Mercedes-Benz

Mutual Influence of Concurrent IEEE 802.11 Wireless Local Area Networks in an Automotive Environment

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Table of Contents

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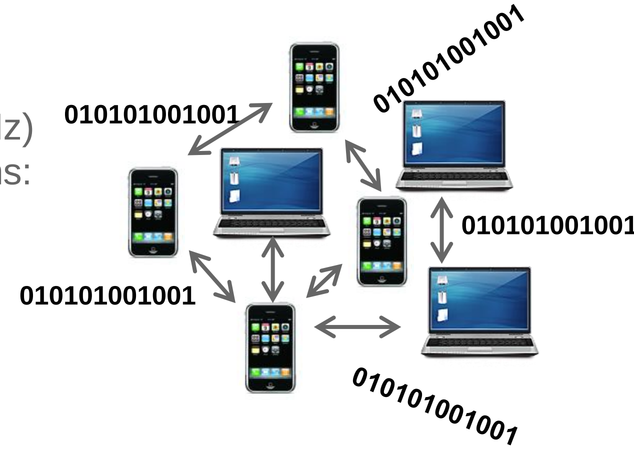
Motivation

- Status: Today in-car WLAN is…
  - broadly introduced in vehicle infotainment systems (at 2.4GHz)
  - mainly used to allow internet services for the passengers
  - limited to a relative small number of vehicles

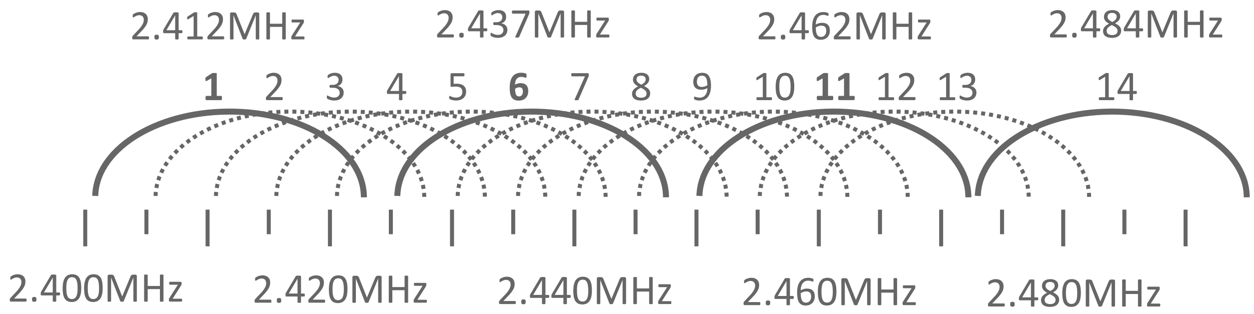


- Future: In-car WLAN will be…
  - a standard for vehicle infotainment systems (at 2.4GHz and 5GHz)
  - used for a large range of high data and time sensitive applications:
    - High-speed Internet access for the passengers
    - streaming applications
      - video from a central media server to several displays
      - MirrorLink
      - VoIP
  - in every car

→ Mutual influence of in-car WLANs will become more and more an issue especially as customer will not tolerate a degradation of an vehicle infotainment system

Frequency Situation

- 2.4GHz WLAN



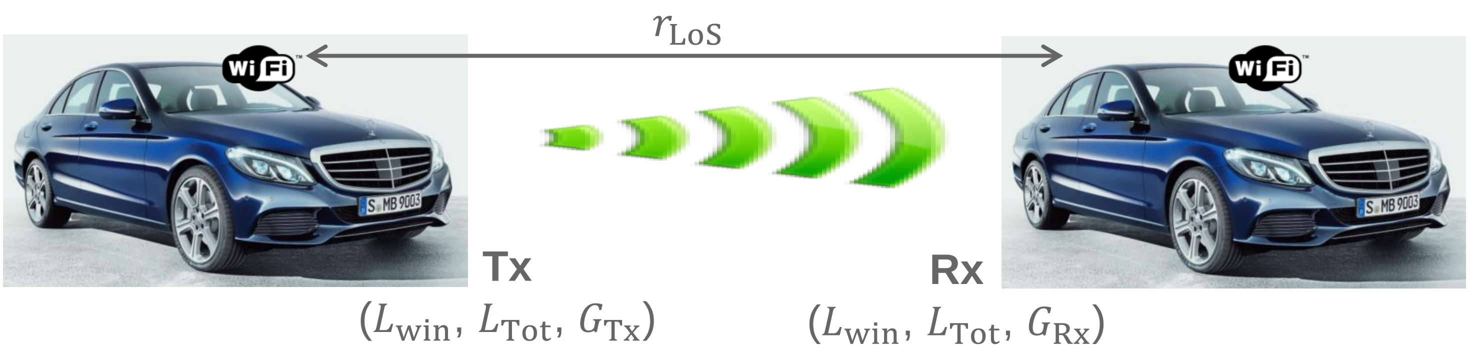
- 5GHz WLAN
  - Situations is not clear and still evolving
  - Up to 25 channels divided into several sub-bands with different regulatory requirements
  - Main requirement is the coexistence with existing systems (e.g. satellite communications, meteorology and military radars)

Collision Avoidance Mechanism

- WLAN IEEE 802.11 uses a Carrier Sense Multiple Access (CSMA) method
  The Clear Channel Assessment (CCA) operation differentiates two cases for 20MHz OFDM:

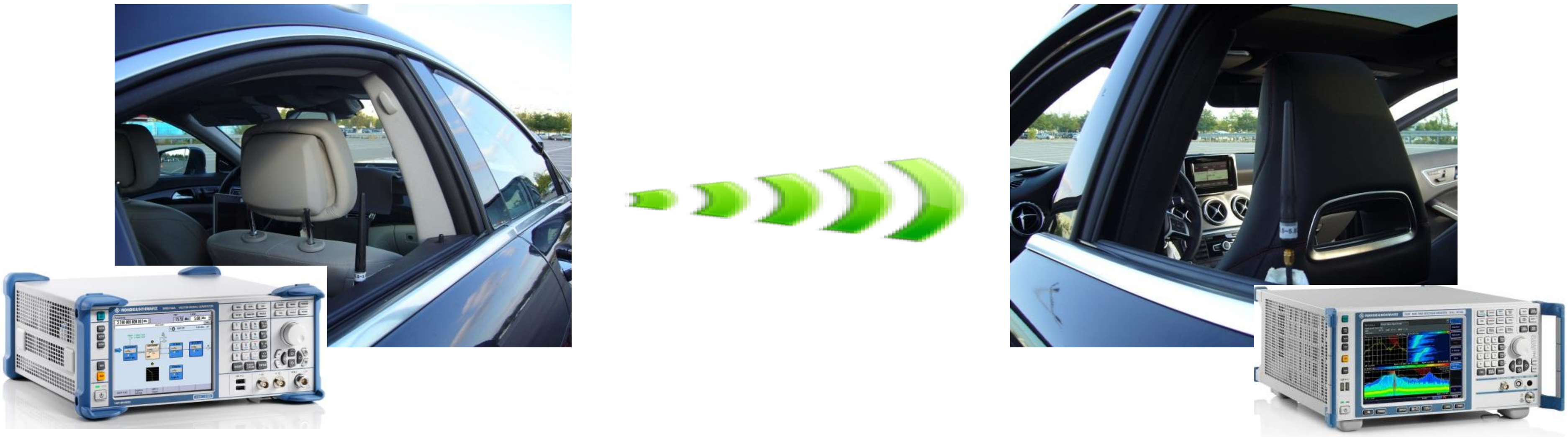
  - Signal detect CA threshold
    If the start of a valid OFDM signal is detected, the channel has to be hold busy for the packet duration for a signal level **at or above -82dBm**
  - Energy detect CA threshold
    If no valid OFDM signal is detected, the channel has to be hold busy for any signal **at or above – 62dBm**

Theoretical Propagation Model

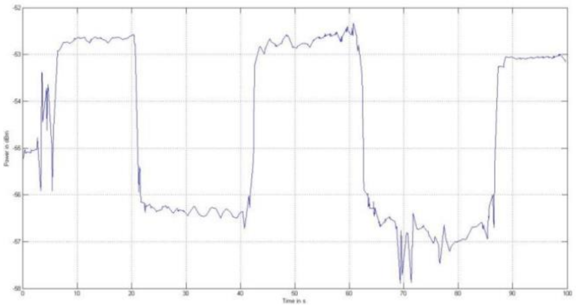


- For a worse case scenario with antenna directly at the car glass, the following assumption can be made:
    - Free space loss as propagation loss: $L_{\text{Free space}}[\mathrm{dB}] = 10\log_{10}\left(\frac{4\pi\cdot r_{\mathrm{LoS}}}{\lambda}\right)^2$
    - Fading loss of car body (approx. 13dB per car)
    - Window loss ?

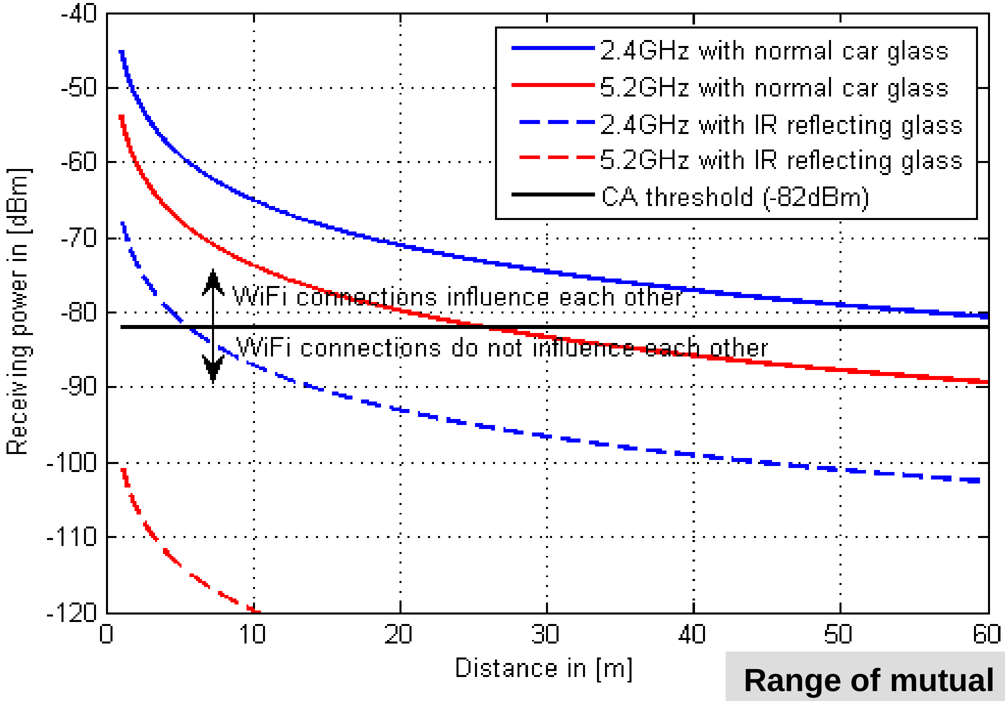
Characterization of car glass



Window Attenuation	2.4GHz	5.2GHz
Non IR reflecting glass	1dB	2dB
IR reflecting glass	12dB	25dB



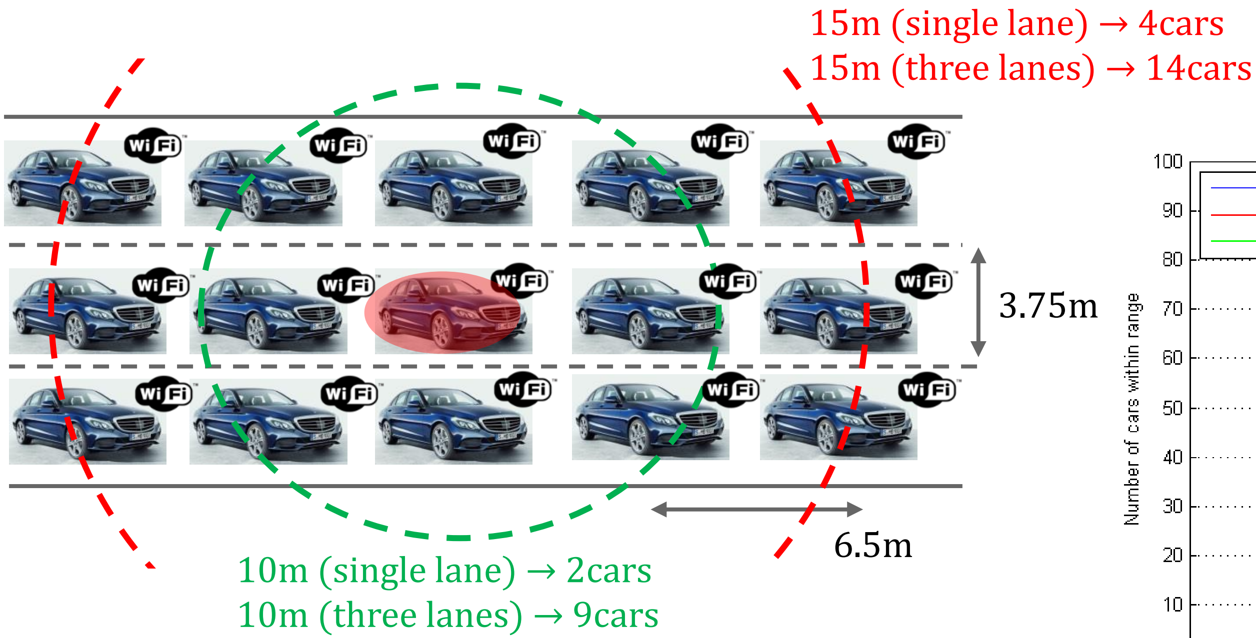
Results of theoretical Calculations

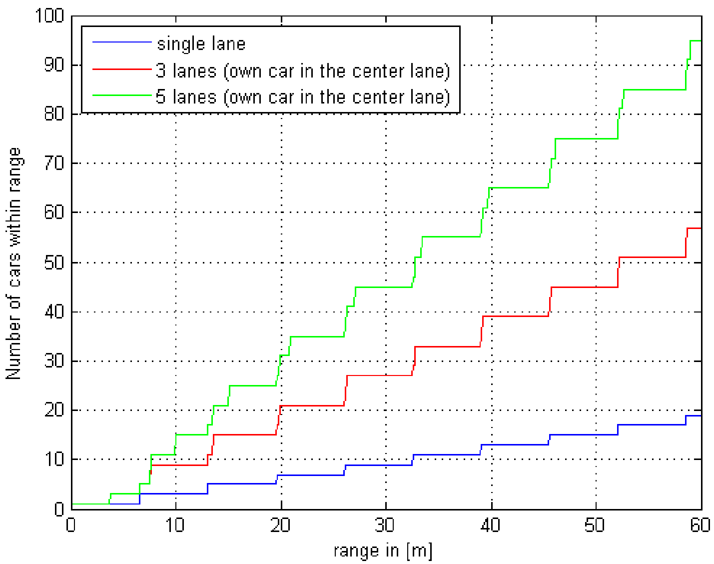


Model assumptions:
Rx,Tx Antenna gain: 3dBi
Tx power: 14dBm
Car loss: ~10dB (approximation from measurements)

Range of mutual influence	2.4GHz	5GHz
Non IR reflecting glass	up to 60m	up to 25m
IR reflecting glass	up to 5.6m	none

Number of Cars within influence range





- Number of potential concurrent WLAN systems strongly increase with number of road lanes and the influence range

WLAN IEEE 802.11n:
Ch. 6 (2.4GHz) / Ch. 36 (5GHz)
20MHz Channel BW / SiSO

Vehicle Measurements

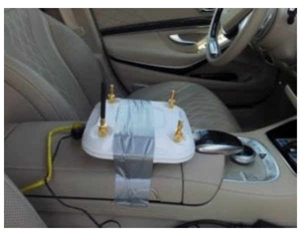
TCP-Throughput Measurement (Iperf)

Cisco AE6000

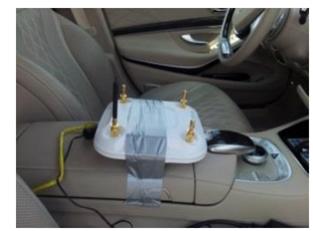
Mutual influence

Cisco AE6000

TCP-Throughput Measurement (iperf)



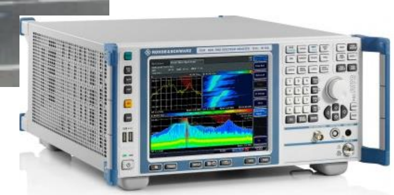
Cisco AP3700



Cisco AP3700

Transmitting a CW-Signal (outside WLAN band)

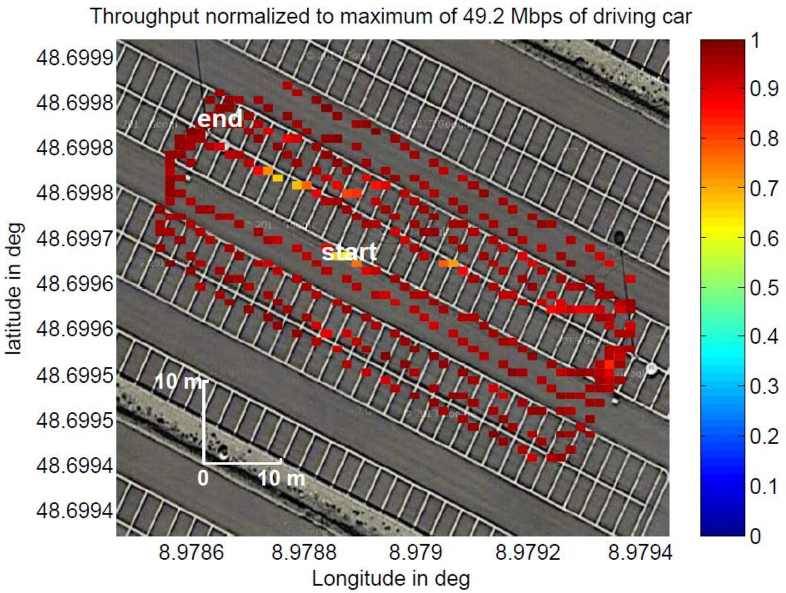
Path loss Measuements



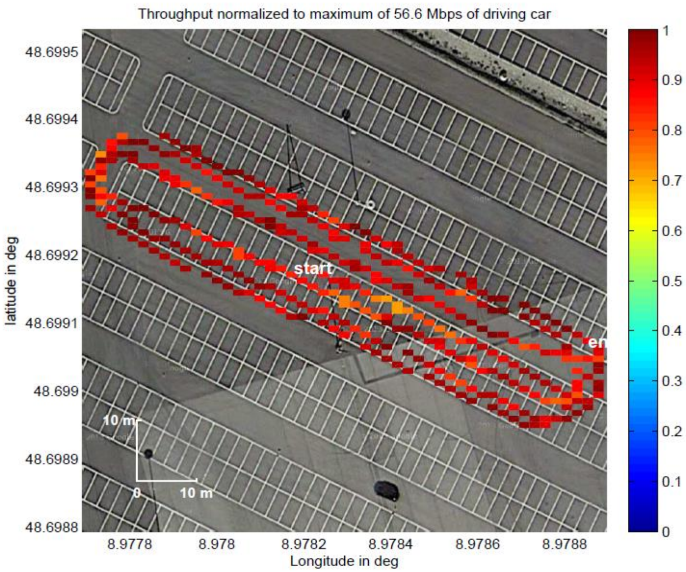
Receiving the CW-Signal

Throughput Measurements (Reference Measurement)

2.4GHz (w/o reflecting car glass)



5GHz (w/o reflecting car glass)

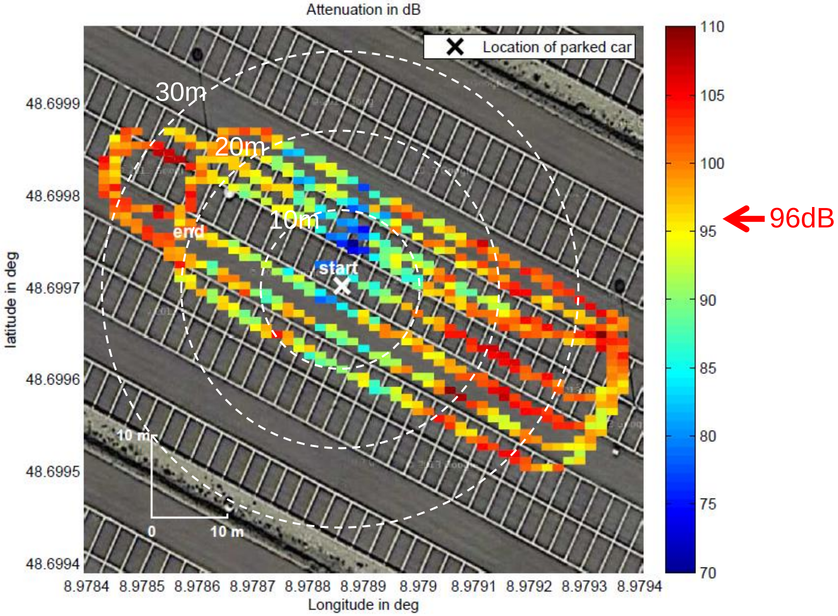


- Constant high data rate without any other WLAN around

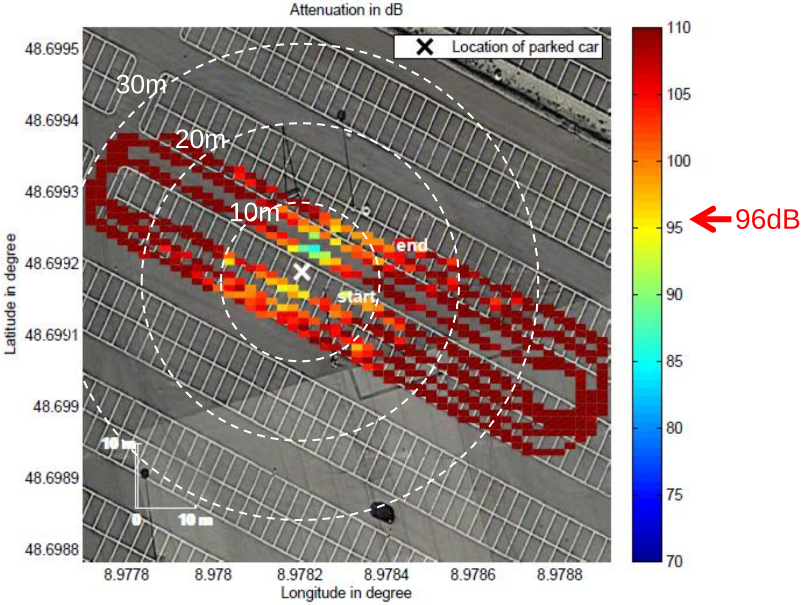
Map data © GeoBasis-DE/BKG (©2009), Google

Path Loss Results

2.4GHz (w/o reflecting car glass)



5GHz (w/o reflecting car glass)



- With a transmission power of +14dBm, a path loss of 96dB is necessary that no Influence will occur

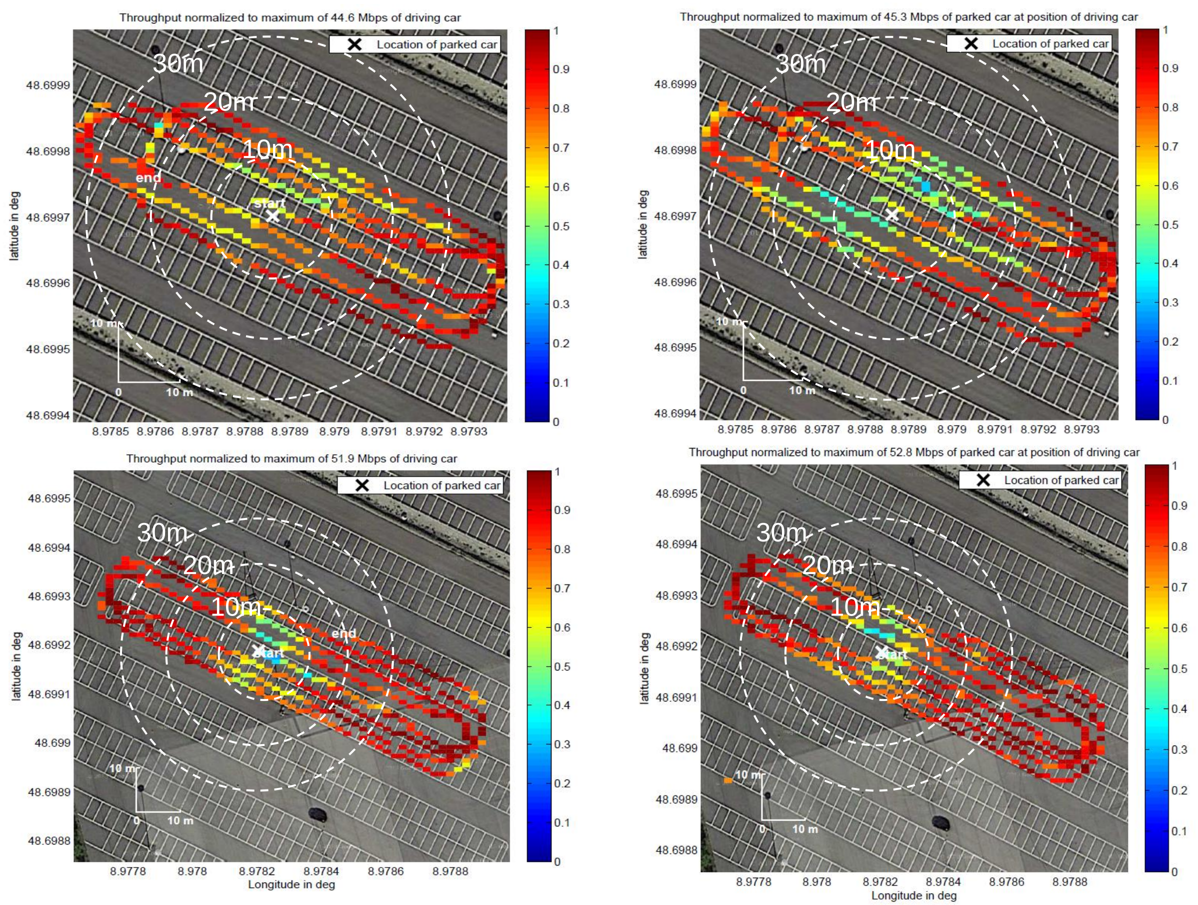
Throughput Measurements Results (w/o IR reflecting car glass)

Normalized throughput of driving car

Normalized throughput of parked car

2.4GHz

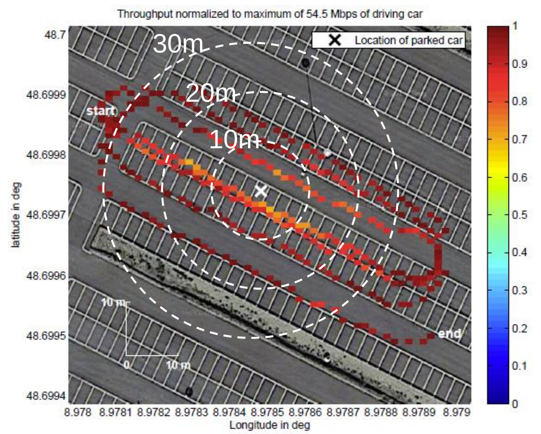
5GHz

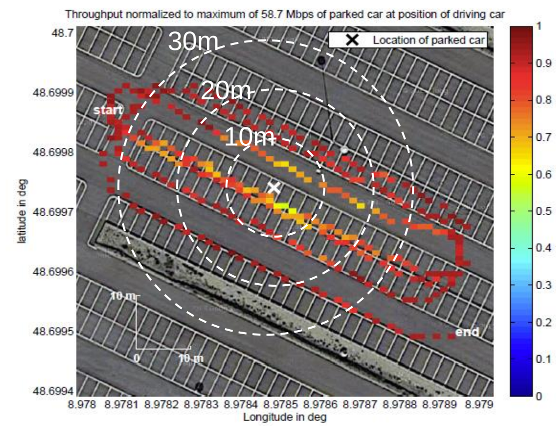


Throughput Measurements Results (w/ IR reflecting car glass)

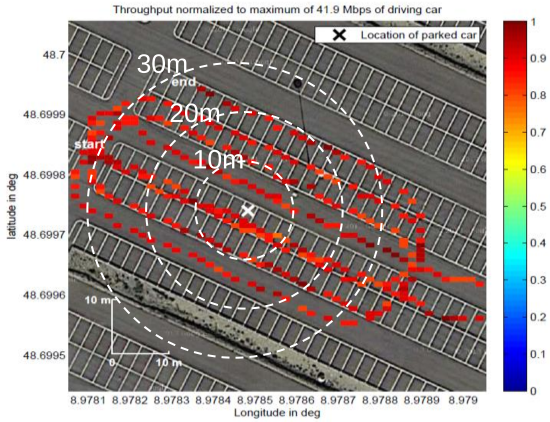
Normalized throughput of driving car | Normalized throughput of parked car

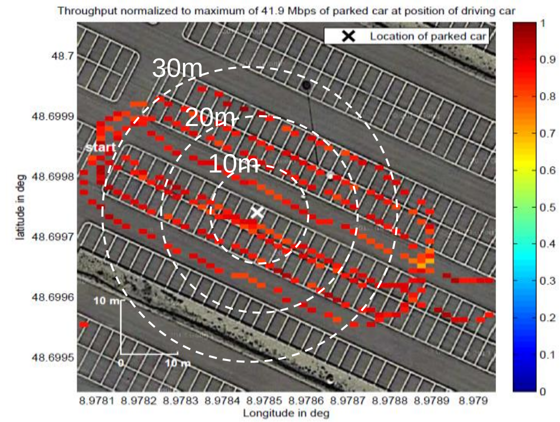
2.4GHz





5GHz





Conclusion

- The mutual influence of two concurrent WLAN connections strongly depends on frequency and the car glass
  - With increasing frequency the mutual influence range decreases
  - IR reflecting car glass strongly reduces the influence range
- With increasing use of in-car WLAN and upcoming time sensitive and data intensive application the mutual influence will become more and more an issue.
- A shift to 5GHz is helpful but does not completely solve the problem (w/o IR reflecting glass)
- Our measurement were performed with a transmission power of 14dBm but FCC already allows up to 30dBm in certain bands
- Ideally the maximum throughput with minimum power principle should be applied (best with transmission power control); but as the CA threshold does not depend on the transmission power a reduction of power is not directly beneficial

Thank you for your attention….

…any questions?