Vehicular Networking

Overview

- Vehicular Networking
- Part 1: ...in cars
  - Overview and use cases
  - Architectures
  - Bus systems
  - Electronic Control Units
  - Security and safety
- Part 2: ...of cars
  - Overview and use cases
  - Architectures
  - Communication systems
  - Applications
  - Security and safety

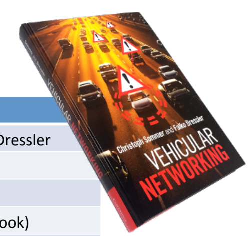
About this slide deck

- These slides are designed to accompany a lecture based on the textbook "Vehicular Networking" by Christoph Sommer and Falko Dressler, published in December 2014 by Cambridge University Press.
- Except where otherwise noted (e.g., logos and cited works) this slide deck is Copyright © 2009-2015 Christoph Sommer, but made available to you under a *Creative Commons Attribution-ShareAlike 4.0 International License*.
- In brief, this means you can share and adapt the slides as long as you follow the terms set out in this license [1]. If you split this slide deck into multiple parts, make sure to include appropriate attribution in each part.
- This slide deck would not have been possible without the contributions of Falko Dressler, David Eckhoff, Reinhard German, and Kai-Steffen Jens Hielscher.
- Please leave this slide intact, but indicate modifications below.
  - Version 2015-02
    - Improved version for release on book website (Christoph Sommer)
- Updated versions of the original slide deck are available online [2].

[1] http://creativecommons.org/licenses/by-sa/4.0/
[2] http://book.car2x.org/

Course Material

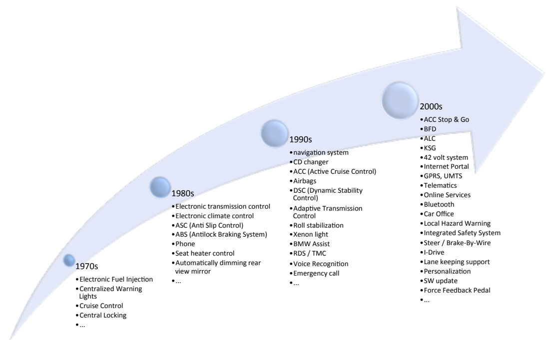
Title	Vehicular Networking
Authors	Christoph Sommer and Falko Dressler
Publisher	Cambridge University Press
Date	December 2014
Format	Hardback (also available as eBook)
ISBN-10	1107046718
ISBN-13	9781107046719
Website	http://book.car2x.org



A Short Introduction

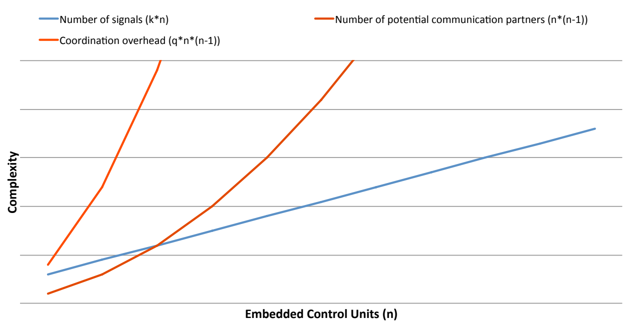
…to Vehicular Networking

Introduction – Electronics in cars



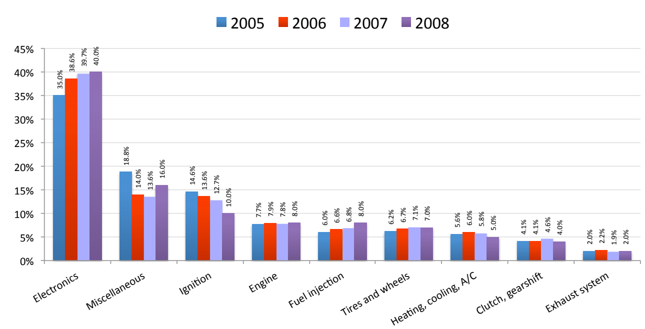
Data Source: U. Weinmann: Anforderungen und Chancen automobilgerechter Softwareentwicklung, 3. EUROFORUM-Fachkonferenz, Stuttgart, Juli 2002

Electronics need communication



Data Source: U. Weinmann: Anforderungen und Chancen automobilgerechter Softwareentwicklung, 3. EUROFORUM-Fachkonferenz, Stuttgart, Juli 2002

Component failure rate



Data Source: ADAC Vehicle Breakdown Statistics 2005-2008

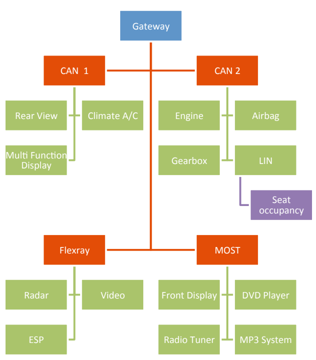
Bus systems

- Until the end of the 80s
  - Cars' control units are isolated, non-networked
  - dedicated wires connect sensors and actors
- Starting with the 90s
  - digital Bus systems
  - CAN-Bus
- Today
  - Rising demands on bus systems
  - networked functionality requires more than one control unit
    - Turn signal: > 8 distinct control units
  - Real time constraints
  - Multimedia

Bus systems

- Complexity is ever increasing
  - From 5 ECUs in a 1997 Audi A6
  - To over 50 ECUs in a 2007 Audi A4
  - Current middle and upper class vehicles carry 80 .. 100 networked Electronic Control Units (ECUs)
- Traditionally: one task ⬄ one ECU
- New trends:
  - distribution of functions across ECUs
  - integration of multiple functions on one ECU

Multiple bus systems



Electronics today

- Up to 100 ECUs
- Up to 30% of value creation
- Up to 90% of Innovations
- Up to 3km of wiring for power and data
- Up to 3800 interface points

Electronics tomorrow

- Data will leave confines of single car: inter-vehicle communication

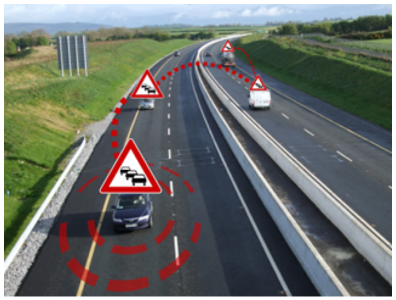


Illustration © 2010 Christoph Sommer

Visionary Applications

- Lane assistant
  - Simple roadside beacons support lane detection
- Lateral collision avoidance
  - More advanced beacons on cars and motorcycles help maintain minimum separation
- Accident reporting
  - Broken down cars can automatically send simple report to central server
- Intersection assistance
  - Pairs of cars automatically coordinate complex maneuvers at intersections
- Cooperative driving
  - The future evolution of autonomous driving: vehicles actively support each other's route planning, navigating, driving

Visionary Applications

- ...and much (much) more:

Emergency Brake Light Warning, Accident Warning, Emergency Flashlights, Traffic Jam Warning, Weather Warning, Emergency Vehicle, Slow Vehicle, Moving and Static Road Works, Obstacle Warning, Intersection Maneuvering Assistance, Intersection Traffic Lights, Lane Change, Maneuvering Assistance, Longitudinal Maneuvering Assistance, Floating Car Data Collection, Free-Flow Tolling, Breakdown Call, Remote Diagnostics, Theft Detection, Emergency Call, Just-In-Time Repair Notification, Roadside Traffic Camera pull, In-vehicle signing pull, Regional Information pull, Car-specific Software Application Download pull, Electronic Payment pull, Logistic for goods being loaded and unloaded, Traffic Information Service pull, Traffic Information Service push, Electronic Payment push, Roadside Traffic Camera push, In-vehicle signing push, Car specific Software Application Download push, Telemetric Onboard/Off-board Diagnostics, Remote Vehicle Status Control, Fleet Management, Server based navigation, Remote lock-down, Remote entry, Mobile Office, Videophone, Personal Data Synchronization at home, General Map Downloads and Updates, Instant Messaging, General internet services, Internet Audio, continuous feed, Web Browsing, Movie rental, Remote Home Activation/Deactivation pull, Remote Home Control pull, Remote Home Activation/Deactivation push, Remote Home Control push, Voice Chat, Games, Electronic Toll Collection, Parking Unit Fee Payment (drive through payment), Goods and services discovery and payment, Guided Tour, Interactive Lights Dimming, Emergency Traffic Light Pre-emption, Traffic Light Assistant, …

Source: C2CCC, Aktiv-AS/VM

Challenges of communication

- Basic challenges
  - Timeliness
  - Throughput
- Communication in vehicles: stresses...
  - Robustness
  - Cost
- Communication across vehicles: also needs...
  - Interoperability
  - Reachability
  - Security
  - Privacy

Part 2

Car-to-X Networking

Car-to-X (C2X) communication patterns

- Vehicle-to-X (V2X),
- Inter-Vehicle Communication (IVC),
- Vehicular ad-hoc network (VANET),
- …

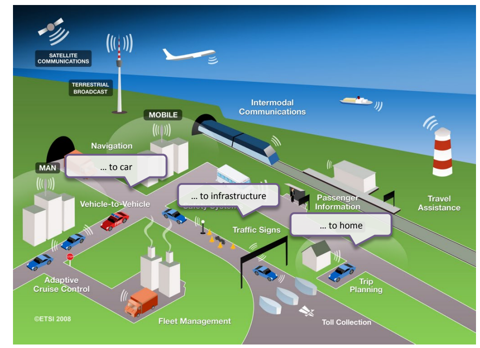


Illustration: ETSI

Use Cases

Illustration: CVIS

Taxonomy of Use Cases

Vehicle-to-X

- Non-Safety
  - Comfort
    - Contextual Information
    - Entertainment
  - Traffic Information Systems
    - Optimal Speed Advisory
    - Congestion, Accident Information
- Safety
  - Situation Awareness
    - Adaptive Cruise Control
    - Blind Spot Warning
  - Warning Messages
    - Traffic Light Violation
    - Electronic Brake Light

Taxonomy of Use Cases

?: What are the main differences among the 2 categories ?

Vehicle-to-X

- Non-Safety
  - Comfort
    - Contextual Information
    - Entertainment
  - Traffic Information Systems
    - Optimal Speed Advisory
    - Congestion, Accident Information
- Safety
  - Situation Awareness
    - Adaptive Cruise Control
    - Blind Spot Warning
  - Warning Messages
    - Traffic Light Violation
    - Electronic Brake Light

Taxonomy of Use Cases

Vehicle-to-X

Non-Safety	Safety
Many messages	Few messages
High data rate	Small packet size
Low latency demands	High latency demands
Low reliability demands	High reliability demands

Diversity of use cases

Application	Distance	Time	Recipient
Hazard warning	250m	10s	All
Location based service	1..5km	Weeks	Subscribers
City wide alarm	20km	Hours	All
Travel time information	5km	Minutes	All
File sharing	250m	Minutes (Index) Days (Content)	Subscribers (Index) Peers (Content)
Interactive Services	1..5km	Minutes	Subscribers

[1] Bai, F. and Krishnamachari, B., "Exploiting the Wisdom of the Crowd: Localized, Distributed Information-Centric VANETs," IEEE Communications Magazine, vol. 48 (5), pp. 138-146, May 2010

Diversity of requirements

Application	Latency	Reliability	# Vehicles	Area	Persistence
Information Query	★	★	★★★	★★★	
Hazard Warning					
ACC, el. Brake Light					
Cooperative Awareness					
Intersection Assistance					
Platooning					

[1] T. L. Willke, P. Tientrakool, and N. F. Maxemchuk, "A Survey of Inter-Vehicle Communication Protocols and Their Applications," IEEE Communications Surveys and Tutorials, vol. 11 (2), pp. 3-20, 2009

Diversity of requirements

Application	Latency	Reliability	# Vehicles	Area	Persistence
Information Query	★	★	★★★	★★★	
Hazard Warning	★★★	★★	★★	★★★	
ACC, el. Brake Light	★★★	★★	★	★	
Cooperative Awareness					
Intersection Assistance					
Platooning					

[1] T. L. Willke, P. Tientrakool, and N. F. Maxemchuk, "A Survey of Inter-Vehicle Communication Protocols and Their Applications," IEEE Communications Surveys and Tutorials, vol. 11 (2), pp. 3-20, 2009

Diversity of requirements

Application	Latency	Reliability	# Vehicles	Area	Persistence
Information Query	★	★	★★★	★★★	
Hazard Warning	★★★	★★	★★	★★★	
ACC, el. Brake Light	★★★	★★	★	★	
Cooperative Awareness					
Intersection Assistance					
Platooning					

[1] T. L. Willke, P. Tientrakool, and N. F. Maxemchuk, "A Survey of Inter-Vehicle Communication Protocols and Their Applications," IEEE Communications Surveys and Tutorials, vol. 11 (2), pp. 3-20, 2009

Diversity of requirements

Application	Latency	Reliability	# Vehicles	Area	Persistence
Information Query	★	★	★★★	★★★	
Hazard Warning	★★★	★★	★★	★★★	
ACC, el. Brake Light	★★★	★★	★	★	
Cooperative Awareness	★★	★★★	★	★	★
Intersection Assistance	★★	★★★	★★	★★	★
Platooning	★★★	★★★	★★	★	★

[1] T. L. Willke, P. Tientrakool, and N. F. Maxemchuk, "A Survey of Inter-Vehicle Communication Protocols and Their Applications," IEEE Communications Surveys and Tutorials, vol. 11 (2), pp. 3-20, 2009

Motivation

- 1970s: bold ideas
  - Very visionary, infrastructure-less solutions
  - Unsupported by current technology
- Early interest of government and industry
  - working prototypes in: Japan *CACS* (1973–1979), Europe *Prometheus* (1986–1995), U.S. *PATH* (1986–1992)
  - No commercial success
- 1980s: paradigm shift
  - From complete highway automation ⇨ driver-advisory only
  - Infrastructure-less ⇨ infrastructure-assisted
  - *chicken-and-egg* type of standoff
- New technology re-ignites interest
  - latest-generation cellular communication ⇨ early "Car-to-X" systems
  - e.g., *On Star* (1995), *BMW Assist* (1999), *FleetBoard* (2000), and *TomTom HD Traffic* (2007).
- Sharp increase in computing power
  - Supports fully-distributed, highly reactive ad hoc systems

[1] W. Zimdahl, "Guidelines and some developments for a new modular driver information system," in 34th IEEE Vehicular Technology Conference (VTC1984), vol. 34., Pittsburgh, PA: IEEE, May 1984, pp. 178–182.

Renewed interest of government and industry

- Numerous field operational tests
  - sim[TD] (€ 69M), Aktiv (€ 60M), Smart Highway (€ 57M), Drive C2X (€ 19M), TeleFOT (€ 15M), SafeTrip (€ 10M), …
- Dedicated spectrum in U.S., Europe, Asia

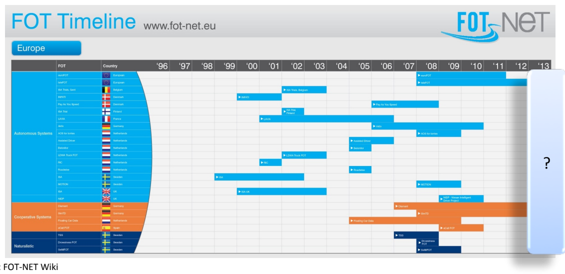
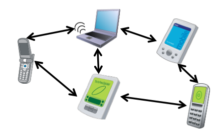
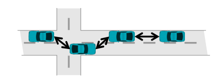


Illustration: FOT-NET Wiki

Motivation

- Traditional Network
  - Connection: wired
  - Nodes: non-moving
  - Configuration: static
- Mobile Ad Hoc Network (MANET)
  - Connection: wireless
  - Nodes: mobile
  - Configuration: dynamic
  - (Infrastructure: optional)
- Vehicular Ad Hoc Network (VANET)
  - Not: “MANET on wheels”
  - Different topology dynamics, communication patterns, infrastructure, …





[1] M. Scott Corson and Joseph Macker, "Mobile Ad hoc Networking (MANET): Routing Protocol Performance Issues and Evaluation Considerations," RFC 2501, January 1999

IMPORTANT INFORMATION

- The missed Class will be given in Early November (Date TBD)
- Please Signup with your e-mail on the Paper
- You will be subscribed to a Google Group

Freeway ⇔ Urban

????
What are the main
characteristics of these two scenarios?

Freeway ⇔ Urban

- 1D mobility
- Bimodal connectivity
  - Stable connection (vehicles on same lane)
  - AND
  - unstable connection (vehicles on opposite lane)
- High speed
- …

- 2D mobility
- Bipolar connectivity
  - Many neighbors (when standing)
  - OR
  - Few neighbors (when driving)
- Obstacles
- …

Levels of infrastructure support

- Pure ad hoc communication
- Stationary Support Units (SSU)
  - Radio-equipped autonomous computer
  - Inexhaustible storage, energy supply
  - Known position, high reliability
- Roadside Units (RSU)
  - SSU plus…
  - Ethernet NIC, UMTS radio, …
  - Connected to other RSUs
- Traffic Information Center (TIC)
  - Central server connected to RSUs

Infrastructure ⇔ No Infrastructure HERE!!!!!!!!!

- Central coordination
  - Resource management
  - Security
- High latency
- High load on core network
- …

- Self organizing system
  - Channel access
  - Authentication
- Low latency
- Low data rate
- …

Source: AKTIV CoCar

Convergence towards heterogeneous approaches

- Same system needs to work in multiple environments
  - Vehicle starts to drive in city with infrastructure support
  - Continues driving on freeway (still with infrastructure support)
  - Loses infrastructure support when turning onto local highway
  - Finishes driving in city without infrastructure support

Adoption

- Prognosis (of providers!) in Germany and the U.S.
  - 14..15 years to 100% market penetration
- Compare to navigation systems in German cars
  - 13 years to 14% market penetration
  - And: it is very easy to retrofit a satnav!

[1] Bai, F. and Krishnamachari, B., "Exploiting the Wisdom of the Crowd: Localized, Distributed Information-Centric VANETs," IEEE Communications Magazine, vol. 48 (5), pp. 138-146, May 2010
[2] Ulrich Dietz (ed.), "CoCar Feasibility Study: Technology, Business and Dissemination," CoCar Consortium, Public Report, May 2009.
[3] Verband der Automobilindustrie e.V., "Auto 2007 – Jahresbericht des Verbands der Automobilindustrie (VDA), ", July 2007.

Challenges of C2X communication

Communication
- Highly varying channel conditions
- High congestion, contention, interference
- Tightly limited channel capacity

Networking
- Unidirectional Links
- Multi-Radio / Multi-Network
- Heterogeneous equipment

Mobility
- Highly dynamic topology
- But: predictable mobility
- Heterogeneous environment

Security
- No (or no reliable) uplink to central infrastructure
- Ensuring privacy
- Heterogeneous user base

Technology

Communication paradigms and media

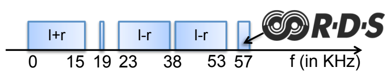
Wireless Communication Technologies

- Infrastructure-based
  - Broadcast
    - FM Radio, DAB/DVB, …
  - Cellular
    - GSM 2G Cellular
    - UMTS 3G Cellular
    - LTE / WiMAX 4G Cell.
- Infrastructureless
  - Short Range
    - Millimeter, Infrared, Visible
    - 802.15.1 Bluetooth
    - 802.15.4 ZigBee
  - Medium Range
    - 802.11 Wi-Fi
    - DSRC / WAVE

[1] Dar, K. et al., "Wireless Communication Technologies for ITS Applications," IEEE Communications Magazine, vol. 48 (5), pp. 156-162, May 2010

Broadcast Media

- Traffic Message Channel (TMC)
  - Central management of traffic information
  - Data sources are varied
    - Federal/local/city police, road operator, radio, …
  - Transmission in RDS channel of FM radio
    - BPSK modulated signal at 57 KHz, data rate 1.2 kBit/s
    - RDS group identifier 8A (TMC), approx. 10 bulletins per minute



[1] ISO 62106, „Specification of the radio data system (RDS) for VHF/FM sound broadcasting in the frequency range from 87,5 to 108,0 MHz“

Broadcast Media

- Traffic Message Channel (TMC)
  - Contents (ALERT-C coded):
    - Validity period
    - Re-routing required?
    - North-east or south-west?
    - Spatial extent
    - Code in event table
      - International
    - Code in location table
      - Country/region specific
      - Must be installed in end device
  - No (real) security measures

101	Standing traffic (generic)
102	1 km of standing traffic
103	2 km of standing traffic
394	Broken down truck
1478	Terrorist incident

1	Deutschland
264	Bayern
12579	A8 Anschlussstelle Irschenberg

[1] ISO 14819-1, „Traffic and Traveller Information (TTI) - TTI messages via traffic message coding - Part 1: Coding protocol for Radio Data System (RDS-TMC) using ALERT-C“

[2] ISO 14819-2, „Traffic and Traveller Information (TTI) - TTI messages via traffic message coding - Part 2: Event and information codes for Radio Data System - Traffic Message Channel (RDS-TMC)“

Broadcast Media

- Traffic Message Channel (TMC)
  - Regional value added services
    - *Navteq Traffic RDS* (U.S.), *trafficmaster* (UK), *V-Trafic* (France)
  - Ex: TMCpro
    - Private service of Navteq Services GmbH
    - Financed by per-decoder license fee
    - Data collection and processing
      - Fully automatic
      - Deployment of 4000+ sensors on overpasses
      - Use of floating car data
      - Downlink from traffic information centers
    - Event prediction
      - Expert systems, neuronal networks
      - Early warnings of predicted events
    - Restricted to major roads

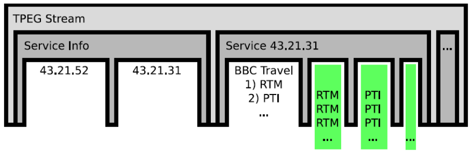
Broadcast Media

- Transport Protocol Experts Group (TPEG)
  - Planned successor of RDS-TMC/Alert-C
  - Published April 2000
  - Principles:
    - Extensibility
    - Media independence
  - Goals:
    - Built for “Digital Audio Broadcast” (DAB)
    - Unidirectional, byte oriented stream
    - Modular concept
    - Hierarchical approach
    - Integrated security

[1] ISO 18234-x, „Traffic and Travel Information (TTI) — TTI via Transport Protocol Experts Group (TPEG) data-streams“

Broadcast Media

- Transport Protocol Experts Group (TPEG)
  - Information types defined by “TPEG Applications”
    - RTM - Road Traffic Message
    - PTI - Public Transport Information
    - PKI - Parking Information
    - CTT - Congestion and Travel-Time
    - TEC - Traffic Event Compact
    - WEA - Weather information for travelers
  - Modular concept:



Transport Protocol Experts Group (TPEG)

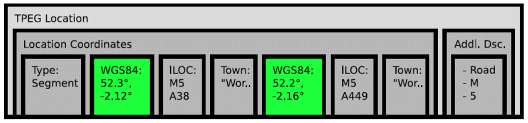
- tpegML: XML variant of regular (binary) TPEG

```xml
<?xml version="1.0" encoding="ISO-8859-1"?>
<!DOCTYPE tpeg_document PUBLIC "-//EBU/tpegML/EN"
     "http://www.bbc.co.uk/travelnews/xml/tpegml_en/tpegML.dtd">
<tpeg_document generation_time="2007-09-19T07:22:44+0">
        <tpeg_message>
                <originator country="UK" originator_name="BBC Travel News"/>
                <summary xml:lang="en">M5 Worcestershire - Earlier accident
                     southbound between J5, Droitwich and J6, Worcester, heavy
                     traffic.</summary>
                <road_traffic_message>
                        <!-- ... tpeg-rtmML ... -->
                </road_traffic_message>
        </tpeg_message>
        <tpeg_message>
                <originator country="UK" originator_name="BBC Travel News"/>
                <summary xml:lang="en">A420 Oxfordshire - The Plain closed westbound
                     at the A4158 Iffley Road junction in Oxford, delays expected.
                     Diversion in operation.</summary>
                <road_traffic_message>
                        <!-- ... tpeg-rtmML ... -->
                </road_traffic_message>
        </tpeg_message>
</tpeg_document>
```

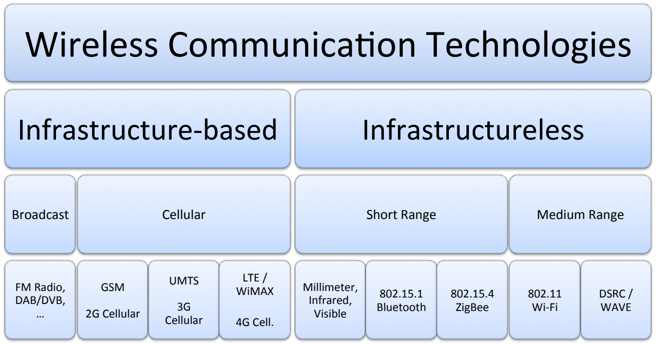
[1] ISO 24530-x, „Traffic and Travel Information (TTI) — TTI via Transport Protocol Experts Group (TPEG) Extensible Markup Language (XML)“

Transport Protocol Experts Group (TPEG)

- Hybrid approach to geo-referencing: one or more of
  - WGS84 based coordinates
  - ILOC (Intersection Location)
    - Normalized, shortened textual representation of street names intersecting at desired point
  - Human readable plain text
  - Code in hierarchical location table



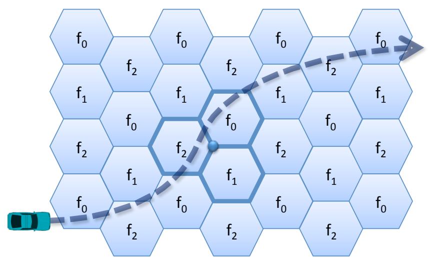
Communication paradigms and media



[1] Dar, K. et al., "Wireless Communication Technologies for ITS Applications," IEEE Communications Magazine, vol. 48 (5), pp. 156-162, May 2010

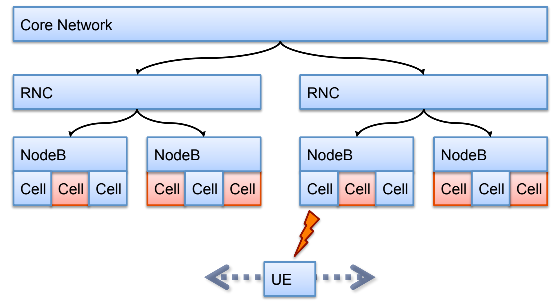
Cellular Networks

- Concept
  - Divide world into cells, each served by base station
  - Allows, e.g., frequency reuse in FDMA



Concept

- Strict hierarchy of network components



Cellular Networks

- Can UMTS support Car-to-X communication?
  - Ex: UTRA FDD Release 99 (W-CDMA)
  - Speed of vehicles not a limiting factor
    - Field operational tests at 290 km/h show signal drops only after sudden braking (➪ handover prediction failures)
  - Open questions
    - Delay
    - Capacity
- Channels in UMTS
  - Shared channels
    - E.g. Random Access Channel (RACH), uplink and Forward Access Channel (FACH), downlink
  - Dedicated channels
    - E.g. Dedicated Transport Channel (DCH), up-/downlink

Cellular Networks

- FACH
  - Time slots managed by base station
  - Delay on the order of 10 ms per 40 Byte and UE
  - Capacity severely limited (in non-multicast networks)
  - Need to know current cell of UE
- RACH
  - Slotted ALOHA – random access by UEs
    - Power ramping with Acquisition Indication
  - Delay approx. 50 ms per 60 Byte and UE
  - Massive interference with other UEs

Cellular Networks

- DCH
  - Delay: approx. 250 ms / 2 s / 10 s for channel establishment
    - Depends on how fine-grained UE position is known
  - Maintaining a DCH is expensive
    - Closed-Loop Power Control (no interference of other UEs)
    - Handover between cells
    - ...
  - Upper limit of approx. 100 UEs

Cellular Networks

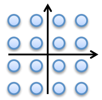
- So: can UMTS support Car-to-X communication?
  - At low market penetration: yes
  - Eventually:
    - Need to invest in much smaller cells (e.g., along freeways)
    - Need to implement multicast functionality (MBMS)
  - Main use case for UMTS: centralized services
    - Ex.: Google Maps Traffic
      - Collect information from UMTS devices
      - Storage of data on central server
      - Dissemination via Internet (⇨ ideal for cellular networks)

IEEE 802.11p

- IEEE 802.11{a,b,g,n} for Car-to-X communication?
  - Can't be in infrastructure mode and ad hoc mode at the same time
  - Switching time consuming
  - Association time consuming
  - No integral within-network security
  - (Massively) shared spectrum (⇨ ISM)
  - No integral QoS
  - Multi-path effects reduce range and speed

IEEE 802.11p

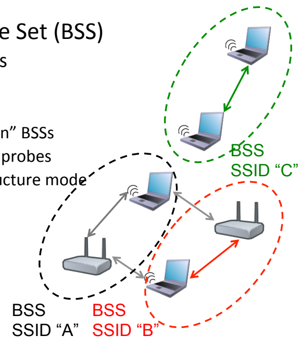
- IEEE 802.11p
  - PHY layer mostly identical to IEEE 802.11a
    - Variant with OFDM and 16 QAM
    - Higher demands on tolerances
    - Reduction of inter symbol interference because of multi-path effects
      - Double timing parameters
      - Channel bandwidth down to 10 MHz (from 20 MHz)
      - Throughput down to 3 ... 27 Mbit/s (from 6 ... 54 Mbit/s)
      - Range up to 1000 m, speed up to 200 km/h



  - MAC layer of IEEE 802.11a plus extensions
    - Random MAC Address
    - QoS (EDCA priority access, cf. IEEE 802.11e, ...)
    - Multi-Frequency and Multi-Radio capabilities
    - New Ad Hoc mode
    - ...

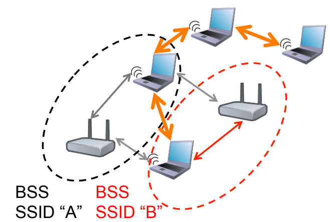
IEEE 802.11p

- Classic IEEE 802.11 Basic Service Set (BSS)
  - Divides networks into logical units
    - Nodes belong to (exactly one) BSS
    - Packets contain BSSID
    - Nodes ignore packets from “foreign” BSSs
    - Exception: Wildcard-BSSID (-1) for probes
    - Ad hoc networks emulate infrastructure mode
  - Joining a BSS
    - Access Point sends beacon
    - Authentication dialogue
    - Association dialogue
    - Node has joined BSS



IEEE 802.11p

- New: 802.11 WAVE Mode
  - Default mode of nodes in WAVE
  - Nodes may always use Wildcard BSS in packets
  - Nodes will always receive Wildcard BSS packets
  - May join BSS and still use Wildcard BSS

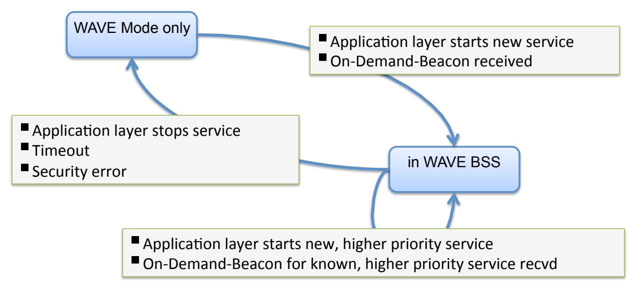


IEEE 802.11p

- New: 802.11 WAVE BSS
  - No strict separation between Host and Access Point (AP)
  - Instead, loose classification according to:
    - Equipment: Roadside Unit (RSU) / On-Board Unit (OBU)
    - Role in data exchange: Provider / User
  - No technical difference between Provider and User
  - Provider sends On-Demand Beacon
    - Analogous to standard 802.11-Beacon
    - Beacon contains all information and parameters needed to join
  - User configures lower layers accordingly
    - Starts using provided service
    - No additional exchange of data needed
  - BSS membership now only implied
    - BSS continues to exist even after provider leaves

WAVE BSS Internal state machine

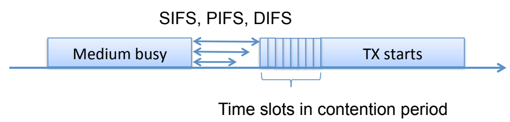
- Node will not join more than one WAVE BSS



[1] IEEE Vehicular Technology Society, "IEEE 1609.3 (Networking Services)," IEEE Std, April, 2007

IEEE 802.11p

- IEEE 802.11 Distributed Coordination Function (DCF)
  - aka “Contention Period”



  - Priority access via SIFS (ACK, CTS, ...) and DIFS (payload)
  - Wait until medium has been free for duration of DIFS
  - If medium busy, wait until idle, then wait DIFS plus random backoff time

IEEE 802.11p

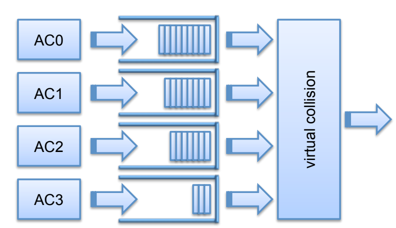
- IEEE 802.11 Distributed Coordination Function (DCF)
  - Backoff if
    a) Node is ready to send and channel becomes busy
    b) A higher priority queue (⇨ next slides) becomes ready to send
    c) Unicast transmission failed (no ACK)
    d) Transmission completed successfully
  - Backoff: Random slot count from interval [0, CW]
  - Decrement by one after channel was idle for one slot (only in contention period)
  - In cases b) and c), double CW (but no larger than CW_{max})
  - In case d), set CW to CW_{min}

IEEE 802.11p

- QoS in 802.11p (HCF)
  - cf. IEEE 802.11e EDCA
  - DIFS ⇨ AIFS (Arbitration Inter-Frame Space)
    - DCF ⇨ EDCA (Enhanced Distributed Channel Access)
  - Classify user data into 4 ACs (Access Categories)
    - AC0 (lowest priority)
    - ...
    - AC3 (highest priority)
  - Each ACs has different...
    - CW_{min}, CW_{max}, AIFS, TXOP limit (max. continuous transmissions)
  - Management data uses DIFS (not AIFS)

IEEE 802.11p

- QoS in 802.11p (HCF)
  - Map 8 user priorities ⇨ 4 access categories ⇨ 4 queues
  - Queues compete independently for medium access



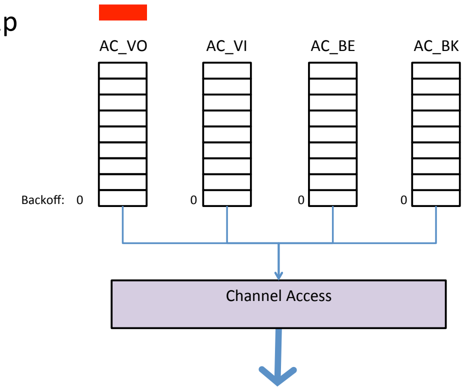
IEEE 802.11p

- QoS in 802.11p (HCF)
  - Parameterization

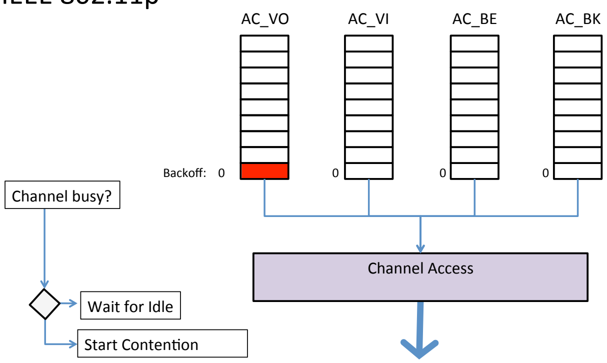
Parameter	Value
SlotTime	13µs
SIFS	32µs
CW_{min}	15
CW_{max}	1023
Bandwidth	3 .. 27 mbit/s

Parameter	AC_BK	AC_BE	AC_VI	AC_VO
CW_{min}	CW_{min}	CW_{min}	$(CW_{min}+1)/2-1$	$(CW_{min}+1)/4-1$
CW_{max}	CW_{max}	CW_{max}	CW_{min}	$(CW_{min}+1)/2-1$
AIFSn	9	6	3	2

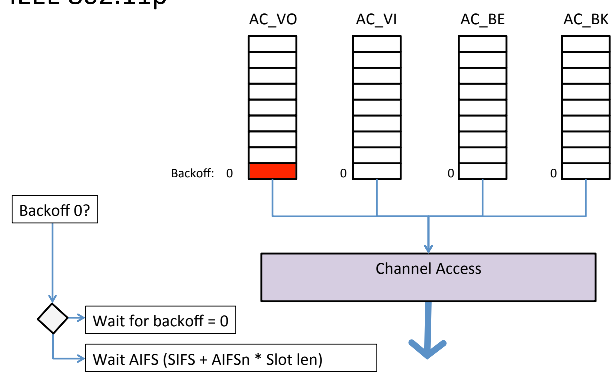
IEEE 802.11p



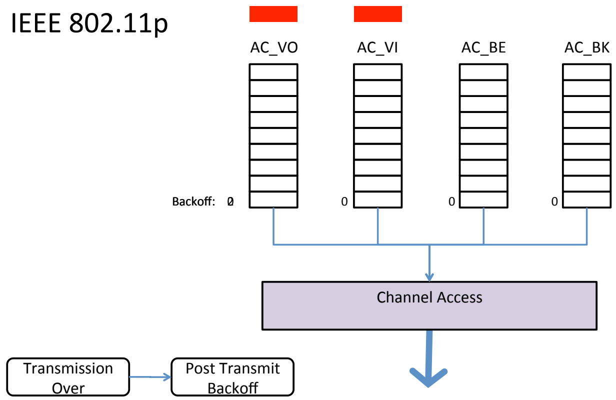
IEEE 802.11p



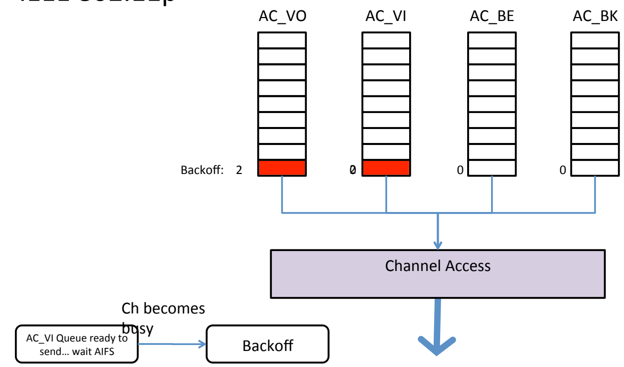
IEEE 802.11p



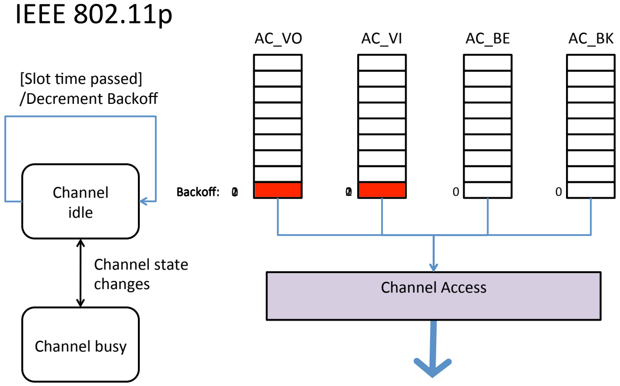
IEEE 802.11p



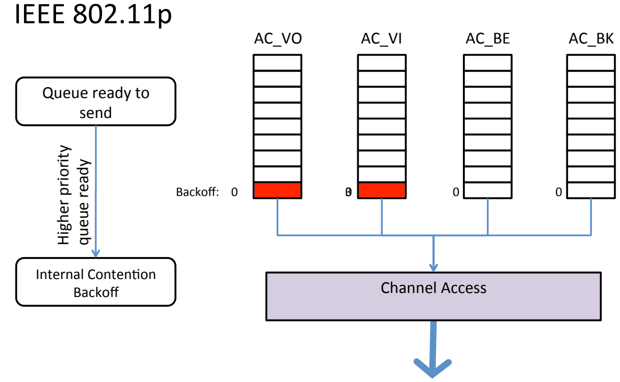
IEEE 802.11p



IEEE 802.11p



IEEE 802.11p



IEEE 802.11p

- QoS in WAVE
  - mean waiting time for channel access, given sample configuration (and TXOP Limit=0 ⇨ single packet)
  - when channel idle:
  - when channel busy:

AC	CW_{min}	CW_{max}	AIFS	TXOP	t_w (in µs)
0	15	1023	9	0	264
1	7	15	6	0	152
2	3	7	3	0	72
3	3	7	2	0	56

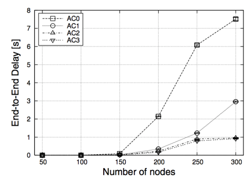


Figure Source: Eichler, S., "Performance evaluation of the IEEE 802.11p WAVE communication standard," Proceedings of 66th IEEE Vehicular Technology Conference (VTC2007-Fall), Baltimore, USA, October 2007, pp. 2199-2203

UMTS/LTE vs. 802.11p

- Pros of UMTS/LTE
  + Easy provision of centralized services
  + Quick dissemination of information in whole network
  + Pre-deployed infrastructure
  + Easy migration to (and integration into) smartphones
- Cons of UMTS/LTE
  - High short range latencies (might be too high for safety)
  - Network needs further upgrades (smaller cells, multicast service)
  - High dependence on network operator
  - High load in core network, even for local communication

UMTS/LTE vs. IEEE 802.11p

- Pros of 802.11p/Ad hoc
  + Smallest possible latency
  + Can sustain operation without network operator / provider
  + Network load highly localized
  + Better privacy (⇨ later slides)
- Cons of 802.11p/Ad hoc
  - Needs gateway for provision of central services (e.g., RSU)
  - No pre-deployed hardware, and hardware is still expensive
- The solution?
  - hybrid systems:
    deploy both technologies to vehicles and road,
    decide depending on application and infrastructure availability

Higher Layer Standards: CALM

- Mixed-media communication
  - „Communications access for land mobiles“
  - ISO TC204 Working Group 16
  - Initiative to transparently use best possible medium
  - Integrates:
    - GPRS, UMTS, WiMAX
    - Infrared, Millimeter Wave
    - Wi-Fi, WAVE
    - Unidirectional data sources (DAB, GPS, ...)
    - WPANs (BlueT, W-USB, ...)
    - Automotive bus systems (CAN, Ethernet, ...)

[1] ISO 21210, "Intelligent transport systems -- Communications access for land mobiles (CALM) -- IPv6 Networking"

Higher Layer Standards for IEEE 802.11p

- Channel management
  - Dedicated frequency band at 5.9 GHz allocated to WAVE
    - Exclusive for V2V und V2I communication
    - No license cost, but strict rules
    - 1999: FCC reserves 7 channels of 10 MHz (“U.S. DSRC”)
      - 2 reserved channels, 1+4 channels for applications
    - ETSI Europe reserves 5 channels of 10 MHz

U.S. allocation	…	Critical Safety of Life	SCH	SCH	Control Channel (CCH)	SCH	SCH	Hi-Power Public Safety	…
European allocation		SCH	SCH	SCH	SCH	CCH	SCH	SCH	
IEEE Channel		172	174	176	178	180	182	184	
Center frequency		5.860 GHz	5.870 GHz	5.880 GHz	5.890 GHz	5.900 GHz	5.910 GHz	5.920 GHz	

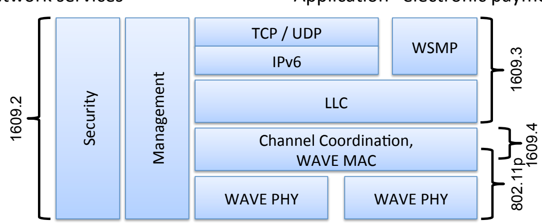
[1] ETSI ES 202 663 V1.1.0 (2010-01) : Intelligent Transport Systems (ITS); European profile standard for the physical and medium access control layer of Intelligent Transport Systems operating in the 5 GHz frequency band

Higher Layer Standards for IEEE 802.11p

- Need for higher layer standards
  - Unified message format
  - Unified interfaces to application layer
- U.S.
  - IEEE 1609.*
  - WAVE („Wireless Access in Vehicular Environments“)
- Europe
  - ETSI
  - ITS G5 (“Intelligent Transportation Systems”)

IEEE 1609.* upper layers (building on IEEE 802.11p)

- IEEE 1609.2: Security
- IEEE 1609.3: Network services
- IEEE 1609.4: Channel mgmt.
- IEEE 1609.11: Application “electronic payment”

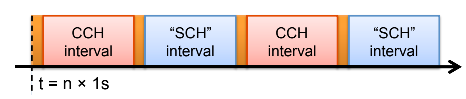


[1] Jiang, D. and Delgrossi, L., "IEEE 802.11p: Towards an international standard for wireless access in vehicular environments," Proceedings of 67th IEEE Vehicular Technology Conference (VTC2008-Spring), Marina Bay, Singapore, May 2008

[2] Uzcátegui, Roberto A. and Acosta-Marum, Guillermo, "WAVE: A Tutorial," IEEE Communications Magazine, vol. 47 (5), pp. 126-133, May 2009

IEEE 1609

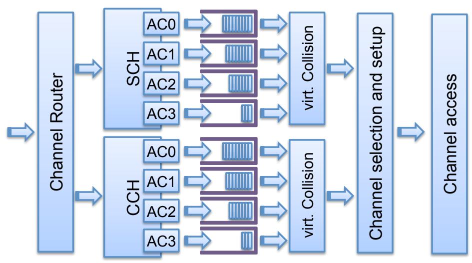
- Channel management
  - WAVE allows for both single radio devices & multi radio devices
  - Dedicated Control Channel (CCH) for mgmt and safety messages
    ⇨ single radio devices need to periodically listen to CCH
  - Time slots
    - Synchronization envisioned via GPS receiver clock
    - Standard value: 100ms sync interval (with 50ms on CCH)
    - Short guard interval at start of time slot
      - During guard, medium is considered busy (⇨ backoff)



[1] IEEE Vehicular Technology Society, "**IEEE 1609.4 (Multi-channel Operation)**," IEEE Std, November, 2006

IEEE 1609

- Packet transmission
  - Sort into AC queue, based on WSMP (or IPv6) EtherType field, destination channel, and user priority
  - Switch to desired channel, setup PHY power and data rate
  - Start medium access

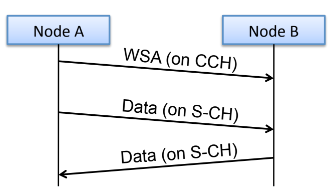


IEEE 1609

- Channel management
  - Control Channel (CCH):
    - Default channel upon initialization
    - WAVE service advertisements (WSA),
      WAVE short messages (WSM)
    - Channel parameters take fixed values
  - Service Channel (SCH):
    - Only after joining WAVE BSS
    - WAVE short messages (WSM),
      IP data traffic (IPv6)
    - Channel parameters can be changed as needed

IEEE 1609

- WAVE service advertisement (WSA)
  - Broadcast on Control Channel (CCH)
  - Identifies WAVE BSSs on Service Channels (SCHs)
  - Can be sent at arbitrary times, by arbitrary nodes
  - Only possibility to make others aware of data being sent on SCHs, as well as the required channel parameters to decode them



IEEE 1609

- WAVE service advertisement (WSA)
  - WAVE Version (= 0)
  - Provider Service Table (PST)
    - n × Provider Service Info
      - Provider Service Identifier (PSID, max. 0x7FFF FFFF)
      - Provider Service Context (PSC, max. 31 chars)
      - Application priority (max priority: 63)
      - (opt.: IPv6 address and port, if IP service)
      - (opt.: Source MAC address, if sender ≠ data source)
      - Channel number (max. 200)
    - 1..n × Channel Info (for each channel used in PST table)
      - Data rate (fixed or minimum value)
      - Transmission power (fixed or maximum value)
  - (opt.: WAVE Routing Announcement)

[1] IEEE Vehicular Technology Society, "**IEEE 1609.3 (Networking Services)**," IEEE Std, April, 2007

WAVE service advertisement (WSA)

- Provider Service Identifier (PSID) defined in IEEE Std 1609.3-2007

0x000 0000	system	0x000 000D	private
0x000 0001	automatic-fee-collection	0x000 000E	multi-purpose-payment
0x000 0002	freight-fleet-management	0x000 000F	dsrc-resource-manager
0x000 0003	public-transport	0x000 0010	after-theft-systems
0x000 0004	traffic-traveler-information	0x000 0011	cruise-assist-highway-system
0x000 0005	traffic-control	0x000 0012	multi-purpose-information system
0x000 0006	parking-management	0x000 0013	public-safety
0x000 0007	geographic-road-database	0x000 0014	vehicle-safety
0x000 0008	medium-range-preinformation	0x000 0015	general-purpose-internet-access
0x000 0009	man-machine-interface	0x000 0016	onboard diagnostics
0x000 000A	intersystem-interface	0x000 0017	security manager
0x000 000B	automatic-vehicle-identification	0x000 0018	signed WSA
0x000 000C	emergency-warning	0x000 0019	ACI

IEEE 1609

- WAVE Short Message (WSM)
  - Header (11 Byte)
    - Version (= 0)
    - Content type: plain, signed, encrypted
    - Channel number (max. 200)
    - Data rate
    - Transmission power
    - Provider Service Identifier (Service type, max. 0x7FFF FFFF)
    - Length (max. typ. 1400 Bytes)
  - Payload

IEEE 1609

- IP traffic (UDP/IPv6 or TCP/IPv6)
  - Header (40+n Byte)
    - Version
    - Traffic Class
    - Flow Label
    - Length
    - Next Header
    - Hop Limit
    - Source address, destination address
    - (opt.: Extension Headers)
  - Payload
  - No IPv6-Neighbor-Discovery (High overhead)
  - All OBUs listen to host multicast address,
    all RSUs listen to router multicast address

IEEE 1609

- Channel quality monitoring
  - Nodes store received WSAs, know SCH occupancy
  - Received Channel Power Indicator (RCPI) polling
    - Nodes can send RCPI requests
    - Receiver answers with Received Signal Strength (RSS) of packet
  - Transmit Power Control (TPC)
    - Nodes can send TPC requests
    - Receiver answers with current transmission power and LQI
  - Dynamic Frequency Selection (DFS)
    - Nodes monitor transmissions on channel (actively and passively)
    - If higher priority third party use (e.g., RADAR) is detected,
      nodes cease transmitting

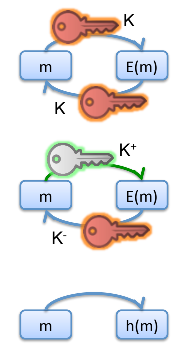
IEEE 1609

- Security in WAVE
  - Nature of WAVE messages mandates trust between nodes
    - Ex: Green wave for emergency vehicles
  - Security is built into WAVE (IEEE 1609.2)
  - WAVE can transparently sign, verify, encrypt/decrypt messages when sending and receiving
    - Ex: WSA → Secure WSA
  - Authorization of messages needed
    - By role: CA, CRL-Signer, RSU, Public Safety OBU (PSOBU), OBU
    - By application class (PSID) and/or instance (PSC)
    - By application priority
    - By location
    - By time

[1] IEEE Vehicular Technology Society, "**IEEE 1609.2 (Security Services)**," IEEE Std, July, 2006

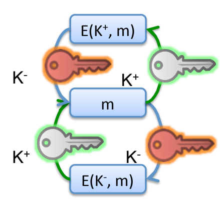
IEEE 1609

- Security concepts
  - Basic security goals
    - Integrity, Confidentiality, Authenticity
    - Non-Repudiation
  - Mechanisms
    - Symmetric encryption
      - Secret Key Cryptography
      - Ex: Caesar cipher, Enigma, AES
    - Asymmetric encryption
      - Public Key Cryptography
      - Ex: RSA, ElGamal, ECC
    - (cryptographic) hashing
      - Ex: MD5, SHA-1



IEEE 1609

- Asymmetric Cryptography
  - Relies on certain mathematical procedures being very hard to invert
    - Product ⇔ factorization (RSA)
    - Nth power ⇔ Nth logarithm (DH, ElGamal)
  - Two keys: Public Key (K^+), Private Key (K^-)
  - Can be used in both directions
  - Encryption: $E(K^+, m)$, Signing: $E(K^-, h(m))$
  - Drawback:
    - Much slower than symmetric cryptography



IEEE 1609

- Asymmetric Cryptography Example: RSA
  - Chose two primes: q, p with q != p
  - Calculate $n = p \cdot q$
  - Calculate $\phi(n) = (p-1) \cdot (q-1)$
    $\phi(x)$ gives number of (smaller) co-primes for x.
    Based on $\phi(a \cdot b) = \phi(a) \cdot \phi(b) \cdot (d/\phi(d))$ with $d = \gcd(a, b)$
    If x is prime, this is $x - 1$.
  - Choose e co-prime to $\phi(n)$ with $1 < e < \phi(n)$
  - Calculate d using EEA, so that $e \cdot d \bmod \phi(n) = 1$
  - Public Key: $K^+ = \{e, n\}$, Private Key: $K^- = \{d, n\}$.
  - En/Decryption:
    $M^e \bmod n = C$
    $C^d \bmod n = M$

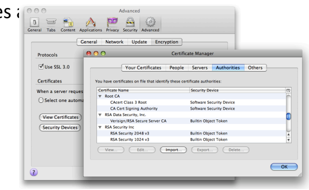
IEEE 1609

- Certificates
  - Encryption is useless without authentication
    - Alice ⇔ Eve ⇔ Bob
    - Eve can pretend to be Alice,
      replace K^+_A with own key K^+_E
  - Solution: use Trusted Third Party (TTP) and certificates
    - TTP signs (Name, Key) tuple, vouches for validity and authorization:
      "Alice has Public Key K^+_A, may participate as OBU until 2019"
    - not: "~~whoever sends this packet is Alice~~"
    - not: "~~whoever sends this packet has Public Key K^+_A~~"
  - Send K^+_A together with certificate vouching for tuple

IEEE 1609

- Implementation in WAVE
  - Certificate signature chains
    - Root certificate ⇨ certificate ⇨ certificate ⇨ payload
    - Root certificates pre-installed with system
    - Other certificates cannot be assumed to be present
  - Nodes must download certificates
    - Include chain of certificates
    - …or SHA-256 of first certificate in chain

      (if receiver can be assumed to have all required certificates)



IEEE 1609

- Implementation in WAVE
  - X.509 formats too large ⇨ new WAVE certificate format
    - Version
    - Certificate
      - Role (RSU, PSOBU, OBU, …)
      - Identity (dependent on role)
      - Restrictions (by application class, priority, location, …)
      - Expiration date
      - Responsible CRL
      - Public Keys
    - Signature
  - New: Restriction by location
    e.g.: none, inherited from CA, circle, polygon, set of rectangles
  - Public Key algorithms (motivated by key size):
    ECDSA (NIST p224), ECDSA (NIST p256), ECIES (NIST p256), …

Complete packet format of a WSM:

Ex: Signed WSM of an OBU, Certificate issuer is known

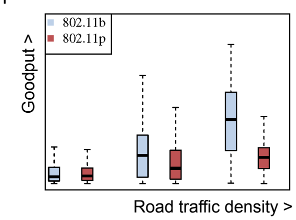
Length	Field			
1	WSM version			
1	Security Type = signed(1)			
1	Channel Number			
1	Data Rate			
1	TxPwr_Level			
4	PSID			
1	PSC Field Length			
7	PSC			
2	WSM Length			
1	WSM Data	signer	type = certificate	
125			certificate	⇨ next slide
2		unsigned_wsm	message flags	
32			application_data	
8			transmission_time	
4			transmission_location	latitude
4				longitude
3				elevation_and_confidence
28		signature	ecdsa_signature	r
28				s

Complete packet format of a WSM (certificate part):

Length	Field			
1	certificate_version = 1			
1	unsigned_certificate	subject_type = obu_identified		
8		signer_id		
1		scope	subject_name length	
8			subject_name	
2			applications	length of applications field
1				type = from_issuer
4		expiration		
4		crl_series		
1		public_key	length of public key field	
1			algorithm = ecdsa nistp224..	
29			public_key	point
32	signature	ecdsa_signature	r	
32			s	

Drawbacks of Channel Switching

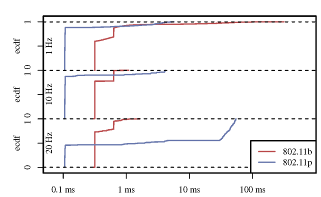
- 1) Goodput
  - User data must only be sent on SCH, i.e. during SCH interval
    ⇨ goodput cut in half



Picture source: David Eckhoff, Christoph Sommer and Falko Dressler, "On the Necessity of Accurate IEEE 802.11p Models for IVC Protocol Simulation," Proceedings of 75th IEEE Vehicular Technology Conference (VTC2012-Spring), Yokohama, Japan, May 2012.

Drawbacks of Channel Switching

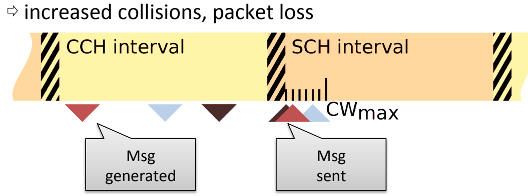
- 2) Latency
  - User data generated during CCH interval is delayed until SCH intv.



Picture source: David Eckhoff, Christoph Sommer and Falko Dressler, "On the Necessity of Accurate IEEE 802.11p Models for IVC Protocol Simulation," Proceedings of 75th IEEE Vehicular Technology Conference (VTC2012-Spring), Yokohama, Japan, May 2012.

Drawbacks of Channel Switching

- 3) Collisions
  - Delay of data to next start of SCH interval
    ⇨ increased frequency of channel accesses directly after switch
    ⇨ increased collisions, packet loss



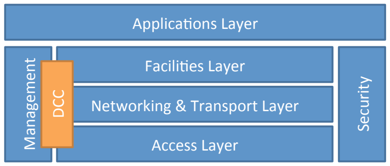
Picture source: David Eckhoff, Christoph Sommer and Falko Dressler, "On the Necessity of Accurate IEEE 802.11p Models for IVC Protocol Simulation," Proceedings of 75th IEEE Vehicular Technology Conference (VTC2012-Spring), Yokohama, Japan, May 2012.

ETSI ITS G5

- Motivation
  - European standardization effort based on IEEE 802.11p
  - Standardization to include lessons learned from WAVE
  - Different instrumentation of lower layers
  - Different upper layer protocols
  - Fine-grained service channel assignment
    - ITS-G5A (safety)
    - IST-G5B (non safety)

ETSI ITS G5

- Protocol stack
  - PHY and MAC based on IEEE 802.11p
  - Most prominent change:
    cross layer Decentralized Congestion Control (DCC)



ETSI ITS G5

- Channel management
  - Multi radio, multi antenna system
    - No alternating access
      ⇨ Circumvents problems with synchronization
      ⇨ No reduction in goodput
    - Direct result of experiences with WAVE
  - One radio tuned to CCH
    - Service Announcement Message (SAM)
    - Periodic:
      Cooperative Awareness Messages (CAM)
    - Event based:
      Decentralized Environment Notification Message (DENM)
  - Addl. radio tuned to SCH
    - User data

ETSI ITS G5

- Medium access
  - Separate EDCA systems
  - Different default parameters:

Parameter	AC_BK	AC_BE	AC_VI	AC_VO
CW_{min}	CW_{min}	**$(CW_{min}+1)/2-1$**	**$(CW_{min}+1)/4-1$**	$(CW_{min}+1)/4-1$
CW_{max}	Cw_{max}	CW_{max}	**$(CW_{min}+1)/2-1$**	$(CW_{min}+1)/2-1$
AIFSn	9	6	3	2

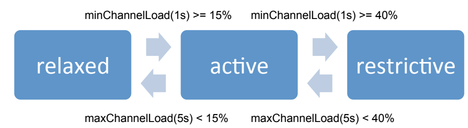
  - *Contention Window* – less distance to lower priority queues
    ⇨ less starvation of lower priority queues

ETSI ITS G5

- DCC
  - Core feature of ETSI ITS G5
  - Adaptive parameterization to avoid overload
  - Configurable parameters per AC:
    - TX power
    - Minimum packet interval
    - Sensitivity of CCA (Clear Channel Assessment)
    - Data rate
  - State machine determines which parameters are selected; available states:
    - Relaxed
    - Active (multiple sub states)
    - Restrictive

ETSI ITS G5

- DCC
  - State machine for Control Channel:



- min/maxChannelLoad(x): record fraction of time in [t_{now}-x .. t_{now}] that channel was sensed busy subdivide interval into equal parts (e.g. 50 ms), take min/max
- Channel busy ⇔ measured received power (signal or noise) above configured sensibility

ETSI ITS G5

- DCC
  - Selection of parameters when changing states
  - Service Channel: Active state has four sub-configurations
  - Control Channel: Single configuration for active state
  - *Example (“ref”*: Value remains unchanged)

	State					
	Relaxed	Active				Restrictive
		AC_VI	AC_VO	AC_BE	AC_BK	
TX power	33dBm	ref	25dBm	20dBm	15dBm	-10dBm
Min pkt interval	0,04s	ref	ref	ref	ref	1s
Data rate	3Mbit/s	ref	ref	ref	ref	12 Mbit/s
Sensitivity	-95 dBm	ref	ref	ref	ref	-65 dBm

ETSI ITS G5

- Cooperative Awareness Message
  - Periodic (up to 10Hz) safety message
  - Information on state of surrounding vehicles:
    - Speed, location, …
  - Message age highly relevant for safety
    - Need mechanisms to discard old messages
  - Safety applications rely on CAMs:
    - Tail end of jam
    - Rear end collision
    - Intersection assistance…
  - Sent on CCH
  - Generated every 100ms .. 1s, but only if Δangle (>4°), Δposition (>5m), Δspeed (>1m/s)

ETSI ITS G5

Length[byte]	Field		
1	messageId (0=CAM, 1=DENM)		
8	generationTime		
4	StationId		
1	StationCharacteristics	mobileITSStation	
1		privateITSStation	
1		physicalRelevantITSStation	
8+8+4	ReferencePositon	Longitude/Longitude/Elevation	
4		Heading	
32+4		Streetname/RoadSegment ID	
1		Position/Heading Confidence	
1	CamParameters	vehicleCommonParameters	vehicleType
2+2			Length/Width
4			Speed
2			Acceleration
1			AccelerationControl (break, throttle, ACC)...
1			exteriorLights
1			Occupancy
1+1			crashStatus/dangerousGoods

ETSI ITS G5

- Decentralized Environmental Notification Message (DENM)
  - Event triggered (e.g., by vehicle sensors)
    - Hard braking
    - Accident
    - Tail end of jam
    - Construction work
    - Collision imminent
    - Low visibility, high wind, icy road, …
  - Messages have (tight) local scope, relay based on
    - Area (defined by circle/ellipse/rectangle)
    - Road topology
    - Driving direction

DENM format (excerpt)

Length[byte]	Field		
1	messageId (0=CAM, 1=DENM)		
6	generationTime		
4	Management	Originator ID	Who sent this?
2		Sequence Number	
1		Data Version	Is this an update on a situation?
6		Expiry Time	Is this still valid?
1		Frequency	When can I expect an update?
1		Reliability	Should I trust a single notification?
		IsNegation	Does this cancel an earlier notification?
1	Situation	CauseCode	
1		SubCauseCode	
1		Severity	
4	LocationContainer	Situation_Latitude	
4		Situation_Longitude	
2		Situation_Altitude	
4		Accuracy	
N-40		Relevance Area	

ETSI ITS G5

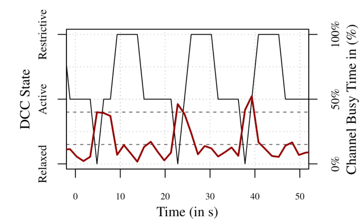
- Service Announcement
  - Message on Control Channel to advertise services offered on Service Channels
    - Channel number
    - Type of service
    - …
  - Similar to WAVE Service Announcement (WSA)
  - Receiver can tune (its second radio) to advertised channel

ETSI ITS G5

- Security and privacy
  - No published specification (yet)
    - Kerberos or WAVE-like PKI
    - Restrict participation to authorized vehicles
    - Sign messages
    - Limit V2I and I2V traffic where possible
  - Use pseudonyms to protect privacy
    - Use base identity (in permanent storage) to authenticate with infrastructure
    - Infrastructure generates pseudonym for vehicle

ETSI ITS G5: Analysis and Problems

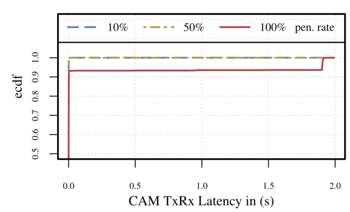
- Oscillating channel load (both local and global!)
  - …caused by channel access being too restrictive (standard parameters)



Picture source: David Eckhoff, Nikoletta Sofra and Reinhard German, "A Performance Study of Cooperative Awareness in ETSI ITS G5 and IEEE WAVE," Proceedings of 10th IEEE/IFIP Conference on Wireless On demand Network Systems and Services (WONS 2013), Banff, Canada, March 2013.

ETSI ITS G5: Analysis and Problems

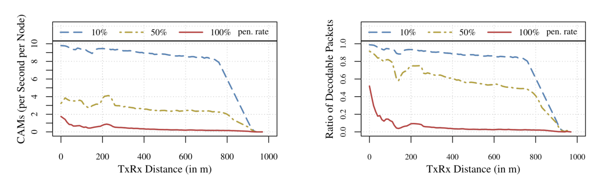
- Latencies
  - Choosing minimum packet intervals (TRC) too high can introduce high latencies



Picture source: David Eckhoff, Nikoletta Sofra and Reinhard German, "A Performance Study of Cooperative Awareness in ETSI ITS G5 and IEEE WAVE," Proceedings of 10th IEEE/IFIP Conference on Wireless On demand Network Systems and Services (WONS 2013), Banff, Canada, March 2013.

ETSI ITS G5: Analysis and Problems

- Update frequency
  - Standard parameters are too restrictive
  - Channel resources are not used optimally



Picture source: David Eckhoff, Nikoletta Sofra and Reinhard German, "A Performance Study of Cooperative Awareness in ETSI ITS G5 and IEEE WAVE," Proceedings of 10th IEEE/IFIP Conference on Wireless On demand Network Systems and Services (WONS 2013), Banff, Canada, March 2013.

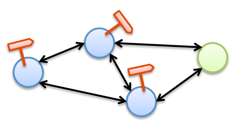
Main Takeaways

- Broadcast Media
  - TMC, TPEG
- UMTS
  - Channels, Pros / Cons
- DSRC/WAVE lower layers
  - 802.11p vs. old 802.11: commonalities and differences
  - HCF (EDCA QoS)
- IEEE 1609.* upper layers
  - Channel management
  - Security / Certificates
- ETSI ITS G5
  - Channel management
  - DCC: Decentralized Congestion Control
  - Message types
  - Commonalities and differences wrt. IEEE 1609.*

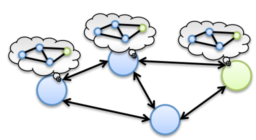
Broadcast, Geocast, Routing

Routing

- Classical approaches to routing
  - Distance Vector Routing
    - Nodes keep vector of known destinations, store distance and next hop
    - Ex: DSDV

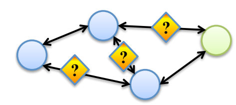


  - Link State Routing
    - Nodes keep track of of all links in network
    - Pro: fast and guaranteed convergence
    - Con: high overhead
    - Ex: OLSR

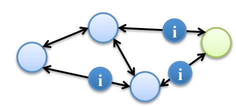


Routing

- Classical approaches to routing (II)
  - Reactive (on demand) routing
    - Routes established when needed
    - Routing messages only exchanged if (or while) user data is exchanged
    - Unused routes expire
    - Ex: AODV, DYMO

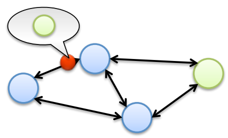


  - Proactive (table driven) routing
    - Routes are established and maintained continuously
    - No route setup delay when data needs to be sent
    - High overhead
    - Ex: OLSR, DSDV

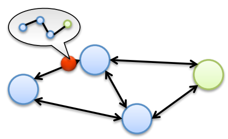


Routing

- Classical approaches to routing (III)
  - Hop-by-Hop Routing
    - Each packet contains destination address
    - During routing, each hop choses best next hop
    - Ex: AODV

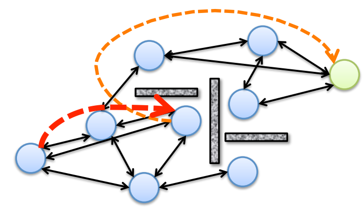


  - Source Routing
    - Each packet contains complete route to destination
    - During routing, nodes rely on this information
    - Ex: DSR



Routing

- Georouting
  - Primary metrics: position / distance to destination
  - Requires node positions to be known (at least for the destination)
  - Two operation modes (typ.):
    - Greedy mode: choose next hop according to max progress
    - Recovery mode: escape dead ends (local maxima)
  - Must ensure that message never gets lost



Routing

- Georouting: CBF
  - „Contention Based Forwarding“
  - Reduction (or complete avoidance) of duplicates
- Outline
  - Given: position of message destination, position of last hop
  - Do not forward message immediately, but wait for time T
  - Choose wait time T according to suitability of node
  - Do not forward message if another forward was overheard
- Problem
  - Potential forwarders must be able to overhear each others' transmissions

[1] Füßler, Holger and Widmer, Jörg and Käsemann, Michael and Mauve, Martin and Hartenstein, Hannes, "**Contention-based forwarding for mobile ad hoc networks**," *Ad Hoc Networks*, vol. 1 (4), pp. 351-369, 2003

Routing

- Georouting: CBF
  - Potential forwarders are contained in Reuleaux triangle (1) (use estimated communication range for thickness of triangle)
  - Waiting time is T = 1-P

    (z: destination, f: last hop forwarder)
  - If last hop overhears no node forwarding the message, message is re-sent for nodes in (2), then (3)

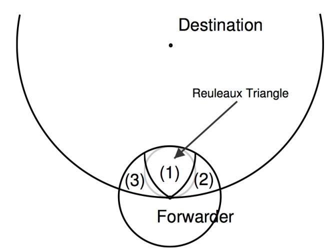
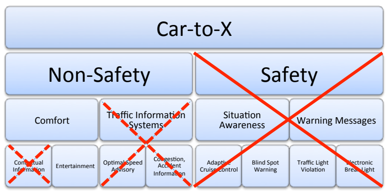


Illustration source: Füßler, Holger and Widmer, Jörg and Käsemann, Michael and Mauve, Martin and Hartenstein, Hannes, "**Contention-based forwarding for mobile ad hoc networks**," *Ad Hoc Networks*, vol. 1 (4), pp. 351-369, 2003

Routing

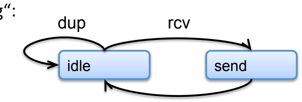
- Reflection on classical routing approaches
  - Q: Can (classical) routing work in VANETs?
  - A: Only in some cases.
  - Commonly need multicast communication, low load, low delay
  - Additional challenges and opportunities: network partitioning, dynamic topology, complex mobility, …



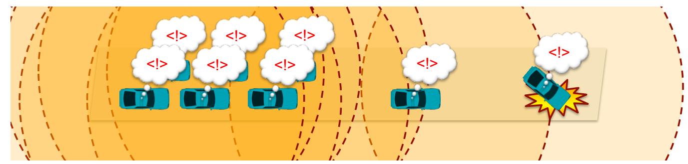
[1] Toor, Yasser and Mühlethaler, Paul and Laouiti, Anis and Fortelle, Arnaud de La, "**Vehicle Ad Hoc Networks: Applications and Related Technical Issues,**" IEEE Communications Surveys and Tutorials, vol. 10 (3), pp. 74-88, 2008

Flooding

- Flooding (Multi-Hop Broadcast)
  - Simplest protocol: „Smart Flooding“:



  - Problem: Broadcast Storm
    - Superfluous re-broadcasts overload channel



Flooding

- Consequences of a broadcast storm
  - Interference → impact on other systems
  - Collision → impact on other users
  - Contention → impact on other applications

Flooding

- Solving the broadcast storm problem

- Classical approaches
  - Lightweight solutions (e.g., probabilistic flooding)
  - Exchange of neighbor information, cost/benefit estimations
  - Topology creation and maintenance (Cluster, Cord, Tree, …)

- Drawbacks
  - Blind guessing (or scenario dependent parameterization)
  - Additional control message overhead
  - Continuous maintenance of topology

Flooding

- VANET specific solution: Broadcast Suppression
  - Needs no neighbor information
  - Needs no control messages
  - Maximizes distance per hop
  - Minimizes packet loss
- Approach
  - Node receives message, estimates distance to sender
  - Selectively suppresses re-broadcast of message
  - Alternatives
    - weighted p-persistence
    - slotted 1-persistence
    - slotted p-persistence

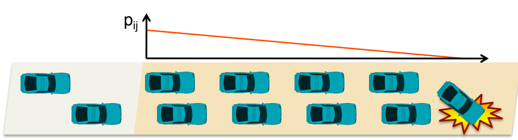
[1] Wisitpongphan, Nawaporn and Tonguz, Ozan K. and Parikh, J. S. and Mudalige, Priyantha and Bai, Fan and Sadekar, Varsha, "**Broadcast Storm Mitigation Techniques in Vehicular Ad Hoc Networks**," IEEE Wireless Communications, vol. 14 (6), pp. 84-94, December 2007

Flooding

- Broadcast Suppression
  - Estimate distance to sender as based on ("approximate transmission radius")
  - Variant 1: GPS based
  - Variant 2: RSS based

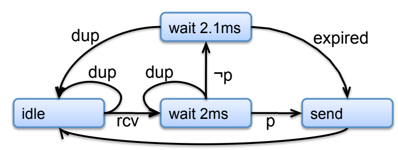
Flooding

- Broadcast Suppression
  - Weighted p-persistence
    - Probabilistic flooding with variable p_{ij} for re-broadcast
    - Thus, higher probability for larger distance per hop



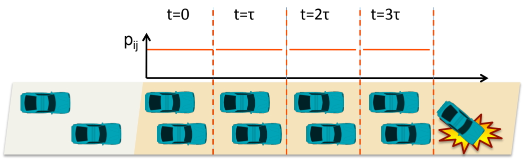
Flooding

- Broadcast Suppression
  - Weighted p-persistence
    - Wait WAIT_TIME (e.g., 2 ms)
    - choose $p=\min(\rho_{ij})=\min(\rho_{ij})$ of all received packets (probability for re-broadcast of packet)
    - Ensure that at least one neighbor has re-broadcast packet



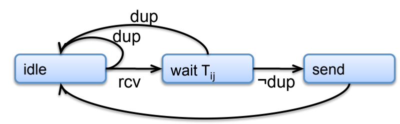
Flooding

- Broadcast Suppression
  - Slotted 1-persistence
    - Suppression based on waiting and overhearing
    - Divide length of road into slots
    - More distant slots send sooner
    - Closer slots send later (or if more distant slots did not re-broadcast)
    - Thus, higher probability to transmit over longer distance



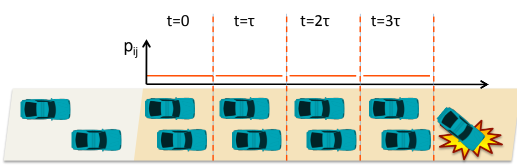
Flooding

- Broadcast Suppression
  - Slotted 1-persistence
    - Divide "communication range" into N_s slots of length τ
    - Nodes wait before re-broadcast, waiting time $T_{ij}=\tau\times\lceil N_s(1-\rho_{ij})\rceil$
    - Duplicate elimination takes care of suppression of broadcasts



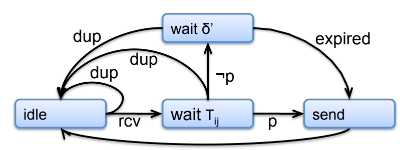
Flooding

- Broadcast Suppression
  - Slotted p-persistence
    - Cf. slotted 1-persistence
    - Fixed forwarding probability p (instead of 1)



Flooding

- Broadcast Suppression
  - Slotted p-persistence
    - Wait for T_{ij} (instead of fixed WAIT_TIME)
    - Use probability p (instead of 1)
    - Ensure that at least one neighbor has re-broadcast the packet by waiting for δ' > max(T_{ij})

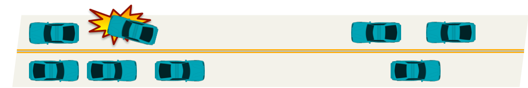


Flooding

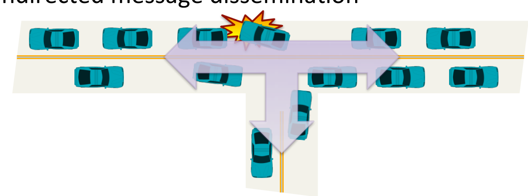
- Broadcast Suppression
  - Solves Broadcast Storm Problem
  - Maximizes distance per hop
  - Minimizes packet loss
  - But: Much higher per-message delay

Remaining problems

- Temporary network fragmentation

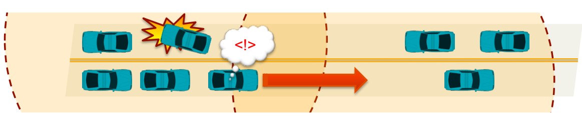


- Undirected message dissemination



Flooding + X

- DV-CAST
  - Idea: detect current scenario, switch between protocols
  - Check for fragmented network
    - Network connected → perform broadcast suppression
    - Network fragmented → perform Store-Carry-Forward



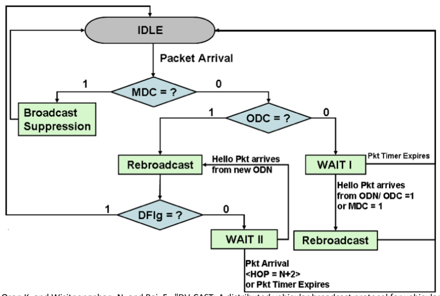
[1] Tonguz, Ozan K. and Wisitpongphan, N. and Bai, F., "DV-CAST: A distributed vehicular broadcast protocol for vehicular ad hoc networks," IEEE Wireless Communications, vol. 17 (2), pp. 47-57, April 2010

Flooding + X

- DV-CAST: Mechanism
  - Nodes periodically send *Hello* beacons containing position, speed
  - Nodes maintain 3 neighbor tables
    - Same direction, ahead
    - Same direction, driving behind
    - Opposite direction
  - Messages contain source position and Region of Interest (ROI)
  - For each message received, evaluate 3 Flags:
    - Destination Flag (DFlg):
      Vehicle in ROI, approaching source
    - Message Direction Connectivity (MDC):
      ∃ neighbor driving in same direction, further away from source
    - Opposite Direction Connectivity (ODC):
      ∃ neighbor driving in opposite direction

Flooding + X

- DV-CAST
  - Algorithm:



Picture source: Tonguz, Ozan K. and Wisitpongphan, N. and Bai, F., "DV-CAST: A distributed vehicular broadcast protocol for vehicular ad hoc networks," IEEE Wireless Communications, vol. 17 (2), pp. 47-57, April 2010

Flooding + X

- DV-CAST
  - Decision matrix:

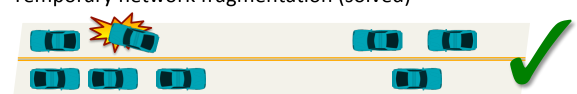
MDC	ODC	DFlg	Derived Scenario	Actions Taken by DV-CAST Protocol
1	×	1	Well Connected	Broadcast Suppression
1	×	0	Well Connected	Help relay the packet by doing broadcast suppression
0	1	1	Sparsely Connected	Rebroadcast and assume that the ODN will help relay or rebroadcast
0	1	0	Sparsely Connected	Rebroadcast and help carry & forward the packet to the first new neighbor in the opposite direction or in the message direction encountered
0	0	×	Totally Disconnected	Wait and forward the packet to the first neighbor in the opposite direction or in the message direction encountered.

Flooding + X

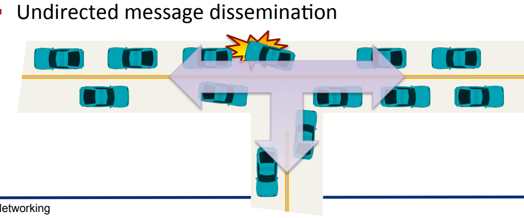
- DV-CAST
  - Simulation results show that (on freeways with low to medium node densities) DV-CAST beats simple flooding in terms of broadcast success rate and distance covered

Intermediate Summary

- Remaining problems
  - Temporary network fragmentation (solved)

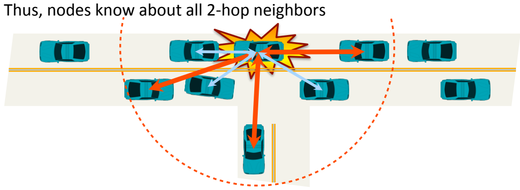


  - Undirected message dissemination



Geocast

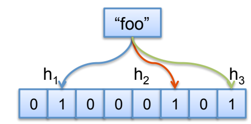
- TO-GO
  - „Topology-Assisted Geo-Opportunistic Routing"
  - Nodes periodically send *Hello* beacons; Contents:
    - Number of neighbors
    - Bloom filter of neighbor IDs
    - IDs of neighbors furthest down the road/roads
  - Thus, nodes know about all 2-hop neighbors



[1] Lee, K.C. and Lee, U. and Gerla, M., "**Geo-Opportunistic Routing for Vehicular Networks**," *IEEE Communications Magazine*, vol. 48 (5), pp. 164-170, May 2010

Geocast

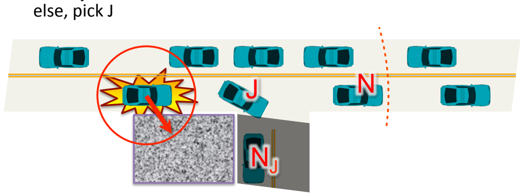
- Bloom Filter
  - Idea:
    - Bloom filter is a bit field X
    - Hash functions h_1 to h_k map input data x → one bit (each) in X
    - Insertion of x: Set $X[h_i(x)] \leftarrow 1 \quad \forall i \in [1..k]$
    - Test for $x \in X$: Check $X[h_i(x)] \stackrel{?}{=} 1 \quad \forall i \in [1..k]$
  - Probabilistic test for "$x \in X$"
    - Possible results: no / maybe (→ chance of false positives)
  - Allows for very compact representation of X



[1] Bloom, Burton H., "**Space/time trade-offs in hash coding with allowable errors**," *Communications of the ACM*, vol. 13 (7), pp. 422-426, 1970

Geocast

- TO-GO
  - Step 1: Find best next hop (Target Node, T)
    - Find N: Furthest neighbor towards destination
    - Find J: Furthest neighbor towards destination, currently on junction
    - Find N_J: Furthest neighbor towards destination, as seen by J
    - if N, N_J are on the same road (and running in greedy mode), pick N
      else, pick J



Geocast

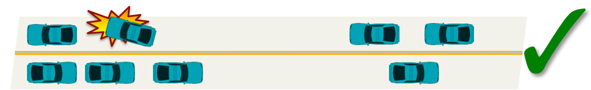
- TO-GO
  - Step 2: Find Forwarding Set (FS)
    - Nodes in the FS will compete for relaying of the message
    - Only one node in FS should relay
      thus, all nodes in FS must hear each other
    - Finding optimal solution is *NP complete*
    - TO-GO uses approximation:
    - Bloom filter entries indicate who can hear whom
    - Given the target node T,
      find its neighbor M with the maximum number of neighbors
    - Include all those neighbors in FS, which
      - can hear M, and
      - are heard by M, and
      - are heard by all current members of FS

Geocast

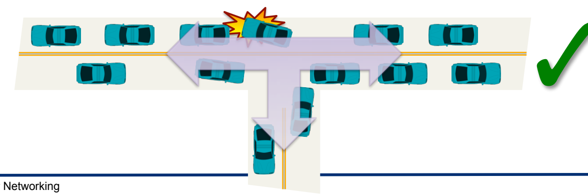
- TO-GO
  - Step 3: Multicast message to all nodes in FS
    - Nodes in the FS compete for relaying of the message
    - Ensure maximum progress within FS
    - Delay re-broadcast by t
    - Suppress re-broadcast if another nodes forwards within t
    - $t = \tau \times d_T / d_{max}$
      with:
      - τ: Maximum delay per hop
      - d_T: Distance to Target Node
      - d_{max}: Distance from last hop to Target Node

Intermediate Summary

- Remaining problems
  - Temporary network fragmentation (solved)

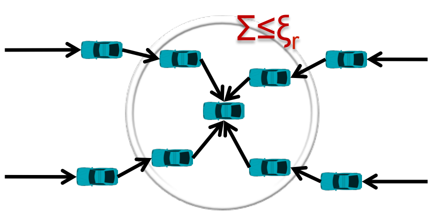


  - Undirected message dissemination (solved)



Scalability

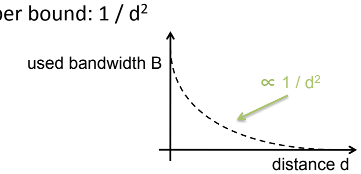
- Do the presented approaches scale?
- Analytical evaluation [1]:
  - Capacity of wireless channel is limited
  - Amount of information transported across any (arbitrary) border must be upper-bounded



[1] B. Scheuermann, C. Lochert, J. Rybicki, and M. Mauve, "**A Fundamental Scalabiliy Criterion for Data Aggregation in VANETs**," in ACM MobiCom 2009. Beijing, China: ACM, September 2009

Scalability

- Solution?
  - Define maximum dissemination range of any information
  - Reduce update frequency with increasing distance
  - Aggregate information as distance increases
- Pre-condition for scalability of dissemination approach?
- Used bandwidth reduces as distance to source increases
- Upper bound: $1 / d^2$



Main Takeaways

- Classic information dissemination
  - Distance vs. link-state
  - Reactive vs. proactive
  - Hop-by-hop vs. source routing
  - Geo-routing (CBF)
- Examples of VANET-centric information dissemination
  - Flooding (Weighted/Slotted 1/p-Persistence)
  - Fragmentation (DV-Cast)
  - Directedness (To-Go)
- Scalability