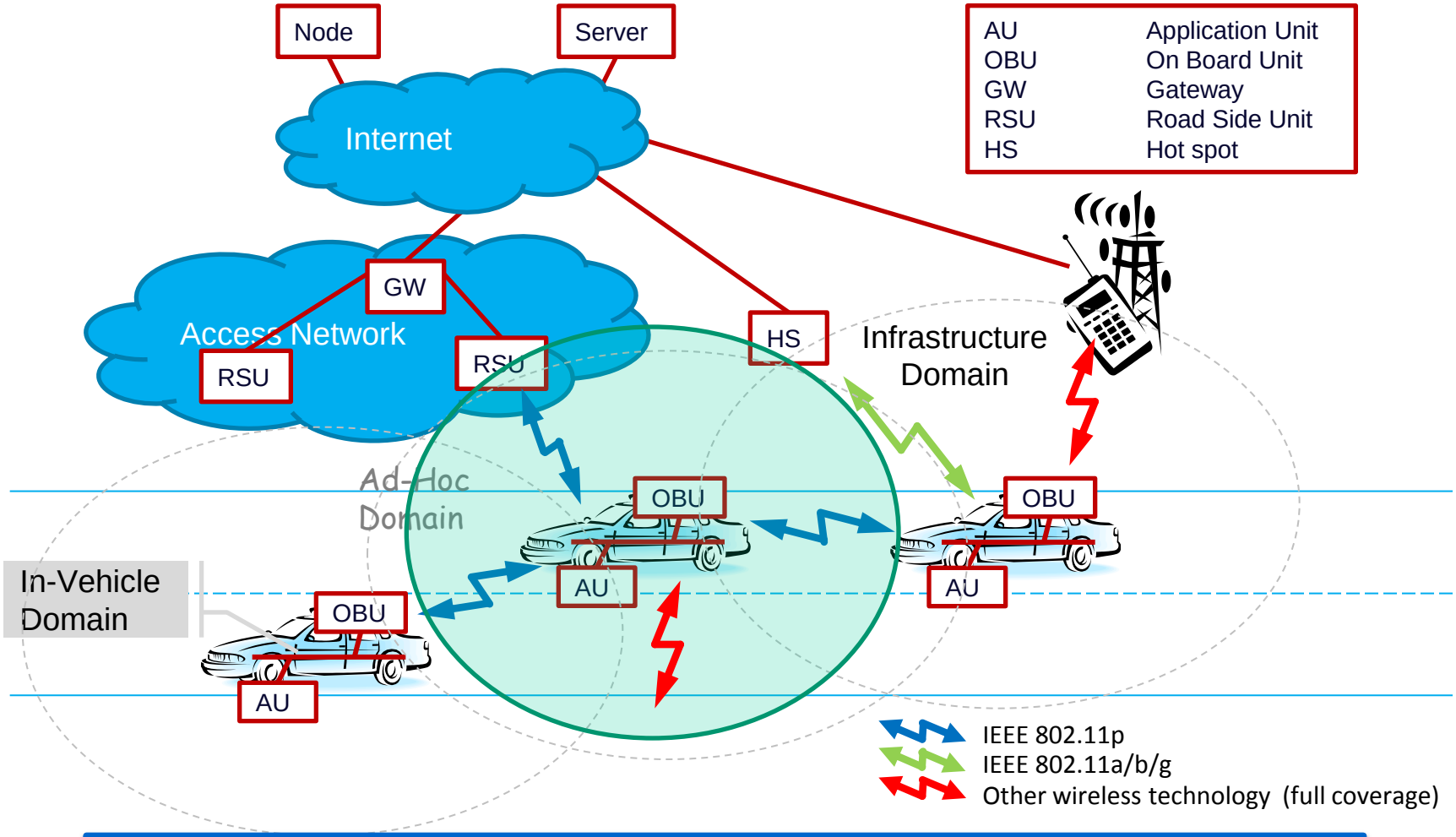
oCPS

Intelligent Transportation Systems
V2V communications

Johan Lukkien

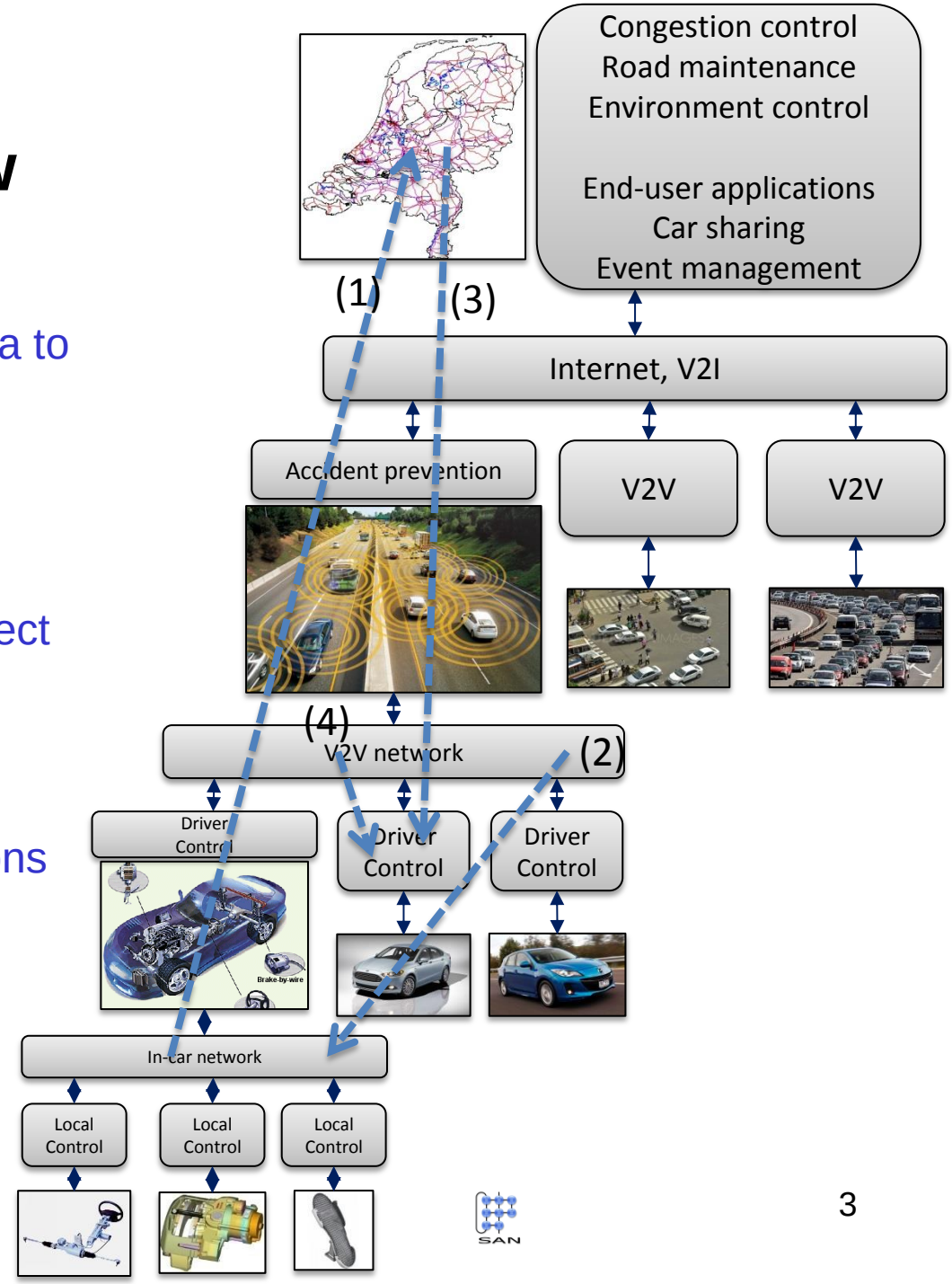
Multiple network technologies



C2C-CC (Car2Car Communication Consortium initiated by six European car manufacturers) architecture (~2010)

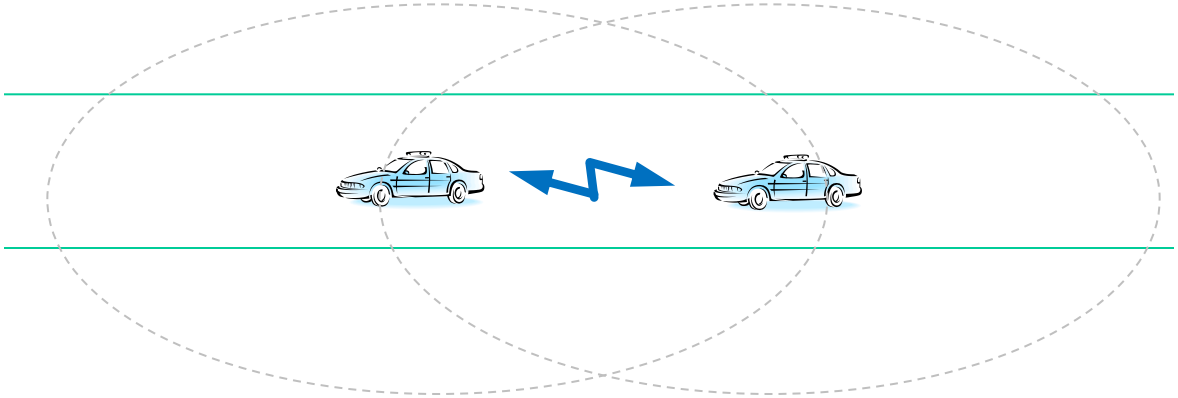
Remember: conceptual view

- Example data flows:
  - (1) gather detailed driving data to determine
    - local weather
    - road condition
  - (2) accident prevention by direct intervention
  - (3),(4) informing driver about upcoming road conditions

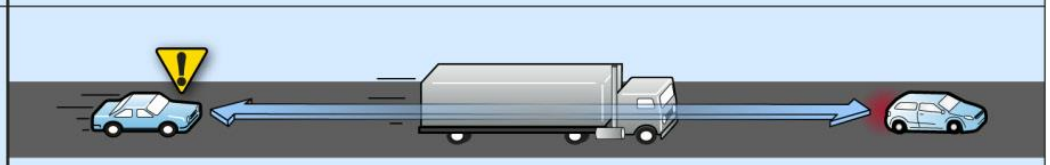
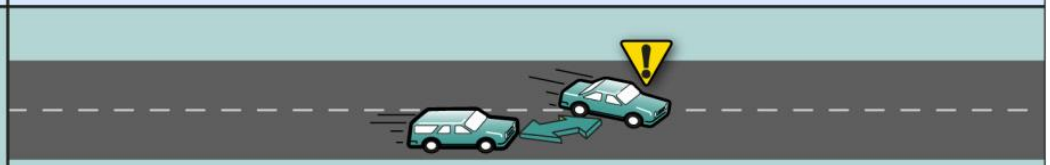
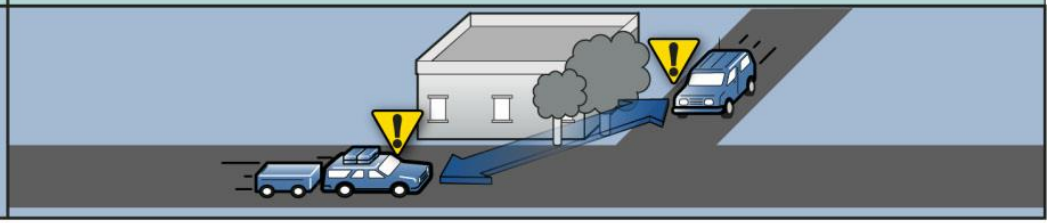


V2V: goals and characteristics

- Goals
  - Safety
  - Comfort
  - Traffic efficiency



- Main characteristics
  - Very high mobility of network nodes
  - Fully distributed system
  - IEEE 802.11p (CSMA/CA) as underlying technology
- Safety applications have strict requirements on (communication-)
  - Reliability
  - Delay

Scenario and warning type		Scenario example
Rear end collision scenarios	**Forward collision warning** Approaching a vehicle that is decelerating or stopped.	
	Emergency electronic brake light warning Approaching a vehicle stopped in roadway but not visible due to obstructions.	
Lane change scenarios	**Blind spot warning** Beginning lane departure that could encroach on the travel lane of another vehicle traveling in the same direction; can detect vehicles not yet in blind spot.	
	Do not pass warning Encroaching onto the travel lane of another vehicle traveling in opposite direction; can detect moving vehicles not yet in blind spot.	
Intersection scenario	**Blind intersection warning** Encroaching onto the travel lane of another vehicle with whom driver is crossing paths at a blind intersection or an intersection without a traffic signal.	

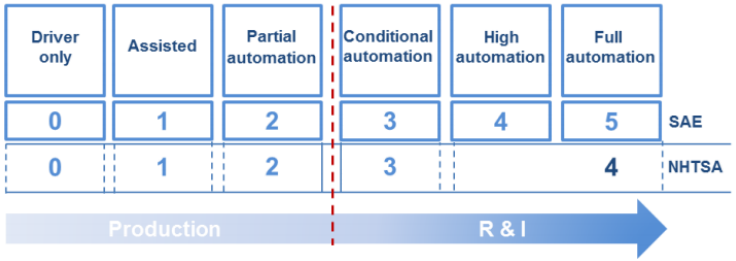
Source: GAO analysis of Crash Avoidance Metrics Partnership information.

from: Vehicle-to-Vehicle Communications: Readiness of V2V Technology for Applications, NHTSA, August 2014

ADAS

- Equipped with a user interface these applications end up as *Advanced Driver Assistance Systems* (ADAS)
  - e.g. a vibrating seat or other warning

5 steps to fulll automation



- Currently under R&D:
  - Collaborative Adaptive Cruise Control
    - 2 or more vehicles in a platoon
  - multiple CACC: merging

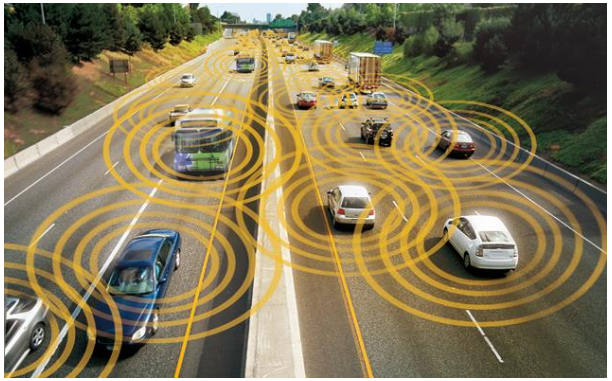
C’est le Rush

https://www.youtube.com/watch?v=Johmxw3cspA

How does this work?

- It is *cooperative, dynamic* and *ad-hoc*

- Two different approaches, same network technology (IEEE 802.11p)
  - **US**: *Wireless Access in Vehicular Environments* – WAVE – over Dedicated Short Range Communications – DSRC
  - **EU**: ETSI TC ITS standards, using Geo-networking



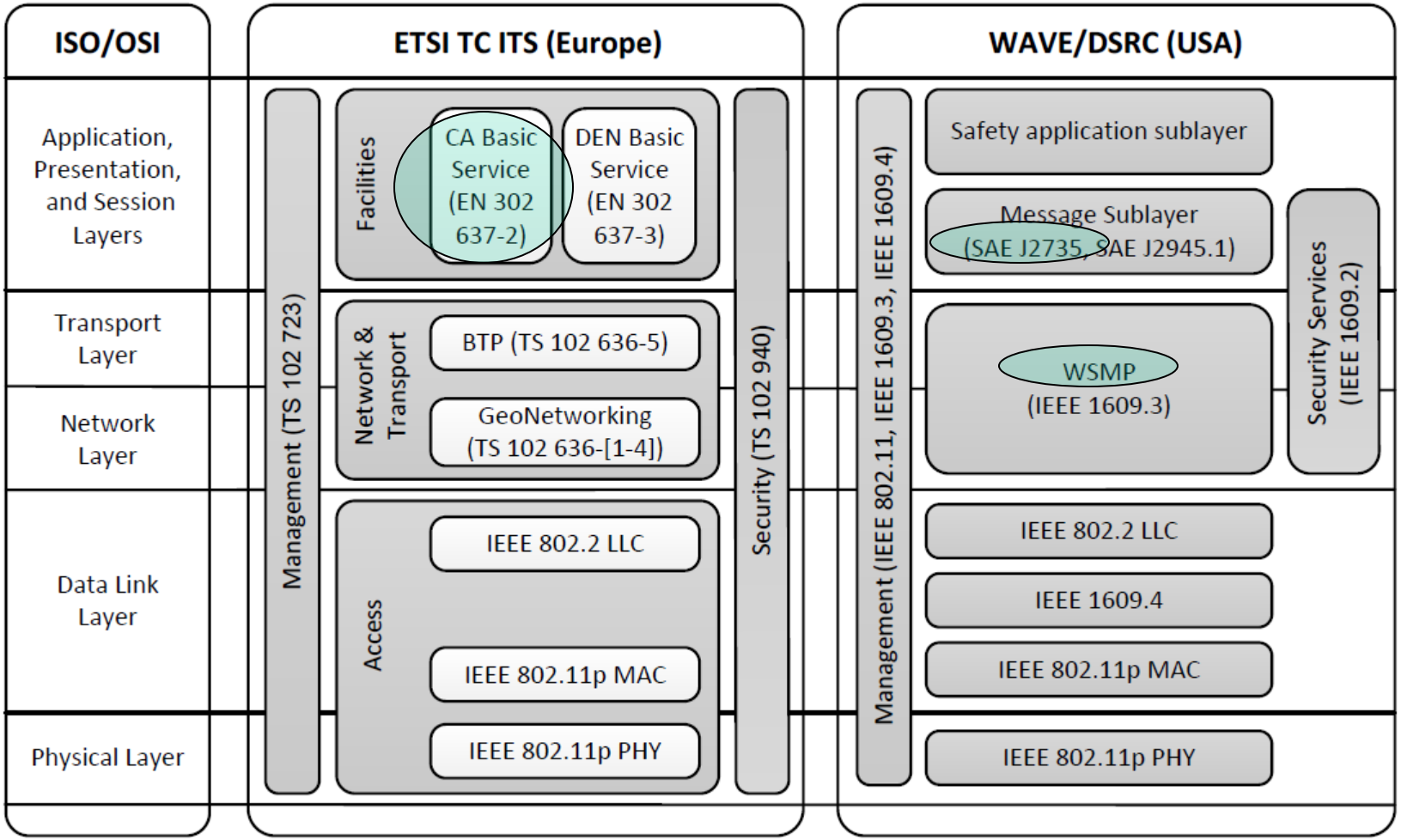
picture from the Internet

- Essentially: vehicles emit *periodically* or *event-driven* status information
  - called *Basic Safety Messages* (BSM, US)
  - and *Cooperative Awareness Messages* (CAM, EU)

IEEE 802.11p

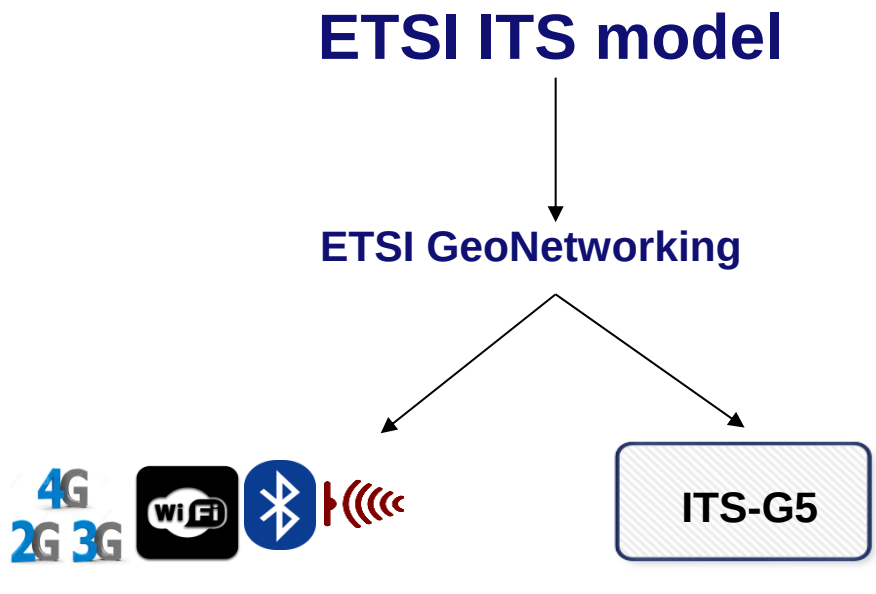
- part of the full IEEE 802.11 (2800page) specification: enhancements for use in Vehicles
- channels in the 5.9 GHz range (~300m in free field, max 1000)
- connect without BSS (stations with access point): no association, authentication
  - just direct, ad-hoc messaging when in range
- deal with high relative speeds of terminals
  - throughput 3-27Mbit/s per channel, typically 6Mbit/s per channel
- support prioritizing of traffic: EDCA (from 802.11e)
- UTC-based timing reference for synchronizing time accurately

(partial) Communication Stack: EU and US

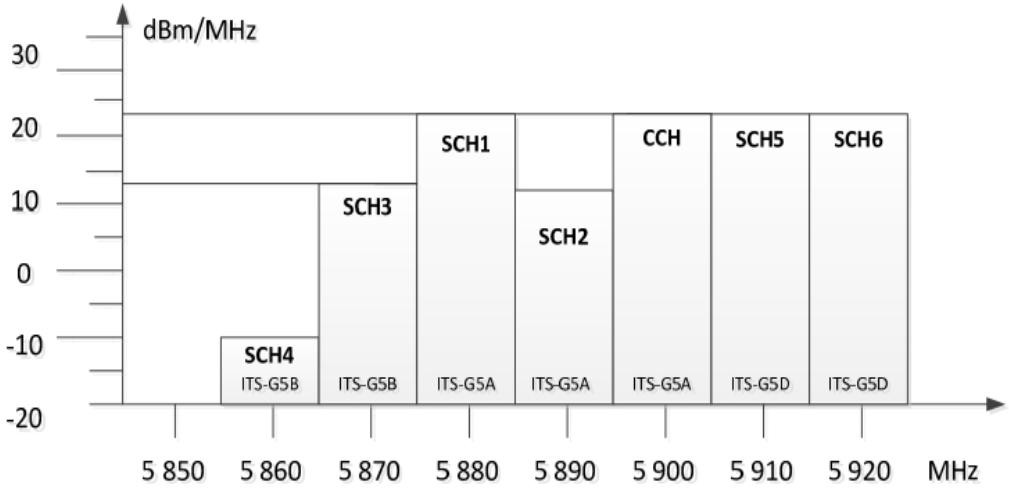


Rate-adaptation Based Congestion Control for Vehicle Safety Communications, PhD thesis Tessa Tielert

ETSI GeoNetworking

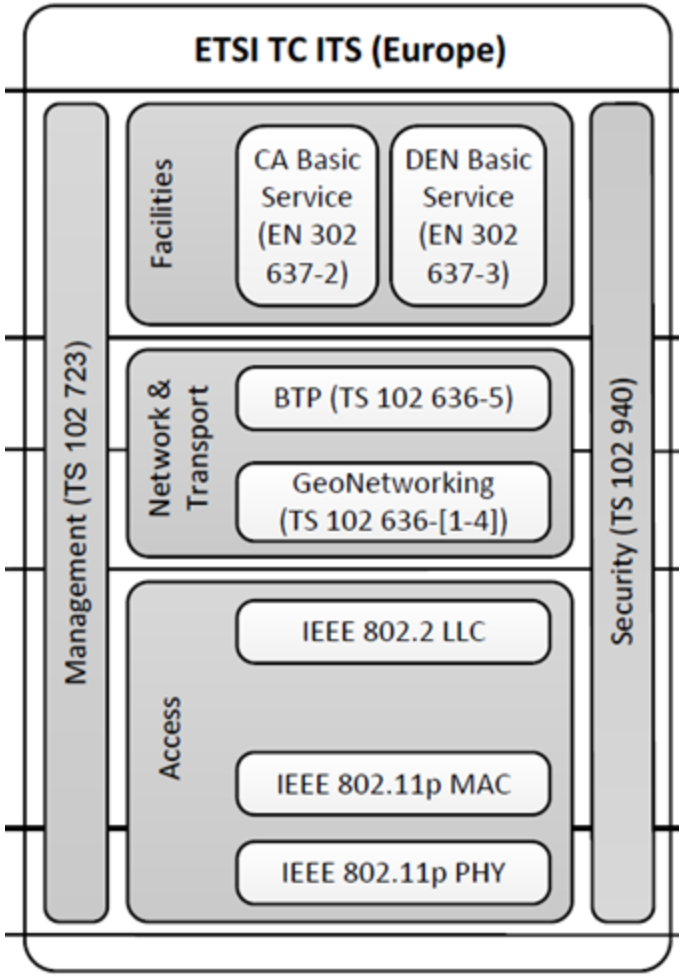


- ETSI GN
  - Intended to work on different access technologies
- ITS-G5:implementation on IEEE 802.11p
  - three frequency classes
    - A:safety
    - B: non-safety
    - D: future
  - control and service channels
    - common control channel: primary channel for unsollicited traffic
  - protocols for channel switching



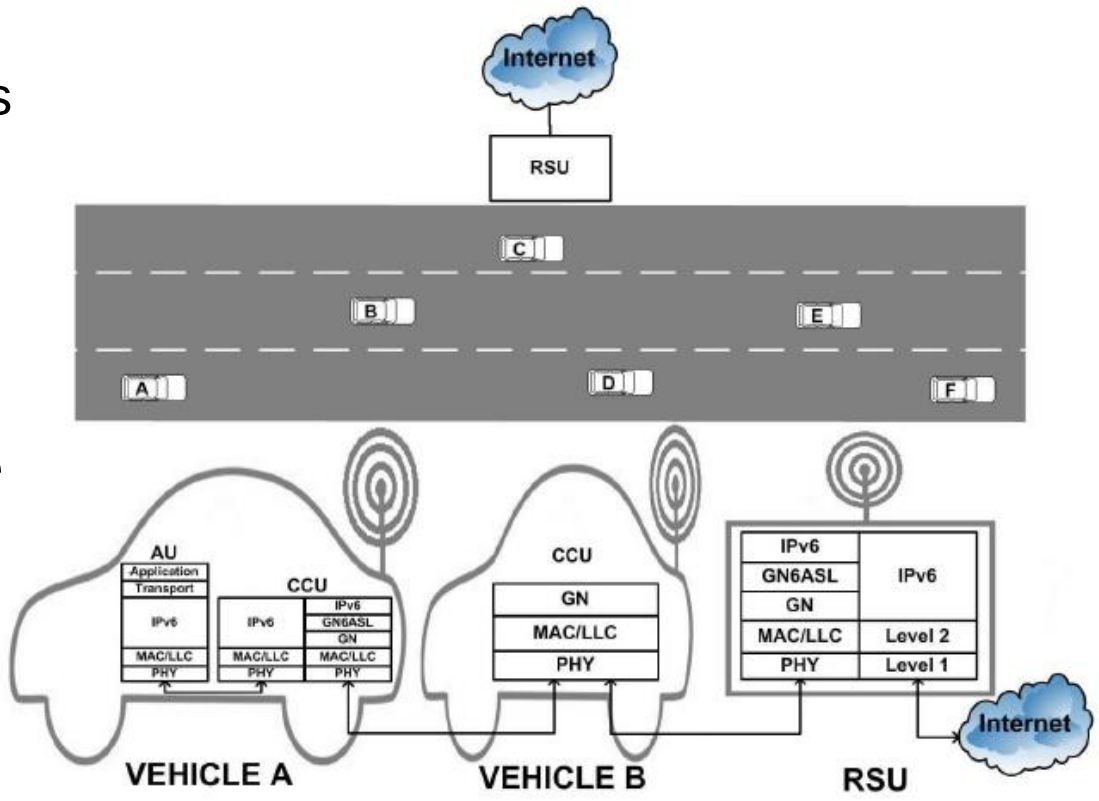
ETSI GeoNetworking

- ETSI GN provides ad-hoc local connectivity
  - Addressing: 48bit interface address extended with station information
  - use of a *location table* about neighbors
    - updated by info from incoming messages
  - GN routers, role of some stations
  - Services, e.g:
    - SHB: single hop broadcast (repeated)
    - unicast
    - geobroadcast: limit physical extent and limited number of hops
  - BTP: add multiplexing to the GN services



ETSI GN: Internet connectivity

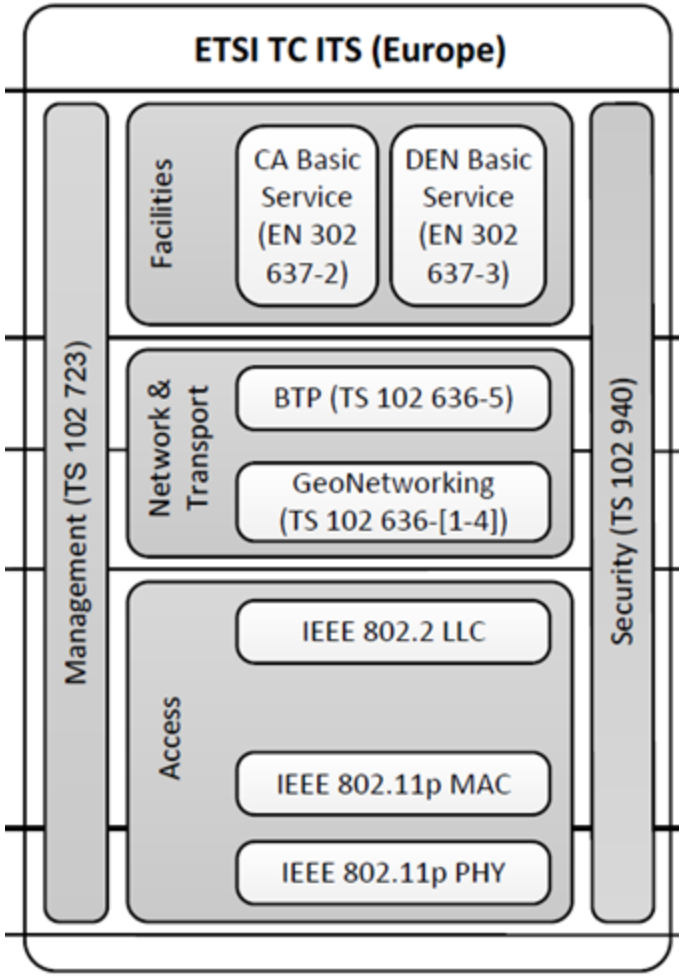
- Forwarded to IPv6 gateway by GN protocols
- Adaptation layer provides transparency
- IPv6 of lower importance than safety applications



(draft) Vehicle to Internet communications using the ETSI ITS GeoNetworking protocol
Victor Sandonis, Ignacio Soto, Maria Calderon, Manuel Urue˜na

ETSI GN: safety messages

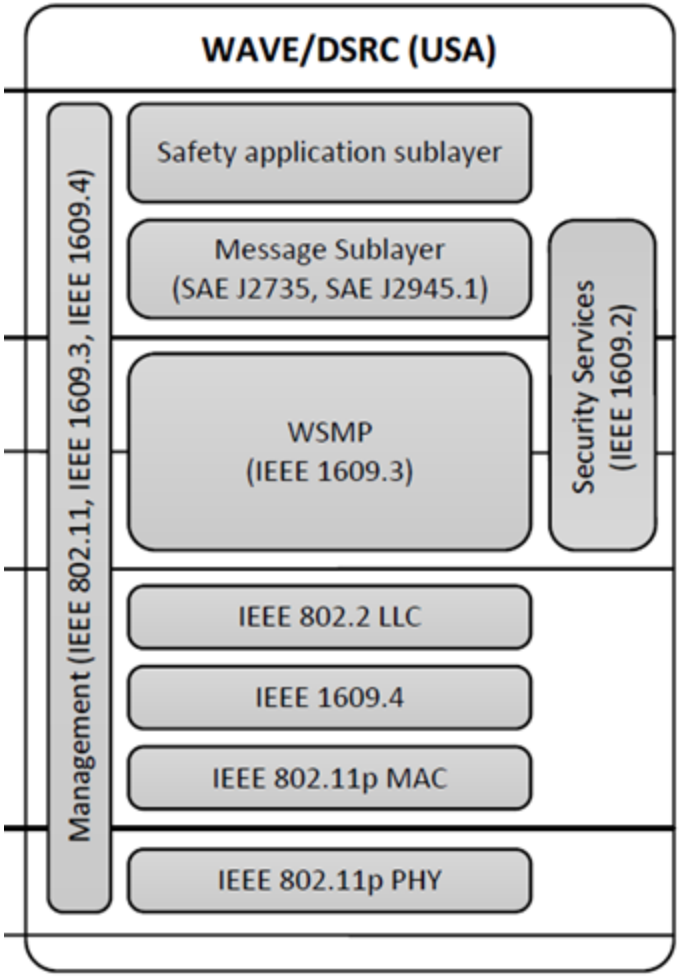
- **CAM**: cooperative awareness messages
  - use the SHB protocol
  - repeated broadcast vehicle state in one-hop neighborhood
- **DENM**: decentralized environment notification messages
  - use the geocast protocol
  - inform about hazards and road conditions



US: WAVE/DSRC

- IEEE 1609 standardizes Wireless Access in Vehicular Environments over Dedicated Short Range Communication
  - 1609.1: resource management
  - 1609.2: security services
  - 1609.3: networking services (a.o. wave short message protocol)
    - broadcasting of basic safety messages
    - define channel number and power per message
  - 1609.4; multi-channel operation

- SAE J2735
  - defines the message content of WSMP



Some application examples
(US WAVE BSM ~SAE J2735)

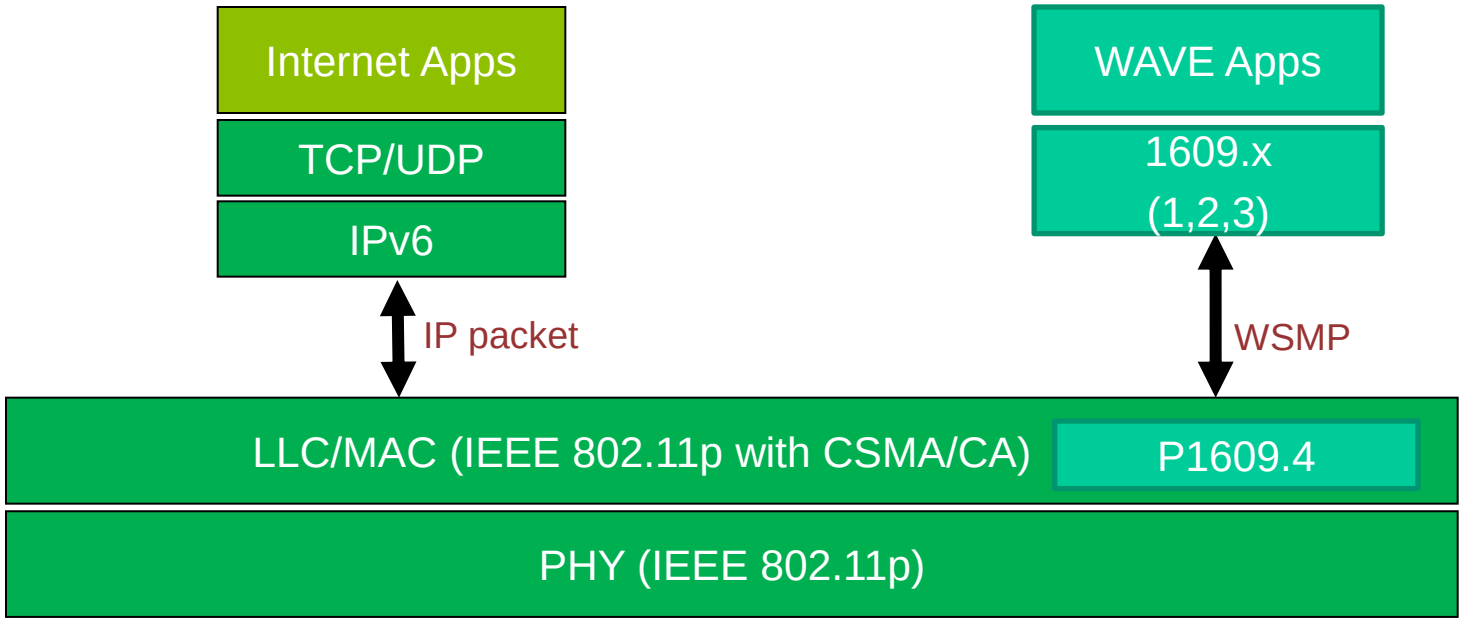
Apps.	Comm.type	Freq.	Latency	Range
Lane Change Warning	V2V, periodic, P2M	10Hz	100ms	150m
Collision Warning	V2V, periodic, P2M	10Hz	100ms	150m
Emergency Brake Lights	V2V, event-driven, P2M	10Hz	100ms	300m
Pre-Crash Sensing	V2V, event-driven, P2P	50Hz	20ms	50m
Stop Sign Assists	I2V and V2I, periodic	10Hz	100ms	250m
Left Turn Assistance	I2V and V2I, periodic, P2M	10Hz	100ms	300m
Traffic Signal Violation	I2V, periodic, P2M	10Hz	100ms	250m
Curve Speed Warning	I2V, periodic, P2M	1Hz	1s	200m

V2V = Vehicle to Vehicle
P2M = Point to Multipoint
I2V = Infra structure to Vehicle

Eight high priority vehicle safety applications as chosen by NHTSA and VSCC.

NHTSA – US National Highway Traffic Safety Administration
VSCC – Vehicle Safety Communication Consortium of CAMP (Crash Avoidance Metrics Partnership)

Combining with Internet



WAVE (Wireless Access in Vehicular Environment) standards: IEEE 802.11p standard and 1609.x standards

Discussion

a CPS communication system

- What is the influence of the ‘physical’ on the ‘cyber’?
- Which layers are involved?
- Is there further opportunity for optimization?
  - what should be optimized then, what are metrics?
- Which transparencies are maintained and where is the layering broken?

- Examine your own projects. What (wireless) communication concerns do you see?

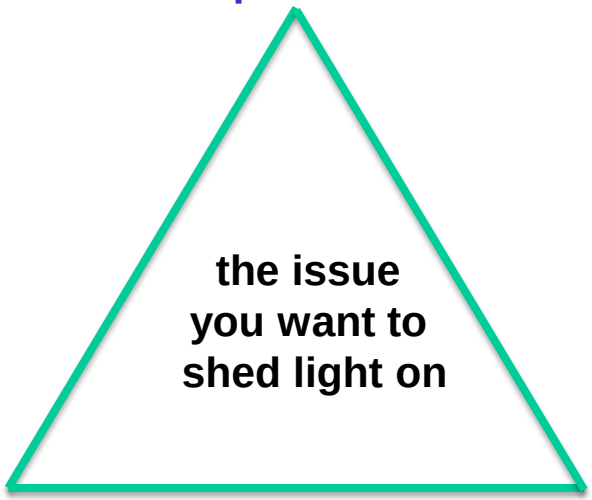
Modeling, Simulation, Testing

- What do we want to know / show / prove of this system?
  - functional properties and consistency of the specification
    - are the use cases addressed?
  - extra-functional properties of the specification
    - these are not always made explicit, e.g. performance
    - these are not directly following from design choices
    - these rely on a wide range of assumptions about
      - the environment of the system
      - the properties of subsystems
  - properties of the implementation
    - adherence to the specification
    - validation of the results above
    - … does it work?

Choose at least 2 out of 3

real world

experiment



model world

simulation

analytical description

Concerns of safety

- What is the combined behavior of application components distributed over several vehicles?
  - agreements on and effects of actuations?
  - which situational information needs to be taken into account?
    - road condition, #passengers in other car, #vehicles in certain range, …. ?
  - development and acceptance procedures for applications
    - https://blogs.nvidia.com/blog/2016/05/06/self-driving-cars-3/
    - https://www.youtube.com/watch?v=qhUvQiKec2U

- Communication from perspective of a given vehicle
  - do I know who is in my neighborhood?
    - how long does it take to know this?
  - are my messages received by vehicles in my neighborhood?
  - do I receive the messages of vehicles in my neighborhood?
  - how does this scale in function of vehicle density? of …?

Case study: scalability of periodic broadcast

- When the number of vehicles increases, collisions will increase as well
- Nodes will suffer losses through Near Neighbor and Hidden Node effects

- Questions:
  - what are effects on reliability, delay and fairness?
    - fairness: all vehicles taking the same loss?
  - what is the impact of HN, NN?
  - what is the impact of the *phase,* and of changes therein?
  - what are relevant metrics?

From: *Model, Analysis, and Improvements for Inter-Vehicle Communication Using One-Hop Periodic Broadcasting Based on the 802.11p Protocol,* T.Batsuuri, R.J.Bril, J.J.Lukkien

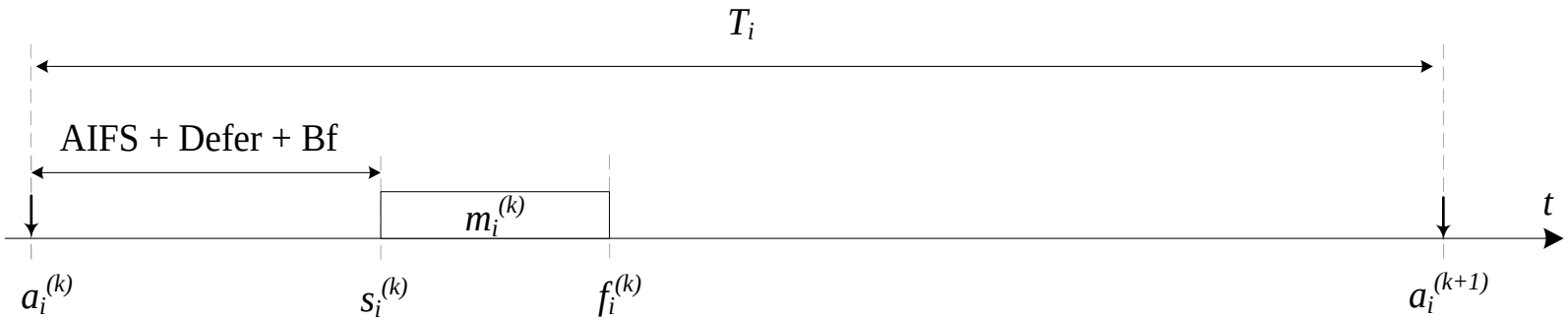
Periodic Broadcast in IEEE 802.11p

$$a_i^{(k)} \stackrel{def}{=} \phi_i + k \cdot T_i$$

$$k : k^{th}\ message$$

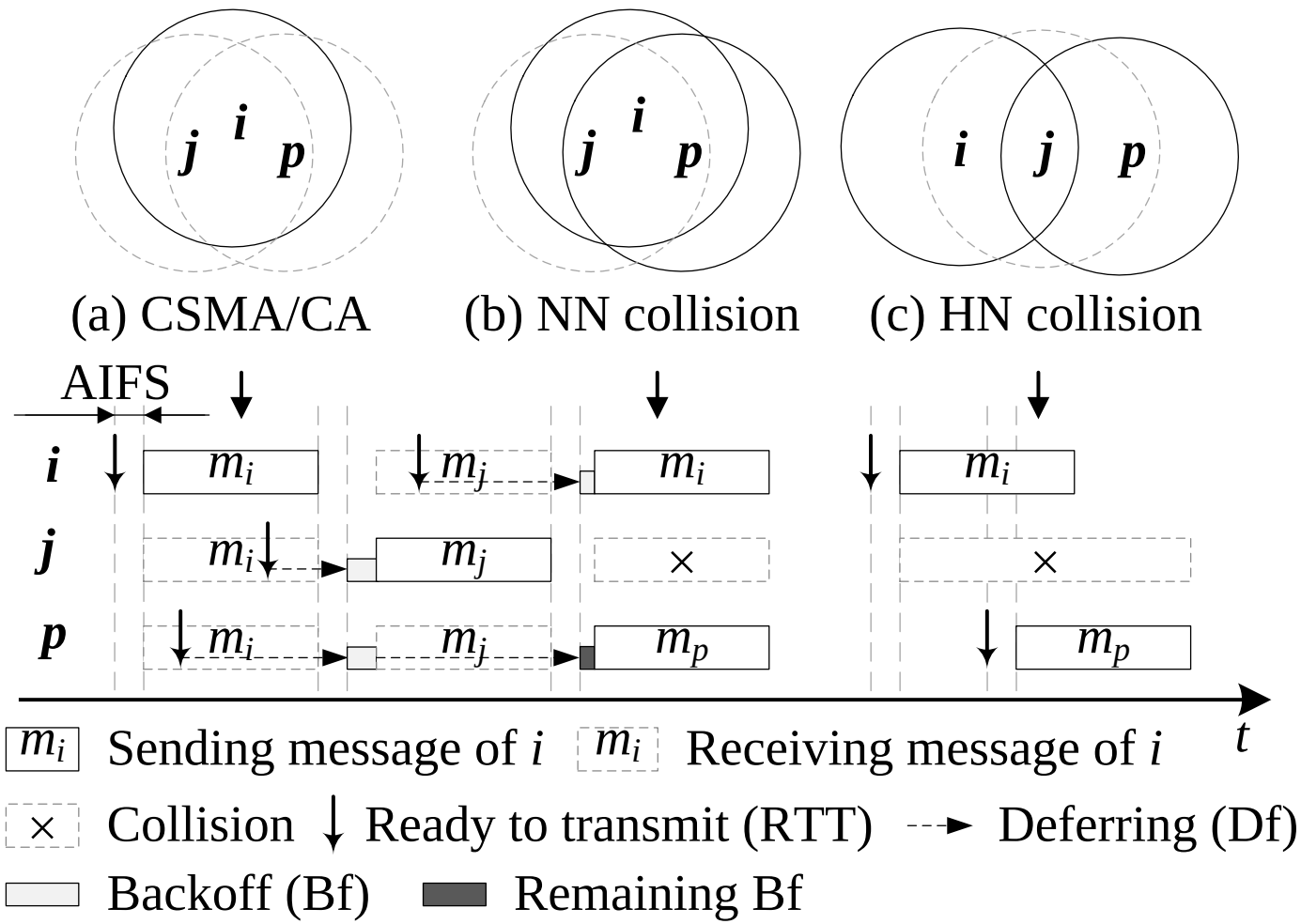
$$\phi_i = initial\ phase\,(or\ offset)\,with\ respect\ to\ a\ common\ zero$$

$$T_i : period$$



- *Defer: waiting until channel is free; Bf: backoff; AIFS: see EDCA*
- For broadcast, randomization in back-off process is limited
- Point-to-point techniques for solving hidden node problems do not work
  - MAC layer acknowledgement
  - RTS/CTS

Collisions


i
j
p
(a) CSMA/CA
(b) NN collision
(c) HN collision
AIFS
m_i
m_j
m_p
×
t
Sending message of i
Receiving message of i
Collision
Ready to transmit (RTT)
Deferring (Df)
Backoff (Bf)
Remaining Bf

How to setup the simulation?

- Two ‘independent’ parts:
  - Simulate vehicles, and vehicle movement
  - Simulate communication
    - how detailed should this be?

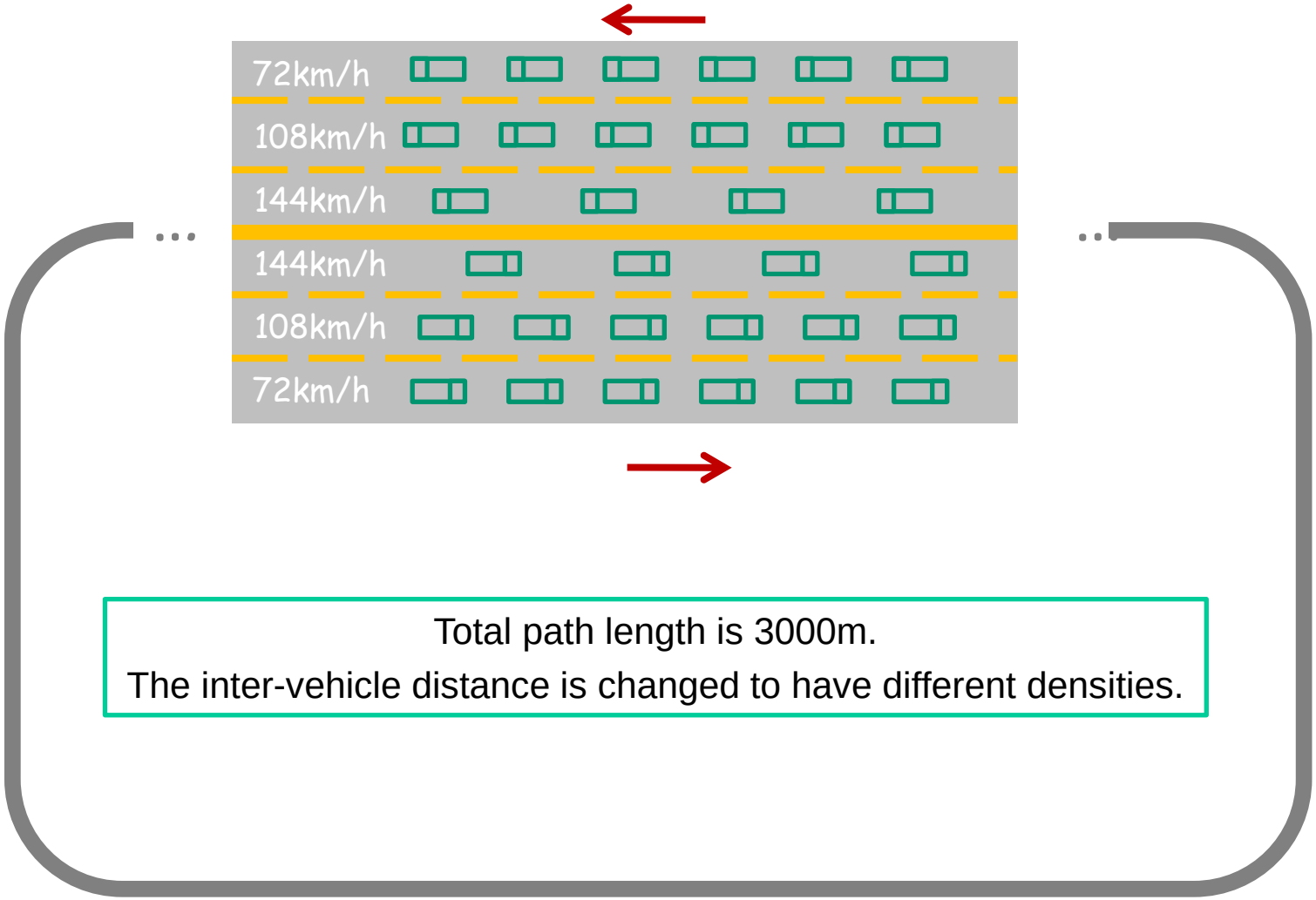
- Vehicle movement
  - idealized, parameterized
  - or real-world traces?

Simulation setup

Scenario: Every vehicle periodically broadcasts messages at 10Hz frequency within its communication range.

Simulator	VNS & NS2
Packet size (bytes)	555
Channel rate	6Mbps
Communication Range(CR, m)	300
A slot time(us)	13
SIFS(us)	32
AIFS(us)	SIFS + 6*slots
CW(us)	7*slots

Highway model



Total path length is 3000m.
The inter-vehicle distance is changed to have different densities.

Assumptions

- All vehicles have the same fixed period for broadcasting.
- All vehicles broadcast messages of the same fixed size.
- For each vehicle, the phase is determined randomly.

- Definition: we say that *there is a link from vehicle A to vehicle B* iff B can receive messages from A (i.e., B is in the communication range of A).

- Channel model:
  - Two-Ray Ground
  - Communication range is effectively a sphere

Antenna gain	0 dB
Antenna height	1.5 m
Noise floor(nF)	−99 dBm
Power sense threshold($PsTh$)	−92 dBm
Carrier sense threshold ($CsTh$)	−85 dBm
SINR threshold ($SrTh$)	8 dB

Metrics

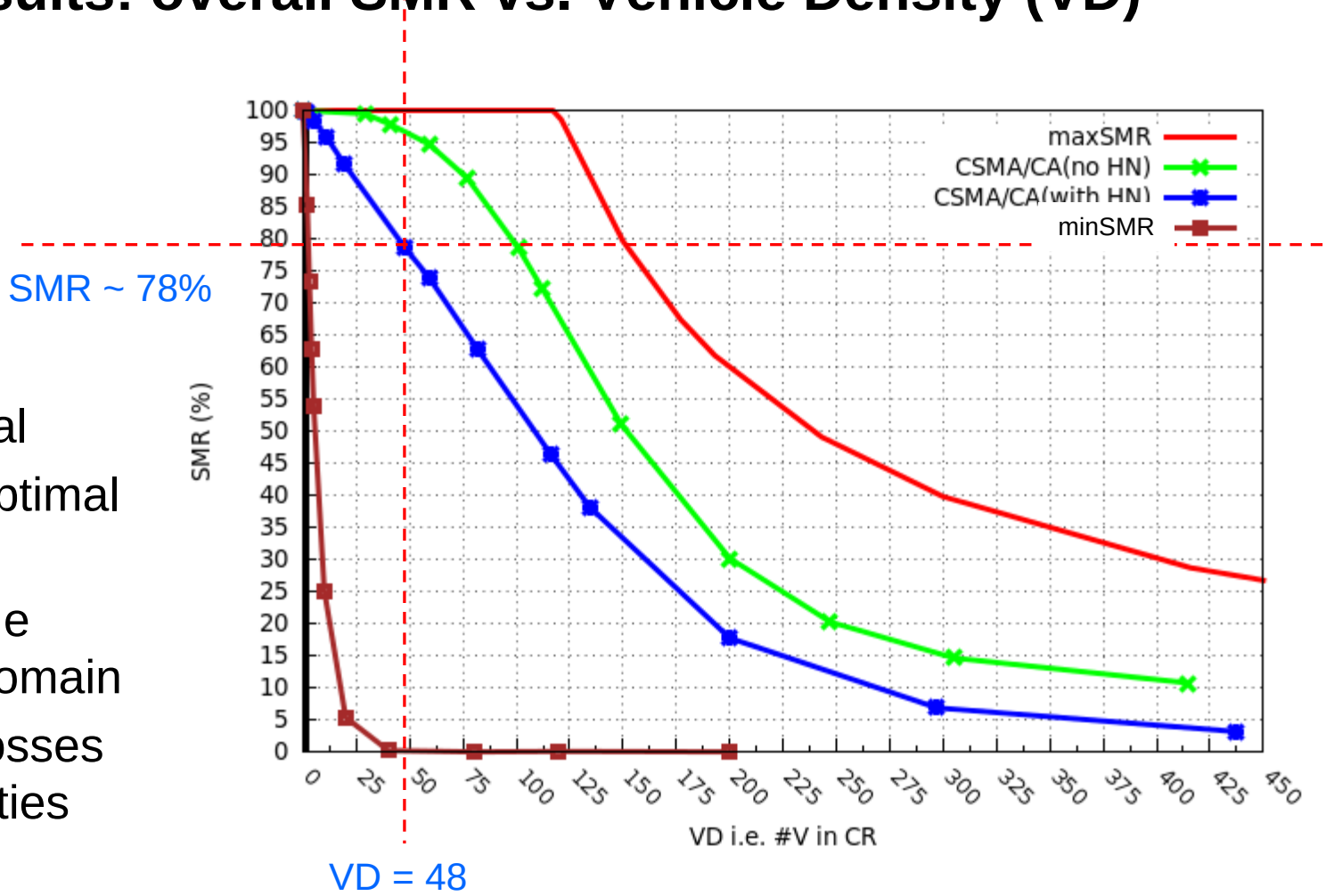
- Successful Message Ratio (SMR) – the fraction of vehicles in Communication Range that receive a broadcast message.
  - Example: if a network has vehicles with 10 neighbors on average and on average 7 receive the message then SMR=70%
  - SMR is also defined per vehicle and per message

- First Delay (FD) – the longest interval in which no message is successfully delivered between two vehicles since they established a link (i.e. a delay to discover each other)

- No Message Interval (NoM) – the longest interval in which no message is successfully delivered in a link

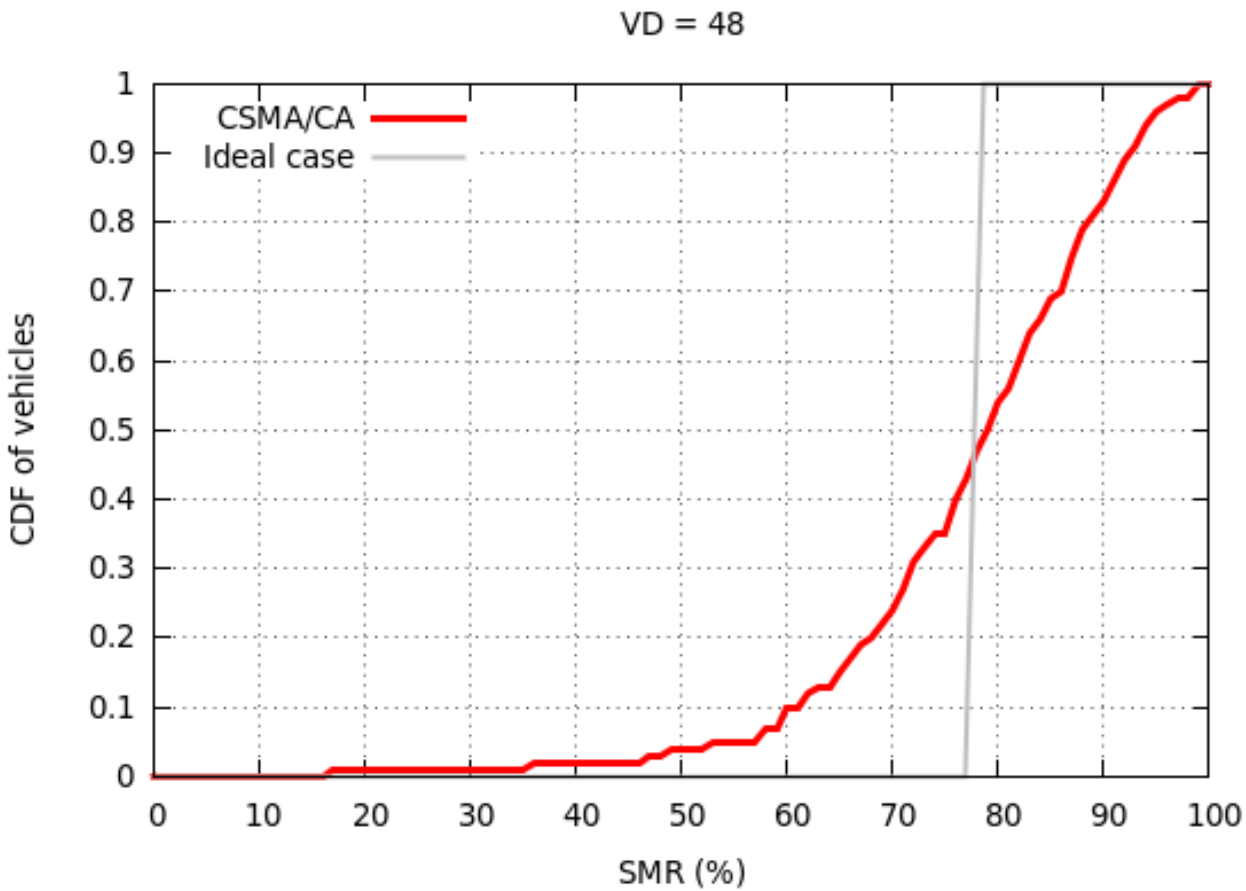
Results: overall SMR vs. Vehicle Density (VD)

- minSMR: all phases equal
- maxSMR: optimal scheduling
- no HN: single broadcast domain
- significant losses at low densities



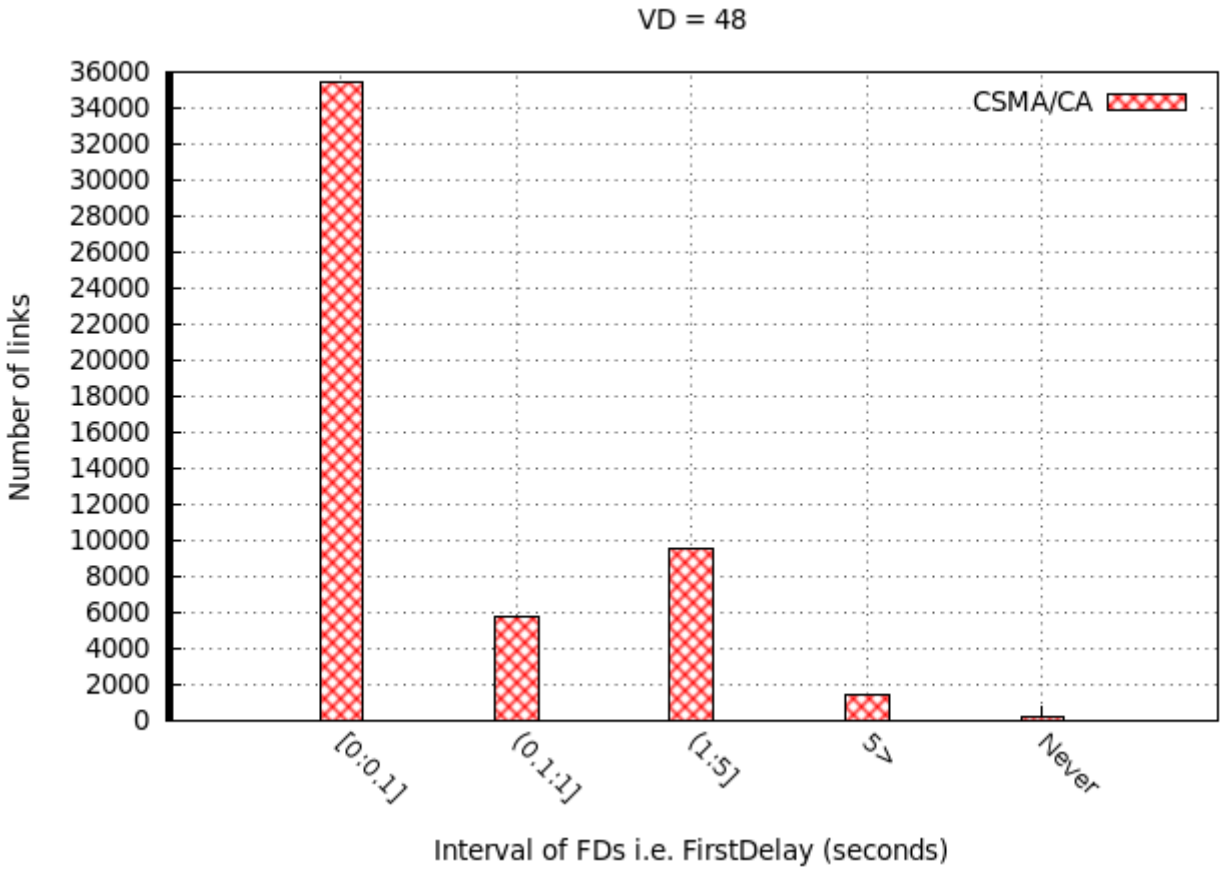
CDF of vehicles by its SMR

- CDF: Cumulative Distribution Function
  - y% vehicles have at most x% SMR
- Some vehicles have SMR of 15%,and some of 100%
  - unfair!
- Ideal case: all the same



First Delay (60 simulated seconds)

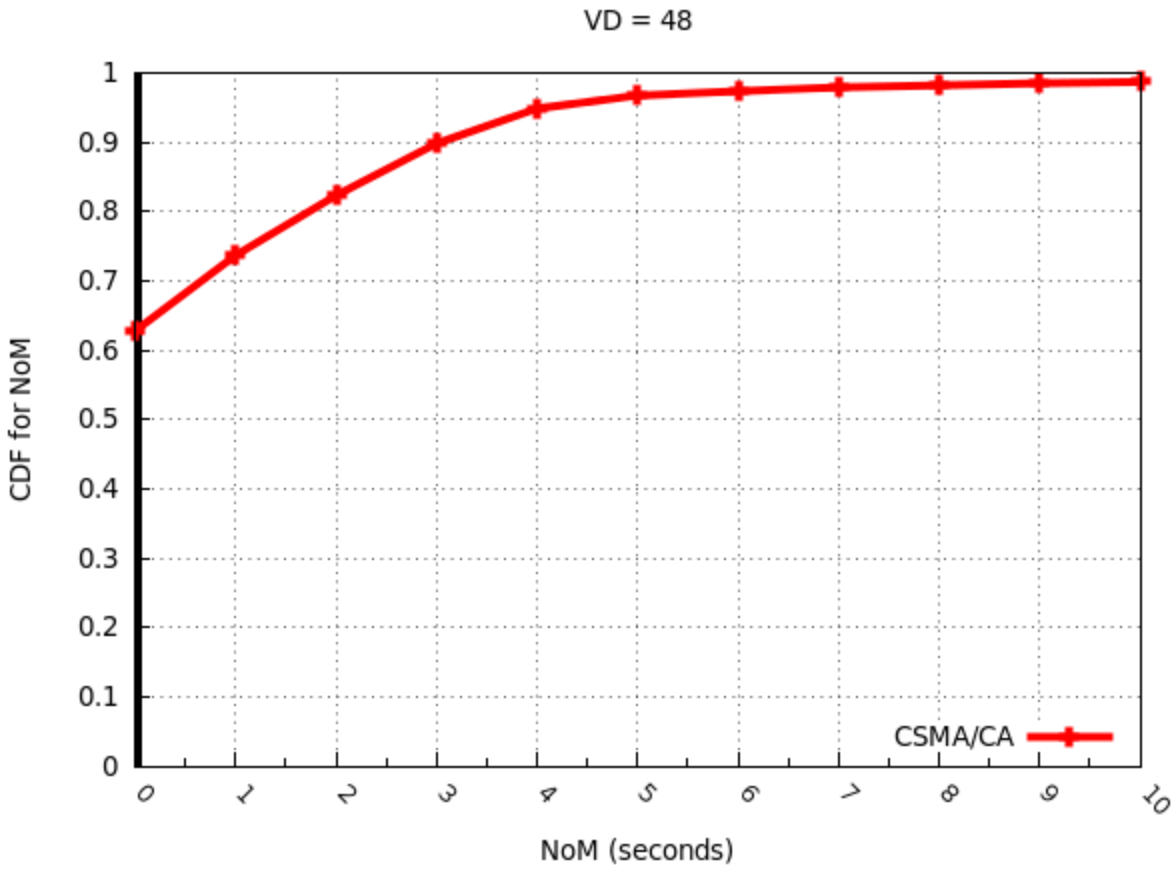
- Most vehicles see each other within 100ms
- Some vehicles never see each other



- 52644 links are established (~36000 links between vehicles traveling in opposite directions, ~17000 links for the same direction)

CDF of NoMessage Interval

- y% links have up to x seconds NoM
- Most NoMs are short
- However, a positive number of NoMs is larger than 10s



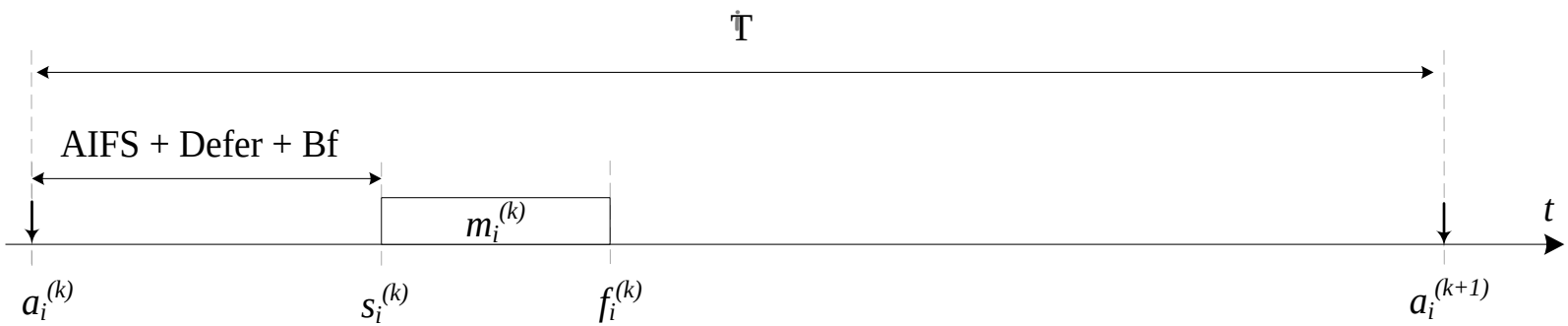
Possible adjustments

$$a_i^{(k)} \overset{def}{=} \phi_i + k \cdot T_i$$ + jitter

$k : k^{th}$ *message*

ϕ_i = *initial phase (or offset) with respect to a common zero*

T_i : *period*



- Elastic:
  - randomize the phase every ***er*** (elastice rate) messages
    - appears to improve fairness
- Jitter:
  - give a jitter of ***AJ*** msec (Activation Jitter) to the arrival moment
    - appears to improve long delays

- Strict periodic scheme

$$a_i^{(k)} \stackrel{def}{=} \phi_i + k \cdot T_i$$

- Elastic scheme

$$a_i^{(k)} \stackrel{def}{=} \begin{cases} \phi_i & if\ k = 0 \\ a_i^{(k-1)} + T_i & if\ k \bmod er_i \neq 0 \\ a_i^{(k-1)} + rand(2 \cdot T_i) & if\ k > 0, k \bmod er_i = 0 \end{cases}$$

$$er - elastic\ rate,\ rand - random\ function$$

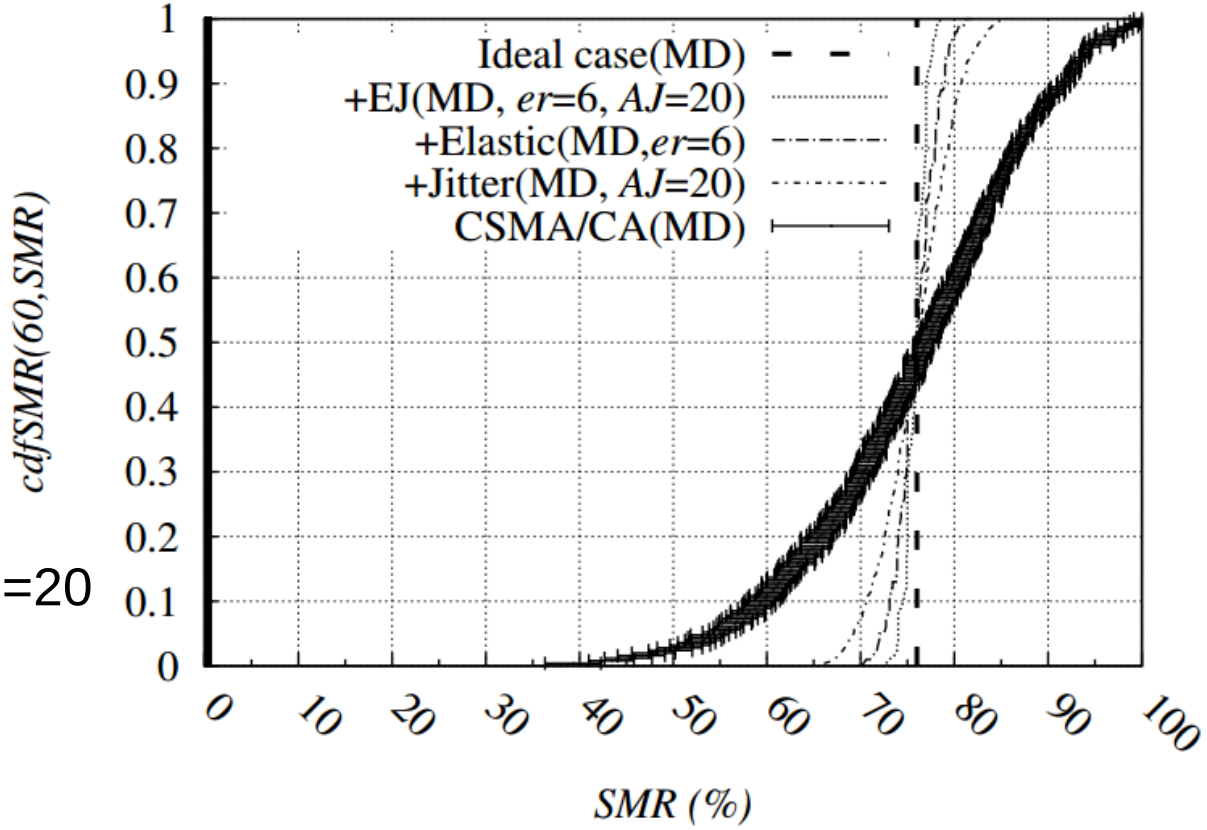
- Jitter scheme

$$a_i^{(k)} \stackrel{def}{=} \phi_i + k \cdot T_i + rand(AJ_i)$$

$$AJ - Activation\ Jitter\ (in\ units\ of\ message\ transmission\ time)$$

Two solutions into one: SMR

- Neither Jitter nor Elastic changes SMR!
- Combined: best results
- MD: multi-domain
- Choice of er=6, AJ=20 based on experimentation



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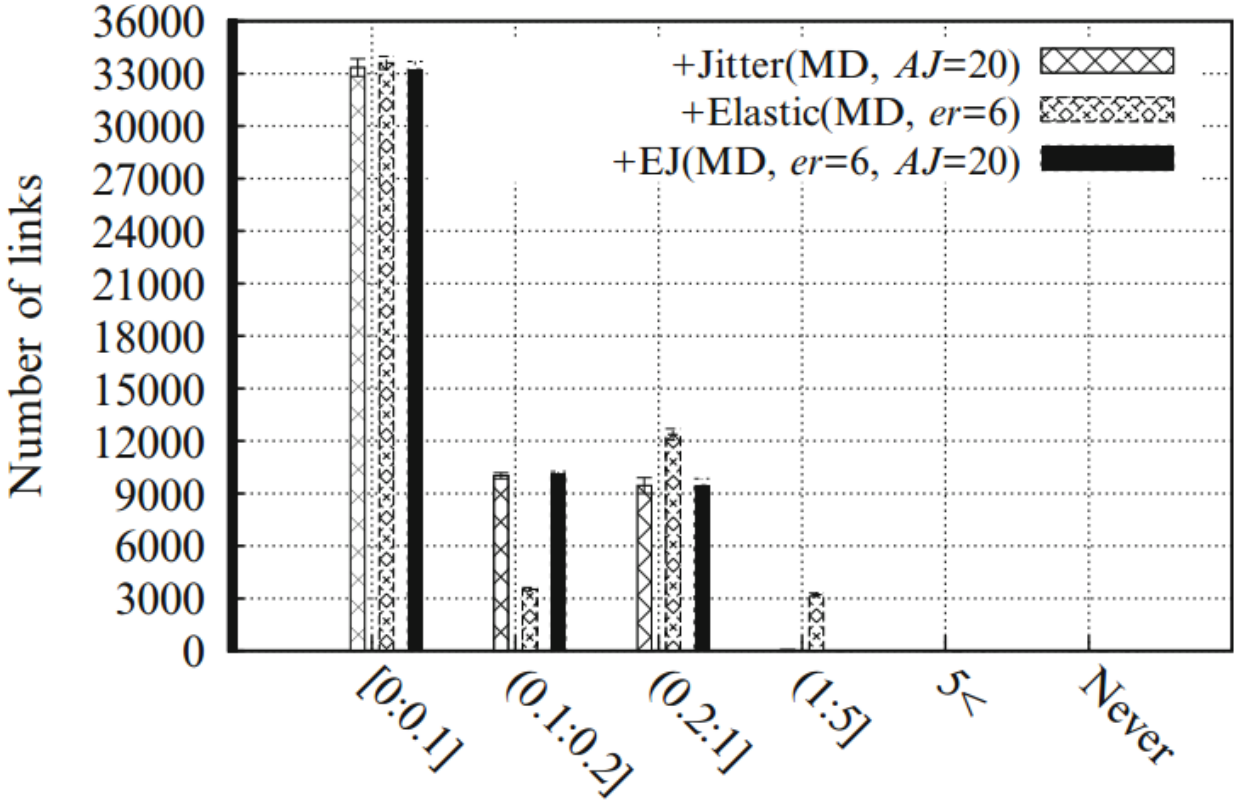

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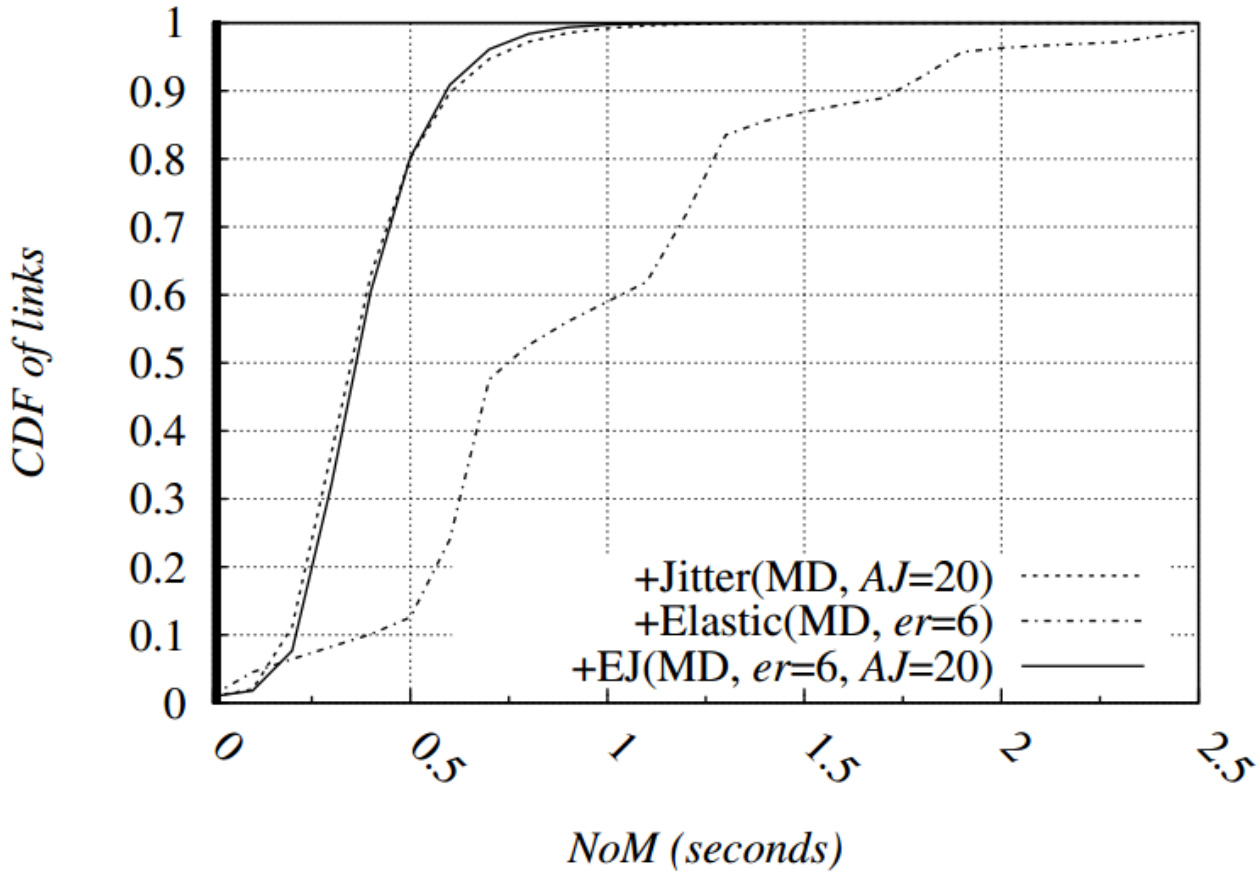


Literature

- Vehicle ad-hoc Network, Standards, Solutions, and Research, edited by Campolo, Molinaro, Scopigo, Springer
- Vehicle-to-Vehicle Communications: Readiness of V2V Technology for Applications, NHTSA, August 2014
- Rate-Adaptation Based Congestion Control for Vehicle Safety Communications, PhD thesis Tessa Tielert
- Model, analysis, and improvements for inter-vehicle communication using one-hop periodic broadcasting based on the 802.11p protocol, Batsuuri, Lukkien, Bril, Wireless Sensor and Mobile Ad-hoc Networks

Concluding

- What further analysis is required?
  - to increase understanding of the communication system operation, in more circumstances, or in a more accurate model
    - will a real implementation exhibit the behavior of the previous slides
  - to understand application operation, quality

- What further physical aspects could be taken into account such that the system will behave better
  - need metrics that need to be improved

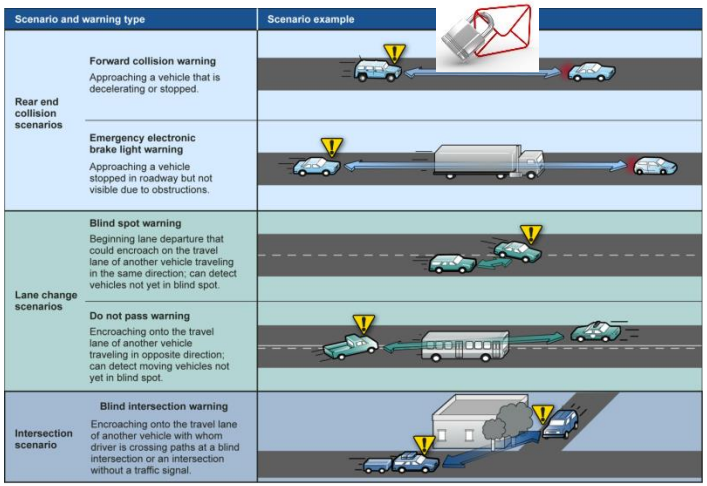
- There are strong concerns of privacy and security that may influence system design and operation significantly

Privacy, Safety, and Security

- **Privacy**: control over personal information
- **Safety**: freedom from danger or risk on injury resulting from recognized but potentially hazardous events
- **Security**: regulating access to (electronic) assets according to some policy
  - *policy*: allowed and disallowed actions
  - *security mechanisms*: can be regarded as enforcing the policy
- Privacy and safety restrictions result in *security policies*
  - *security for privacy and security for safety*
- In addition: security for protection of the business case
  - *security for the business case*, quite often an *availability concern*

Security to protect *safety* in BSM

- A vehicle could perform a (physical) action upon receiving certain messages. This response must be on good grounds, and safe.
  - authentication: does this message really come from
    - that particular car?
    - the car left behind me?
  - authorization: what is allowed
    - by this party?
    - by this message?
  - integrity: was this message not tampered with?



Source: GAO analysis of Crash Avoidance Metrics Partnership information.

- Further concerns regarding safety:
  - are messages really delivered (and not lost or jammed)?
  - functional safety
    - maintain safe and responsive behavior while executing normal functions