From Connected Cars to Smart Cities: On Wireless Communication Latency and Reliability

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Outline

- Motivation
  - Trends towards autonomous driving and integrated inter-vehicle communication
- Green and safe driving in smart cities
  - Interactions with traffic lights or no traffic lights at all
- Platooning as one of the killer applications
  - Inherently interdisciplinary
  - Reliability and real-time requirements

Towards Autonomous Driving

Inter-Vehicle Networking for Situation Awareness

Illustrations: C2C-CC

Standardization and Open Research

- Dedicated spectrum for inter-vehicle communication in Europe (ECC), the US (FCC), and Japan
- IEEE DSRC/WAVE and ETSI ITS G5
  - Both build upon IEEE 802.11p
- Situation awareness as major year-one-application
  - ETSI DCC (Decentralized Congestion Control)
- **But many fundamental research questions still unanswered**
  - **Scalability, real-time capabilities, use of heterogeneous networks**
- Dagstuhl seminar series identified key challenges
  - Falko Dressler, Hannes Hartenstein, Onur Altintas and Ozan K. Tonguz, "**Inter-Vehicle Communication - Quo Vadis**," *IEEE Communications Magazine*, vol. 52 (6), pp. 170-177, June 2014.

GREEN AND SAFE DRIVING IN SMART CITIES

Intersection Management

- Efficiency

No Traffic Lights

Regular Traffic Lights

[1] No Traffic Lights Vs Traffic Lights © studio tdes CC BY-NC-SA 2.5 – http://www.youtube.com/watch?v=hFOo3e0nxSI

- Safety

No Traffic Lights

[1] Авария! Проигнорировал знак стоп © SmexaMnogo, CC BY – http://www.youtube.com/watch?v=TO-eRnw1hTo

Safe and Efficient Traffic in Smart Cities

- STEP 1: Communication between traffic lights and vehicles

- First ideas date back to the 1970ies
  - Analog communication
  - Transmission of switching times to approaching vehicles

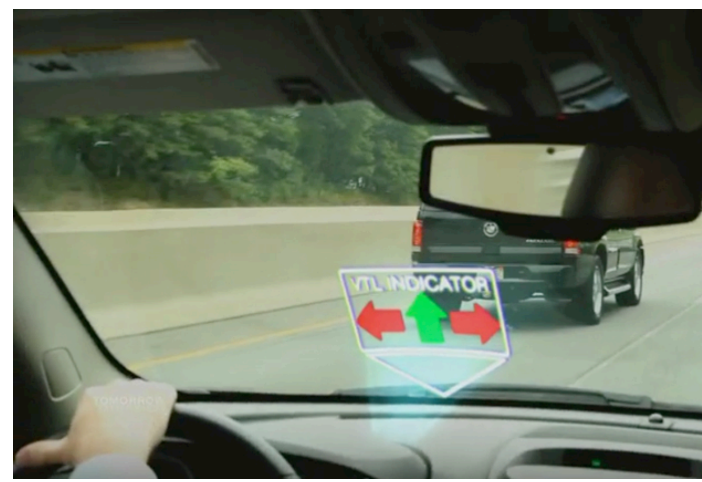
- Reality today especially in Asian countries
  - Large displays indicating the end of the current light phase

- Vehicular networking enables the solutions for tomorrow
  - WiFi or DSRC based
  - Investigated, for example, in Travolution project

- STEP 2: Enabling Virtual Traffic Lights

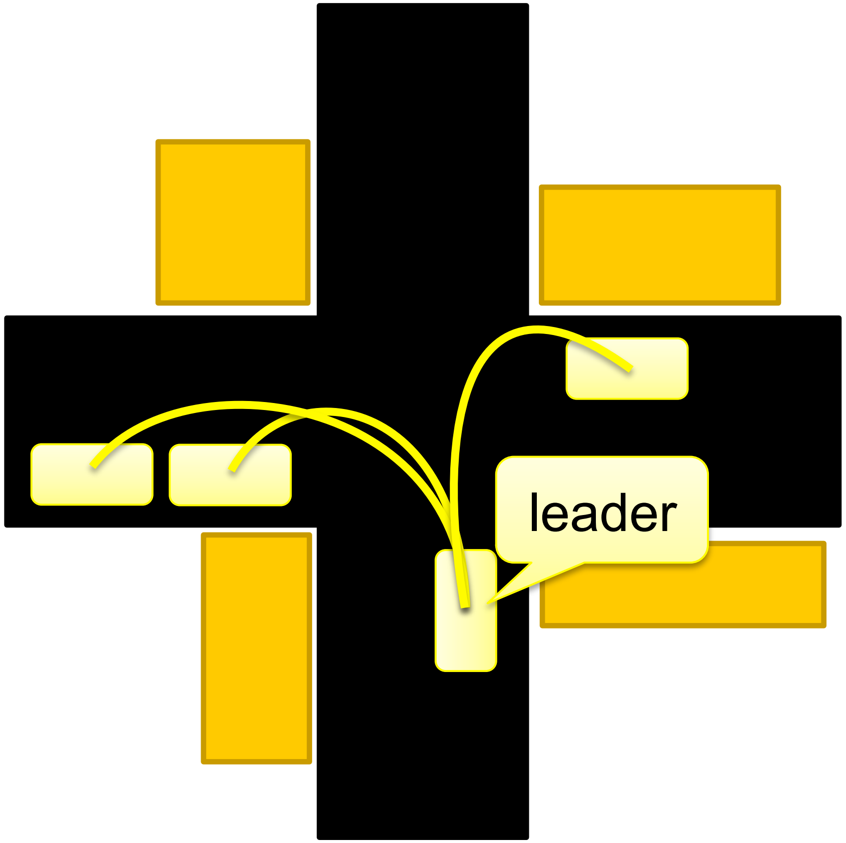
- Status as of today
  - Only 1-20% of all intersections are equipped with traffic lights
  - Many of these are not appropriately connected → may cause artificial traffic jams
  - New installations are very expensive

- VTL – Virtual Traffic Lights
  - First investigated by CMU/U Porto



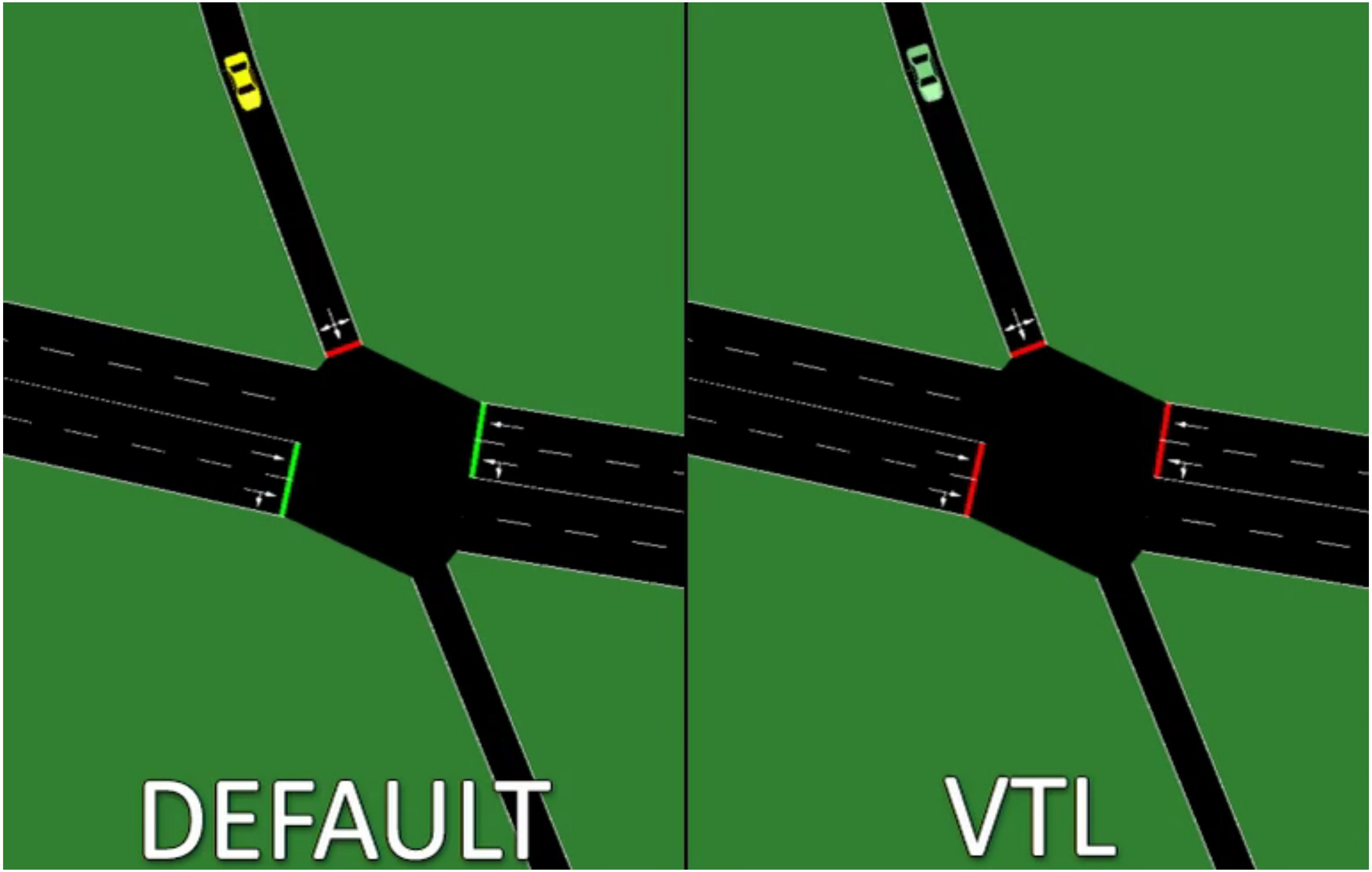
Virtual Traffic Lights

1. Wait for intersection
2. Perform leader election
3. Send/receive TL program



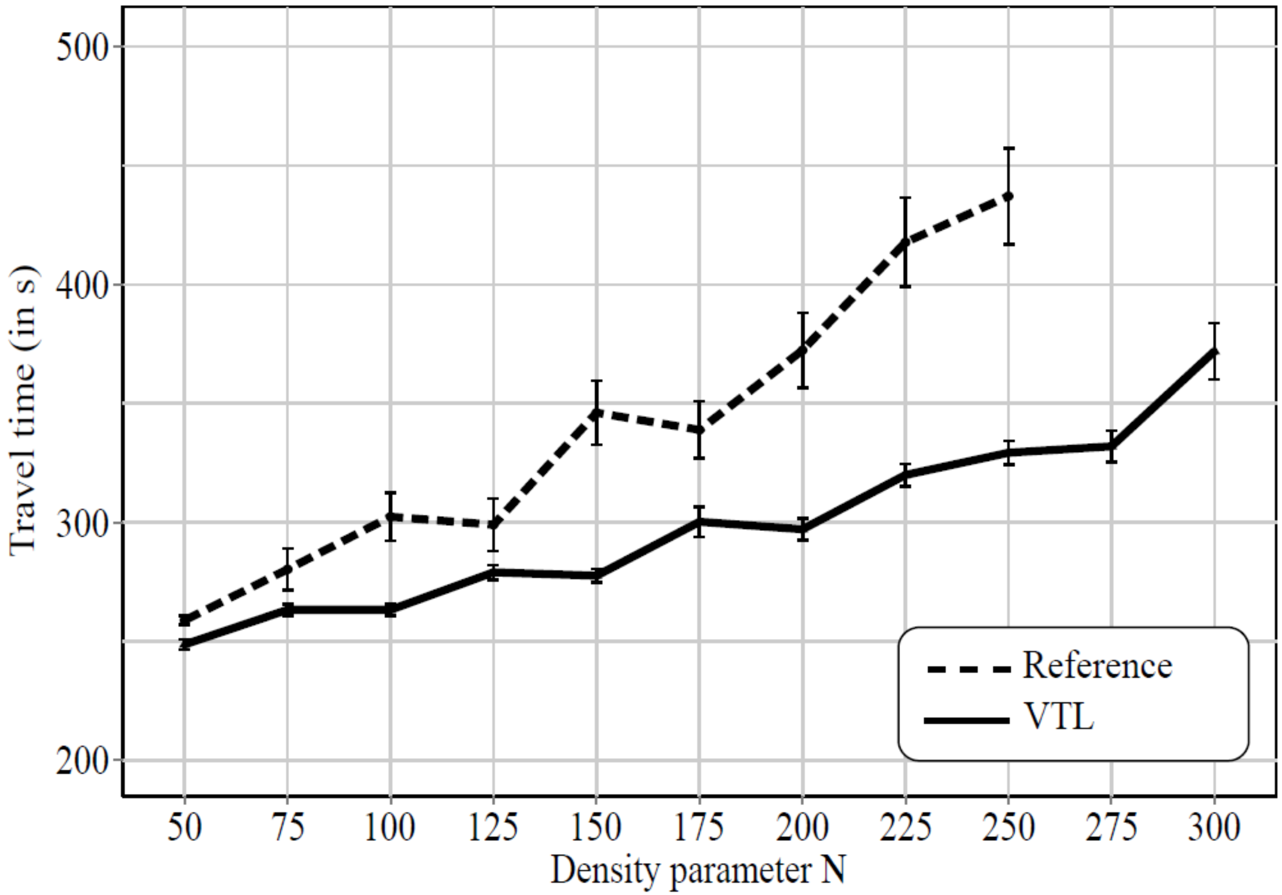
✧ Research avenues:
- Leader election
- TL program computation
- Scalability and load?

Virtual Traffic Lights



Virtual Traffic Lights

- ✧ Travel time compared to (static) traffic lights



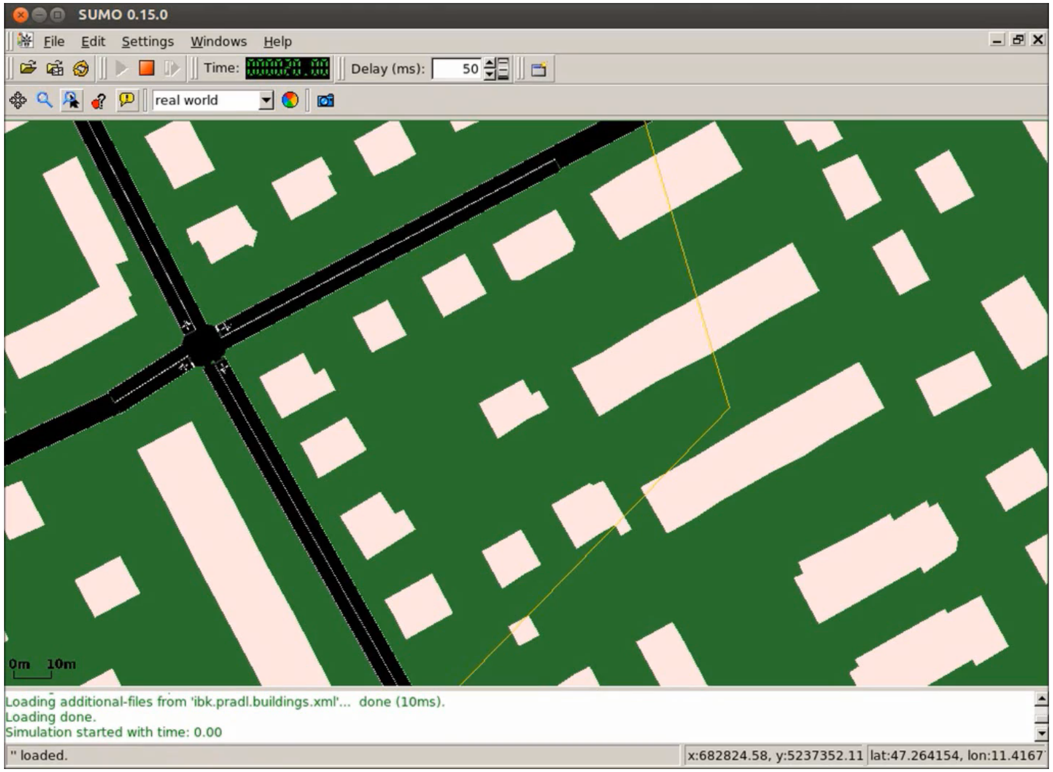
- STEP 3: Using Heterogeneous Networks

- Today
  - Bluetooth
  - WiFi (IEEE 802.11a/b/g/n/ac)
  - 3G/4G (UMTS/LTE)

- Tomorrow
  - DSRC/WAVE (IEEE 802.11p)
  - 60 GHz (IEEE 802.11ad)
  - 4G+ (LTE Advanced/LTE Direct)
  - Millimeter wave (Radar)
  - Visible light communication

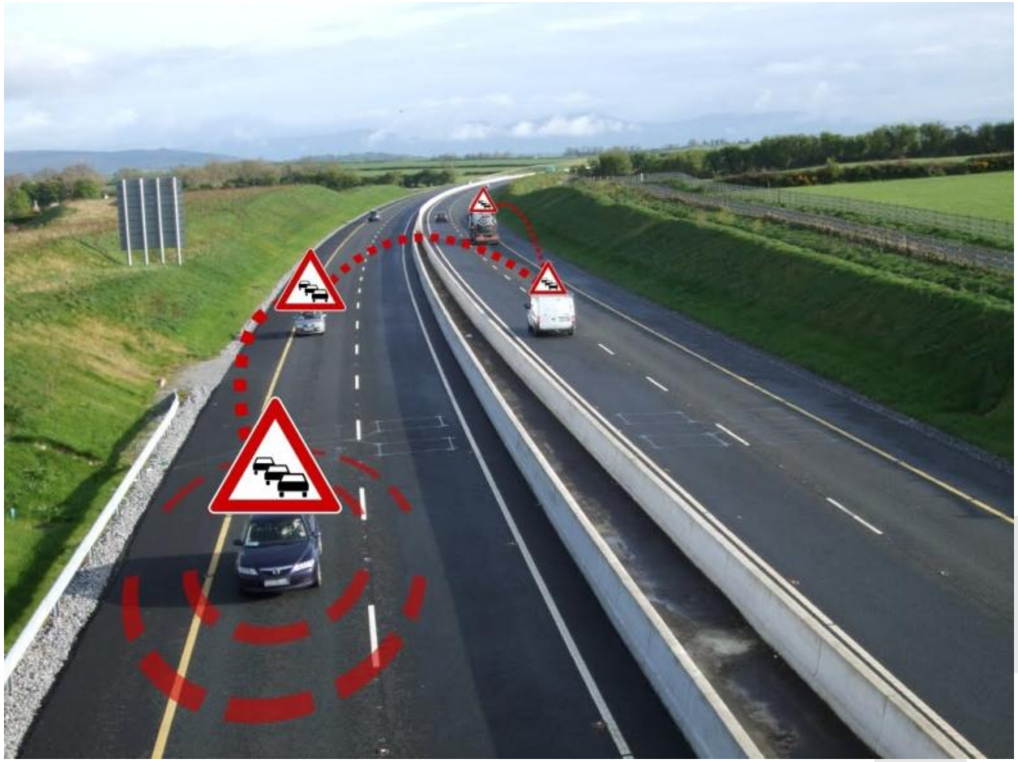
- STEP 3: Using Heterogeneous Networks

- Causes new challenges but provides many new opportunities
  - Clustering
  - Selecting the communication channel
  - Cooperation and self-organization



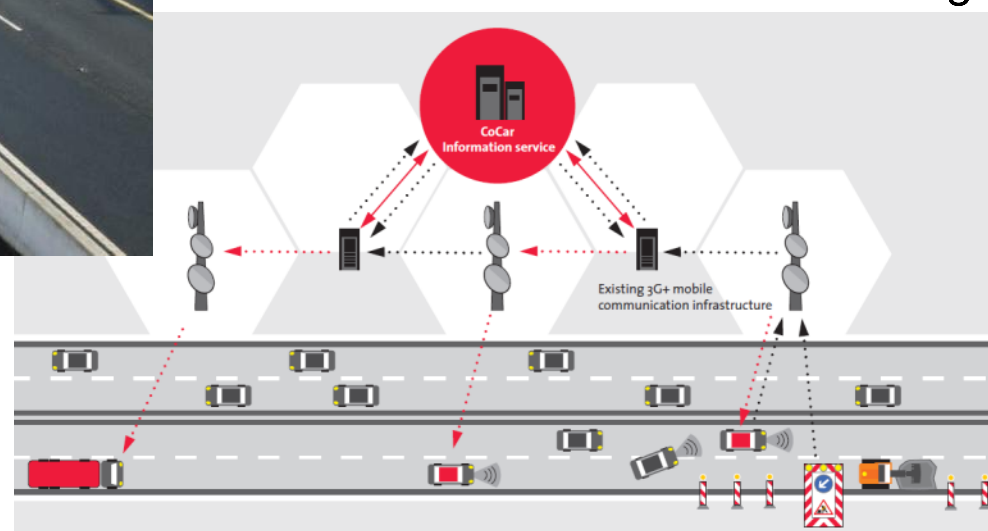
VEHICULAR NETWORKING PROTOCOLS

Communication Paradigms



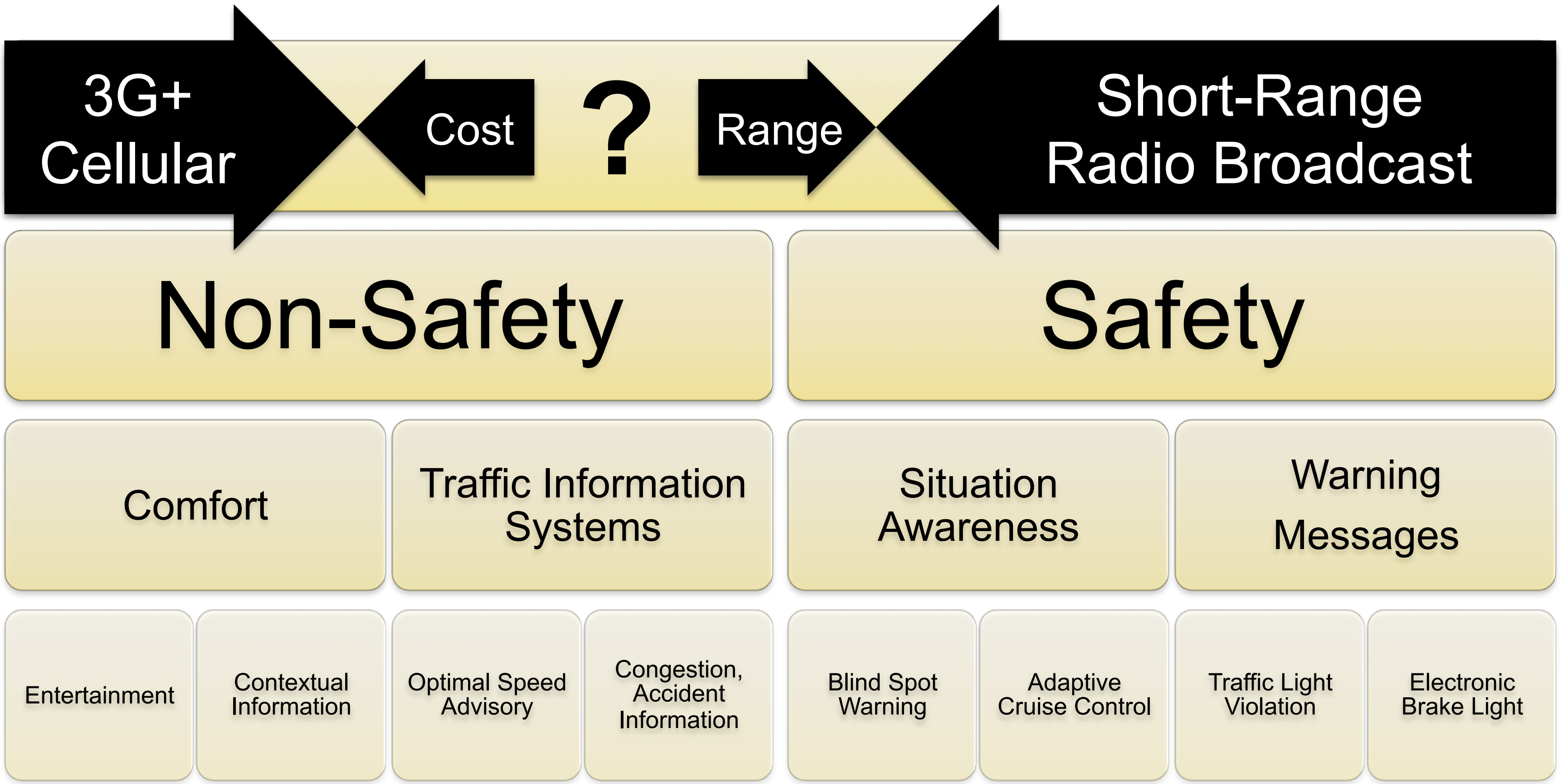
Ad Hoc Multihop Broadcasting

Infrastructure-assisted Data Exchange



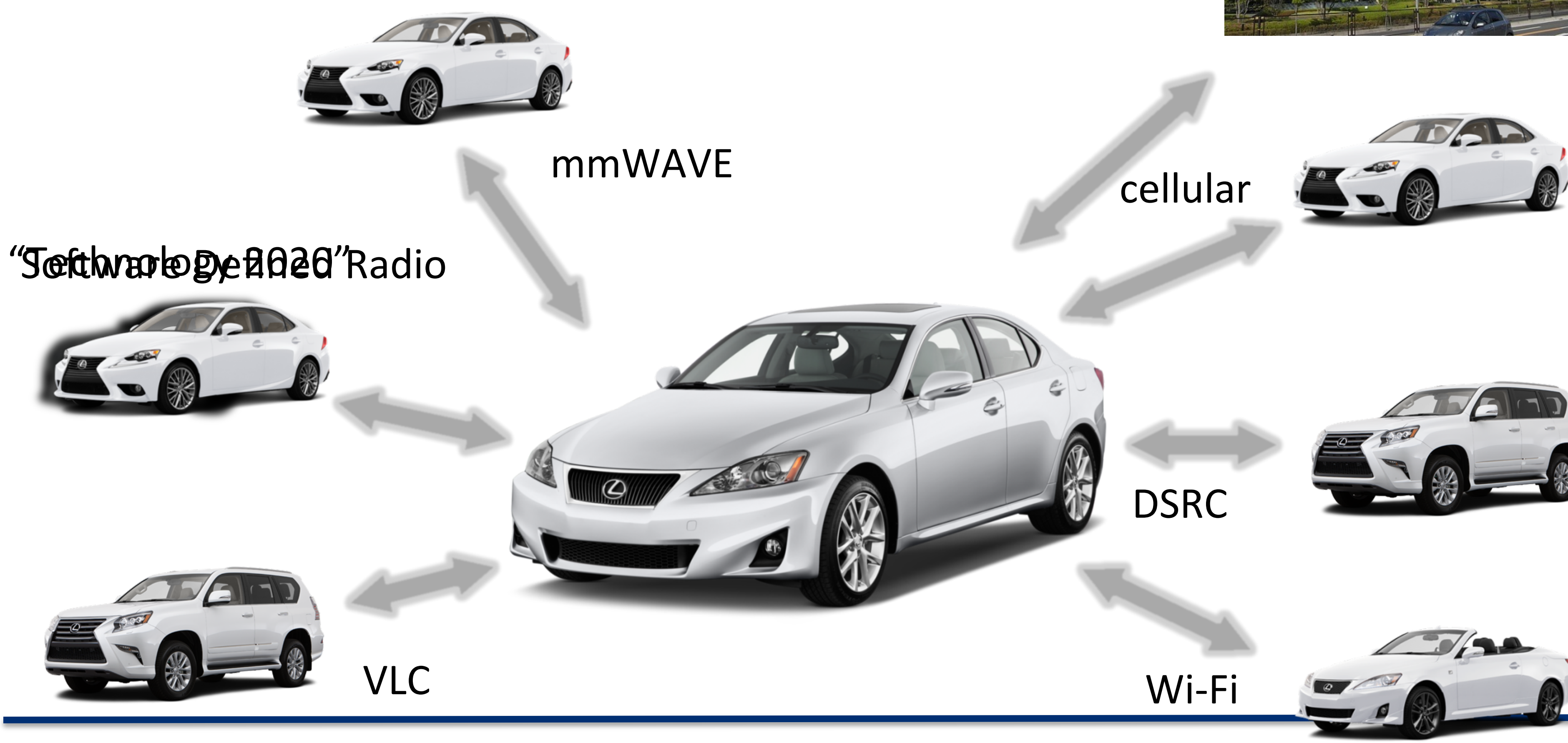
Taxonomy

- Wealth of applications [T. L. Willke 2009]



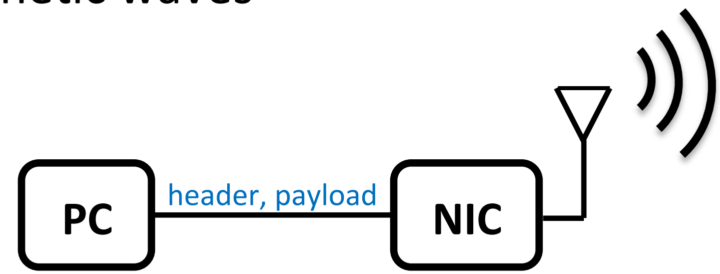
[1] G. T. L. Willke, P. Tientrakool, and N. F. Maxemchuk, "A Survey of Inter-Vehicle Communication Protocols and Their Applications," IEEE Communications Surveys and Tutorials, vol. 11 (2), pp. 3-20, 2009

- Many communication channels available
  - Which to pick when?



Future Proofing Short Range Communication

- Old: Classic radio hardware
  - Send bit stream to Network Interface Card (NIC)
  - NIC transforms bits from/to electromagnetic waves
  - New radio technology ⇨ new NIC

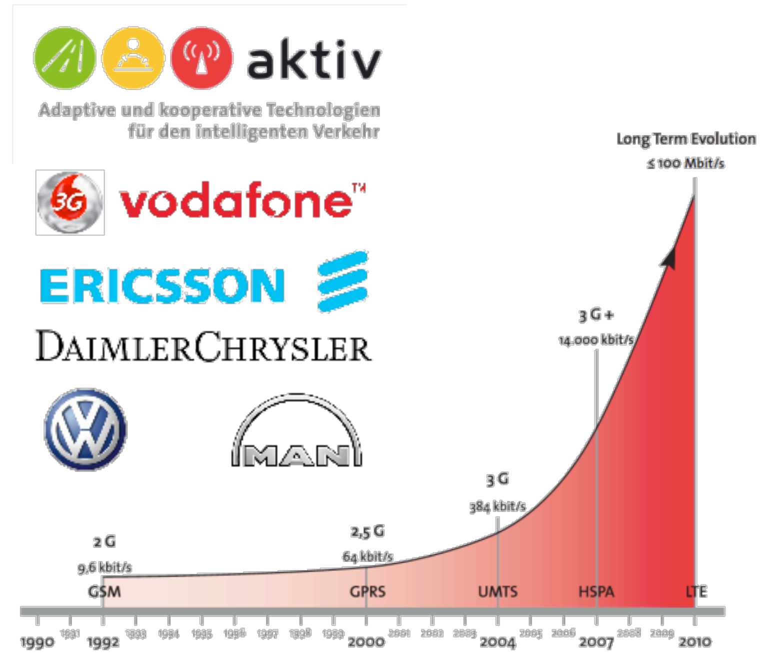


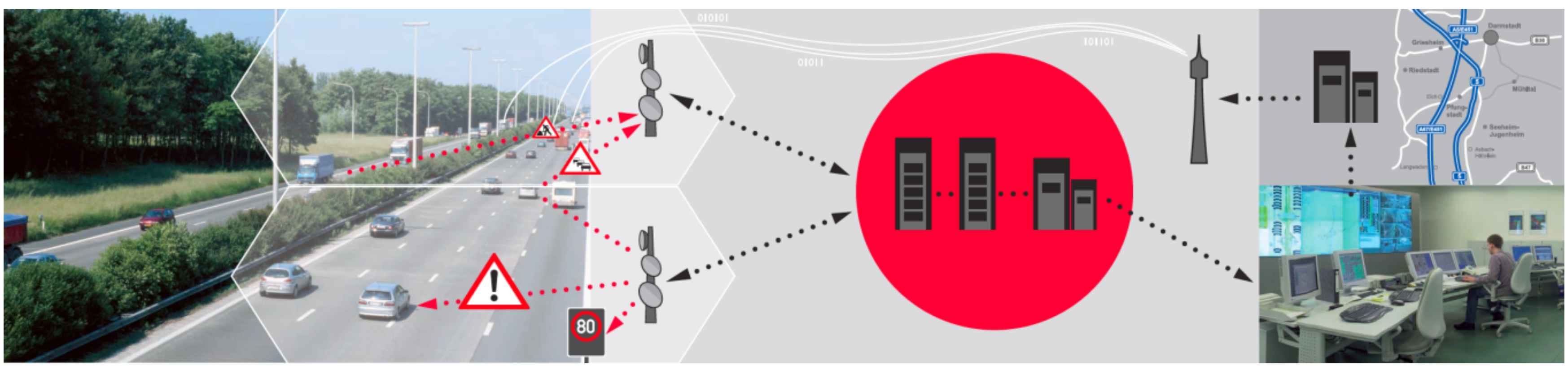
- Which technology to pick?
  - 802.11p, WAVE, ITS G5, future work, …
  - No clear winner
  - Hard to commit today

- Software Defined Radio (SDR)
  - New radio technology ⇨ new software

3G / 4G – aktiv CoCar

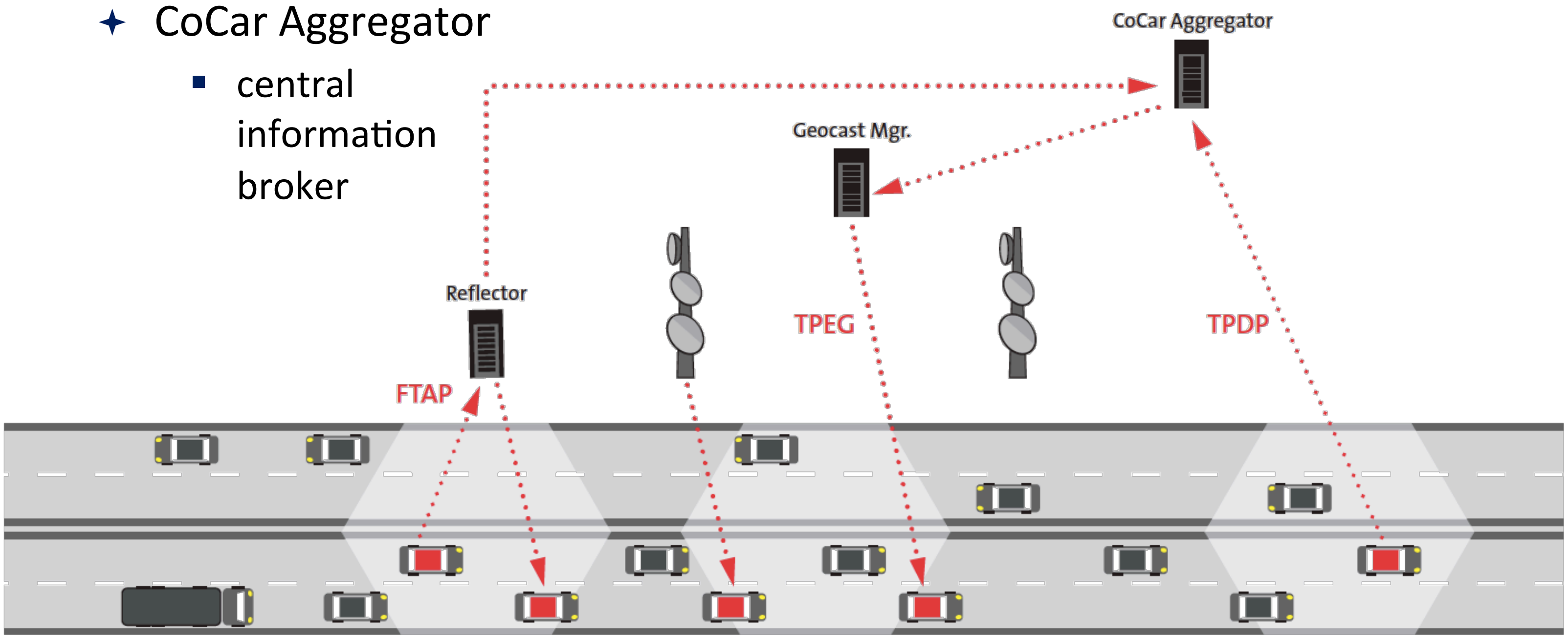
- aktiv CoCar
  - Goals
    - Investigate feasibility of Car-to-X over 3G/3.5G networks
    - Establish business case
  - Cooperation of
    - Telcos, OEMs
    - Car manufacturers
    - Government, automobile association



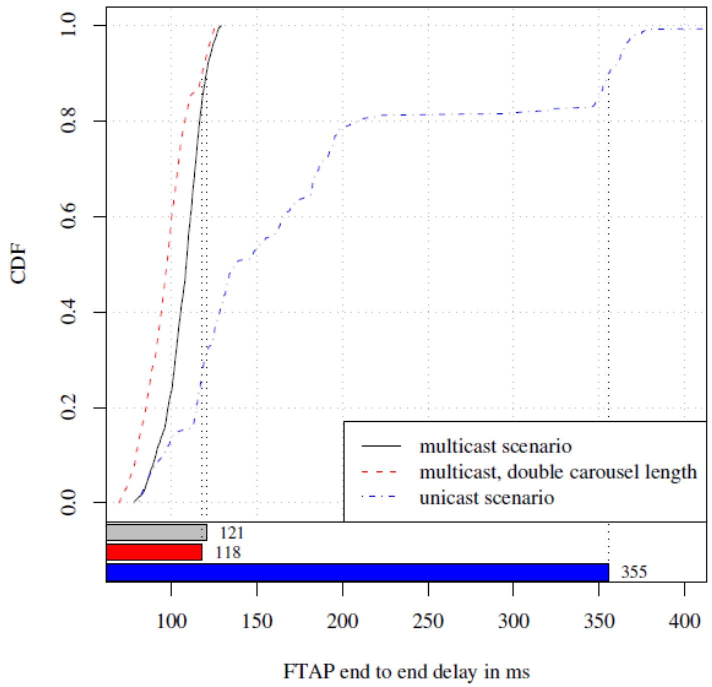


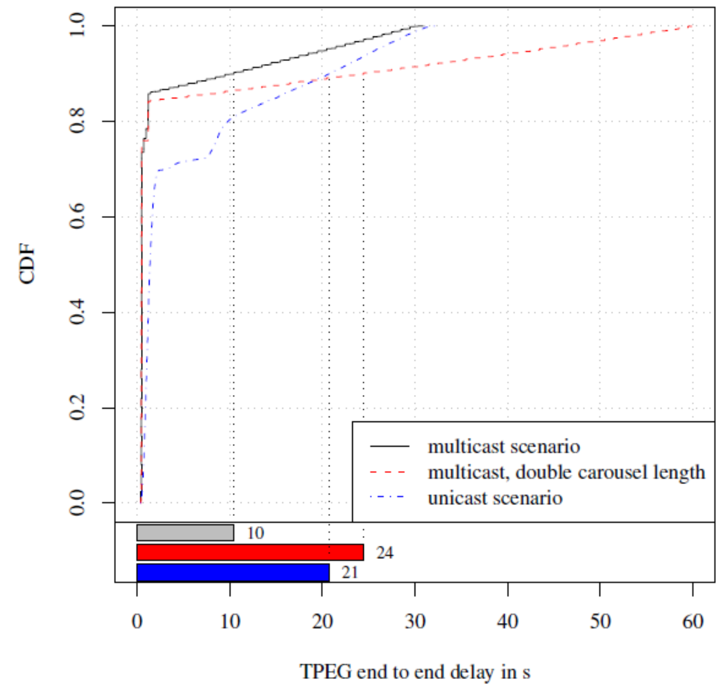
3G / 3.5G – aktiv CoCar

- Hierarchy of (logical) function blocks
  - Reflector
    - blind re-broadcast of received data, copy sent upstream to CoCar Aggregator
    - envisioned to be deployed close to roads, e.g. in base stations
  - Geocast Manager
    - autonomous wide-area dissemination of messages received from upstream
  - CoCar Aggregator
    - central information broker



- Selected performance measures
  - Using MBMS (multicast service), emergency messages can be handled well using the FTAP (~120 ms end-to-end delay)





[1] C. Sommer, A. Schmidt, R. German, W. Koch, and F. Dressler, "**Simulative Evaluation of a UMTS-based Car-to-Infrastructure Traffic Information System**," Proceedings of IEEE Global Telecommunications Conference (GLOBECOM 2008), 3rd IEEE Workshop on Automotive Networking and Applications (AutoNet 2008), New Orleans, LA, December 2008

[2] C. Sommer, A. Schmidt, Y. Chen, R. German, W. Koch, and F. Dressler, "**On the Feasibility of UMTS-based Traffic Information Systems**," Elsevier Ad Hoc Networks, Special Issue on Vehicular Networks, vol. 8 (5), pp. 506-517, July 2010

IEEE 802.11p DSRC

- Definition of PHY and lower layer MAC
  - Roughly WiFi + IEEE 802.11e EDCA + dedicated spectrum
- Network protocol stack
  - IEEE 1609 WAVE – Focus on functionality
  - ETSI ITS-G5 – Focus on congestion control
- First application: Cooperative Awareness (CAM / BSM)
  - Periodic beacons containing
    - Time
    - Speed
    - Position
    - Heading
    - …

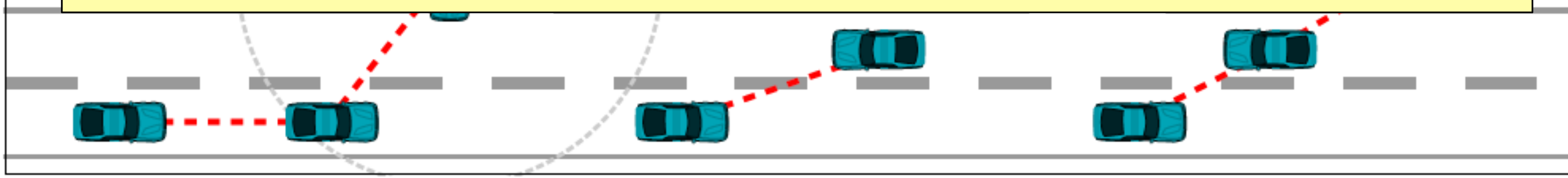
Channel Capacity Matters

Adaptive Traffic Beacon

- ***Beacon interval***: measure of channel quality and message priorities
- ***Infrastructure elements***: RSUs of different capabilities can be included
  - Lightweight SSUs (service support unit)
  - Interconnected RSUs

Challenging questions

- How frequently ***can*** the beacons be sent?
- How frequently ***should*** the beacons be sent?
- ***Which information*** should be included into the beacon?



[1] Christoph Sommer, Ozan K. Tonguz and Falko Dressler, "Traffic Information Systems: Efficient Message Dissemination via Adaptive Beaconing," *IEEE Communications Magazine*, vol. 49 (5), pp. 173-179, May 2011

[2] Christoph Sommer, Ozan K. Tonguz and Falko Dressler, "Adaptive Beaconing for Delay-Sensitive and Congestion-Aware Traffic Information Systems," Proceedings of 2nd IEEE Vehicular Networking Conference (VNC 2010), Jersey City, NJ, December 2010, pp. 1-8

[3] C. Sommer, R. German, and F. Dressler, "Decentralized Traffic Information Systems and Adaptive Rerouting in Urban Scenarios," Proceedings of 29th IEEE Conference on Computer Communications (INFOCOM 2010), Demo Session, San Diego, CA, March 2010

Beacon Interval

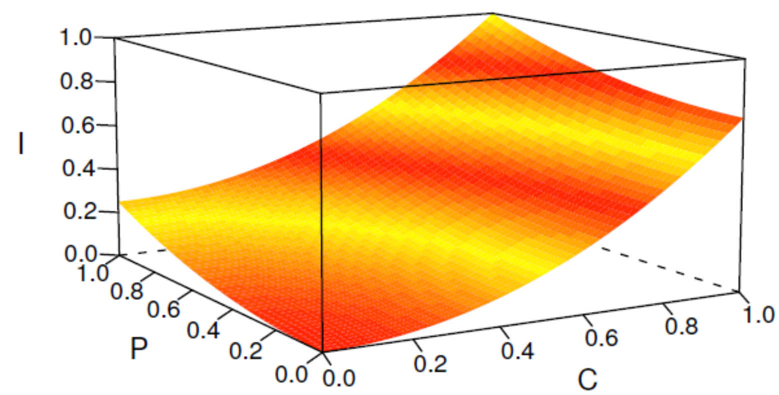
- Interval parameter I

$$I = (1 - w_I) \times P^2 + (w_I \times C^2)$$

C … channel quality

P … message priority

w_I … interval weighting

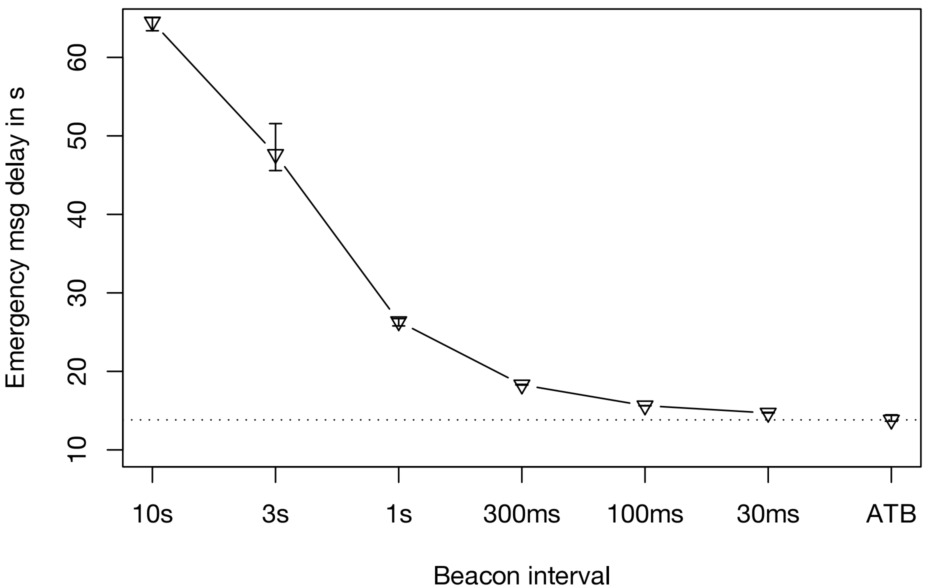


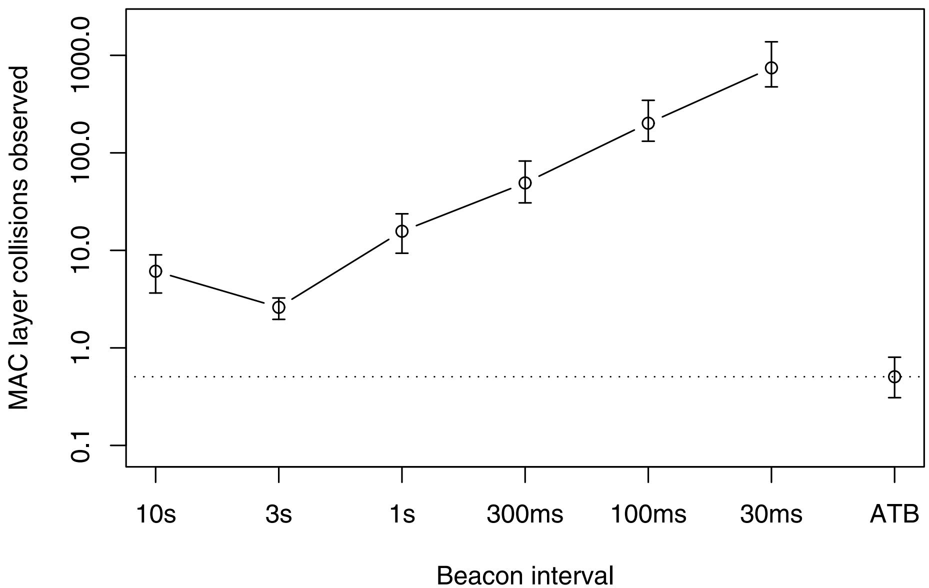
Interval parameter I for an interval weighting $w_I = 0.75$

- <u>Beacon interval ΔI</u>

$$\Delta I = I_{min} + (I_{max} - I_{min}) \times I$$

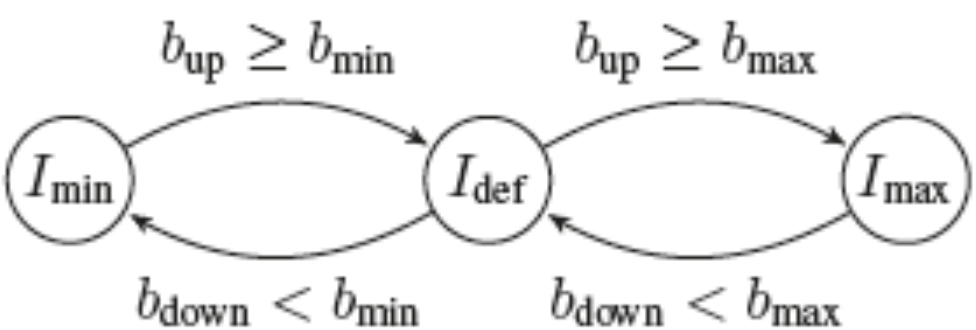
Protocol Performance





Intermediate Conclusion

- These concepts also went into standardization
  - ETSI ITS-G5 developed DCC (Decentralized Congestion Control) with TRC (Transmit Rate Control)
  - b_t is the "busy ratio" of the channel
  - Coarse grained measurement intervals

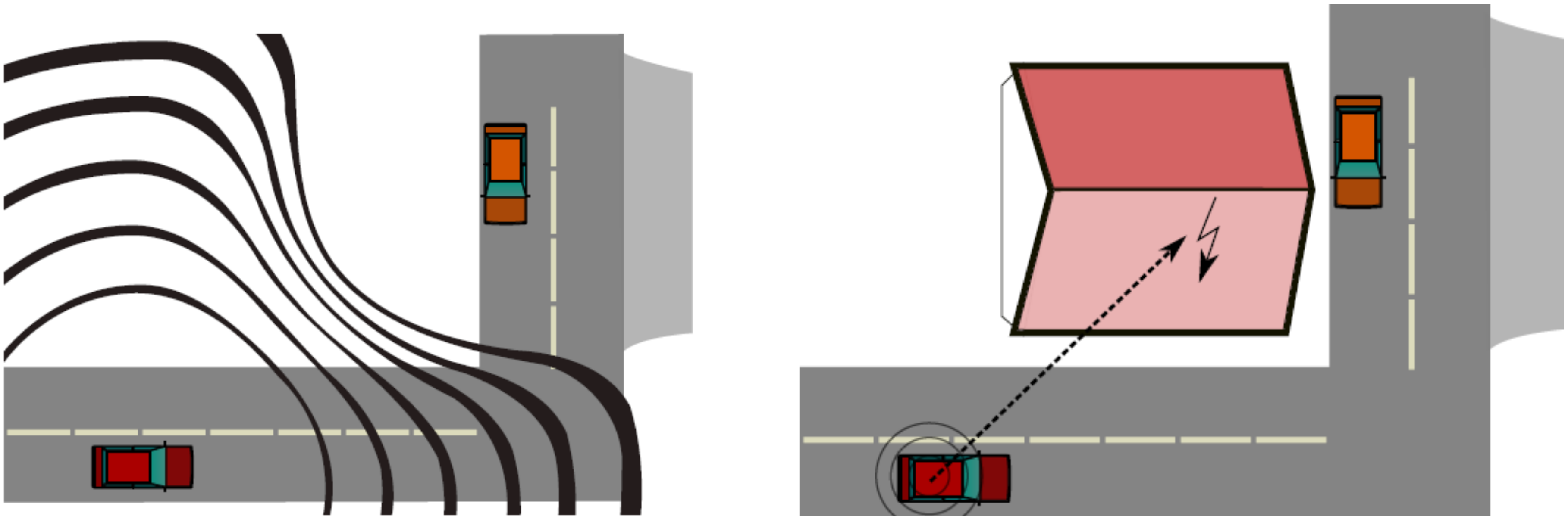


[1] Werner, Marc and Lupoaie, Radu and Subramanian, Sundar and Jose, Jubin, "MAC Layer Performance of ITS G5 - Optimized DCC and Advanced Transmitter Coordination," Proceedings of 4th ETSI TC ITS Workshop, Doha, Qatar, February 2012

Problem Solved?

- Maybe we all overlooked some issues!

- Antenna characteristics
- Radio signal shadowing



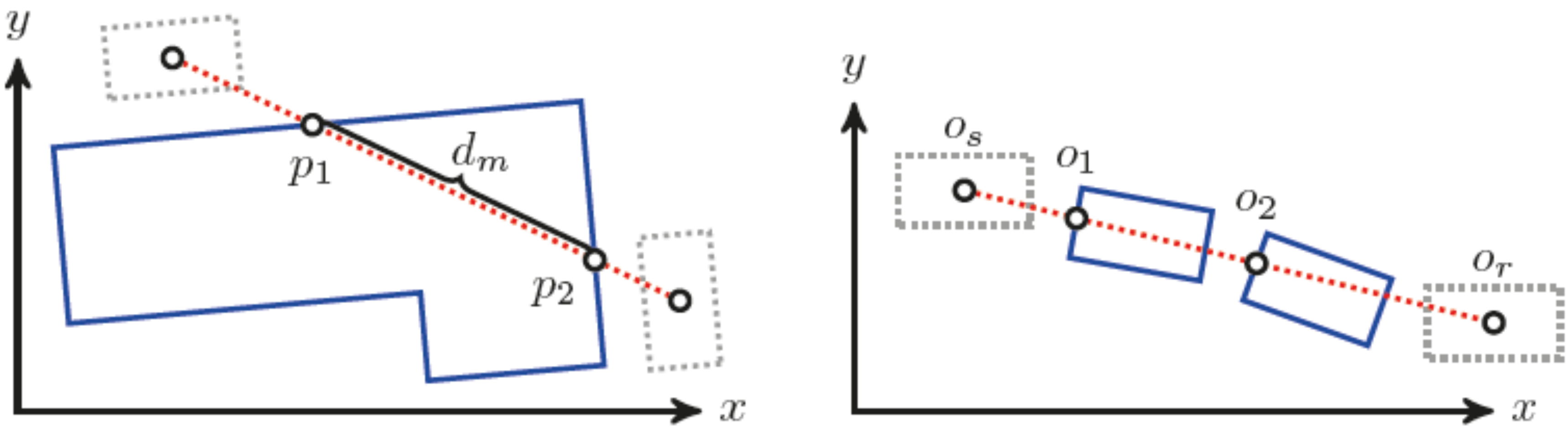
Experimental Validation

[1] Christoph Sommer, David Eckhoff, Reinhard German and Falko Dressler, "A Computationally Inexpensive Empirical Model of IEEE 802.11p Radio Shadowing in Urban Environments," Proceedings of 8th IEEE/IFIP Conference on Wireless On demand Network Systems and Services (WONS 2011), Bardonecchia, Italy, January 2011, pp. 84-90

[2] David Eckhoff, Christoph Sommer, Reinhard German and Falko Dressler, "Cooperative Awareness At Low Vehicle Densities: How Parked Cars Can Help See Through Buildings," Proceedings of IEEE Global Telecommunications Conference (GLOBECOM 2011), Houston, TX, December 2011

Establishment of New Models

- Models allow taking into consideration
  (a) static and
  (b) moving obstacles
- **Research question: What is their impact on beaconing?**



(a) static obstacles (b) moving obstacles

How Busy Can/Should the Channel Be?

- Assuming a payload of l = 512 bit (at 18 Mbit/s), we obtain

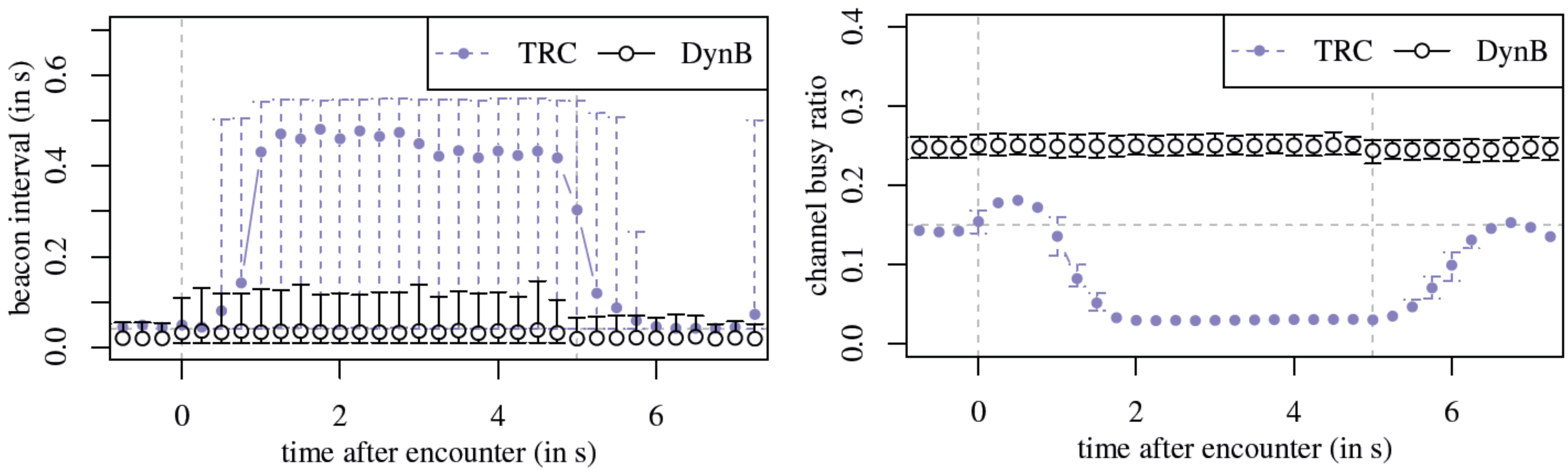
$$t_{busy} = T_{preamble} + T_{signal} + T_{sym} \lceil (16 + l + 6) / N_{DBPS} \rceil = 104\ \mu s$$

Using a minimum AIFS and an average initial backoff counter, we get a maximum b_t

$$b_t = t_{busy} / (t_{busy} + t_{aifs} + t_{idle}) = 0.64$$

DynB – Dynamic Beaconing

- Main idea: continuously observe the load of the wireless channel to calculate the current beacon interval
- Assuming two larger clusters of vehicles meeting spontaneously (e.g., at intersections in suburban or when some big trucks leave the freeway)



[1] Christoph Sommer, Stefan Joerer, Michele Segata, Ozan K. Tonguz, Renato Lo Cigno and Falko Dressler, "How Shadowing Hurts Vehicular Communications and How Dynamic Beaconing Can Help," IEEE Transactions on Mobile Computing, vol. 14 (7), pp. 1411-1421, July 2015.

Conclusions

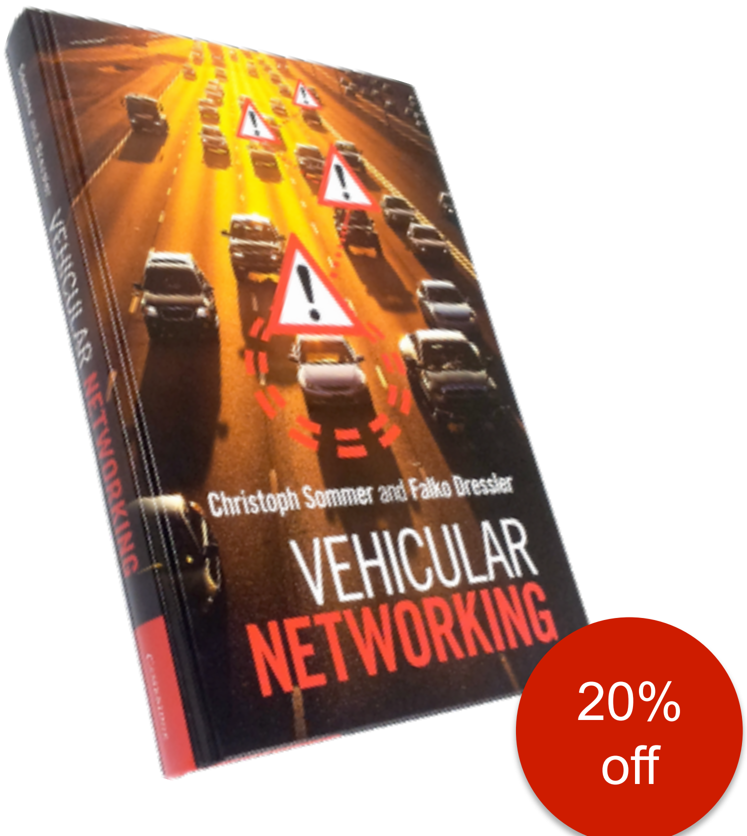
Today, we studied

- Challenges and opportunities of using connected cars concepts
  - Capability to connect everyone and everything
  - Can be seen as a big data storage
  - Help improving our daily road traffic experience and safety
- Not discussed
  - Security issues: Strong debate about privacy vs. security

… as can be seen, there are many open challenges and questions for another decade of interesting research ☺

More Information?

Vehicular Networking
(Cambridge University Press)



IEEE Vehicular Networking Conference (VNC)

- Tokyo, New Jersey, Amsterdam, Seoul, Boston, **Paderborn**

- **Next: Kyoto in Dec 2015**