Vehicular Networking

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IAB Technical Plenary · 93rd IETF · July 2015 · Prague

Motivation

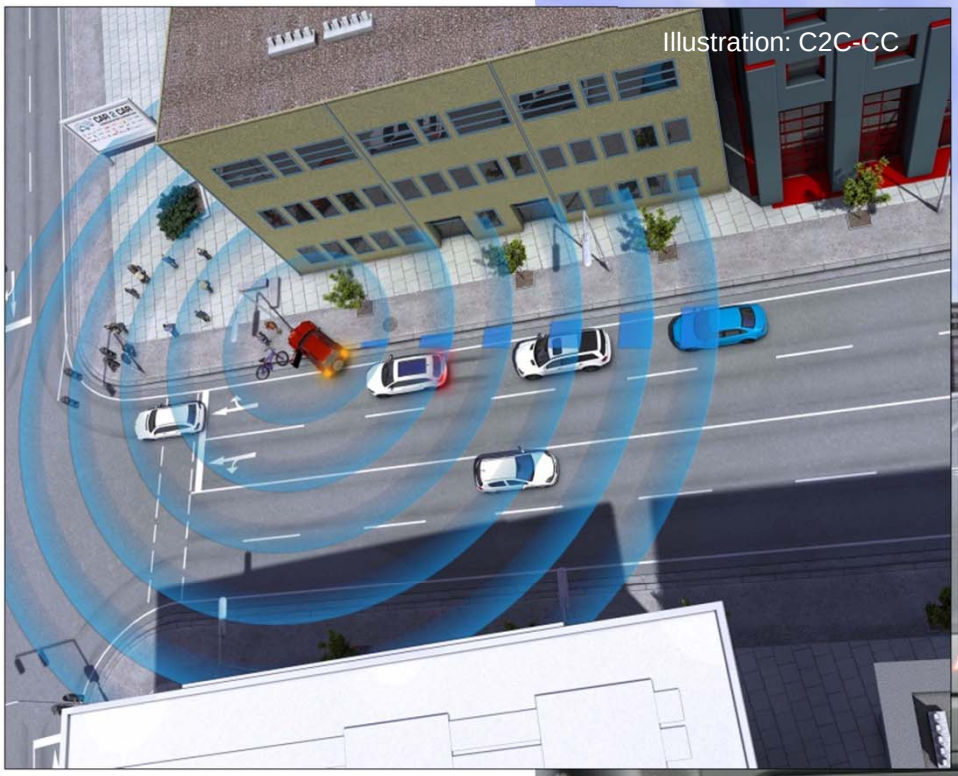


Illustration: C2C-CC


Illustration: C2C-CC
Illustration: Project AKTIV

History

- 1970s: bold ideas
  - Visionary, infrastructure-less solutions
  - Unsupported by current technology
  - Early interest, but no commercial success
- 1980s: paradigm shift
  - Infrastructure-less ⇨ infrastructure-assisted
  - highway automation ⇨ driver-advisory only
  - chicken-and-egg type of standoff
- 1990s: Cellular technology re-ignites interest
  - early “V2X”: OnStar (1995), BMW Assist (1999), …
- 2000s: Sharp increase in computing power
  - Fully-distributed, highly reactive ad hoc systems

Illustrations: [1]

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

The Future

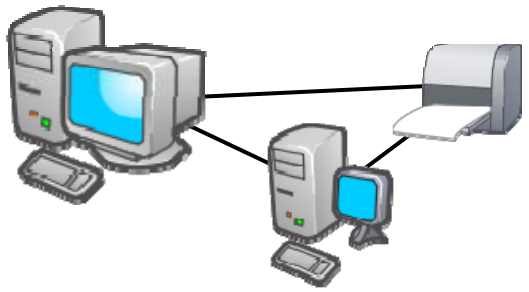
- 2009-2011: Coordinated research programs MoU/MoC
  - January 2009: U.S. ⇔ EU
  - October 2010: U.S. ⇔ Japan
  - June 2011: EU⇔Japan
- Field Trials
  - Numerous (and large scale)
  - NHTSA: Intersection Movement Assist & Left Turn Assist (LTA) could "prevent 412,512 to 592,230 crashes, save 777 to 1,083 lives" [1, deployment scenario 1]
- Aug 2014: U.S. NHTSA announcement
  - "Advance Notice of Proposed Rulemaking" for V2V

[1] Harding, J., Powell, G., R., Yoon, R., Fikentscher, J., Doyle, C., Sade, D., Lukuc, M., Simons, J., & Wang, J.: "*Vehicle-to-vehicle communications: Readiness of V2V technology for application.*" NHTSA Report No. DOT HS 812 014, August 2014.

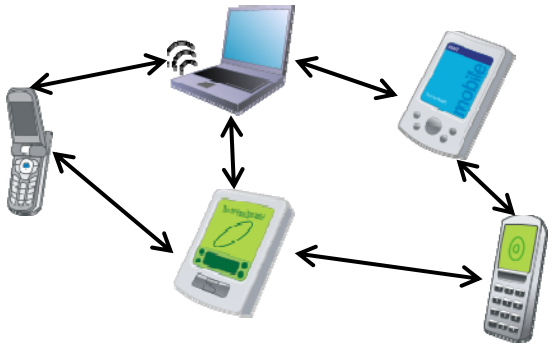
Trends

Evolution

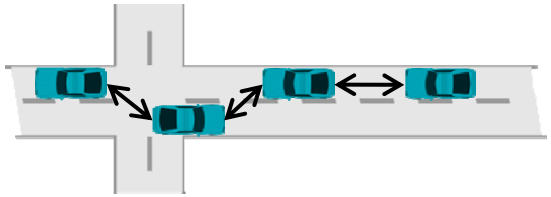
- Traditional Network
  - Wired
  - Non-moving
  - Static config



- Mobile Ad Hoc Network (MANET) [1]
  - Wireless
  - Mobile
  - Dynamic config



- Vehicular Ad Hoc Network (VANET)
  - First approach: “MANET on wheels”
  - More fitting approaches needed



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

Dedicated Short Range Communication (DSRC)

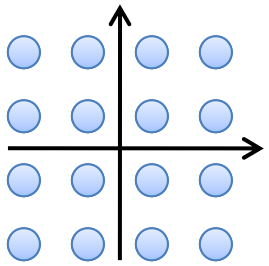
Our new “wire”

Dedicated Short Range Communication (DSRC)

- IEEE 802.11{a,b,g,n} for V2X communication?
  - Two modes, mutually exclusive
    - Infrastructure mode
    - Ad hoc mode
    - Switching & association time consuming
  - Massively shared spectrum
    - ISM (Industrial, Scientific, and Medical) band
  - Phy effects reduce range and speed

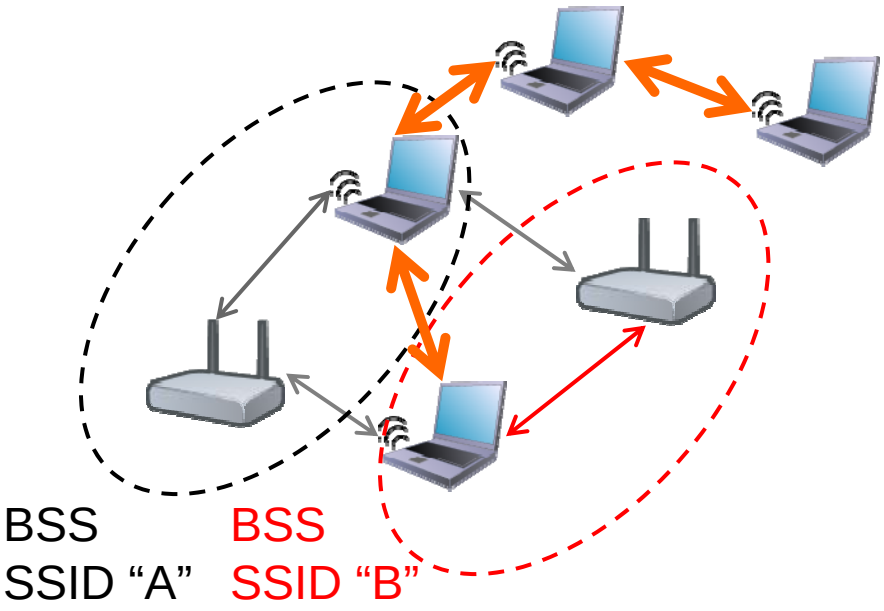
Dedicated Short Range Communication (DSRC)

- IEEE 802.11e
  - QoS (EDCA priority access)
- IEEE 802.11j-2004
  - Half-clocked operation (10 MHz bandwidth)
- IEEE 802.11p (2004-2010)
  - OFDM PHY layer (cf. IEEE 802.11a)
  - High demands on tolerances
  - Operation in 5.9 GHz band
  - New OCB (Outside the Context of a Basic Service Set) mode



OCB (Outside the Context of a Basic Service Set) mode

- Wildcard BSS
  - Nodes may always use Wildcard BSS in packets
  - Nodes will always receive Wildcard BSS packets
  - May join BSS and still use Wildcard BSS
  - Shift coordination from MAC to applications



Operation in 5.9 GHz band

- Dedicated frequency band
  - Exclusive for Vehicle-to-Vehicle (V2V) and V.-to-Infrastructure (V2I)
  - No license cost, but usage rules
  - FCC ⇨ 7 channels of 10 MHz (“U.S. DSRC”)
  - ECC ⇨ 5 channels of 10 MHz (additional ch’s & WiFi in scope)

	…							…
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	

Classical routing in vehicular networks?

[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

Challenges of vehicular networks

- Old challenges:
  - Multicast communication
  - Low load
  - Low delay
- New challenges
  - Highly dynamic topology
  - Safety
  - Partitioning
  - Complex mobility
  - …

Meeting the challenges

- We need something between wire and applications
  - Information dissemination, addressing (security & privacy), trust, integrity, smart use of channels, … [1]
- U.S.
  - IEEE 1609 WAVE (“Wireless Access in Vehicular Environments”)
- Europe
  - ETSI ITS G5 (“Intelligent Transportation Systems”)
- Japan
  - ARIB T109 (“700 MHz Band Intelligent Transport Systems”)

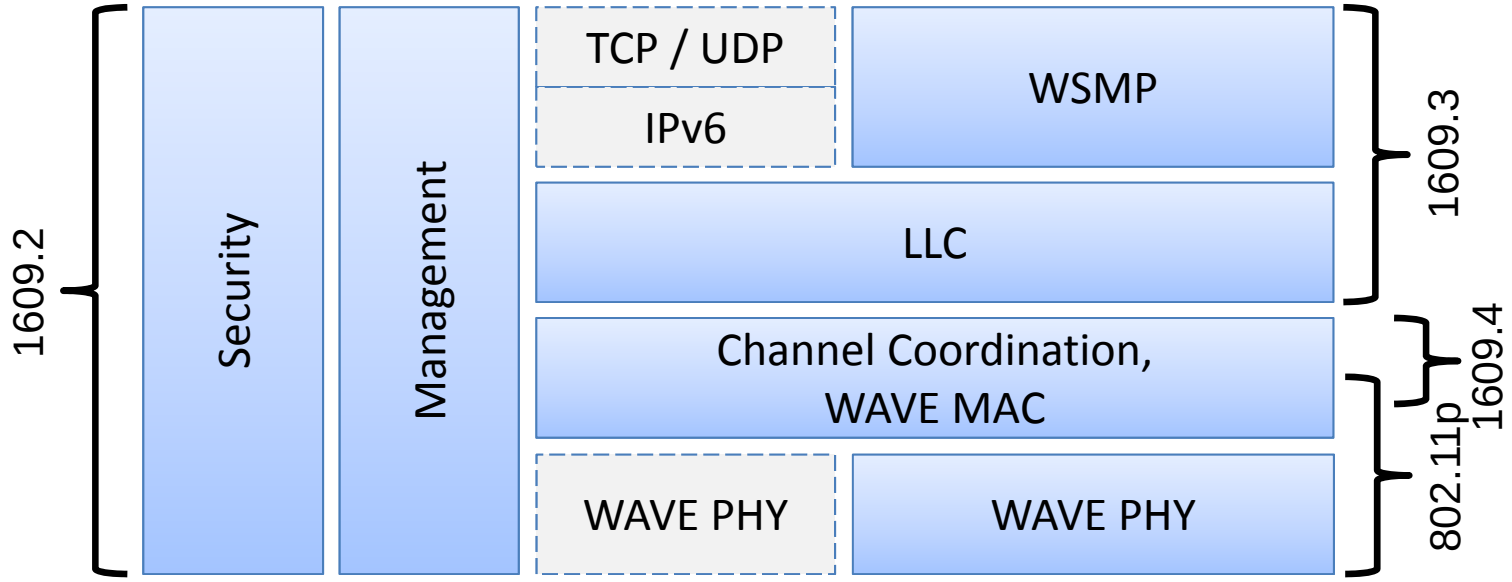
[1] Christoph Sommer and Falko Dressler: *Vehicular Networking*, Cambridge University Press, 2014

IEEE Wireless Access in Vehicular Environments (WAVE)

The U.S. approach

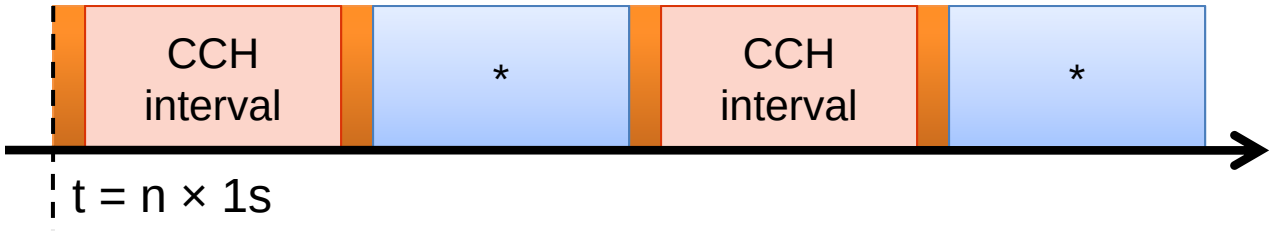
IEEE WAVE Stack

- IEEE 1609.2: Security
- IEEE 1609.3: Netw. services
- IEEE 1609.4: Channel mgmt.
- IEEE 1609.11: Application "electronic payment"



IEEE WAVE Channel Management

- WAVE allows for both single radio devices & multi radio devices
- Single radio devices should periodically tune to well-known channel to not miss important messages ⇨ Control Channel (CCH)
- Time slots [1]
  - Synchronization envisioned via GPS receiver clock
  - Standard value: 100ms sync interval (with 50ms on CCH)
- Announcements advertise services on other channels



[1] IEEE Std 1609.4-2010

ETSI ITS G5

The European approach

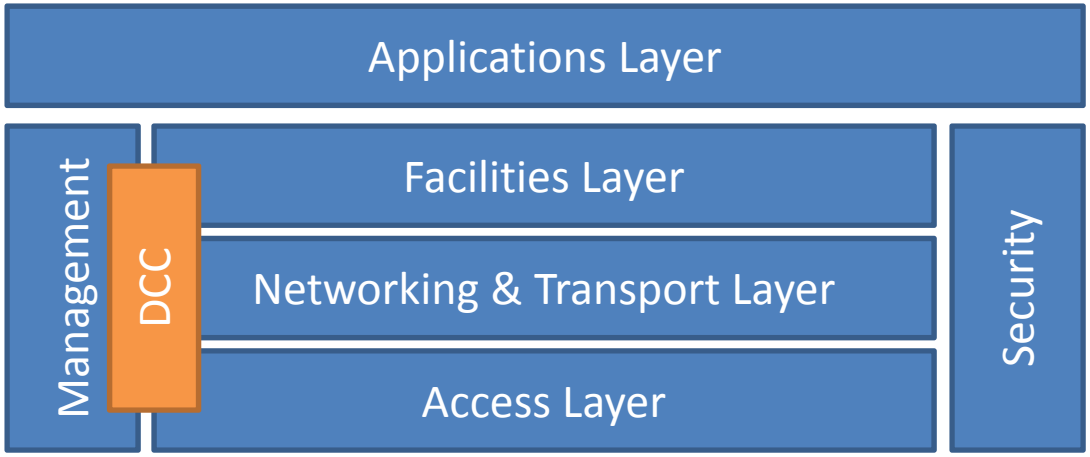
ETSI ITS G5

- Motivation
  - European standardization effort
  - Include lessons learned from WAVE
- No alternating CCH access specified
  - Instead: stronger multi-radio
  - Should keep one radio tuned to CCH [1]
- Cooperative Awareness Messages
  - Periodic (up to 10Hz) safety/management messages
  - Information on state of surrounding vehicles:
    - Speed, location, …

[1] ETSI TS 102 636-4-2 V1.1.1

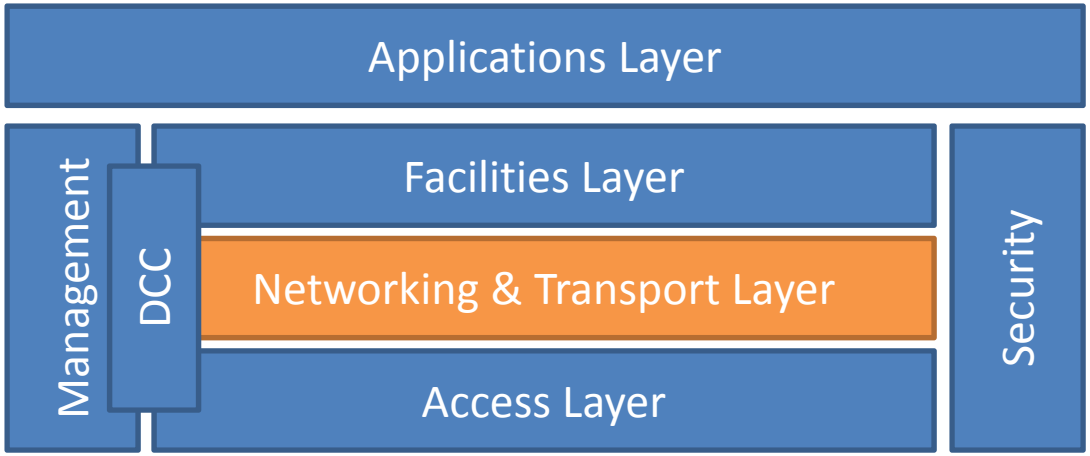
ETSI ITS G5 Protocol Stack: DCC

- PHY and MAC based on IEEE 802.11p
- Cross layer Decentralized Congestion Control (DCC)
  - Measure channel busy ratio
  - ⇨ Derive channel state
  - ⇨ Derive restrictions on message rate, modulation/coding, power, …



ETSI ITS G5 Protocol Stack: GeoNetworking

- Topologically Scoped Broadcast
  - n-hop neighborhood
- GeoBroadcast
  - addressed to area by lon/lat/shape
- GeoUnicast
  - addressed to unique id, supported by lon/lat



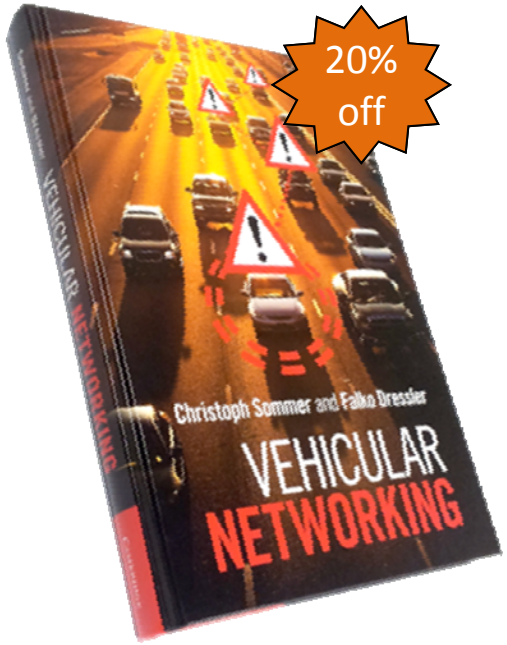
Outlook

Outlook

- Applications
  - IEEE 1609.11: Electronic payment
  - SAE SPAT: Signal phase and timing
  - ETSI CAM & IEEE/SAE BSM: Periodic one-hop broadcasts
  - ETSI DENM: Geocasting of warnings
- Merging of in-vehicle and vehicle-to-vehicle (V2V)
  - Sensor fusion
- Security & Privacy
  - ⇨ next talk

In-depth Information

- Textbook:
  Vehicular Networking



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- Conference:
  IEEE VNC
  - Tokyo (Oct 2009)
  - New Jersey (Dec 2010)
  - Amsterdam (Nov 2011)
  - Seoul (Nov 2012)
  - Boston (Dec 2013)
  - Paderborn (Dec 2014)
  - Kyoto (Dec 2015)