines in fatalities

Share: f X in ✉ Language: English

December 20, 2024 | Washington, DC

The National Highway Traffic Safety Administration today released its early estimates of traffic fatalities for the first nine months of 2024, estimating that traffic fatalities declined for the 10th straight quarter. An estimated 29,135 people died in traffic crashes, representing a decrease of about 4.4% as compared to 30,490 fatalities projected for the first nine months of 2023.

Preliminary data from the Federal Highway Administration show that vehicle miles traveled in the first nine months of 2024 increased by 19.7 billion miles, about a 0.8% increase from the same time last year. More miles driven combined with fewer traffic deaths resulted in a fatality rate of 1.18 fatalities per 100 million VMT, down from the projected rate of 1.24 fatalities per 100 million VMT in the first nine months of 2023.

More of the why

Combat the awful side-effects of road traffic

- In the EU, around 40,000 people die yearly on the roads
    - More than 1.5 million are injured

- Traffic jams generate a tremendous waste of time and of fuel
- Driver error cited as critical reason in 94% of crashes

Most of these problems can be solved by providing appropriate information to the driver or to the vehicle

Why?

Efficiency

- Traffic jams waste time and fuel
- In 2003, US drivers lost a total of 3.5 billion hours and 5.7 billion gallons of fuel to traffic congestion

Profit

- Safety features and high-tech devices have become product differentiators

Auto-driving

- Auto-braking
- Adaptive cruise control
- Autonomy

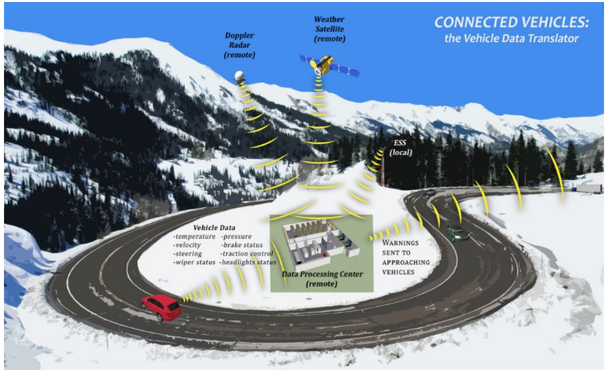
In addition to Safety, Connected Vehicles will Improve Mobility, Road Weather Info, and the Environment

Mobility

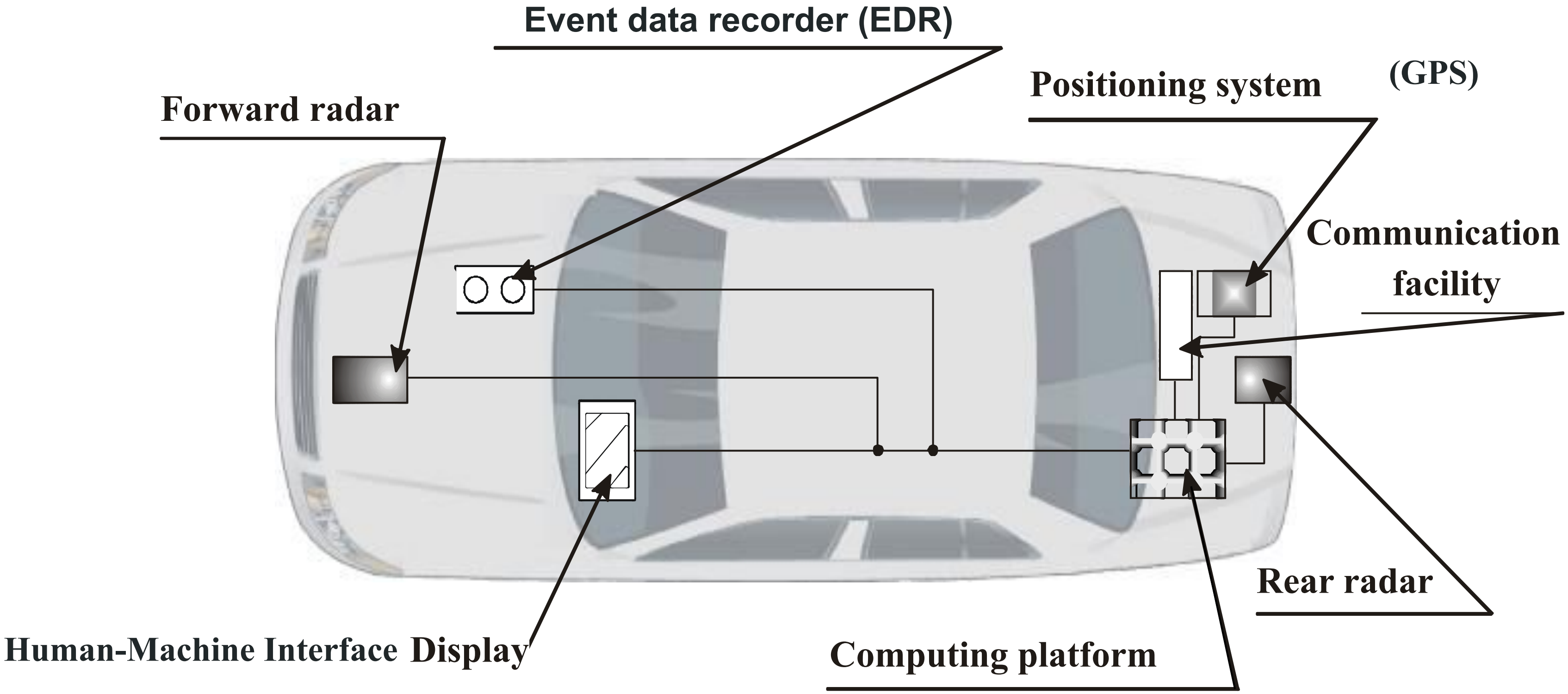
- 5.5 billion hours of travel delay
- $121 billion cost of urban congestion

Environment

- 2.9 billion gallons of wasted fuel
- 56 billion lbs of additional CO2

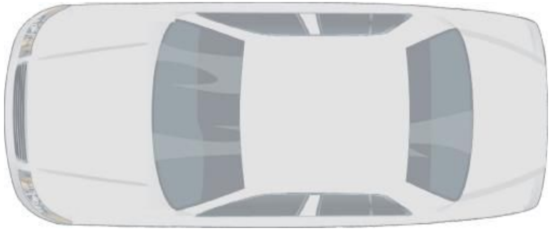


A Modern Vehicle



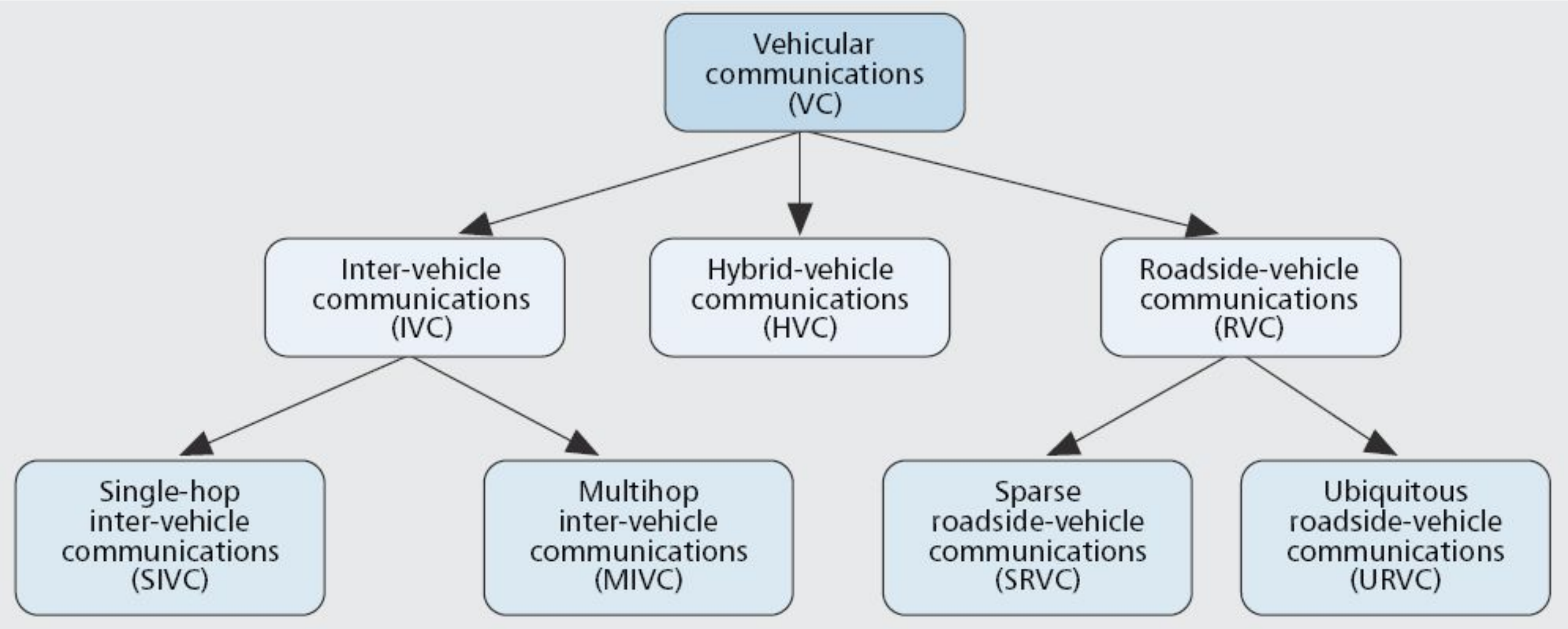
A modern vehicle is a network of sensors/actuators on wheels!

OBU (On Board Unit) for each equipped vehicle (Assumptions)



- A **central processing unit (CPU)** that implements the applications and communication protocols
- A **wireless transceiver** that transmits and receives data to/from the neighboring vehicles and roadside
- A **GPS receiver** that provides relatively accurate positioning and time synchronization information
- Appropriate **sensors** to measure the various parameters that have to be measured and eventually transmitted
- An **input/output interface** that allows human interaction with the system

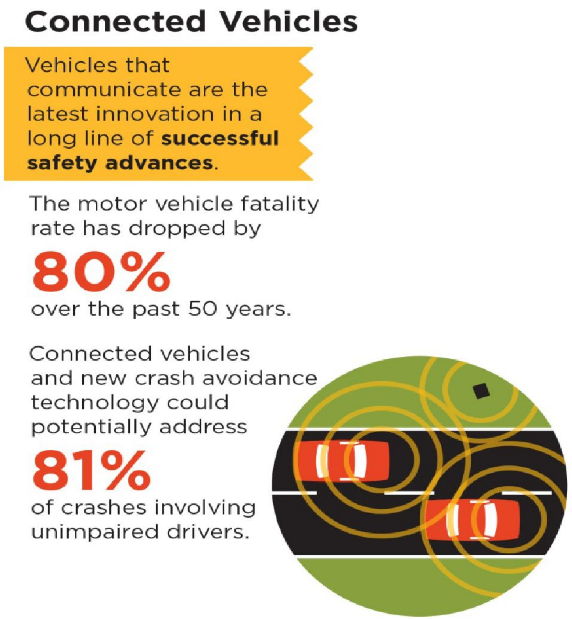
A taxonomy of vehicular communication systems



Inter-vehicle communication (IVC) Systems

IVC systems are completely infrastructure-free; only onboard units (OBUs)

- Also called Vehicle-to-Vehicle (V2V) Communications



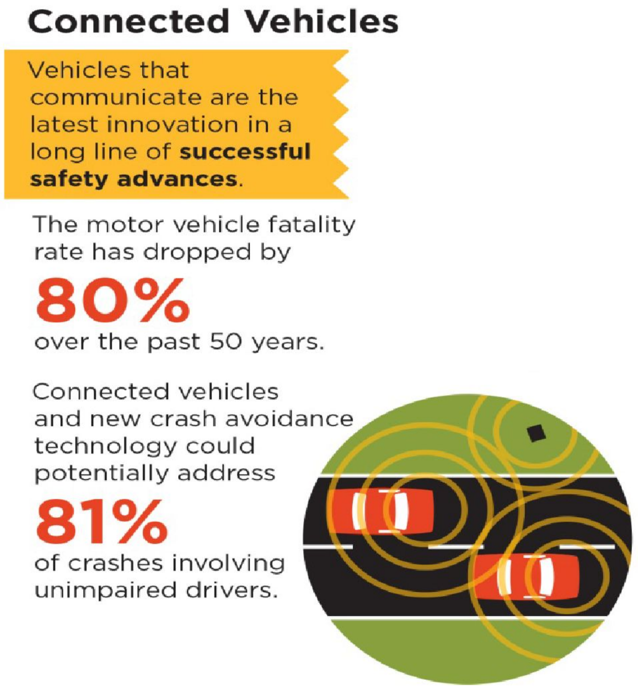
Inter-vehicle communication (IVC) Systems

Vehicle-to-Vehicle (V2V) Communications

- Allows nearby vehicles to **exchange data** on their position and use these data to warn drivers of potential collisions

- V2V technologies are capable of warning drivers of potential collisions that are not visible to sensors
  - Stopped vehicle blocked from view
  - Moving vehicle at a blind intersection
  - …

- Unprecedented and transformative technology: Extendable to other vehicle types, road users, and infrastructure

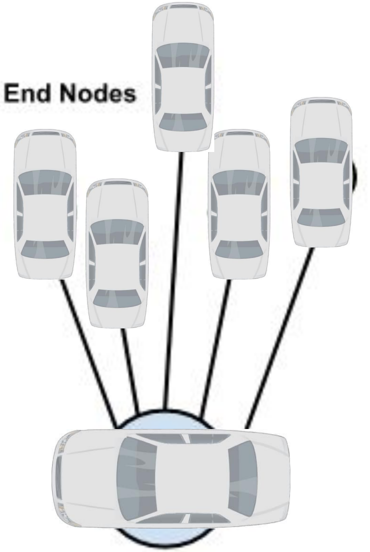


IVC Systems

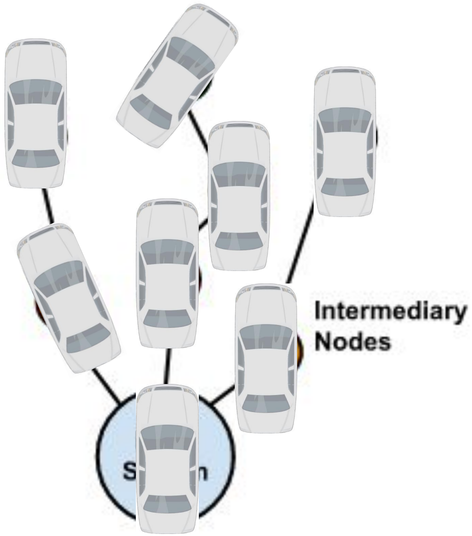
Single-hop and multi-hop IVCs (SIVCs / MIVCs)

Discussion

- Applications/examples for single-hop inter-vehicle communication (IVC)



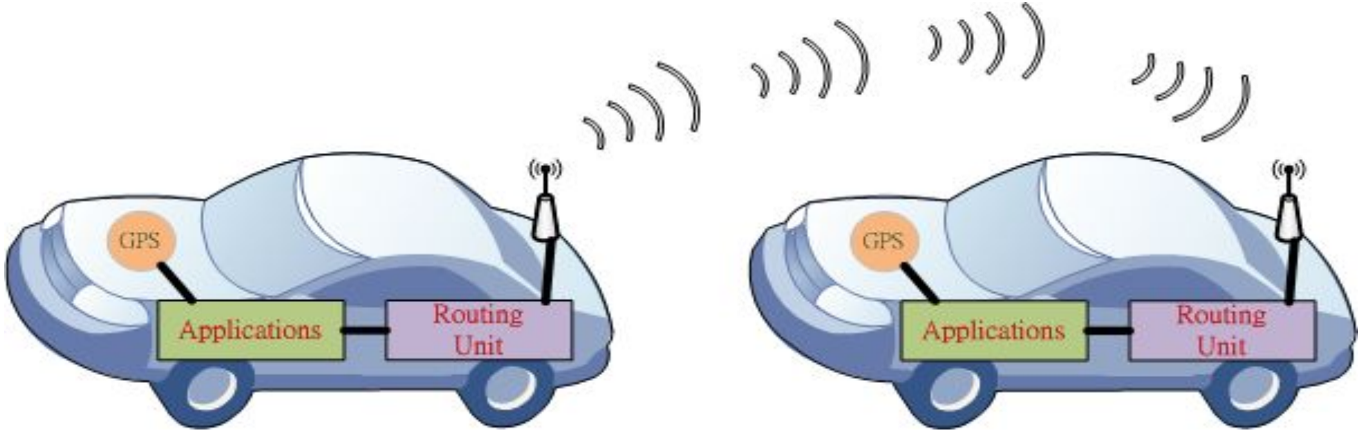
- Applications/examples for multi-hop inter-vehicle communication (IVC)



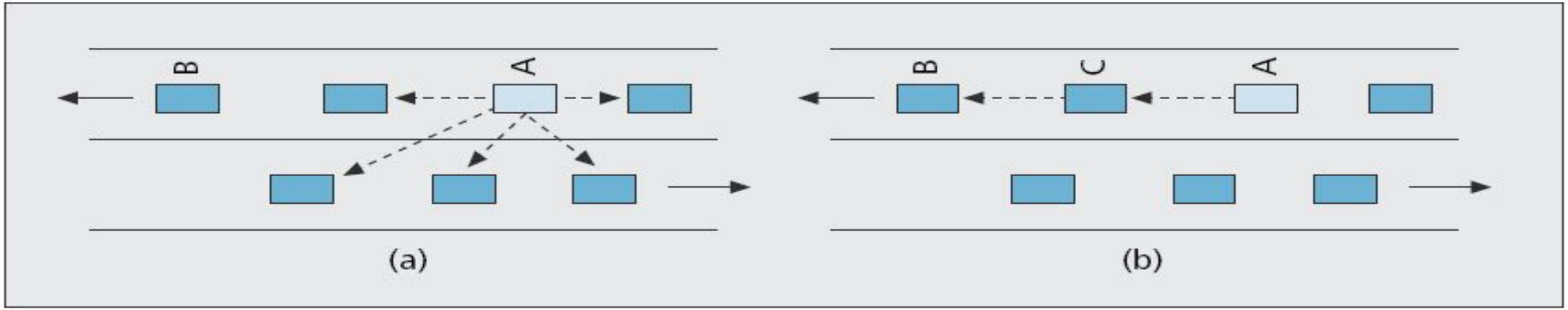
IVC systems (SIVC / MIVC)

SIVC systems are useful for applications requiring **short-range communications** (e.g., lane merging, automatic cruise control)

MIVC systems are **more complex than** SIVCs but can also support applications that require **long-range communications** (e.g., traffic monitoring)



IVC systems



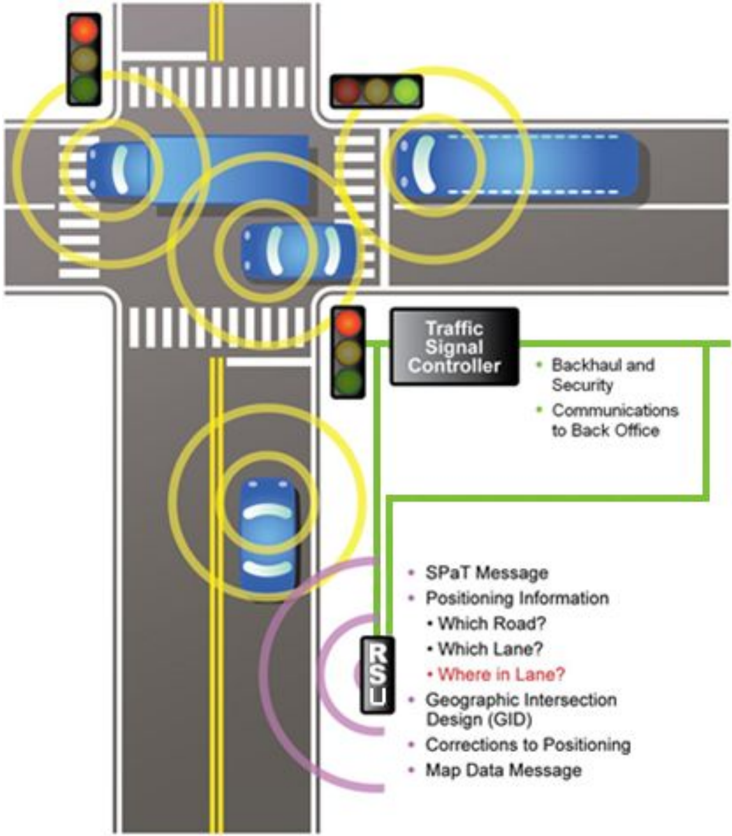
a) Single-hop IVC system

b) Multi-hop IVC system

Roadside-to-Vehicle Communication (RVC) Systems

RVC systems assume that all communications take place between **roadside infrastructure** (including roadside units [RSUs]) and **vehicles**

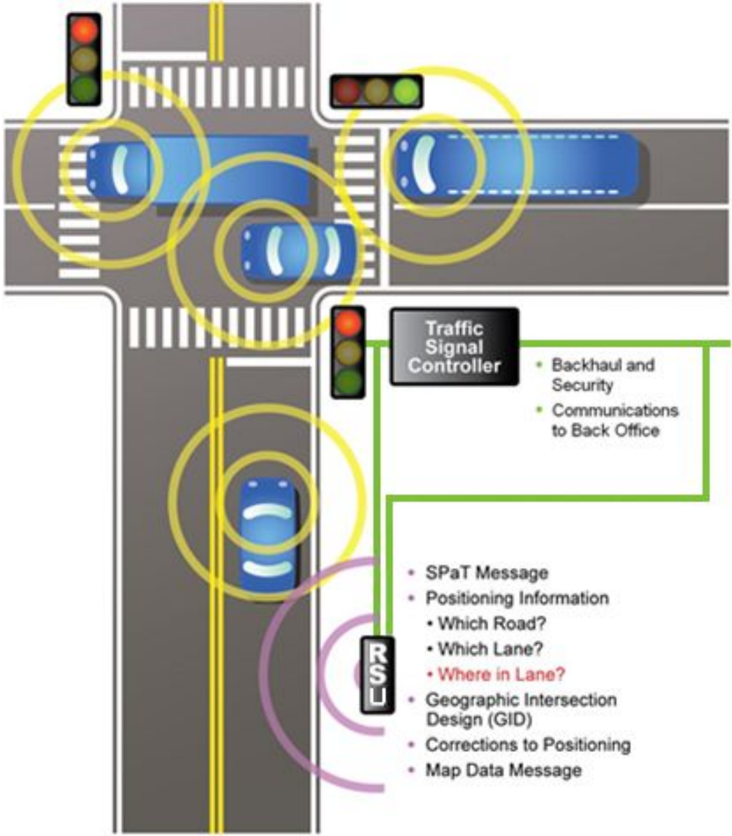
- Also called Vehicle-to-Infrastructure (V2I) Communications
- Could be used to inform drivers about weather, traffic, work zones, and even potholes
- Allows for coordinated signal timing and enhanced parking information systems that may improve urban traffic flow



Roadside-to-Vehicle Communication (RVC) Systems

Depending on the application, two different types of infrastructure can be distinguished

- Sparse RVC (SRVC) system
- Ubiquitous RVC (URVC) system

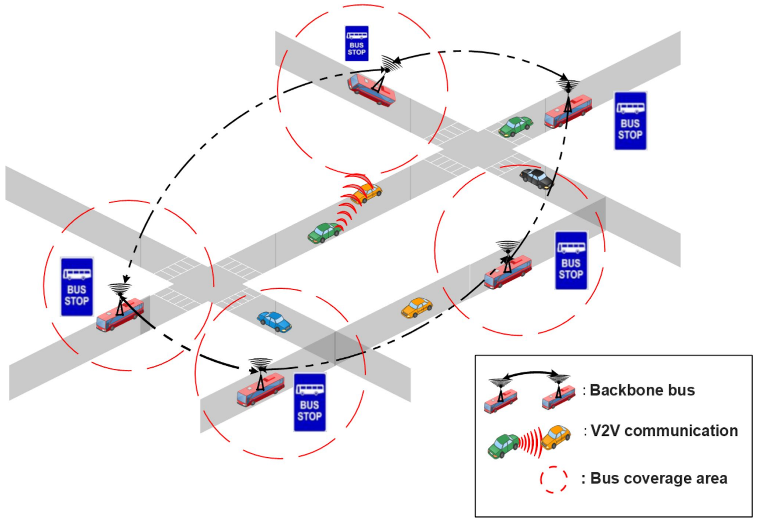


RVC Systems – SRVC

SRVC systems are capable of providing communication services at hot spots.

Examples:

- A busy intersection scheduling its traffic light
- A gas station advertising its existence (and prices)
- Parking availability at an airport



An SRVC system can be deployed **gradually**, thus not requiring substantial investments before any available benefits.

RVC Systems - URVC

Providing **all roads with high-speed communication** would enable applications unavailable with any of the other systems.

- Unfortunately, a URVC system may require **considerable investments** for providing **full** (even significant) coverage of existing roadways
  - Especially in large countries like the United States

Hybrid Vehicular Communication (HVC) Systems

HVC systems are proposed for **extending the range** of RVC systems

- Vehicles communicate with roadside infrastructure **even when they are not in direct wireless range** by using other vehicles as mobile routers

- An HVC system enables the same applications as an RVC system with a **larger transmission range**.

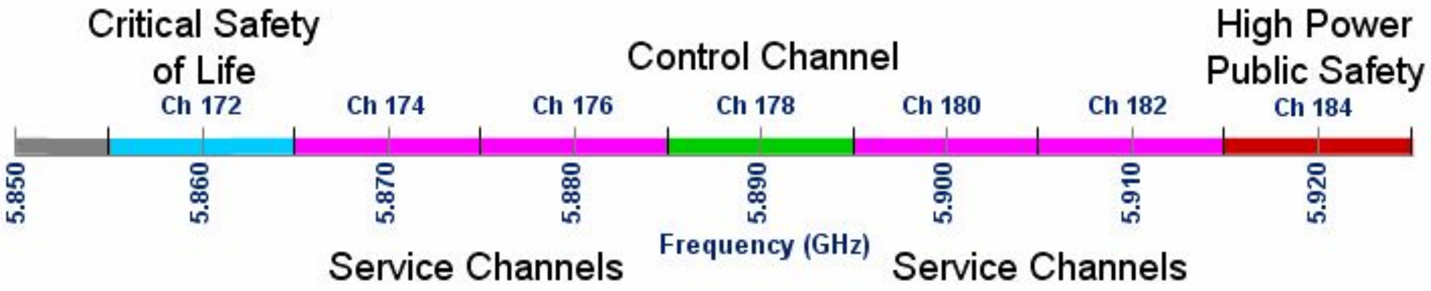
- The main advantage is that it requires **less roadside infrastructure**.

- However, one disadvantage is that **network connectivity may not be guaranteed in scenarios** with low vehicle density.

DSRC Spectrum Allocation

In 1999, the U.S. Federal Communication Commission allocated 75MHz of Dedicated Short Range Communications (DSRC) spectrum at 5.9 GHz to be used exclusively for vehicle-to-vehicle and infrastructure-to-vehicle communications.

- Based on 802.11a PHY and 802.11 MAC
- Supports high mobility of vehicles (120 mph)
- High data rate (27 Mbps), short range (1 km), multi-channel (7)



Discussion

WSN vs. VANET

- Common features

- Differences

Parameter	WSN	VANET
Power	Limited	Not limited
Computational capability	Limited	Not limited
Memory	Limited	Not limited
Node deployment	uniformly distributed	Changeable density

VANETs vs. WSNs

- Common features
  - Wireless communication
  - Collect and transmit data
- Differences
  - Mobility
    - WSNs: most of them are static
    - VANETs: mobile and fast changing; can follow some trajectory
  - Energy
    - WSNs: energy saving is an important consideration
    - VANETs: usually, do not consider energy consumption
  - Infrastructure
    - WSNs: lack infrastructure; self-organized
    - VANETs: with infrastructure (Roadside unit)

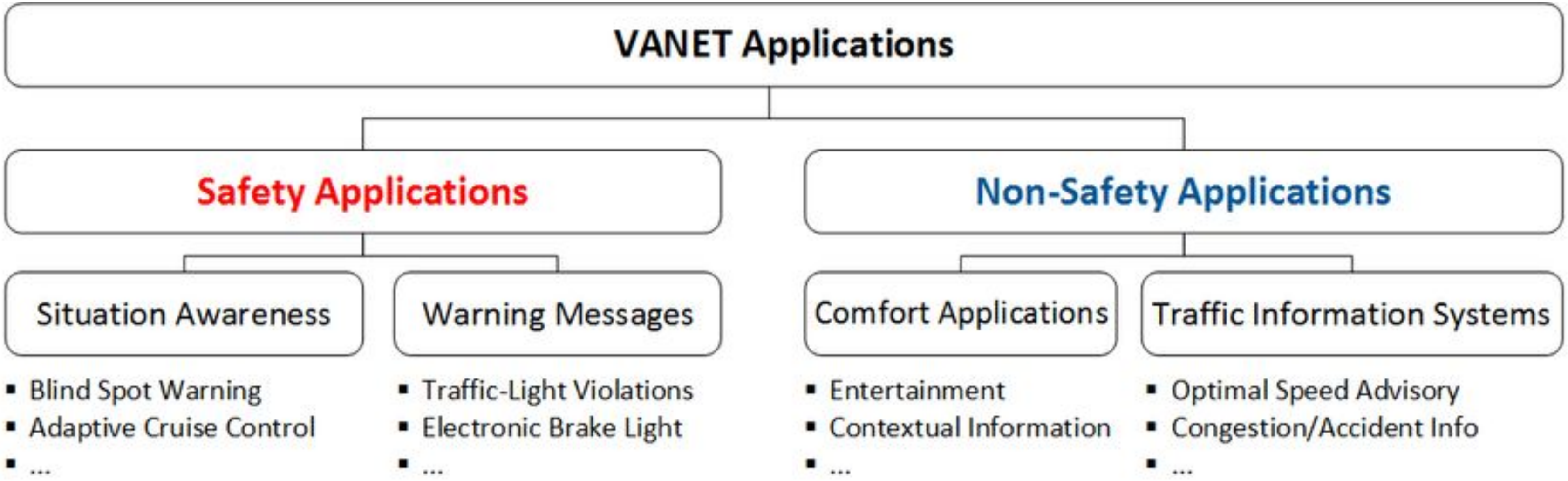
Applications for VANETs

Public Safety Applications

Traffic Management Applications

Traveler Information Support Applications

Comfort Applications

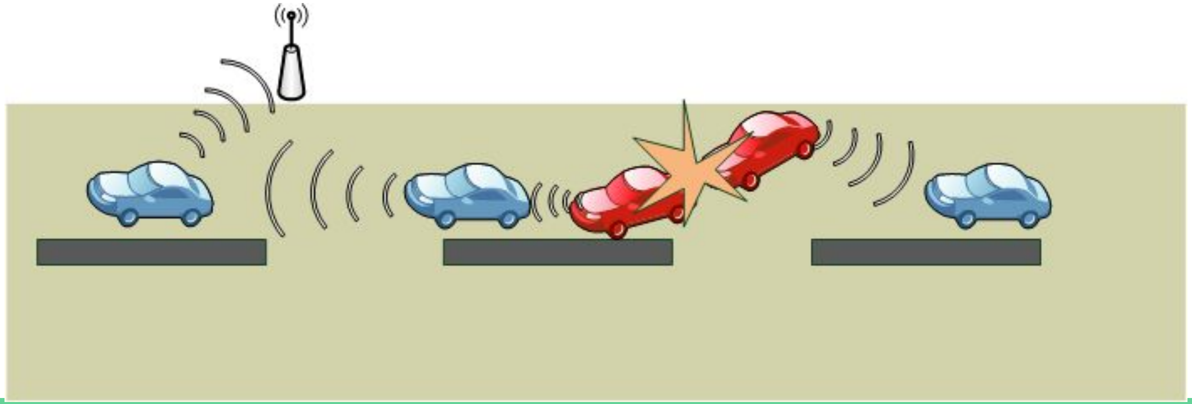


Public Safety Applications

Public safety applications are geared primarily toward **avoiding accidents** and **loss of life** of the occupants of vehicles.

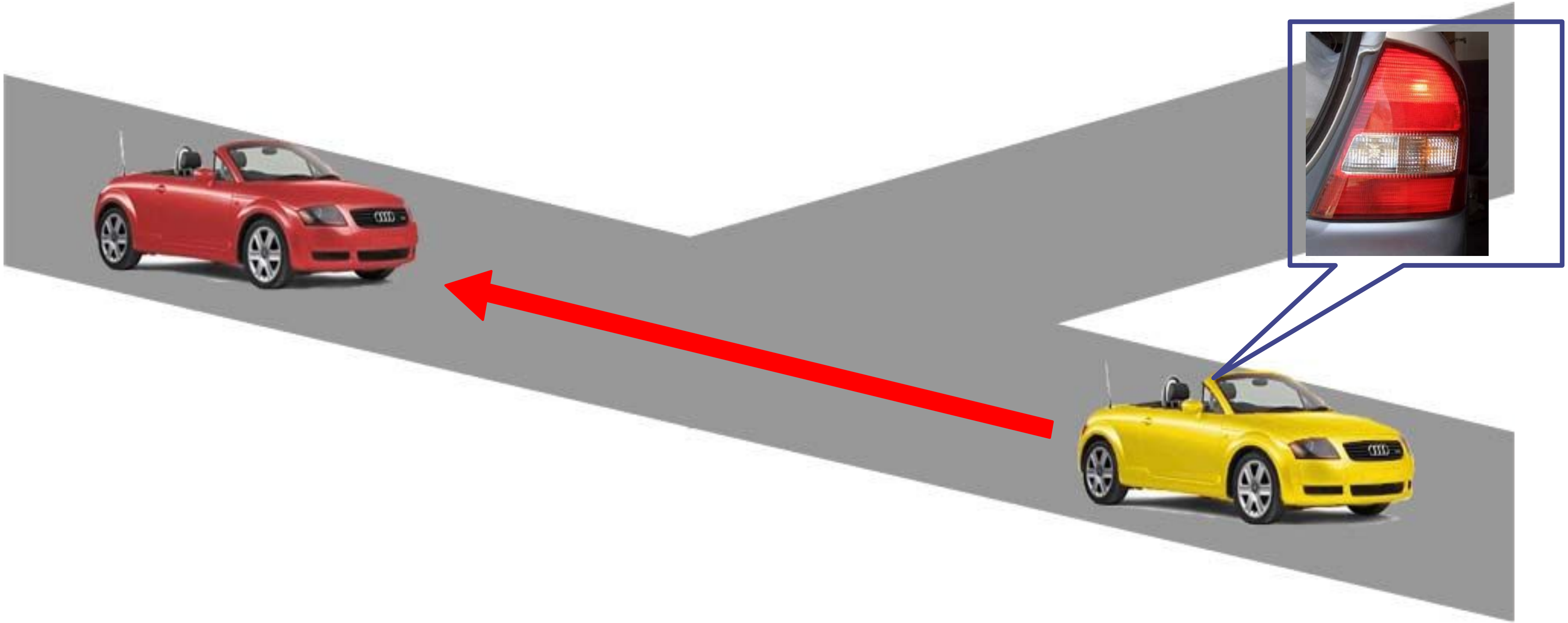
Collision warning systems have the potential to reduce the number of vehicle collisions in several scenarios.

- System sends the warning message immediately after an accident is detected



Deceleration Warning

Prevent potential collision when a vehicle decelerates rapidly



Traffic Management Applications

Improving traffic flow, thus reducing both congestion as well as accidents resulting from congestion, and reducing travel time:

- Traffic monitoring
- Traffic light scheduling
- Emergency vehicles

Platooning (i.e., forming tight columns of vehicles closely following each other on highways)

- https://www.youtube.com/watch?v=iNTKqh7i5jQ
- https://www.youtube.com/watch?v=POEAQxc1nzY

Passing and lane change assistance may reduce or eliminate risks during these maneuvers, since they are often the source of serious accidents.

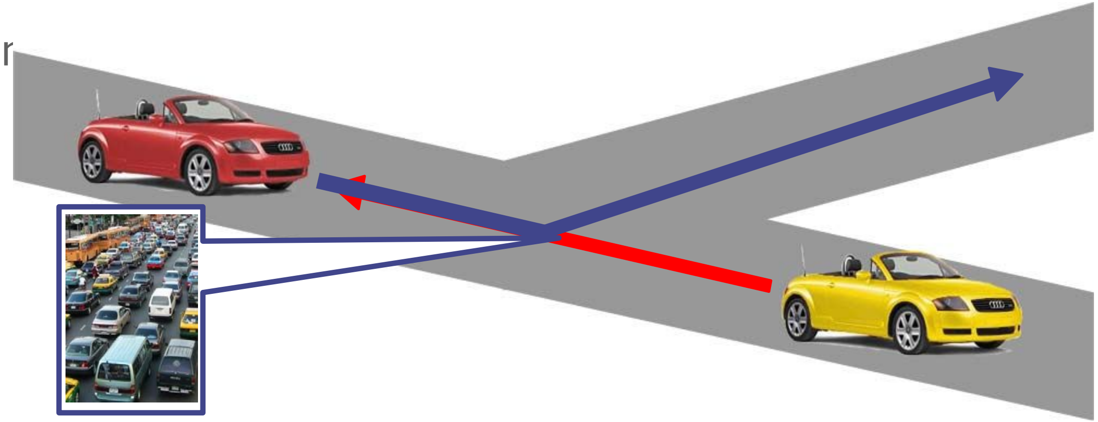
Congestion Detection

Vehicles detect congestion when:

- `# Vehicles > Threshold 1`
- `Speed < Threshold 2`

Relay congestion information

- Hop-by-hop message forwardir
- Other vehicles can choose alternate routes



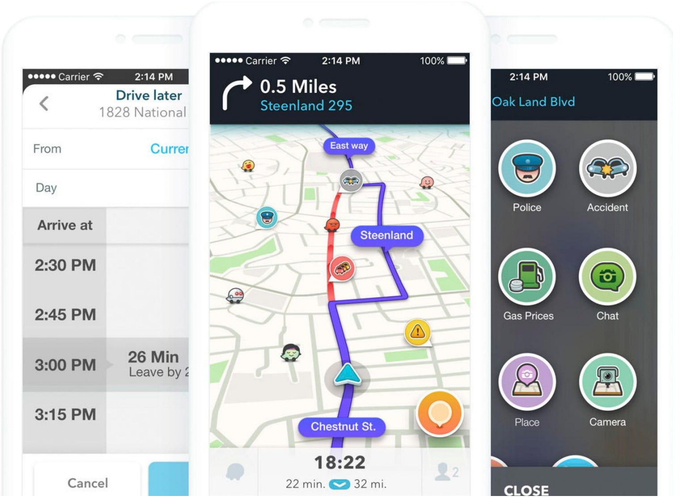
Traveler Information Support Applications

Local information such as:

- Local updated maps, the location of gas stations, parking areas, and schedules of local museums can be downloaded from selected infrastructure places or from other “local” vehicles

- Advertisements may be sent to approaching vehicles

Road warnings of many types (e.g., ice, oil, or water on the road, low bridges, or bumps) may easily be deployed by authorities simply by dropping a beacon in the relevant area.



Comfort Applications

Targeted vehicular communications allow localized communications (potentially multi-hop) between two vehicles

- Voice, instant messaging, or similar communications may occur.

Multimedia files such as music, news, audio books, pre-recorded shows can be uploaded to the car’s entertainment system while the car is in the garage.

Passengers can get access to entertainment via communicating to Road Side Units.

Discussion:

Challenges in **data dissemination** in vehicular networks?

Data Dissemination

Vehicular networks need to handle large amounts of data (emergency messages, videos, etc)

How do we efficiently disseminate this information?

Characteristics

- High mobility
- Dynamic topology
- Receivers are unknown

→ Maintaining routing tables is difficult

- Large scale
- High density

→ Scalability

- High loss rate

→ Dealing with partitions

Challenges

Maintaining routing tables is difficult

Scalability

Dealing with partitions

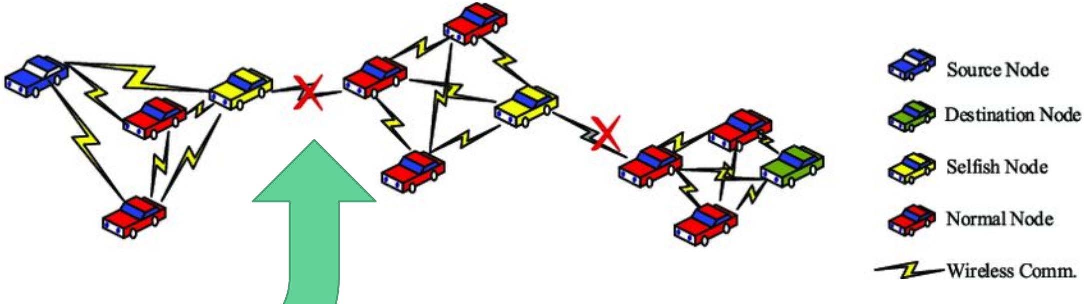
Classification of Dissemination Approaches

V2I / I2V dissemination

- Push based
- Pull based

V2V dissemination

- Simple Flooding
- Forwarding
  - “Simple” forwarding
  - Advanced forwarding
- Other approaches



How to deal with network partitions?

V2I / I2V dissemination: **Push** based dissemination

RSU pushes out the data to everyone

Applications: Traffic alerts, Weather alerts, Ads

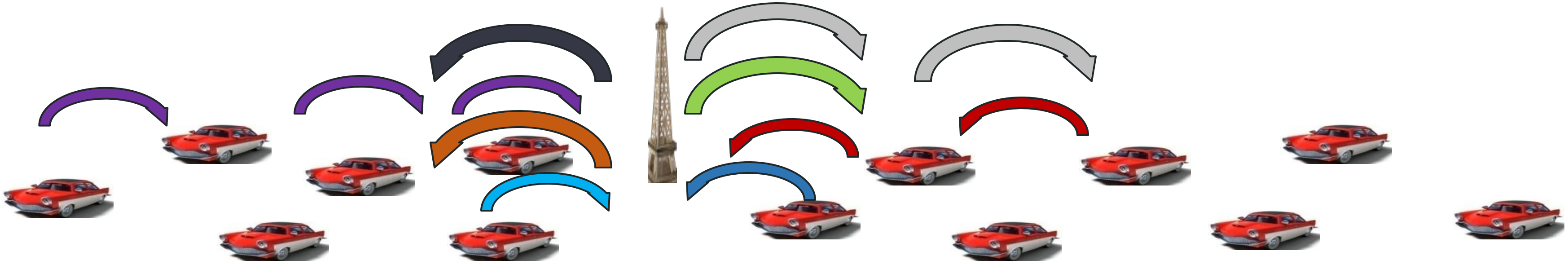
Why is this useful?

- Good for popular data
- No cross traffic → Low contention

Drawback

- Everyone might not be interested in the same data

V2I / I2V dissemination: **Pull** based dissemination



Request – Response model

- Applications: Email, Webpage requests

Why is this useful?

- For unpopular / user-specific data

Drawback

- Lots of cross traffic Contention, Interference, Collisions

V2V dissemination: Simple Flooding

Basic Idea

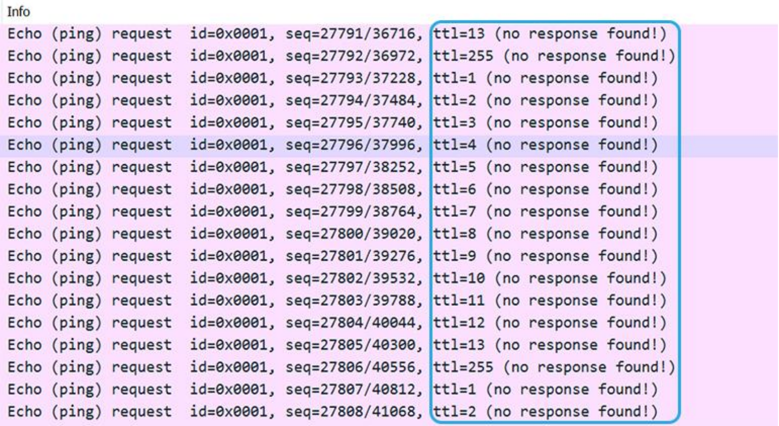
- Broadcast *generated* and *received* data to neighbors
- Usually everyone participates in dissemination

Advantages

- “Good” for delay sensitive applications
- Suitable for *sparse* networks

Key Challenges

- How to avoid **broadcast storm** problem?



Info
Echo (ping) request id=0x0001, seq=27791/36716, ttl=13 (no response found!)
Echo (ping) request id=0x0001, seq=27792/36972, ttl=255 (no response found!)
Echo (ping) request id=0x0001, seq=27793/37228, ttl=1 (no response found!)
Echo (ping) request id=0x0001, seq=27794/37484, ttl=2 (no response found!)
Echo (ping) request id=0x0001, seq=27795/37740, ttl=3 (no response found!)
Echo (ping) request id=0x0001, seq=27796/37996, ttl=4 (no response found!)
Echo (ping) request id=0x0001, seq=27797/38252, ttl=5 (no response found!)
Echo (ping) request id=0x0001, seq=27798/38508, ttl=6 (no response found!)
Echo (ping) request id=0x0001, seq=27799/38764, ttl=7 (no response found!)
Echo (ping) request id=0x0001, seq=27800/39020, ttl=8 (no response found!)
Echo (ping) request id=0x0001, seq=27801/39276, ttl=9 (no response found!)
Echo (ping) request id=0x0001, seq=27802/39532, ttl=10 (no response found!)
Echo (ping) request id=0x0001, seq=27803/39788, ttl=11 (no response found!)
Echo (ping) request id=0x0001, seq=27804/40044, ttl=12 (no response found!)
Echo (ping) request id=0x0001, seq=27805/40300, ttl=13 (no response found!)
Echo (ping) request id=0x0001, seq=27806/40556, ttl=255 (no response found!)
Echo (ping) request id=0x0001, seq=27807/40812, ttl=1 (no response found!)
Echo (ping) request id=0x0001, seq=27808/41068, ttl=2 (no response found!)

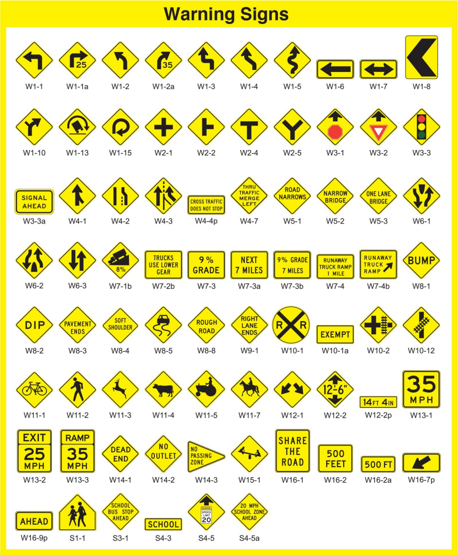
Simple Flooding

For Inter-Vehicle Communication Systems (IVC), flooding is a quick (but may not be an efficient) method to spread messages

Broadcast storm

- In a broadcasting network, the situations of **contentions and collisions** often take place if an efficient broadcasting scheme is not used
- The result incurred by broadcasting is called broadcast storm.
- Simple flooding can cause the broadcast storm.

Broadcast Storm



In VANETs, broadcast is used for disseminating the traffic information :

- Detour route
- Accident alert
- Construction warning
- etc…

Some messages will be periodically broadcasted by roadside unit (RSU) for several hours or even some days.

- The problem of broadcast storm in VANET is more serious than that in other wireless networks!

V2V dissemination: Forwarding

Basic Idea

- Instead of flooding the network, select a forwarding node (next hop)
- Forwarding node forwards the data to next hop and so on

Advantages

- Reduced contention Scalable for dense networks

Forwarding in VANETs

Trade-off between robustness and efficiency.

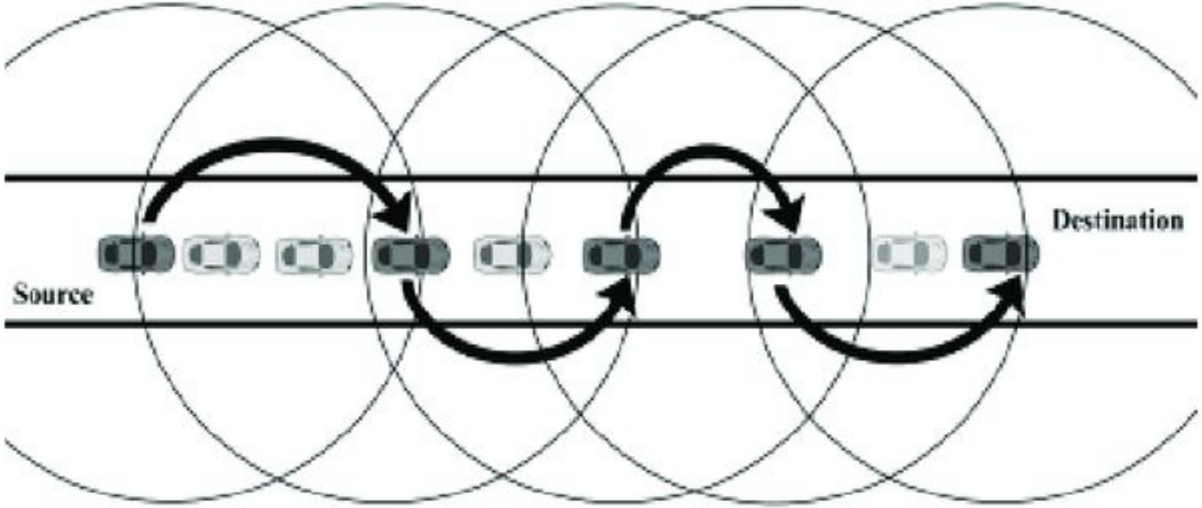
- **Robustness**: more vehicles can receive the messages to forward them, making sure messages will be delivered to destinations.
- **Efficiency**: try to reduce the number of messages in the entire network to reduce the network congestion

The important concern in designing a forwarding scheme in VANET.

- How to design forwarding algorithm to efficiently transmit messages to the target nodes.
- To design a forwarding algorithm to make the desired vehicles to receive the message as soon as possible.

Fundamental question:

- Which ones are the forwarding nodes?


Source
Destination

Forwarding schemes

“Simple” strategies to select the forwarding nodes:

- Select the node farthest from source
- Select the node closest to the destination

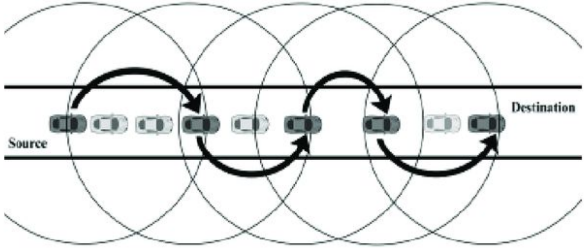
Discussion:

- How to technically achieve those?

Forwarding schemes

"Simple" strategies to select the forwarding nodes:

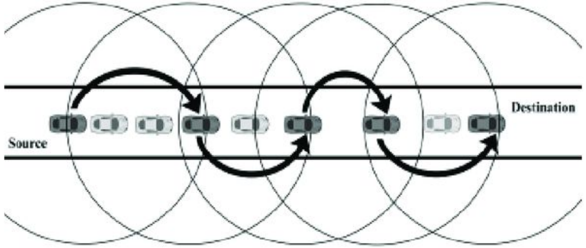
- Select the node farthest from source
    - The source sends the message containing its location.
    - When other nodes receive the message, they need to calculate their distances to the source.
    - Then they should negotiate and decide who is the farthest one from the source.
    - Finally, the farthest one will forward the message.



Forwarding schemes

“Simple” strategies to select the forwarding nodes:

- Select the node closest to the destination
    - We **assume** we know the location of the destination.
    - When nodes receive the message from the source, they need to calculate their distances to the destination.
    - Then they should negotiate and decide who is the closest one from the destination.
    - Finally, the closest one will forward the message.



Forwarding schemes

“Simple” strategies to select the forwarding nodes:

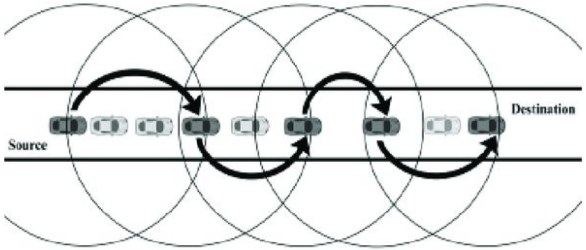
- *Select the node farthest from source*
- *Select the node closest to the destination*

Advanced forwarding strategies to select the forwarding nodes:

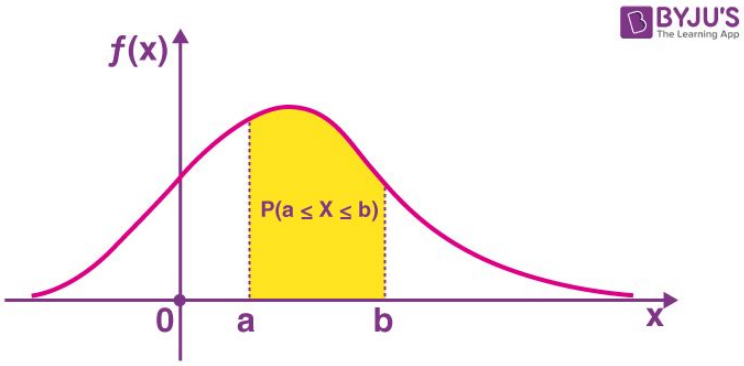
- Probability-based
- Location-based
- Neighbor-based
- Cluster-based

Advanced Forwarding

1. Probability-based:
   - A given PDF determines the decision, for example depending on the number of copies a node has received (to decide the number of neighbors for each node)
   - The strategy is often dynamic.

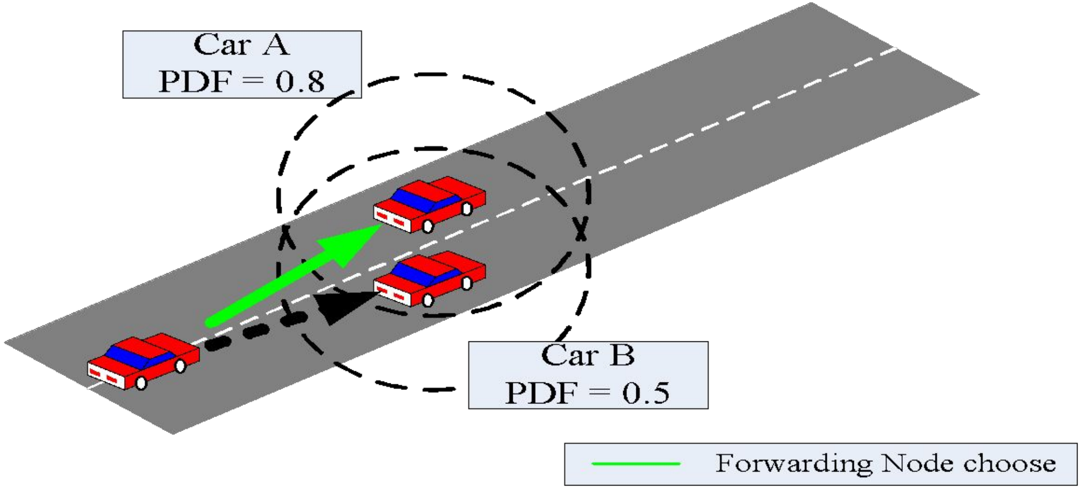


PDF = probability distribution function



Advanced Forwarding

Probability-based



A>B

Advanced Forwarding

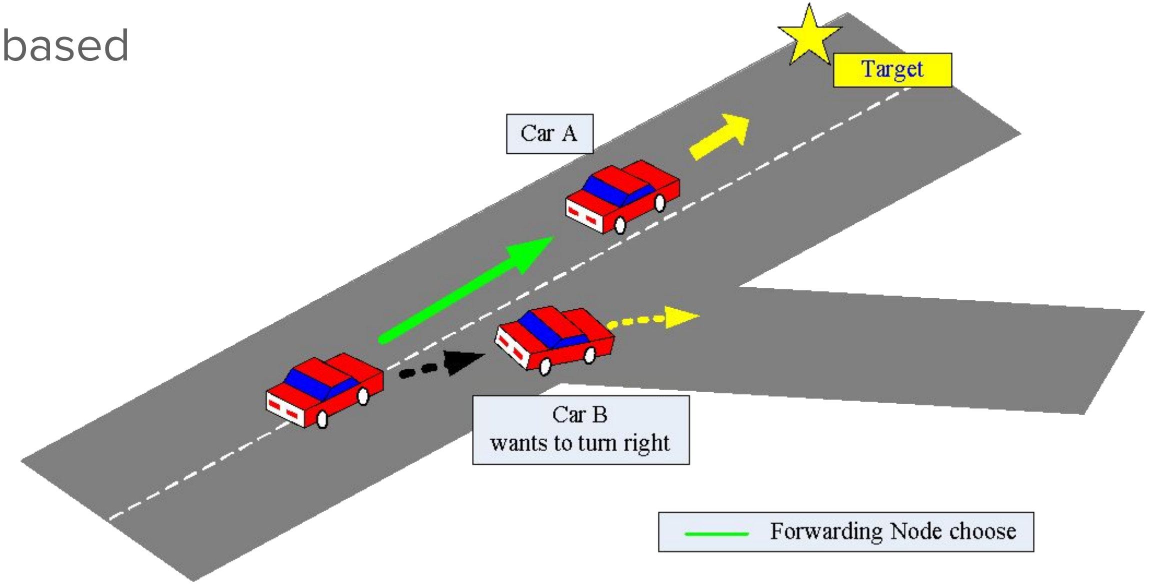
2. Location-based

- Selection criterion is the amount of **additional area** that would be covered by enabling a node to forward.

- Some proposals also compute **position prediction** as useful input information.

Advanced Forwarding

Location-based



Advanced Forwarding

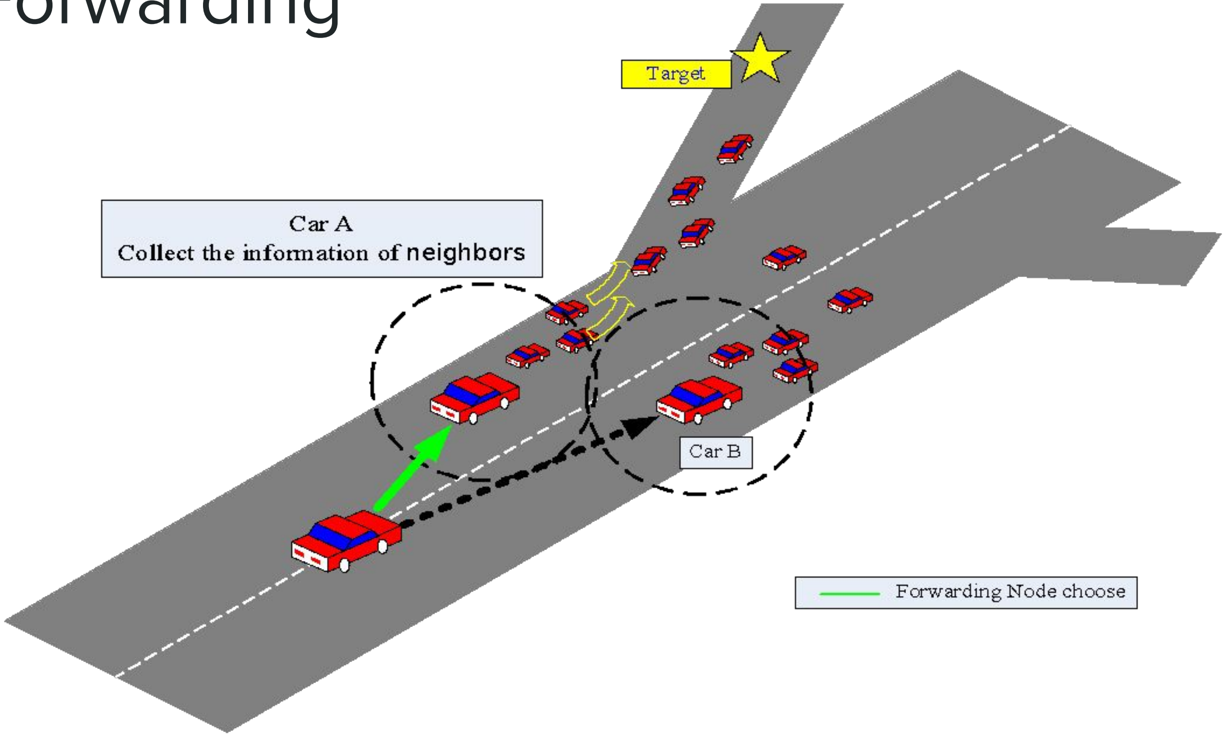
3. Neighbor-based

- A node is selected depending on its neighbors’ status

- For instance, how neighbor is connected to the network (protocol, signal strength, etc.)

Advanced Forwarding

Neighbor-based



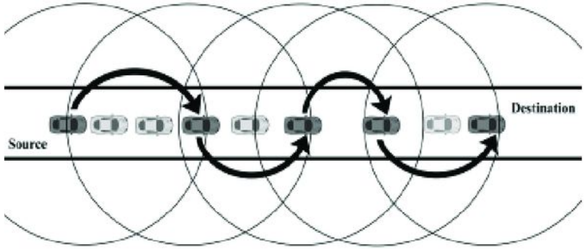
Advanced Forwarding

4. Cluster-based

- Nodes are grouped in clusters represented by an elected cluster-head.
    - Only cluster-heads forward packets.

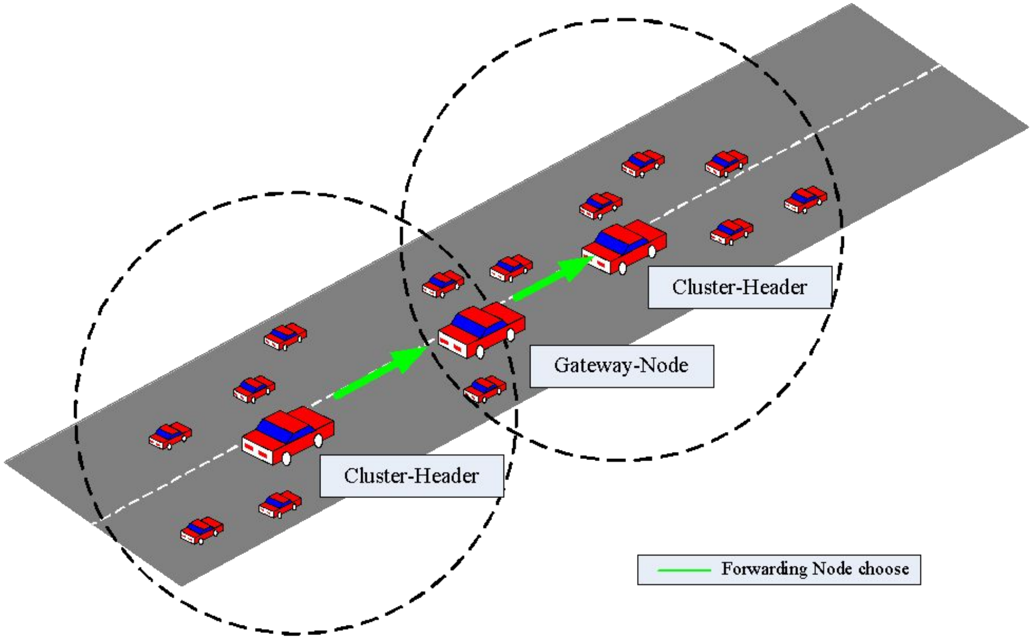
- Nodes in the same cluster share some features (e.g., relatively similar speed in VANETs).

- Re-clustering on-demand or periodically.



Advanced Forwarding

Cluster-based



V2V dissemination: other techniques to avoid the broadcast storm problem

Timer based

- Only broadcast in a certain amount of time

Hop limited

- Only broadcast in a certain amount of hops

Data Aggregation

- Reduce the data amount to be sent

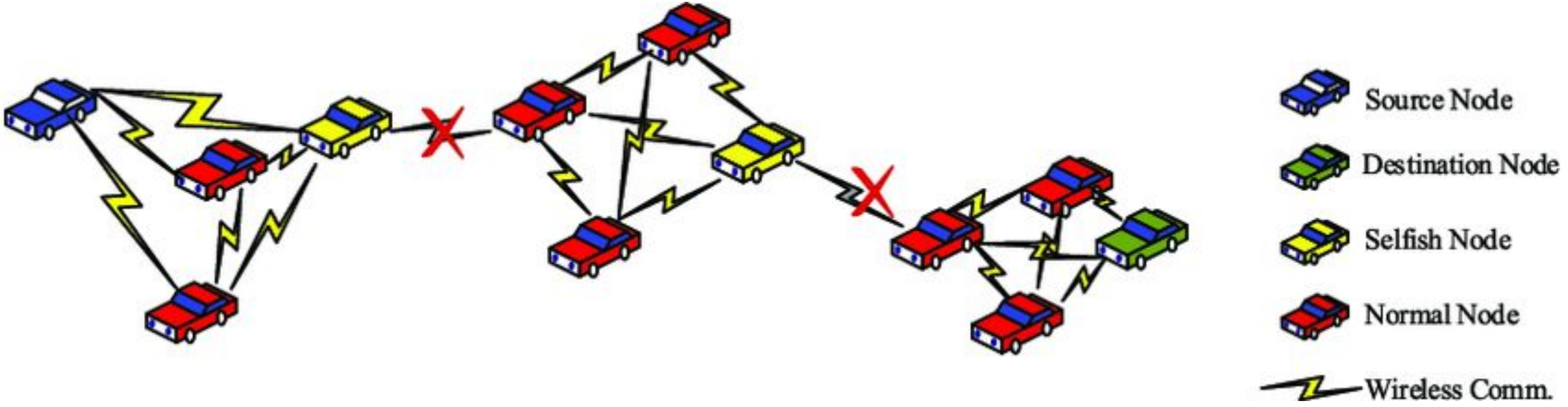
How to deal with partitioned networks?

Problem with partitioned networks

- Next hop is not *always* present

Discussion

- Possible approaches to deal with partitioned networks for V2V communication



How to deal with partitioned networks?

Problem with partitioned networks

- *Next hop is not always present*

Approaches:

- Through Roadside Units (RSU):
    - Vehicle -> RSU, RSU-> RSU, RSU-> vehicle

- Store and Forward: delay tolerant
- Broadcast repeatedly

Through RSUs

Vehicle -> RSU, RSU-> RSU, RSU-> vehicle

Advantage:

- Fast, little delay

Disadvantage:

- RSU should participate
- No RSU in remote areas

Store and forward

The vehicle stores (multiple) data, waits, and delivers the data when vehicles are close enough.

Advantages:

- No RSU
- Delay tolerant

Disadvantages:

- Slow
- Extra storage space to store data

Broadcast repeatedly

Advantage:

- No RSU
- More active compared with “store and forward”

Disadvantage:

- Slow

Challenge: What is the right re-broadcast interval?

- It is difficult to select the *correct* re-broadcast interval
  - Too soon □ high overhead
  - Too late □ doesn’t deal with partitions effectively