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Chapter 13: Introduction to Vehicular Networks

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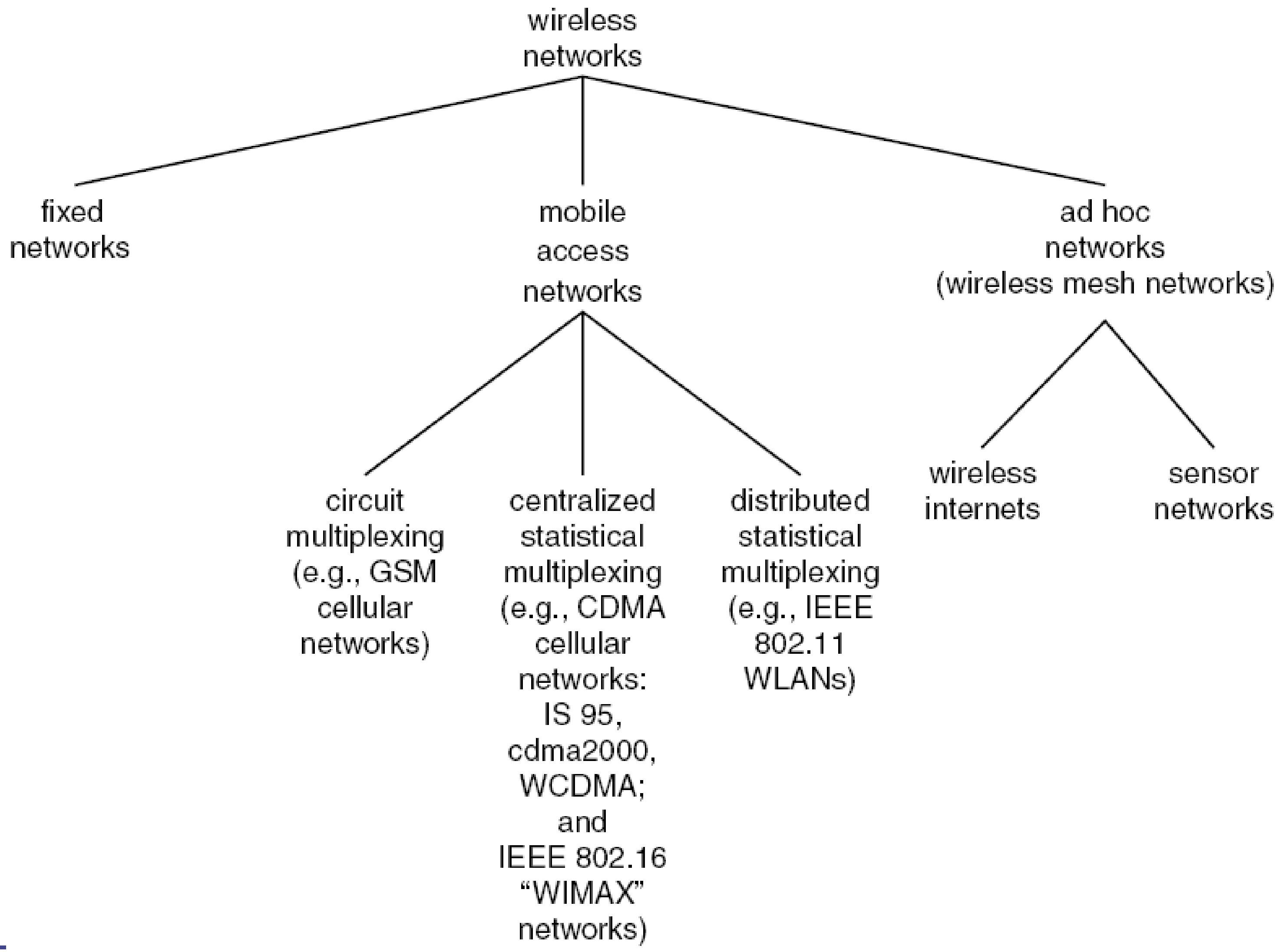
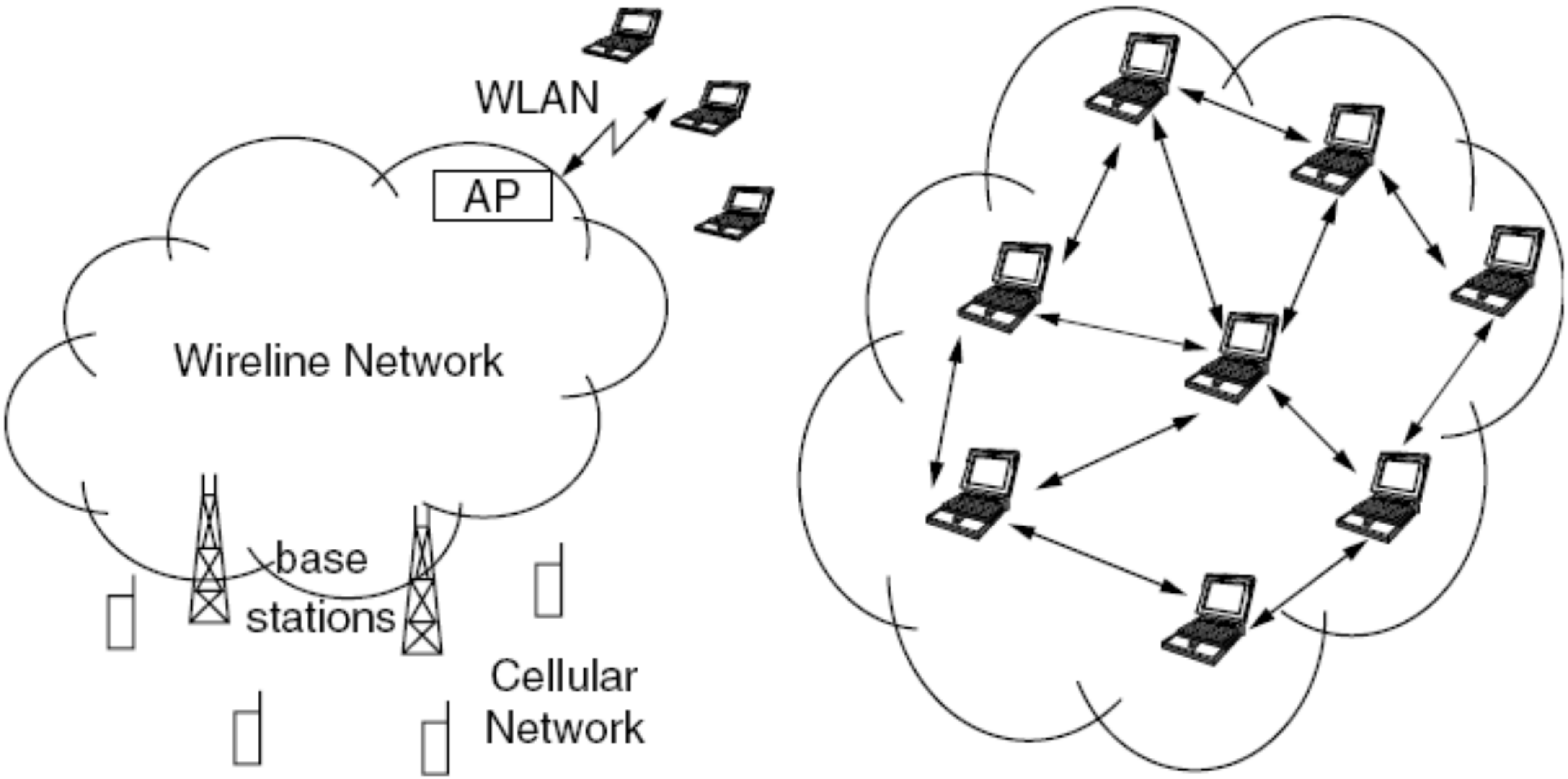
Wireless Networks

A taxonomy of wireless networks



Examples

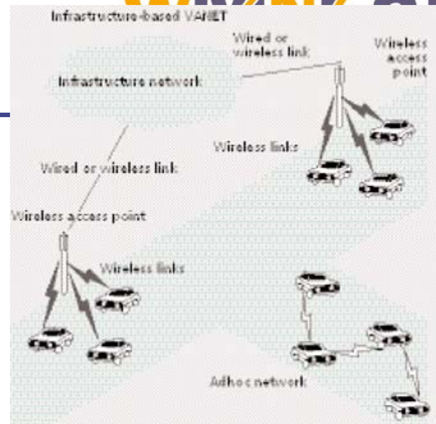


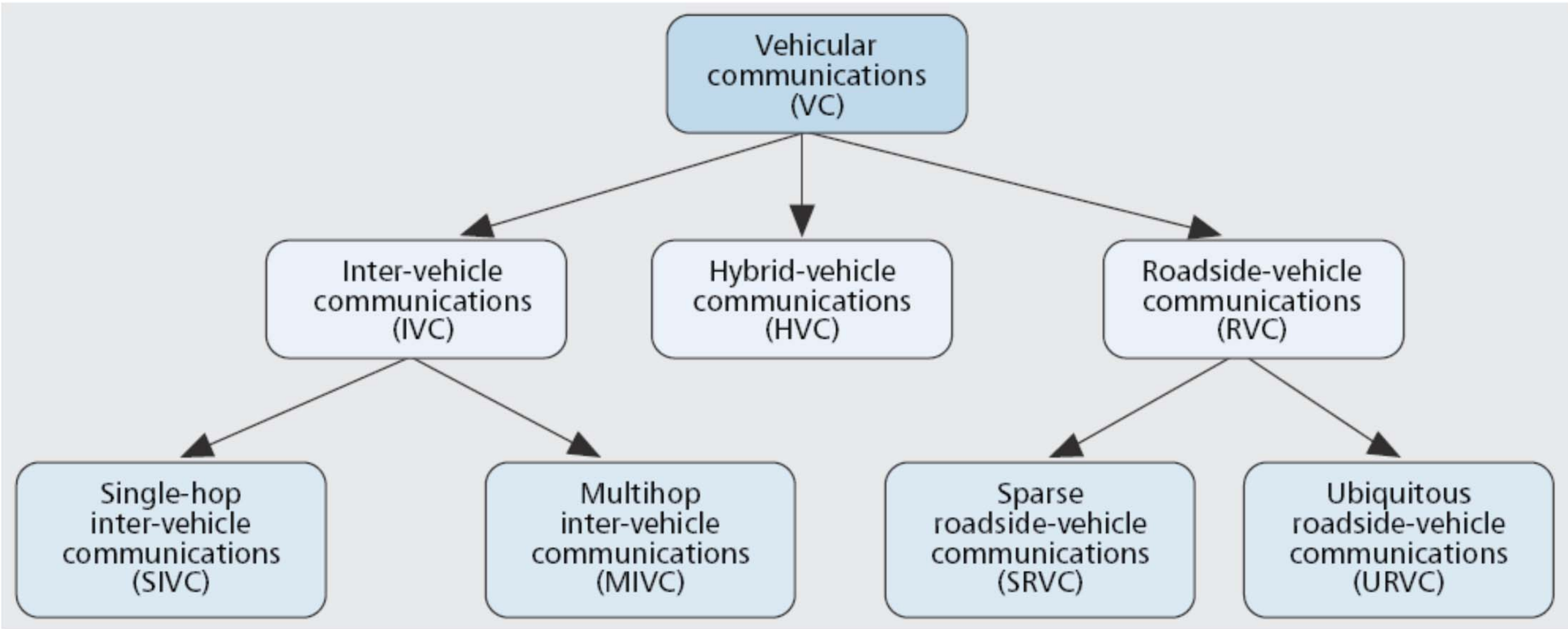
Ad Hoc Networks

- Non-infrastructure
- Fixed and Mobile Nodes
- Special Classes of Ad Hoc Networks
  - Vehicular Ad Hoc Networks
  - Wireless Mesh Networks
  - Wireless Sensor Networks
  - Bluetooth Scatternets …

Vehicular Communications

A taxonomy of vehicular communication





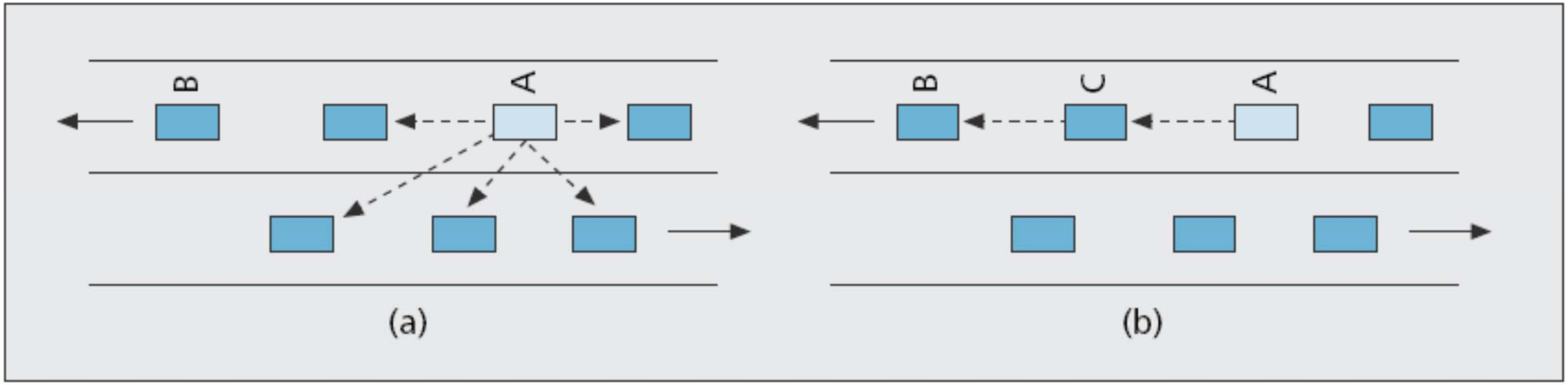
Inter-vehicle communication (IVC) Systems

- IVC systems are completely infrastructure-free; only onboard units (OBUs) sometimes also called in-vehicle equipment (IVE) are needed.

IVC systems

- Single-hop and multihop IVCs (SIVCs and MIVCs).
- 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) multihop IVC system

Roadside-to-Vehicle Communication (RVC) Systems

- RVC systems assume that all communications take place between roadside infrastructure (including roadside units [RSUs]) and OBUs.
- 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.
- A busy intersection scheduling its traffic light, a gas station advertising its existence (and prices), and parking availability at an airport, are examples of applications requiring an SRVC system.
- An SRVC system can be deployed gradually, thus not requiring substantial investments before any available benefits.

RVC Systems - DRVC

- A URVC system is the holy grail of vehicular communication: 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.
- In HVC 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.

IVC vs. MANET (1/6)

- MANETs are wireless multihop networks that lack infrastructure, and are decentralized and self-organizing
- IVC systems satisfy all these requirements, and are therefore a special class of MANETs

IVC vs. MANET (2/6)

- There are several characteristics that differentiate IVCs from the common assumptions made in the MANET literature:
  - Applications
  - Addressing
  - Rate of Link Changes
  - Mobility Model
  - Energy Efficiency

IVC vs. MANET (3/6)

- Applications
  - While most MANET articles do not address specific applications, the common assumption in MANET literature is that MANET applications are identical (or similar) to those enabled by the Internet.
  - In contrast, as we show later, IVCs have completely different applications. An important consequence of the difference in the applications is the difference in the addressing modes.

IVC vs. MANET (4/6)

- Addressing
  - Faithful to the Internet model, MANET applications require point-to-point (unicast) with fixed addressing; that is, the recipient of a message is another node in the network specified by its IP address.
  - IVC applications often require dissemination of the messages to many nodes (multicast) that satisfy some geographical constraints and possibly other criteria (e.g., direction of movement). The need for this addressing mode requires a significantly different routing paradigm.

IVC vs. MANET (5/6)

- Rate of Link Changes
  - In MANETs, the nodes are assumed to have moderate mobility. This assumption allows MANET routing protocols (e.g., Ad Hoc On Demand Distance Vector, AODV) to establish end-to-end paths that are valid for a reasonable amount of time and only occasionally need repairs.
  - In IVC applications, it is shown that due to the high degree of mobility of the nodes involved, even multihop paths that only use nodes moving in the same direction on a highway have a lifetime comparable to the time needed to discover the path.

IVC vs. MANET (6/6)

- Mobility Model
  - In MANETs, the random waypoint (RWP) is (by far) the most commonly employed mobility model. However, for IVC systems, most existing literature recognized that RWP would be a very poor approximation of real vehicular mobility; instead, detailed vehicular traffic simulators are used.
- Energy Efficiency
  - While in MANETs a significant body of literature is concerned with power-efficient protocols, IVC enjoys a practically unlimited power supply.

OBU 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

Addressing Schemes (1/2)

- Two addressing schemes have been commonly considered in wireless ad hoc networks
- Fixed addressing where each node has a fixed address assigned by some mechanism at the moment it joins the network; the node uses this address while it is part of the network. This is the most common addressing scheme in the Internet (with mobile IP being the exception). Most ad hoc networking applications and protocols assume a fixed addressing scheme.

Addressing Schemes (2/2)

- Geographical addressing where each node is characterized by its geographical position. As the node moves, its address changes. Additional attributes may be used to further select a subset of target vehicles. Examples of such attributes are:
  - The direction of movement of the vehicle,
  - The road identifier (e.g., number, name),
  - The type of vehicle (trucks, 18 wheelers, etc.),
  - Some physical characteristics (e.g., taller than, weighing more than, or at a speed higher than),
  - Some characteristic of the driver (beginner, professional, etc.).

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 and vehicle-to-infrastructure 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

Applications for VANETs

- Public Safety Applications
- Traffic Management Applications
- Traffic Coordination and Assistance Applications
- Traveler Information Support Applications
- Comfort Applications

Public Safety Applications (1/2)

- 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.
- Collision avoiding systems (2030 ?)

Public Safety Applications (2/2)

- Safety applications have obvious real-time constraints, as drivers have to be notified before the information is no longer useful. Either an MIVC or a URVC (SRVC for intersections) can be used for these applications. It is possible that, depending on the communication range, an SIVC may be sufficient for these applications.
- In terms of addressing, the destinations in these applications will not be individual vehicles, but rather any relevant vehicle. The zone of relevance (ZOR) (also known as the target area) is determined by the particular application.

Traffic Management Applications

- Traffic management applications are focused on 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

Traffic Coordination and Assistance Applications

- Platooning (i.e., forming tight columns of vehicles closely following each other on highways)
- Passing and lane change assistance may reduce or eliminate risks during these maneuvers, since they are often the source of serious accidents.

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 with, for example, gas or hamburger prices 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 (1/4)

- This class of applications may be motivated by the desire of passengers to communicate with either other vehicles or ground-based destinations such as Internet hosts or the public service telephone network (PSTN).

Comfort Applications (2/4)

- Targeted vehicular communications allow localized communications (potentially multihop) between two vehicles. Voice, instant messaging, or similar communications may occur between the occupants of vehicle caravans traveling together for long distances, or between law enforcement vehicles and their “victims.”
  - Note that this application does not scale to large network sizes.

Comfort Applications (3/4)

- Vehicle to land-based destination communications is arguably a very useful capability as it may enable an entire array of applications, from email and media streaming to Web browsing and voice over IP.
  - Unfortunately, land-based access requires a URVC system that may be prohibitively expensive in the near future.

Comfort Applications (4/4)

- Tolls for roads and bridges can be collected automatically. Many nonstandard systems exist and work well.
- Parking payments can be made promptly and conveniently.
- Repair and maintenance records can be recorded at the garages performing them.
- Multimedia files such as DVDs, music, news, audiobooks, pre-recorded shows can be uploaded to the car's entertainment system while the car is in the garage.

Application Requirements and Characteristics

Application	Can be implemented with				Addressing mode	OBU penetration dependent	Real-time requirements
	SIVC	MIVC	SRVC	URVC			
Collision warning (highway)		√		√	Geo	√	√
Collision warning (intersection)	√	√	√	√	Geo	√	√
Traffic monitoring		√		√	Geo	√	
Traffic light scheduling			√	√	Geo	√	
Traffic coordination	√	√		√	Geo	√	√
Traveler information support			√	√	Geo		
Targeted vehicular communications	√	√		√	Fixed	√	
Car to land communications				√	Fixed		

VANET

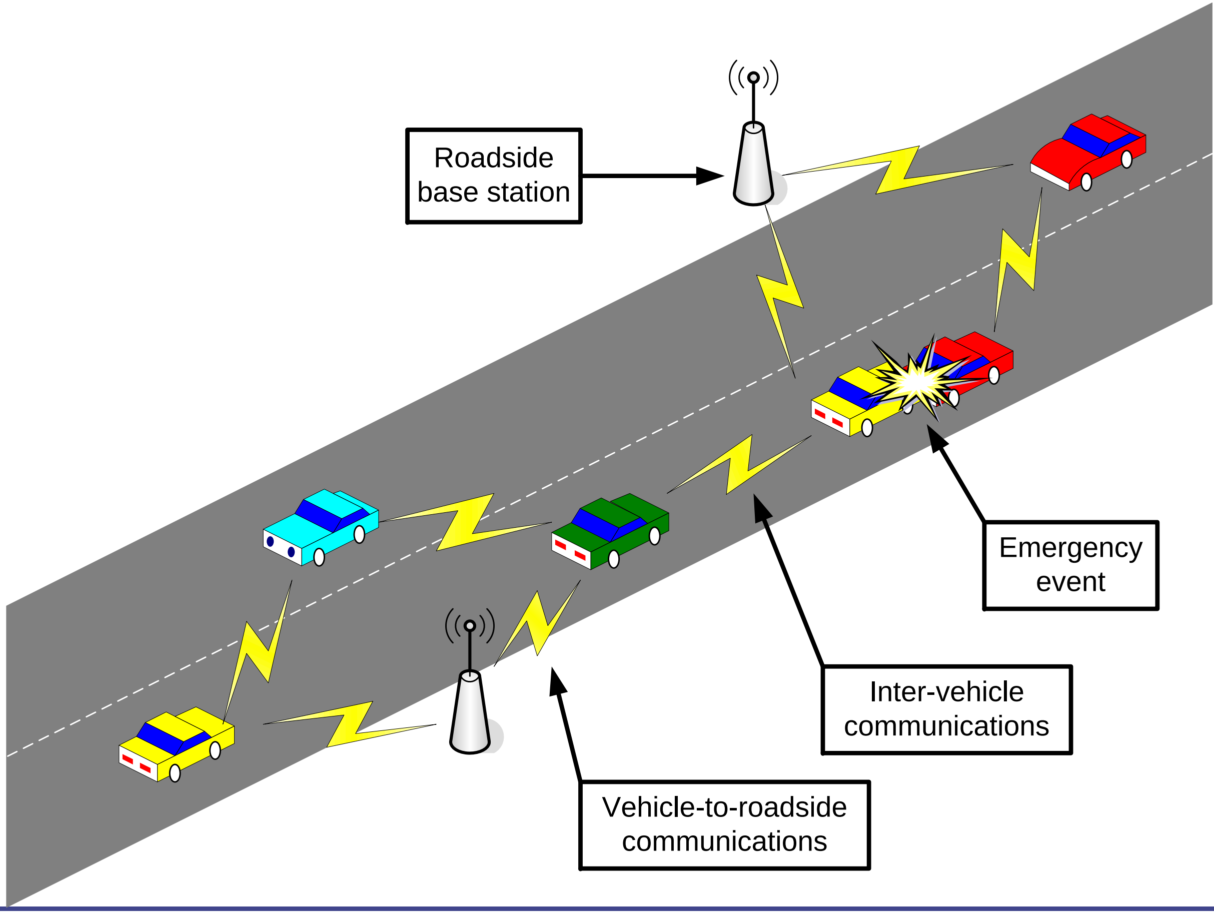
Why Vehicular Networks?

- Safety
  - On US highways (2004):
    - 42,800 Fatalities, 2.8 Million Injuries
    - ~$230.6 Billion cost to society
  - Combat the awful side-effects of road traffic
    - In the EU, around 40’000 people die yearly on the roads; more than 1.5 millions are injured
    - Traffic jams generate a tremendous waste of time and of fuel
  - Most of these problems can be solved by providing appropriate information to the driver or to the vehicle

Why Vehicular Networks? (cont'd)

- 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

What is a VANET (Vehicular Ad hoc NETwork)?



What is a VANET? (cont'd)

- Communication: typically over the Dedicated Short Range Communications (DSRC) (5.9 GHz)
- Example of protocol: IEEE 802.11p
- Penetration will be progressive (over 2 decades or so)
- …

Motivation

- Challenges and demands in surface transportation
- Distances between home and workplaces leads to daily commute by millions of people
  - Persistent heavy traffic flow in and out of cities from 5am through 10pm
  - Congestion
- New applications of wireless ad hoc networks with vehicular traffic

Applications

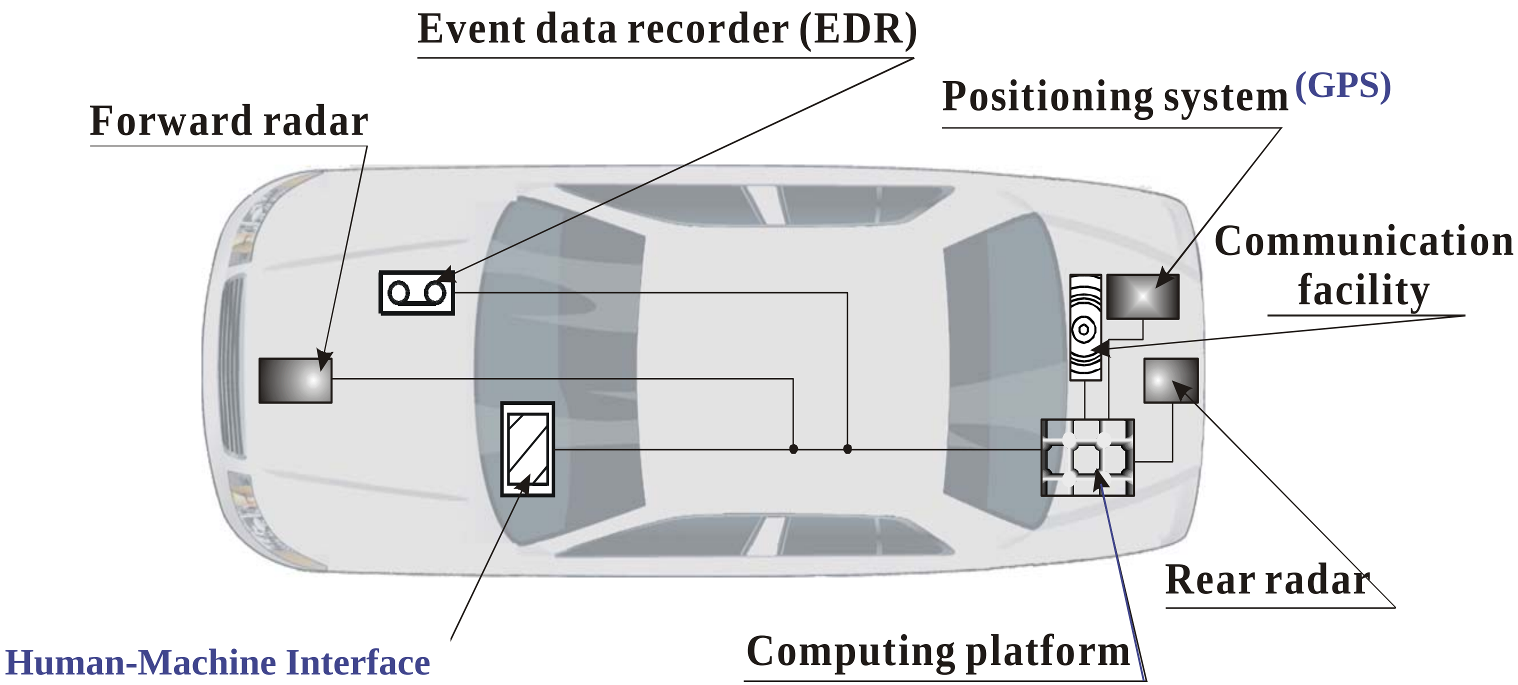
- Vehicular traffic monitoring
- Collision and congestion avoidance
- Broadband services
- Air pollution emission measurement and reduction
- Law enforcement
- Infotainment

Applications (details)

- Congestion detection
- Vehicle platooning
- Road conditions warning
- Collision alert
- Stoplight assistant
- Emergency vehicle warning

- Deceleration warning
- Toll collection
- Border clearance
- Adaptive cruise control
- Drive-through payment
- Merge assistance

A Modern Vehicle



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

Example Scenario - I

- Car pileups
  - Many recent incidents
  - Long Beach October 2002 – 194 cars pileup due to localized fog
- Infrastructure based systems are NOT sufficient
  - Update delays
  - Signs may not be visible
  - Manual systems too slow

Example Scenario – I (cont'd)

- Solution – Virtual Front View
  - Equip cars with wireless devices
    - Devices can form dynamic peer adhoc networks
    - Devices can connect to fixed and or mobile base stations
  - Ad hoc network can be used to provide real-time traffic information to upstream cars
    - Analogous to instrument flying in airplanes

Example Scenario - II

- Vehicular road accident in a busy highway
  - Delays in emergency vehicle reaching the accident point
  - Broadband connectivity to area hospitals to relay patient’s vital information
    - Infrastructure may not be present
    - Infrastructure may be overloaded

Example Scenario - II (cont'd)

- Solution: Dynamic and simultaneous resource allocation in information and vehicular highway networks
  - Use peer adhoc networks to send messages (both upstream and downstream) to reserve highway lanes for emergency vehicles
  - Use peer adhoc networks to provide high bandwidth connectivity and bypass infrastructure limitations

Example Scenario - III

- Vehicular highway congestion causes high concentration of car emissions in a localized area
  - Health hazard and environmental pollution
- Solution: Modify car engine behavior with real-time traffic data exchanged using peer adhoc network
  - Hybrid cars can switch mode
  - Change idling speed
- Analogous to power management in laptops

Other Applications

- Law enforcement
  - Enhanced Amber Alert
- Internet access in cars
  - Information services
  - Entertainment (distributed games)

Related Work (1/2)

- Intelligent Transportation Systems (ITS) - Defines services
- PATH Project (UC Berkeley)
  - http://www.path.berkeley.edu/
  - Traffic modeling and data analysis
  - Communication and road sensor network
- Autonet (UC Irvine)
  - http://www.its.uci.edu/~mcnally/mgm-autonet.html
- FleetNet
  - http://www.et2.tu-harburg.de/fleetnet/

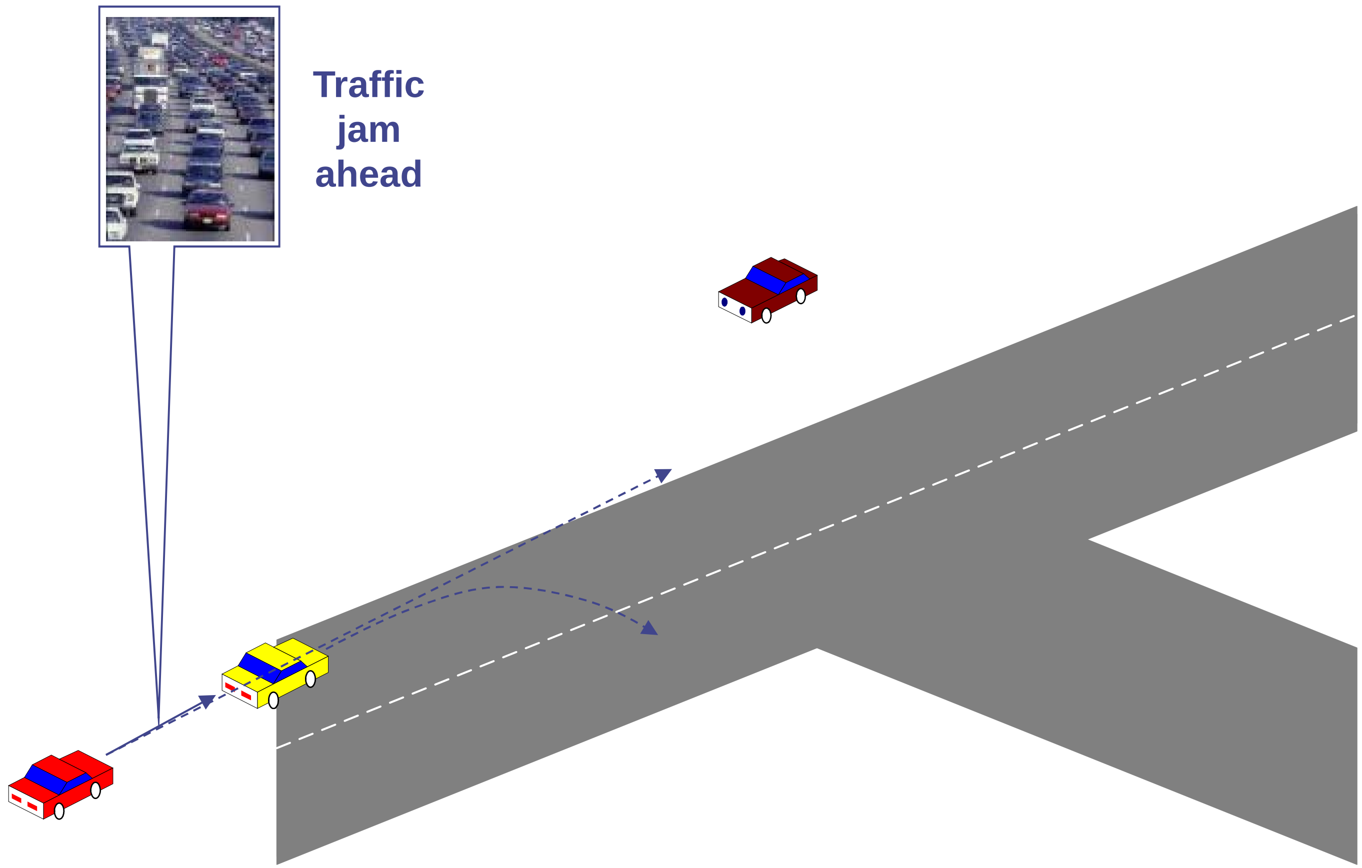
Related Work (2/2)

- SeVeCom (Secure Vehicular Communication)
  - an EU-funded project that focuses on providing a full definition and implementation of security requirements for vehicular communications.
  - http://www.sevecom.org/
- …

Threat model

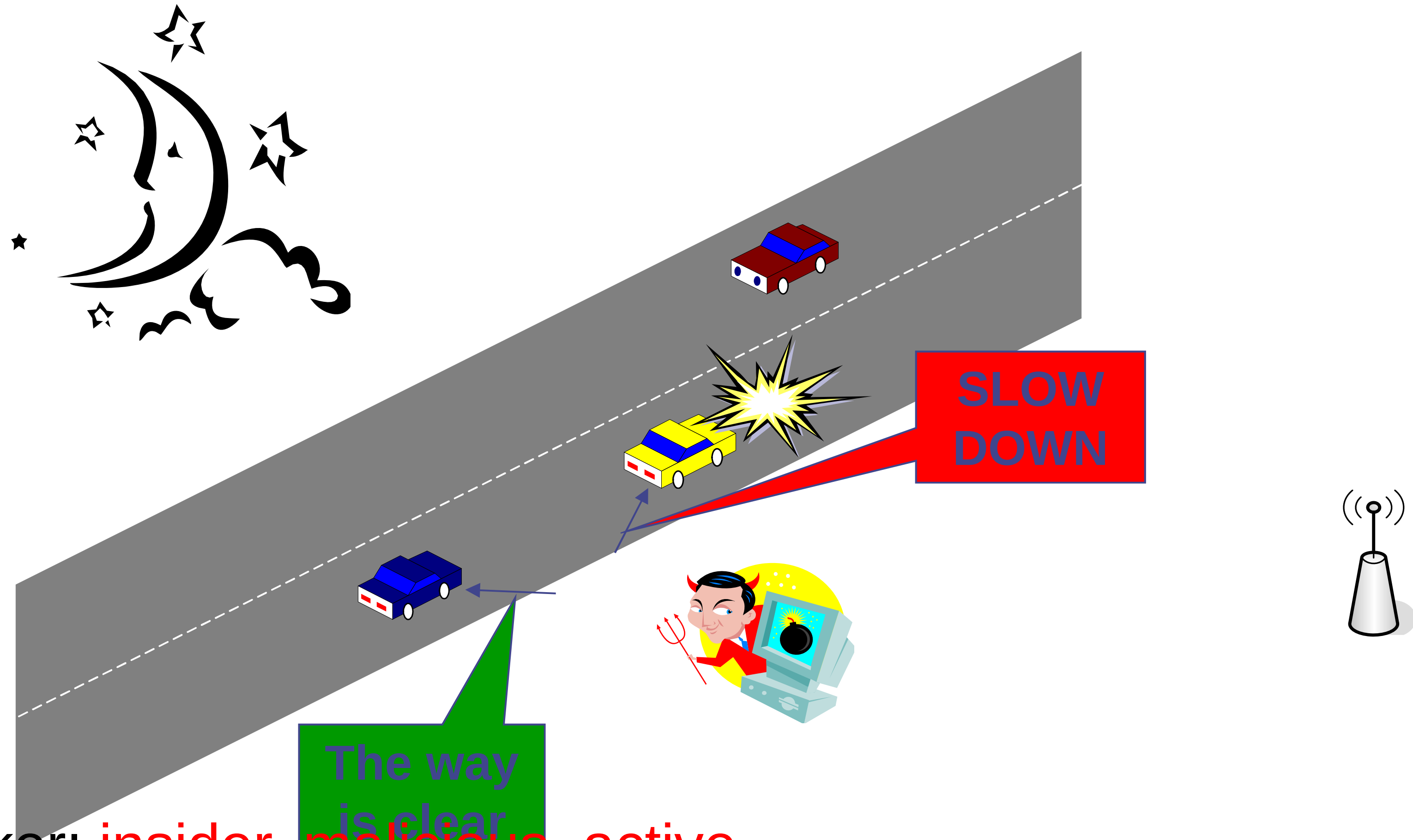
- Presented in SeVeCom (Secure Vehicular Communication) project
- An attacker can be:
  - Insider / Outsider
  - Malicious / Rational
  - Active / Passive
  - Local / Extended
- Attacks can be mounted on:
  - Safety-related applications
  - Traffic optimization applications
  - Payment-based applications
  - Privacy

Attack 1 : Bogus traffic information



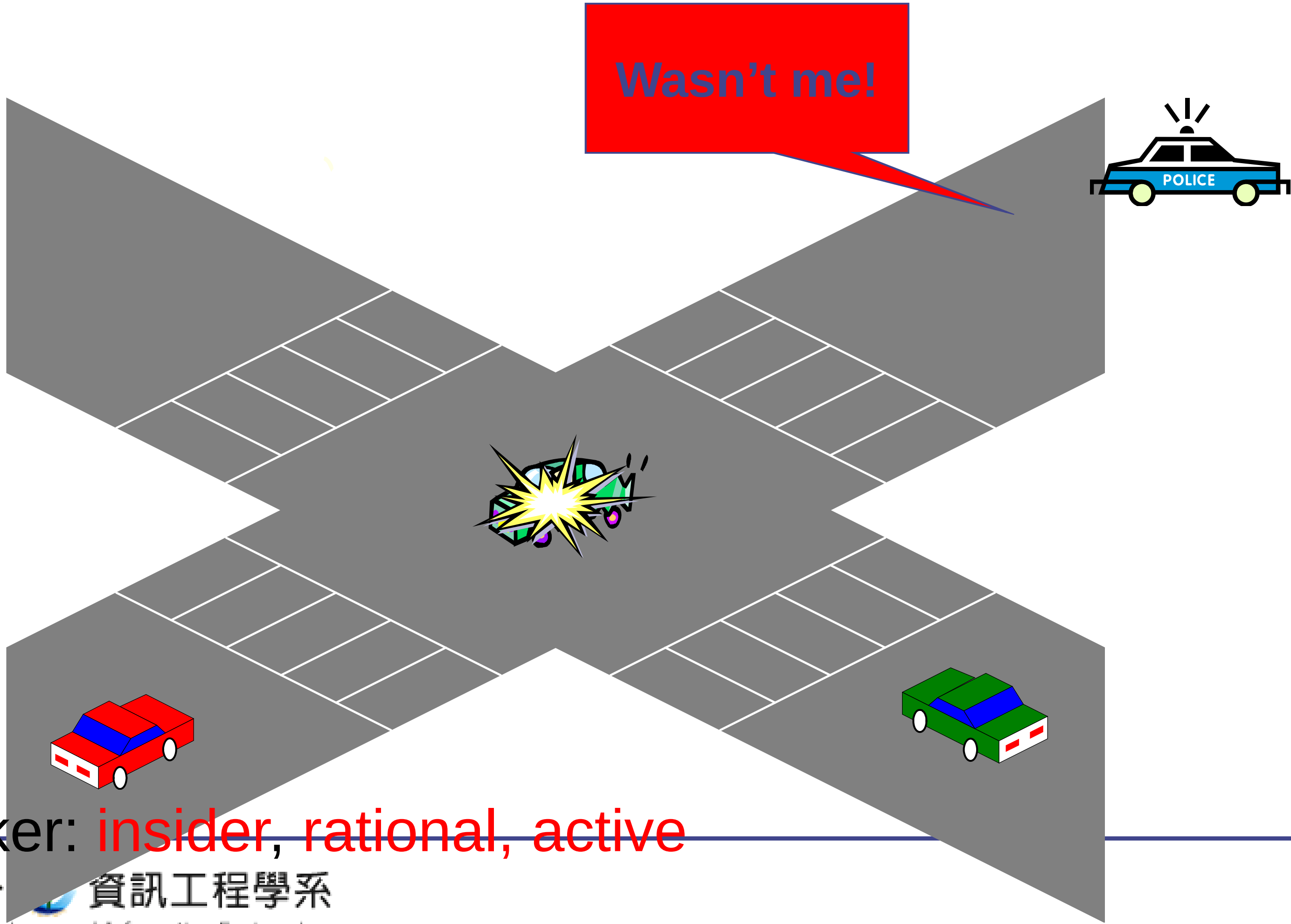
- Attacker: insider, rational, active

Attack 2 : Generate “Intelligent Collisions”



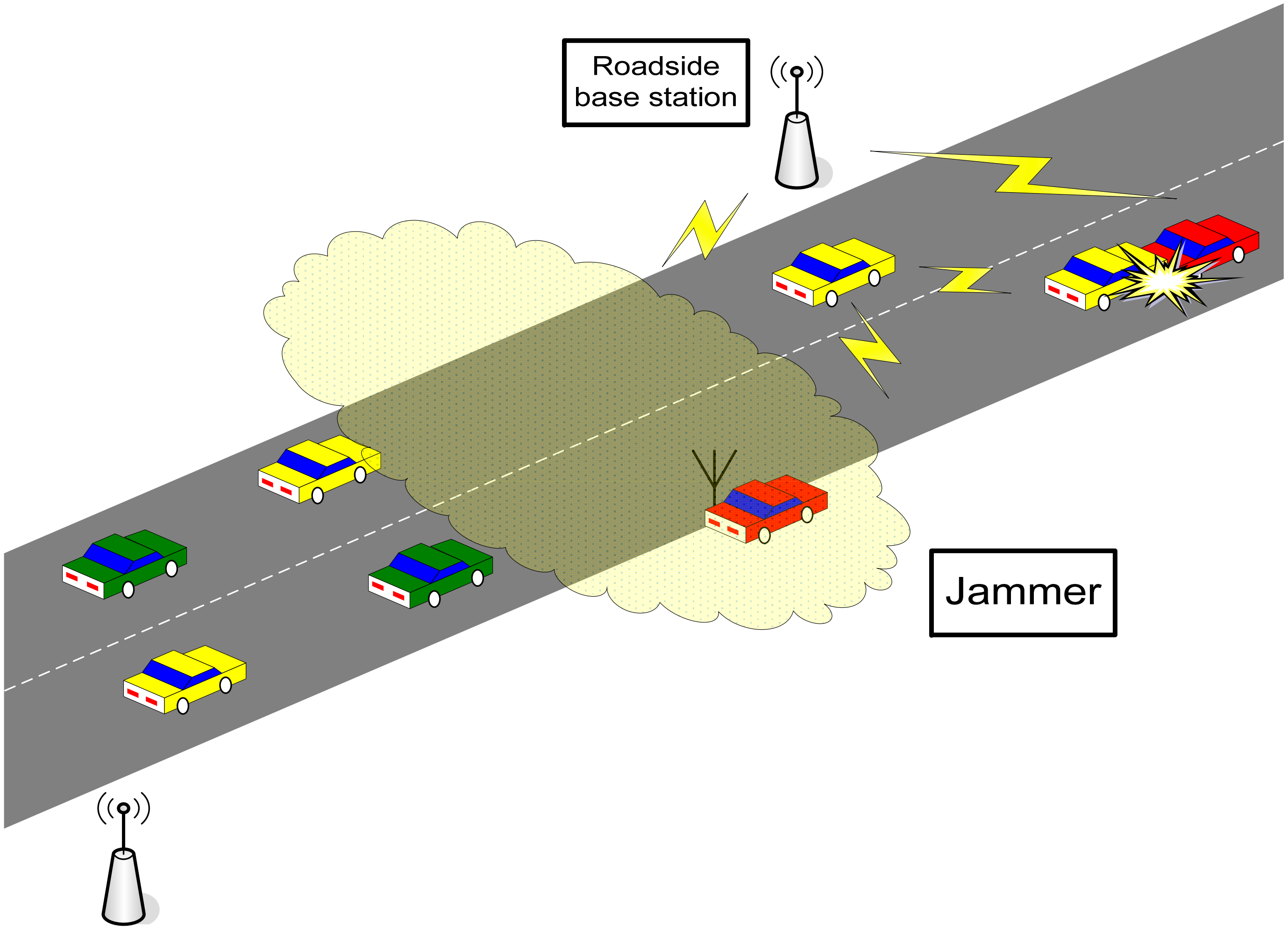
- Attacker: insider, malicious, active

Attack 3: Cheating with identity, speed, or position

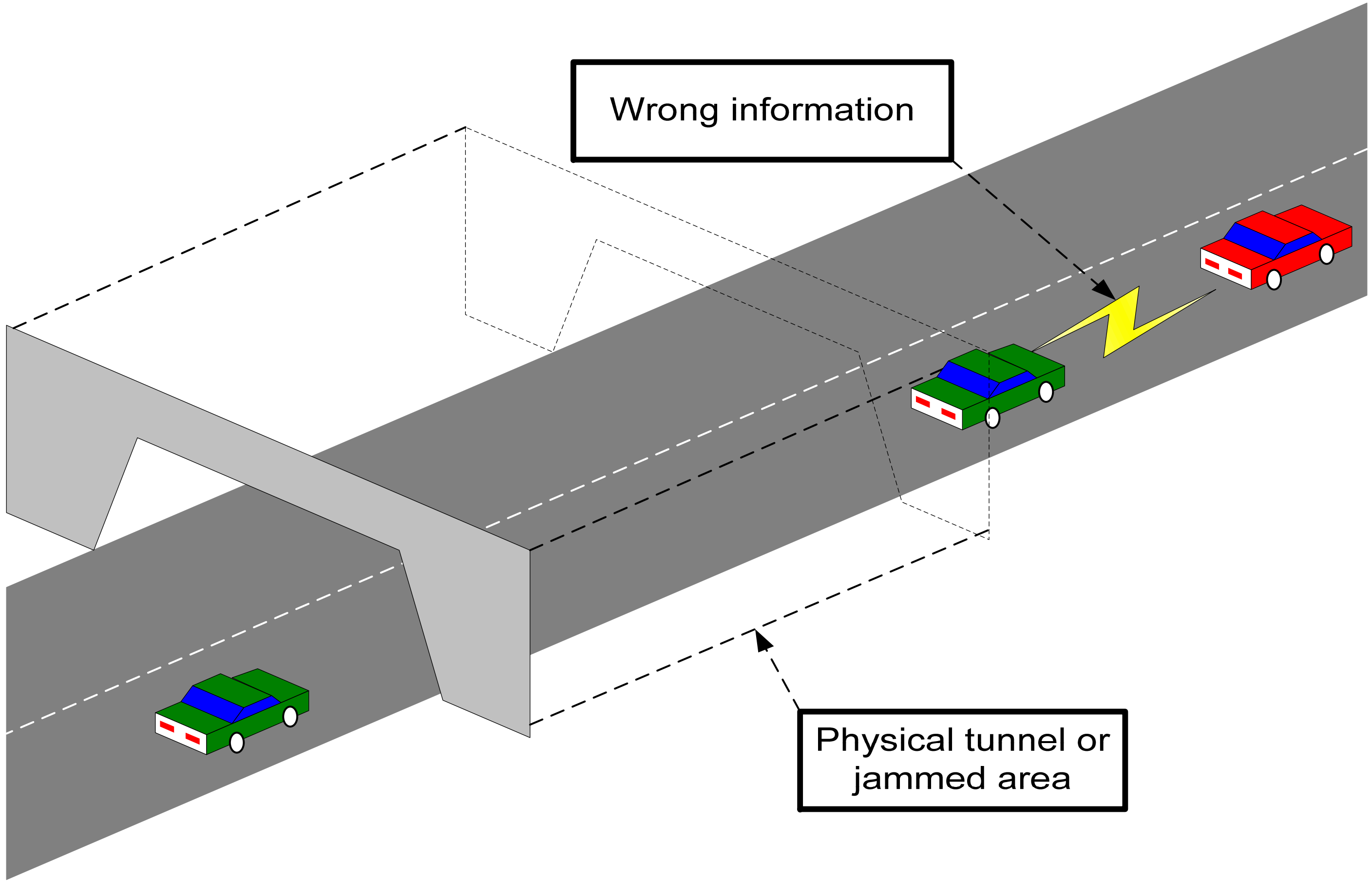


- Attacker: insider, rational, active

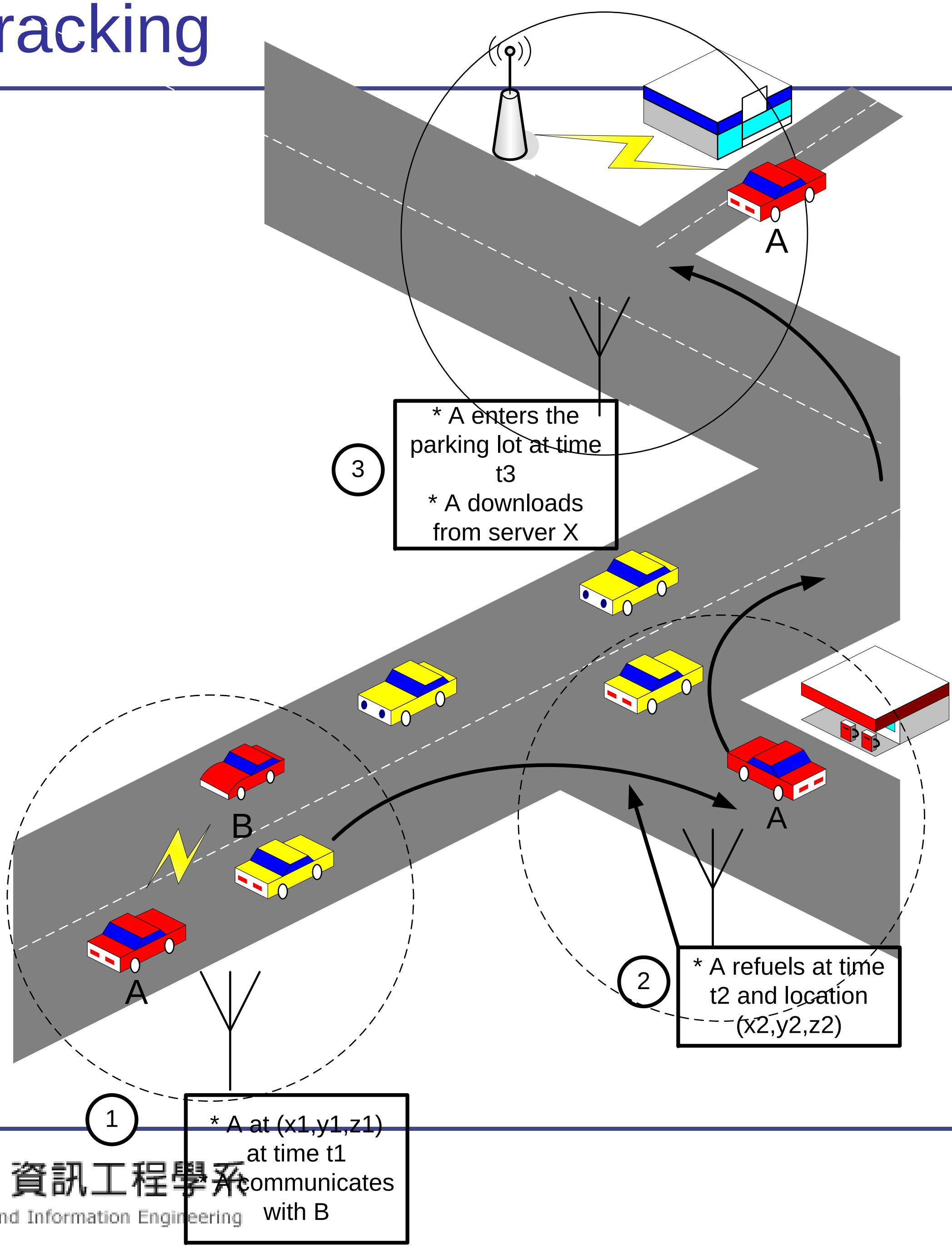
Attack 4: Jamming



Attack 5: Tunnel



Attack 6: Tracking



Issues for IVC

Issues for IVC

- Short-Range Communication Technologies
- Network Access
- Network Layer
- Transport and Security Layers
- Performance Modeling Issues

- Some applications, for example cooperative driving, requires a very short-range communication, possibly with line-of-sight. For these types of applications only a physical and perhaps a simple MAC layer are needed. Several papers have designed and proposed various physical layers for this type of applications
- Communication Technologies
- Coordinated driving and vehicle platooning have been the focus of many research projects. These applications have also been tested in a number of experiments using short-range communication.

Networking Technologies

- Wireless LANs (IEEE 802.11b)
  - Disadvantages
    - Omni directional
    - Current products can work either in ad hoc or infrastructure modes but not both
    - Relatively low bandwidth
- Tunable directional antennas
  - Disadvantage
    - Expensive (at present)

Network Access

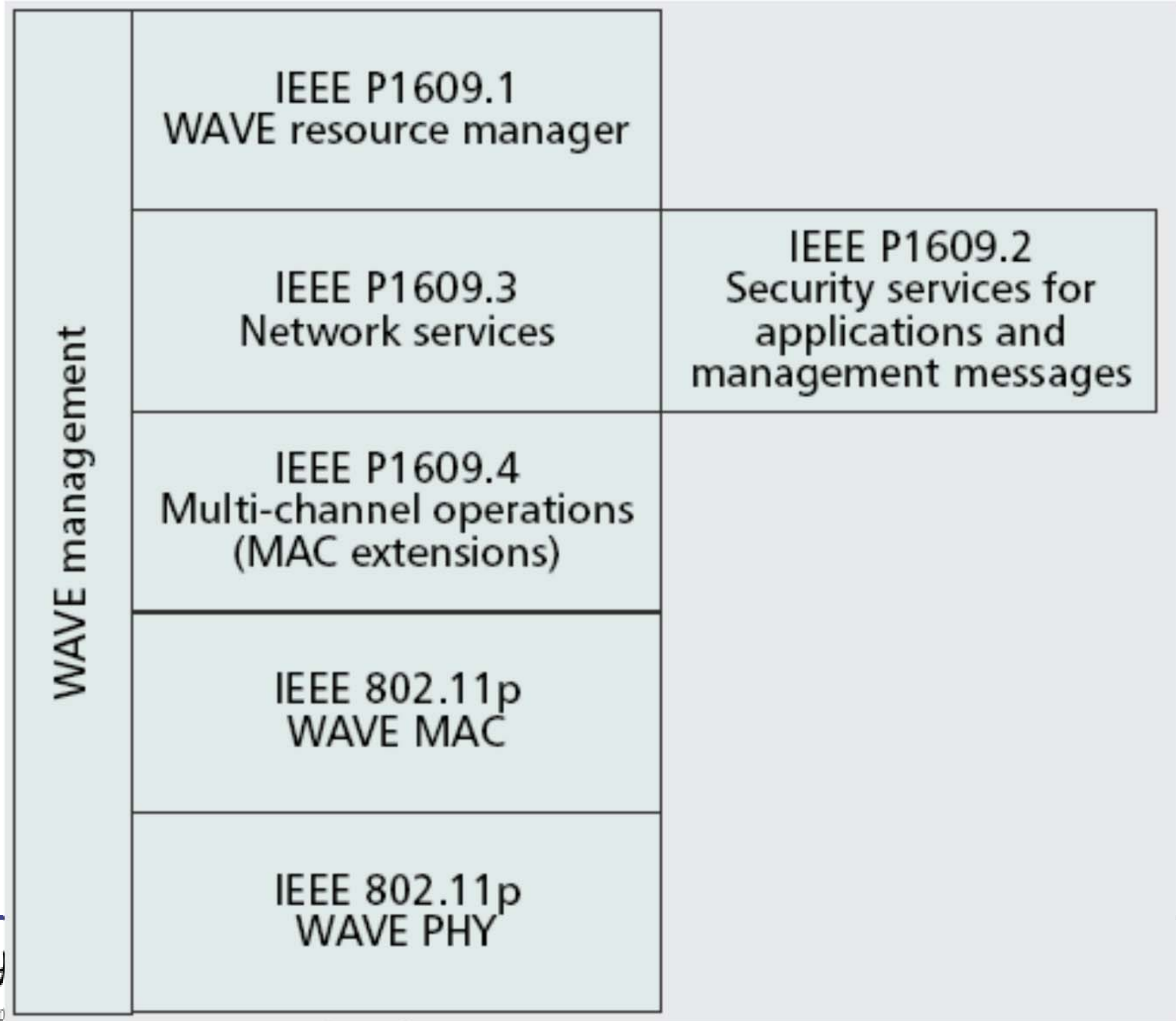
- Network access in the Internet includes the physical and data link layers of the OSI model.
  - IEEE 802.11 AND DSRC
  - BLUETOOTH
  - CELLULAR COMMUNICATION STANDARDS
  - OTHER MEDIUM ACCESS SCHEMES

Comparison of considered IVC MAC protocols

- Comparison of the presented MAC approaches from several perspectives.

Protocol	Range	Data rate	Fully distributed	Slotted	BW and delay guarantees	Standard
DSRC	300 m	10–50 Mb/s	Yes	No	No	Yes
Bluetooth	< 100 m	1 Mb/s	No	Yes	Yes	Yes
3G Cellular	> 1 km	< 1 Mb/s	Custom	Yes	Yes	No
Custom	N/A	N/A	Yes	Most	Most	No

IEEE 802.11p in the IEEE P1609 standard family



Link Layer Issues

- Links between peers will be dynamic and unstable
  - Notion of platoons
  - Nodes leave and join platoons
- Communication links between platoon
  - Platoon leaders
- Links with fixed and mobile (enhanced probe vehicles)
- Mobility is constrained and directional
- Fault-tolerance through redundancy

Network Layer

- the network layer is responsible for addressing (naming the elements of the network), routing (finding good paths), and forwarding (actual movement of the packets) data between sources and destinations.

Address Mapping

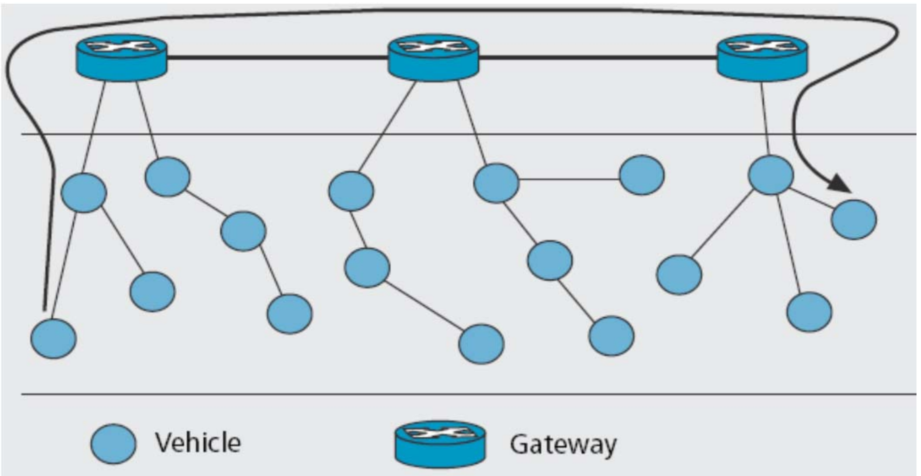
- If fixed addresses are used in an IVC system, a query may be flooded in the target area. Any vehicles in the target area will reply with their fixed addresses. Then the message can be unicast to each vehicle (or better yet, multicast).
- If geographical addresses are used, an additional identification field may augment the geographical address (e.g., destination is a vehicle up to 1 mile behind and a vehicle identification number [VIN] equal to xxxxx) such that the message is delivered to only one vehicle.

Routing Protocols

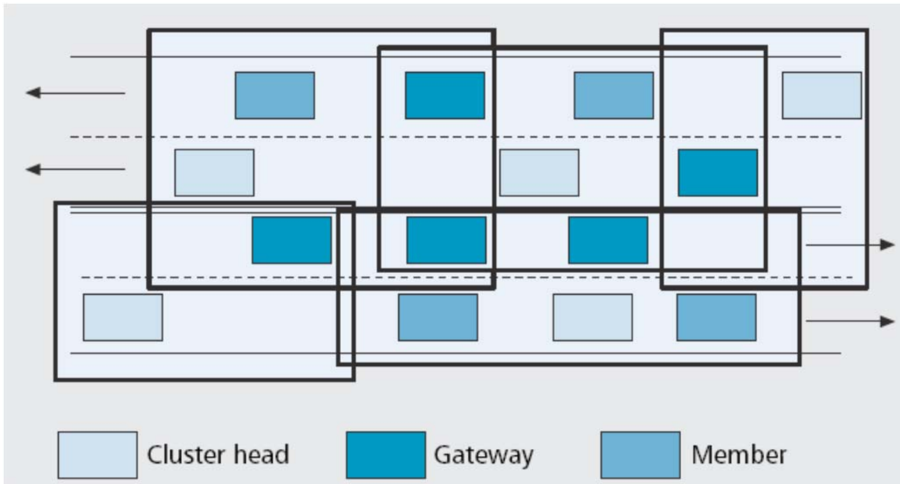
- The routing protocols that has been proposed for MIVC systems can be classified into three basic groups:
  - Unicast routing with fixed addresses may be used by comfort applications (e.g., onboard games and file transfers).
  - Unicast routing with geographical addresses may be used to increase routing efficiency in the same types of applications as unicast with fixed addressing.
  - Although theoretically possible, multicast routing with fixed addresses would incur huge overhead in maintaining the multicast groups.
  - Most envisioned applications in IVC systems will require multicast routing with geographical addresses (e.g., emergency warning messages and traffic monitoring applications).

Unicast Routing with Fixed Addresses

- Protocols Based on AODV
- Cluster-Based Routing Protocols



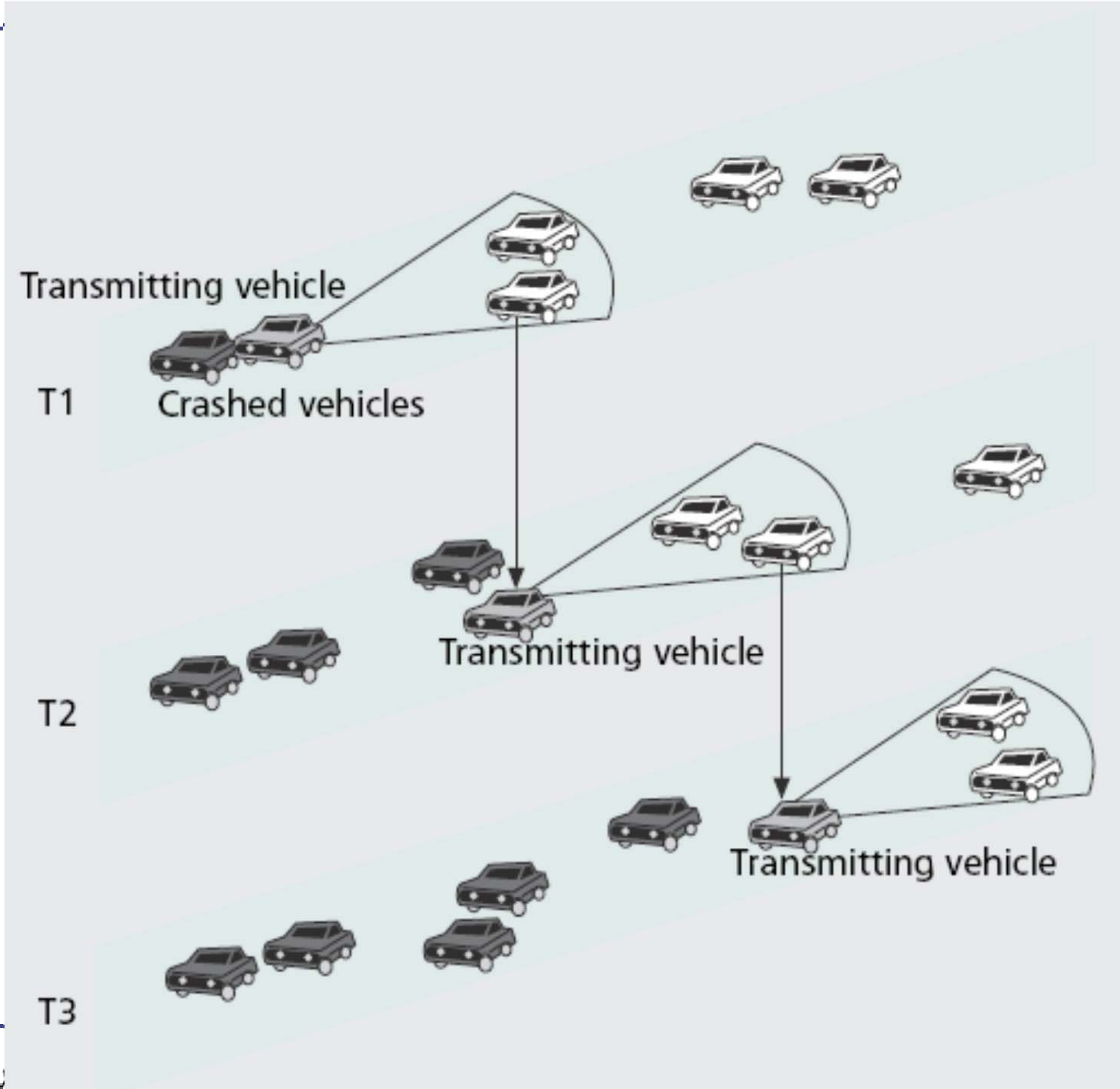
An HVC system featuring gateways providing "shortcuts" to a distant destination



Vehicles organized in clusters featuring cluster heads, gateways, and members

Unicast Routing with Geographical Addresses

- Most papers focusing on unicast routing with geographical addresses propose modified versions of the Greedy Perimeter Stateless Routing (GPSR) protocol


Transmitting vehicle
Crashed vehicles
T1
Transmitting vehicle
T2
Transmitting vehicle
T3

Multicast Routing with Geographical Addresses

- Geocasting protocol that uses geographical addressing. The objective of a geocast protocol is to forward a message from a source node to nodes within a specified target geographical region. The target geographical region is often called the zone of relevance (ZOR), and is usually specified as a rectangular or circular zone rather than a single coordinate. Additional attributes may be used to further select a subset of target vehicles, such as the direction of movement or type of vehicle.

Diffusion Mechanisms

- Several proposed traffic monitoring applications employ a unique dissemination procedure, sometimes called a diffusion mechanism.
- Diffusion works at the application layer (and is only suitable for some applications), thus not being a "true" routing mechanism. However, since it considers multihop forwarding of data, it is described here for completeness. In a diffusion mechanism the application collects data from other neighboring vehicles, and aggregates and stores the data (e.g., by maintaining a table of current speeds for different road segments).
- At regular intervals the current table is broadcast to all neighbors that in turn update their tables, and so on. The result is that the data is "diffused" in the network, each vehicles having more accurate information on the state of nearby traffic (and relatively outdated information from distant regions).

Comparison of the presented routing approaches for IVC systems

Protocol	Addressing	Uni/Multicast	Path state	Neighbor state	Hierarchical	Easy IP integration
AODV	Fixed	Unicast	Yes	Yes	No	Yes
Cluster	Fixed	Unicast	Yes	Yes	Yes	Yes
GPSR	Geographical	Unicast	No	Yes	No	Yes
Geocasting	Geographical	Multicast	No	No	No	No

Network Layer Issues (1/2)

- Routing
  - Hierarchical routing
    - Routing within a platoon
    - Routing across platoon
- Are current routing algorithms for mobile ad hoc networks suitable for this application?
  - Directional mobility
  - Dynamic nature of the network

Network Layer Issues (2/2)

- Addressing
  - Dynamic addressing
    - Highway
    - Direction
    - Lane
    - Platoon
  - How will addresses be assigned?
    - Smart cards and sensors at entry and exit points

Transport and Security Layers

- Transport Layer
  - Throughput experiments in IVC systems

No. of nodes	MAC	Traffic type	Speed	Distance	Throughput
4	802.11b	TCP	40 km/h	N/A	~800 kb/s
3	802.11b	UDP	8–113 km/h	< 145 m	500–2300 kb/s
3	802.11g	UDP	< 5 km/h	N/A	1–5 Mb/s

Transport Layer Issues

- Transport protocols are end-to-end
  - TCP: Transmission Control Protocol
  - UDP: User Datagram Protocol
- Close coupling of error control, flow control, and congestion control in TCP
  - Very poor performance with unstable wireless links
- What are good transport layer protocols?
  - Interactions with lower layer protocols

Security Issues

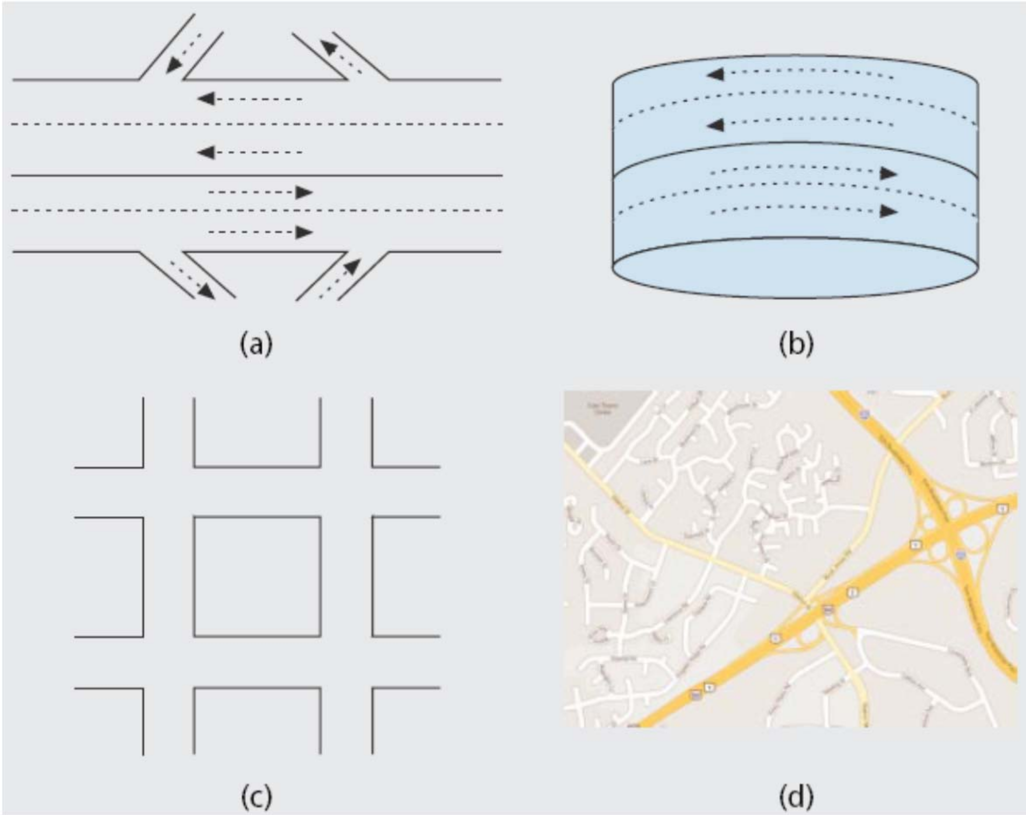
- Access control
  - Only authorized users can participate in the system
- Authenticity and integrity of information
- Denial-of-Service

Performance Modeling Issues

- Due to the cost and difficulties involved in deploying large vehicular testbeds, the majority of proposed IVC systems have been evaluated via simulations. The results obtained from theoretical investigations or simulations are highly dependent on the models used.
- Mobility Models
- Simulation Models
- Communication Channel Models

Mobility Models

- random waypoint model (RWP)
- In a vehicular network nodes (vehicles) can only move along streets
  - road model
  - traffic models



Road models: a) straight road (highway); b) circular road; c) road grid; d) real(istic) road.

Simulation Models

- Usually, the simulation of an IVC system includes two stages.
- In the first stage the vehicle movements are determined, usually using a traffic simulator.
  - L. Owen et al., “Traffic Flow Simulation Using CORSIM,” Proc. 2000 Winter Simulation Conf., 2000, pp. 1143–147.
  - “SHIFT home page,” http://path.berkeley.edu/SHIFT/
- The input of the traffic simulator includes the road model, scenario parameters (maximum speed, rates of vehicle arrivals and departures, etc.). The output is a trace file where every vehicle’s location is determined at every time instant for the entire simulation time.
- In the second stage the trace file is used as input in a network simulator.
  - ns-2, http://www.isi.edu/nsnam/ns/
  - QualNet, http://www.scalable-networks.com/
- Each vehicle becomes a node in an ad hoc network with the trace file specifying the movements of each node.

Communication Channel Models

- Accurate models for the communication channel are a prerequisite for meaningful simulation results.
- Most simulation models for IVC systems use the classical free space propagation model without fading. Packets are received correctly if the receiving node is within a predefined distance from the sender. The model does not consider speed, fading or interference from buildings.
- A classical two-ray ground model is compared with a more realistic Nakagami propagation model. Large differences in the reception probability of 802.11 broadcast packets could be seen. Therefore, there is a clear need for more accurate channel models for IVC systems.

Application Layer Issues

- Caching
  - What are good caching algorithms for sharing data for this environment
- Application layer multicasting
  - Dynamic application layer multicasting for streaming applications

Resource Management

- Unlike other ad hoc and sensor networks CPU and power are NOT key resources
- Bandwidth is the key information network resource
  - Bandwidth and delay guarantees depend on different applications

Economic Models

- Incentive mechanism for user to participate
  - Deploy wireless devices in the car
- Incentive mechanisms to participate in the adhoc network
  - Internal currency
  - External currency
  - Bartering

Theories of Vehicle Traffic

- Primary source paper: “Driven, many-particle systems” Helbing, 2001
- Microscopic analysis – vehicles as separate interacting particles
- Mesoscopic analysis – hybrid particle- and gas-kinetic fluid models
- Macroscopic analysis – vehicle aggregates modeled as viscous fluids

Fundamental Diagram

- Three flow states
  - Free flow traffic
  - Congested flow
  - “Recovering” flow, or homogeneous-in-speed
- Hysteresis, or persistence of current bulk state
- Aside: theory apparently applies to some Internet packet congestion regimes

Speed Distributions in Traffic Flow

- Relation between traffic density and speed variance
- Empirical relation between average vehicle velocity and traffic density
- Propagation of features in flow

Numerical Models of Traffic

- Microscopic follow-the-leader model – Reuschel (1950), Pipes (1953)
- Newell and optimal velocity models –Newell (1961), Bando et al. (1994)
- Intelligent Driver Model – Treiber and Helbing (1999, 2000)
- Cellular Automata Models – Nagel-Schreckenberg (1992), Takayasu (1993), Helbing and Schreckenberg (1999)
- Particle-hopping models – TASEP (totally asymmetric exclusion processes)

Simulating MANETS in Vehicular Traffic

- Cellular Automata based simulation tool for vehicles on arbitrary road networks
- MANET link layer and routing schemes can be developed and tested in realistically simulated traffic

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- Conferences and journals
  - VANET, colocated with Mobicom
  - V2V-Com, co-located with Mobiquitous
  - WIT: Workshop on Intelligent Transportation
  - VTC: Vehicular Technology Conference
  - IV: Conference on Intelligent Vehicles
  - escar: Workshop on Embedded Security in Cars
    - http://www.escarworkshop.org/
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Future Study

- Simulation Tool
- Experiments
  - Ad hoc network testbed
- Architecture
- Routing
- Applications
- The security of VANETs is a difficult and highly relevant problem
- …

Homework #13:

1. What's the kinds of Vehicular Communications (VC) ?
2. What's the Vehicular Ad Hoc Networks (VANET) ?
3. What's possible comfort applications for VANETs ?
4. What's possible emergency applications for VANETs ?