Cars communicating: Automotive Applications of 5G and Millimeter Wave

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Thanks to sponsors including the U.S. Department of Transportation through the Data-Supported Transportation Operations and Planning (D-STOP) Tier 1 University Transportation Center, the Texas Department of Transportation under Project 0-6877 entitled “Communications and Radar- Supported Transportation Operations and Planning (CAR-STOP)”, National Instruments, and Toyota IDC

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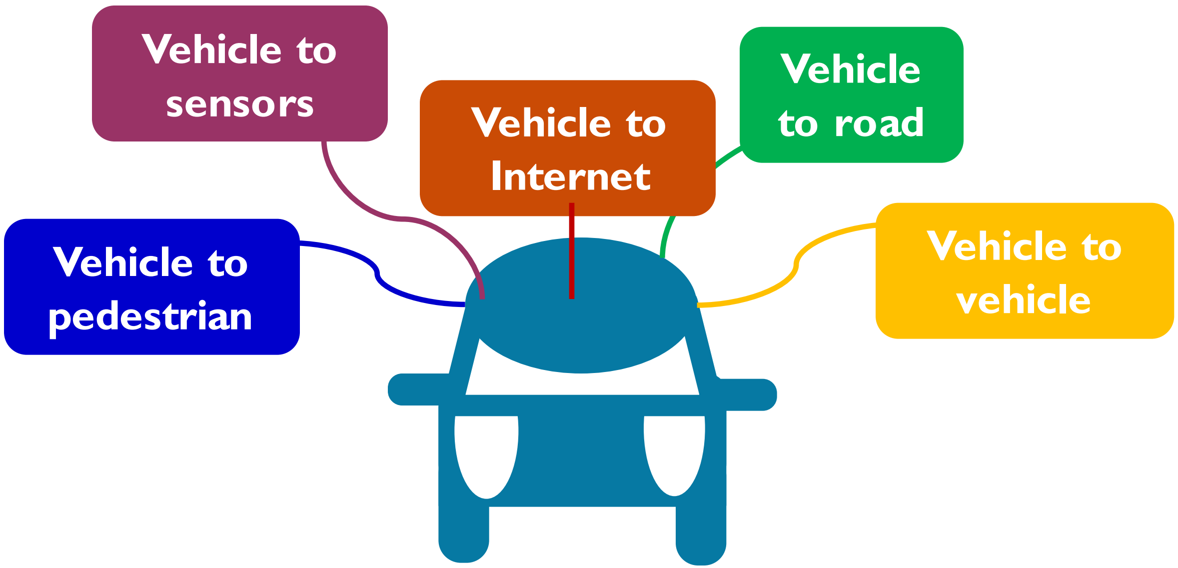
WNCG

The era of connected vehicles



Vehicle to X (V2X) connectivity

- Key element for the new generation Inteligent Transportation Systems
- Governments are pushing for the connected car revolution
  - NHTSA has announced intention to require DSRC in new cars by 2017

N. Lu et al., "Connected vehicles: Solutions and challenges," IEEE Internet of Things Journal, vol. 1, no. 4, pp. 289–299, Aug. 2014.

What is the difference?

VIDEO

CONNECTED

V2X communication capabilities

AUTOMATED

Some safety-critical control functions **without direct driver input**

AUTONOMOUS

Self driving capabilities **without connectivity**

MAY OR NOT MAY BE CONNECTED

MAY OR MAY NOT BE SELF DRIVING

M. Parent, "Automated Vehicles: Autonomous or Connected", IEEE 14th International Conference in Mobile Data Management (MDM), vol. 1, no., pp.2-2, 3-6 June 2013

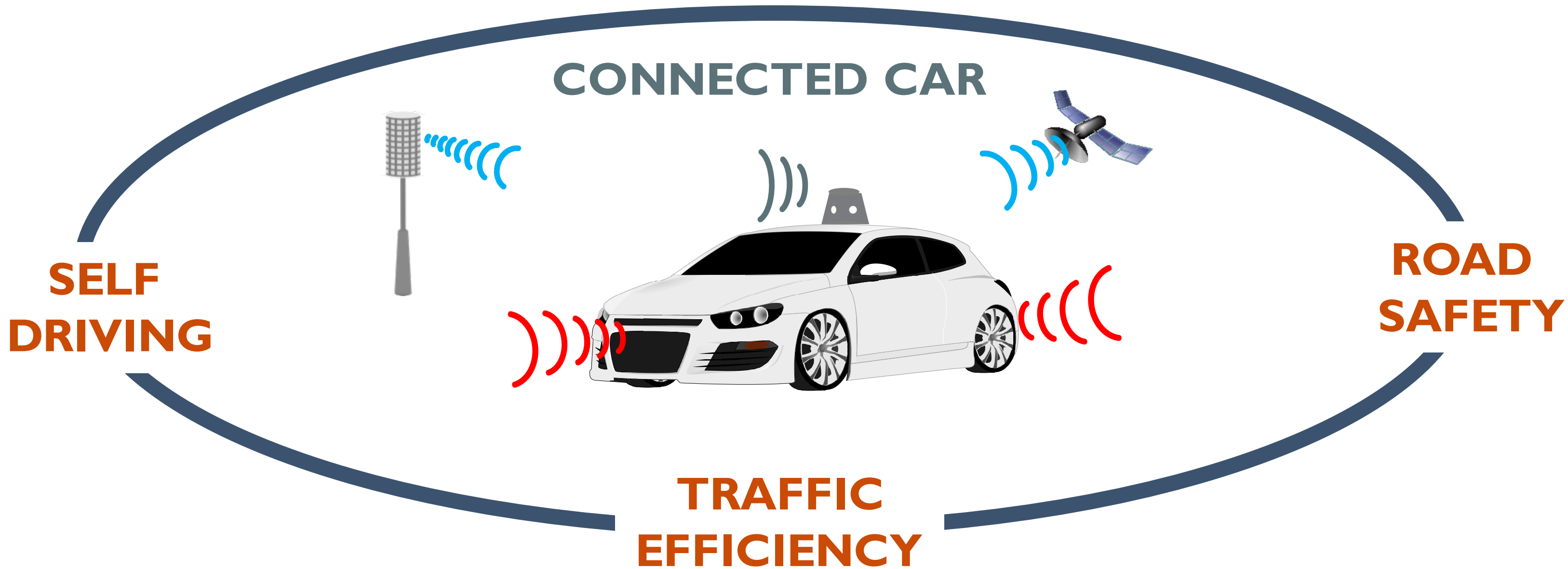
Automated driving

LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
No automation	Function specific automation	Combined function automation	Limited Self-Driving Automation	Fully Self-Driving Automation
Full driver control at all times	Driver can cede control over a primary function (eg. ACC) Responsible for safe operation	Driver can cede control on at least two primaryfunctions Driver responsable for montoring the roadway	Diver can cede full control of all safety-critical functions Driver do not have to monitor the roadway at all times	Driver provides destination Not available for control

Limited/Full self driving cars

NHTSA, "Preliminary Statement of Policy Concerning Automated Vehicles", 2013

Trends in vehicle automation



- To achieve **higher automation levels**, connectivity seems critical
  - Vehicular communications to share sensing data and enhance sensing capability

New challenges for the underlying communication system

*5G-PPP White Paper on Automotive Vertical Sector, October 2015, https://5g-ppp.eu/white-papers/

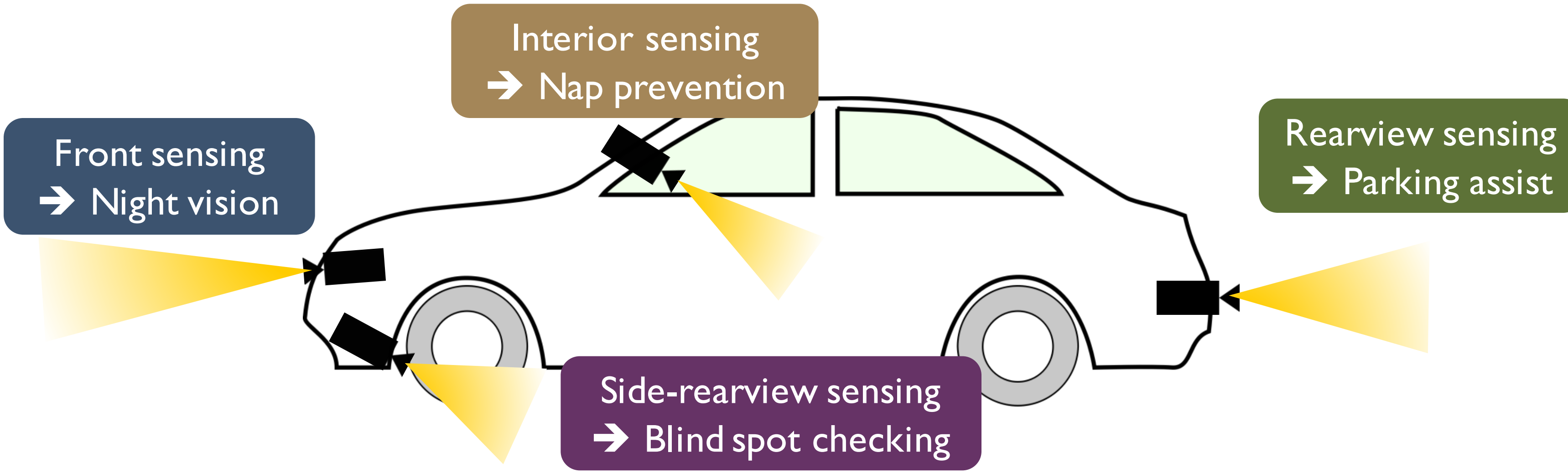
Connected, autonomous and automated

- Main conclusions
  - Connected, automated and autonomous cars are not the same
  - Connected cars may still be driven by humans
  - Automated cars may have limited connectivity

- Claim: Automated cars should exploit connectivity
  - Gives access to a richer set of sensor data
  - Solves key challenges of automated driving in congested urban areas
  - Motivates 5G and the application of millimeter wave

State-of-the-art in vehicular sensing

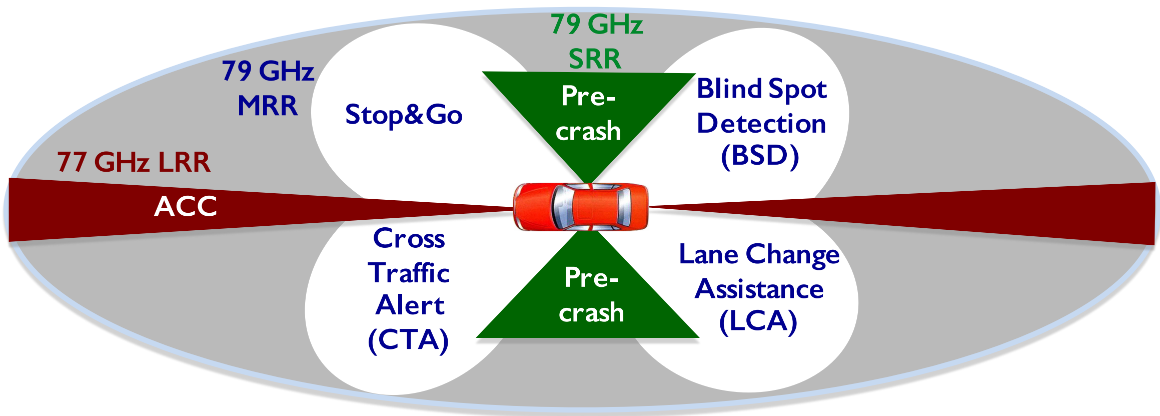
Automotive cameras



- Visual queues for the driver
  - Provides the driver with an additional view, i.e. "virtual mirrors"
- Sensing for driver assist
  - Lane departure, pedestrian detection, smart airbag, speed limit detection, etc.

More cameras will be mandated for safety or integrate for comfort

Automotive radar



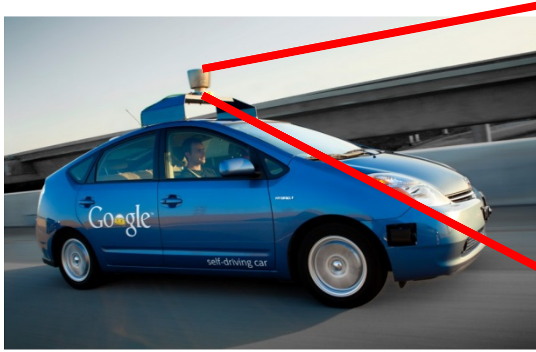
Type	LRR	MRR	SRR
Frequency band (GHz)	76-77	77-81	77-81
Bandwidth (GHz)	0.6	0.6	4
Range (m)	10-250	1-100	0.15-30
Distance accuracy	0.1	0.1	0.02

- Long range radar (LRR) is used for adaptive cruise control (ACC)
- Medium range radar (MRR) supports CTA, LCA, stop & go and BSD
- Short range radar (SRR) is used for parking aid and precrash applications

Radars are already deployed, but not a fool-proof technology

*J. Hasch, E. Topak, R. Schnabel, T. Zwick, R. Weigel, and C. Waldschmidt,"Millimeter-wave technology for automotive radar sensors in the 77 GHz frequency band," IEEE Transactions on Microwave Theory and Techniques, vol. 60, no. 3, pp. 845–860, 2012.
**R. Mende and H. Rohling, "New automotive applications for smart radar systems," in Proc. German Radar Symp., Bonn, Germany, Sep. 3–5, 2002, pp. 35–40.
***R. Lachner, "Development Status of Next generation Automotive Radar in EU", ITS Forum 2009, Tokyo, 2009, [Online]. Available. http://www.itsforum.gr.jp/Public/J3Schedule/ P22/ lachner090226.pdf

Automotive LIDAR



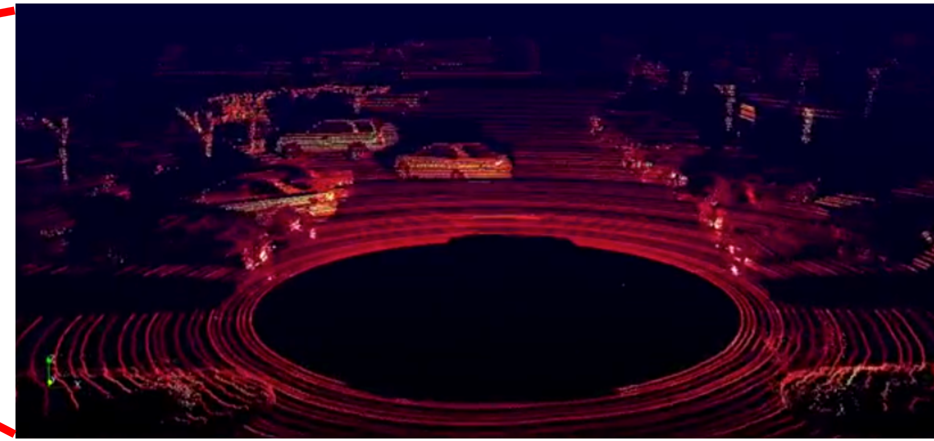


Image by Velodyne's HDL-64E LIDAR

- Radar using laser instead of radio waves
  - Narrow laser beam allows high resolution depth associated range maps
  - Already deployed in autonomous vehicles
- Extremely expensive: $8,000 ~ $80,000 per LIDAR
- Major LIDAR manufacturers: Velodyne, Valeo, Bosch, Google

Powerful sensor technology that generates high data rates

*http://www.extremetech.com/extreme/147940-google-self-driving-cars-in-3-5-years-feds-not-so-fast
**http://articles.sae.org/13899/

Summarizing automotive sensors

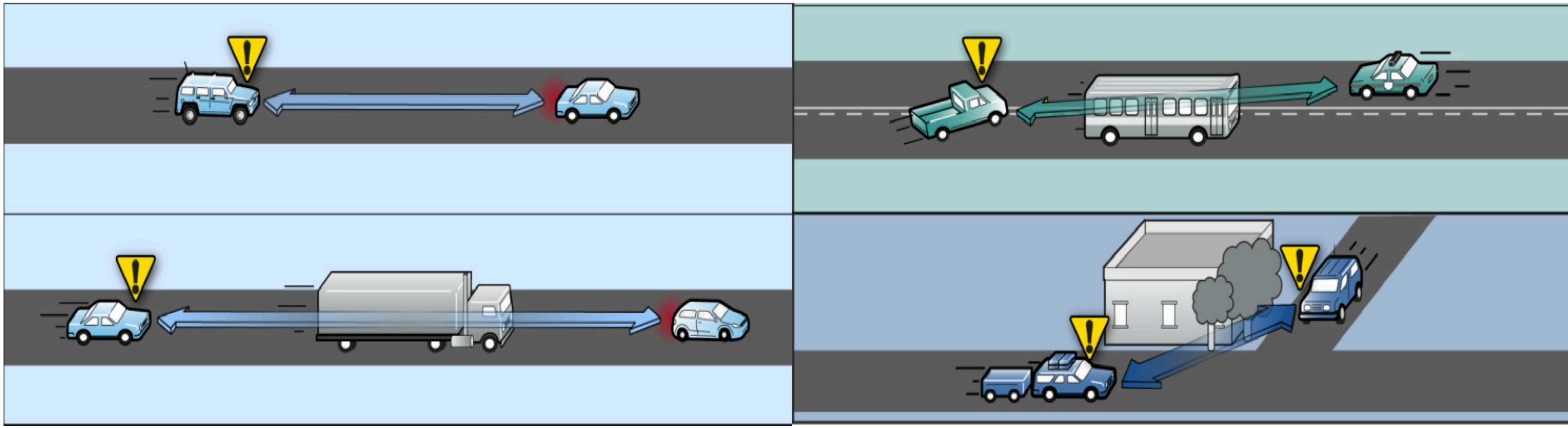
	Purpose	Drawback	Data rate
Radar	Target detection, velocity estimation	Hard to distinguish targets	Less than 1 Mbps
Camera	Virtual mirrors for drivers	Need computer vision techniques	100-700 Mbps for raw images, 10-90 Mbps for compressed images
LIDAR	Target detection and recognition, velocity estimation	High cost	10-100 Mbps

- Is it possible to exchange raw sensor data between vehicles?

Automotve sensors generate a huge amount of data

State-of-the-art in connected cars

DSRC: current technology for vehicular communications

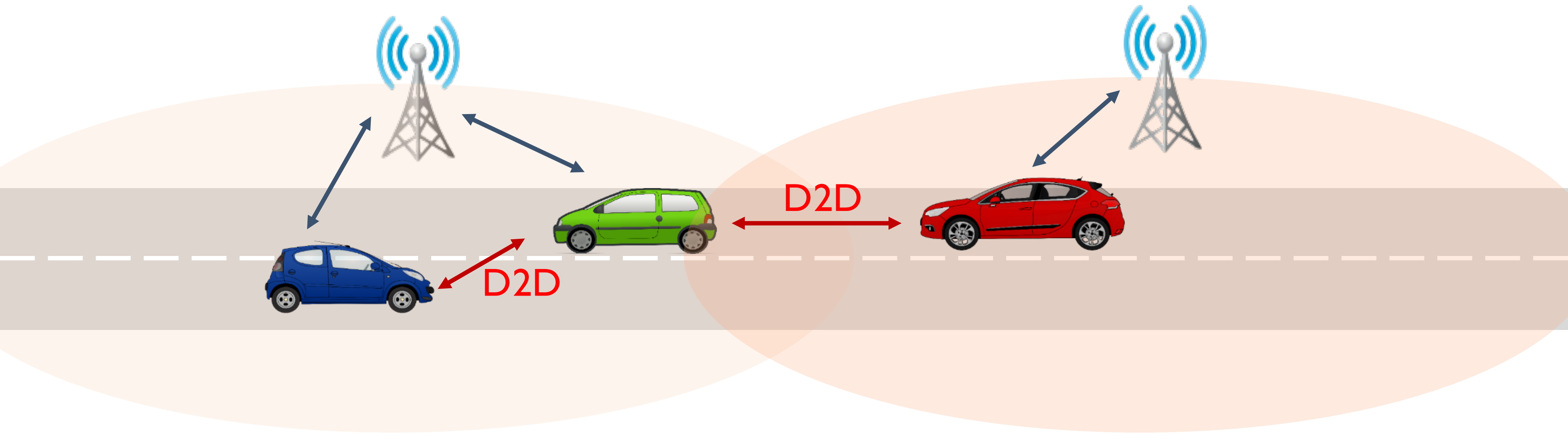


- Forward collision warning, do not pass warning, blind intersection warning, etc.
- Non-safety apps also possible – improve congestion, weather, toll collection
- Based on IEEE 802.11p, IEEE 1609.x, SAE standards
- Supports very low data rates (27 Mbps max, much lower in practice)

DSRC is not designed for the exchange of sensor data

*NHTSA, "Vehicle-to-Vehicle Communications: Readiness of V2V Technology for Application," Aug. 2014
**John B. Kenney, "DSRC: Deployment and Beyond," WINLAB presentation, May 2015.

4G cellular for V2X



- V2V through D2D mode in LTE-A
  - BS helps vehicles discover other nearby vehicles
  - **Cars communicate directly** without routing the traffic through the LTE network
- Higher data rates than DSRC (up to 1Gbps), but
  - Practical **rates limited to several Mbps** by inaccurate CSI

*3GPP. LTE Device to Device Proximity Services; User Equipment (UE) Radio Transmission and Reception. TR 36.877, 3rd Generation Partnership Project (3GPP), 2015.
**M. Rumney et al. LTE and the evolution to 4G wireless: Design and measurement challenges. John Wiley & Sons, 2013

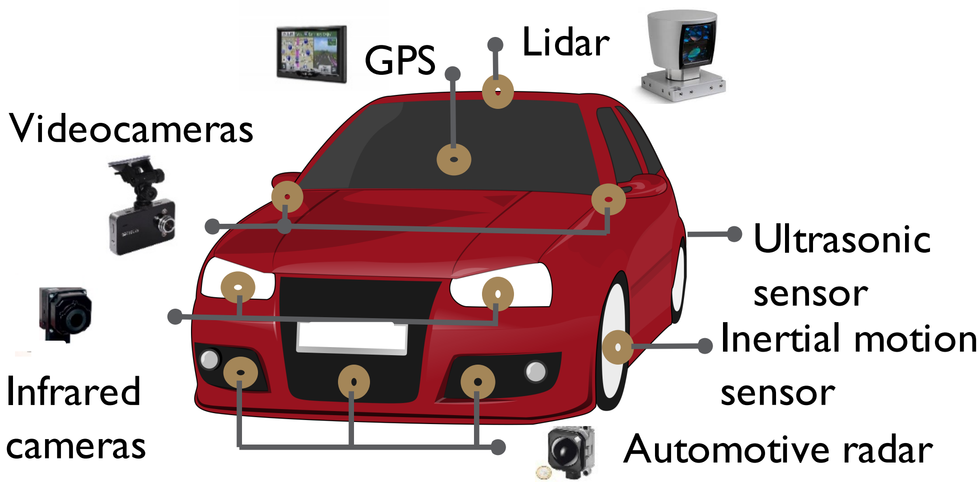
DSRC versus LTE-A for V2X

Features	802.11p	LTE-A
Channel width	10 MHz	Up to 100 MHz
Frequency Band	5.86–5.92 GHz	450 MHz–4.99 GHz
Bit Rate	3–27 Mb/s	Up to 1 Gb/s
Range	Up to 1 km	Up to 30 km
Capacity	Medium	Very High
Coverage	Intermittent	Ubiquitous
Mobility support	Medium	Very high
Market penetration	Low	Potentially high

- LTE-A is interesting because of its wide expected coverage*
- Gbps data rates are not supported

*Giuseppe Araniti et al., "LTE for Vehicular Networking: A Survey", IEEE Commun. Mag., May 2013

Massive data rates from sensors vs DSRC/4G



Each sensor generates data

+

Lots of sensors in a vehicle

=

Massive amount of data per vehicle

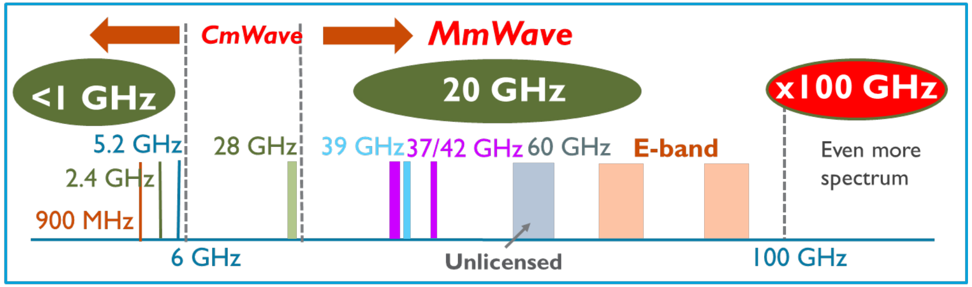
- Connected vehicle is expected to drive 1.5GB monthly mobile data in 2017
  - May be handled with a combination of conventional cellular and DSRC
- Autonomous vehicles can generate up 1 TB per hour of driving
  - 4G and DSRC can not support these data rates

New communication solution is needed for connected cars

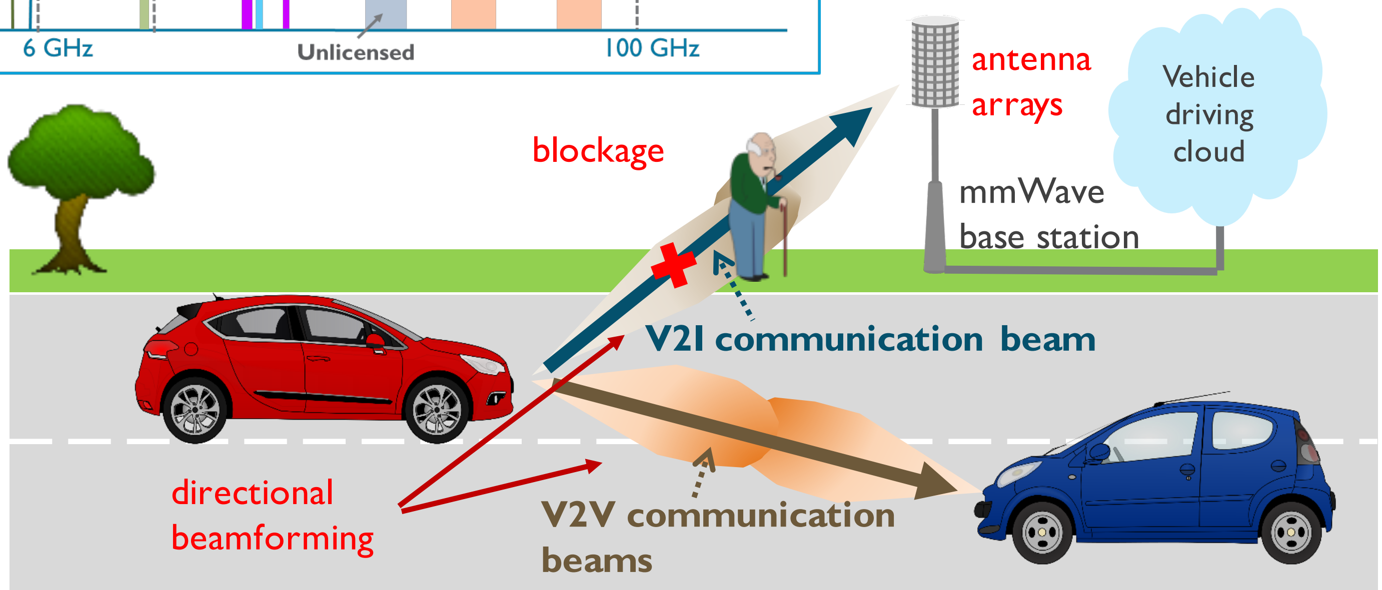
*http://low-powerdesign.com/sleibson/2011/05/01/future-cars-the-word-from-gm-at-idc's-smart-technology-world-conference/
**Cisco, "The Internet of Cars: A Catalyst to Unlock Societal Benefits of Transportation," Mar. 2013
***http://www.sas.com/en_us/insights/articles/big-data/the-internet-of-things-and-connected-cars.html

Millimeter wave and 5G for connected cars

Millimeter wave for connected cars



Spectrum available at mmWave bands

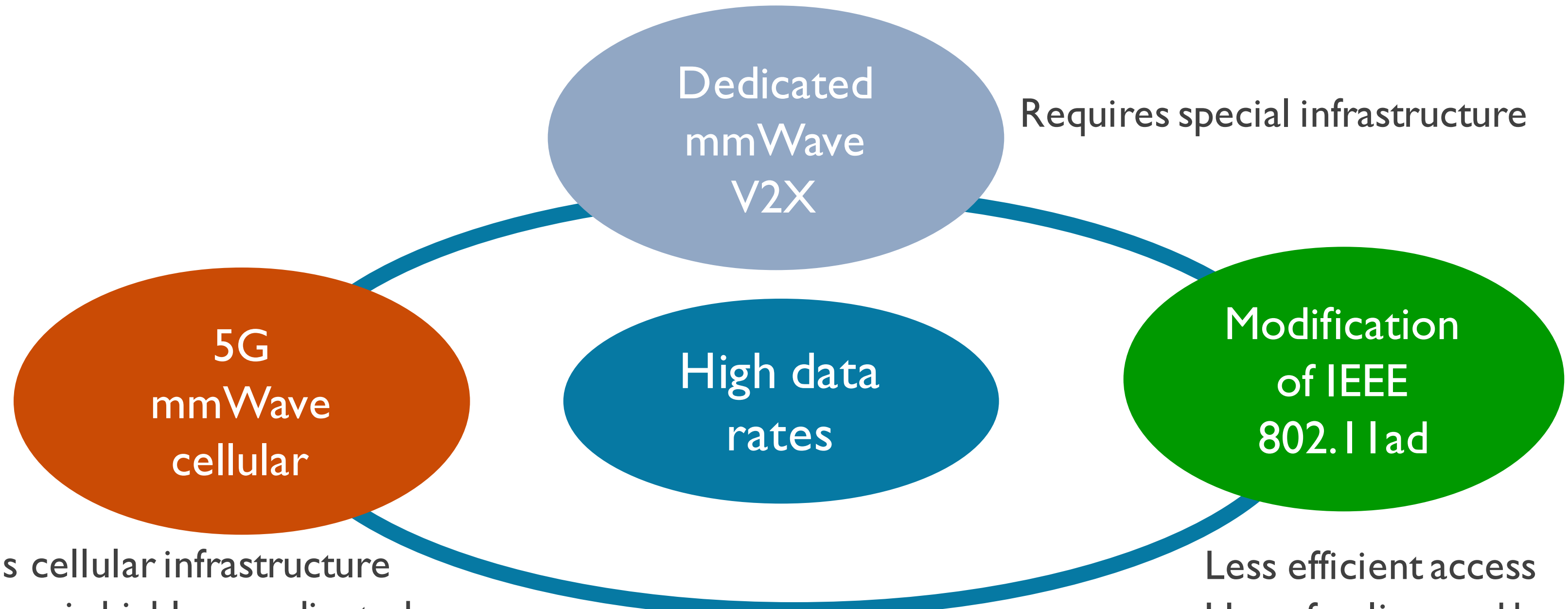


MmWave is the only viable approach for high bandwidth connected vehicles

How will mmWave be realized?

Use new dedicated spectrum

Requires special infrastructure



Uses cellular infrastructure
Access is highly coordinated
Leverages (coming) mmWave spectrum

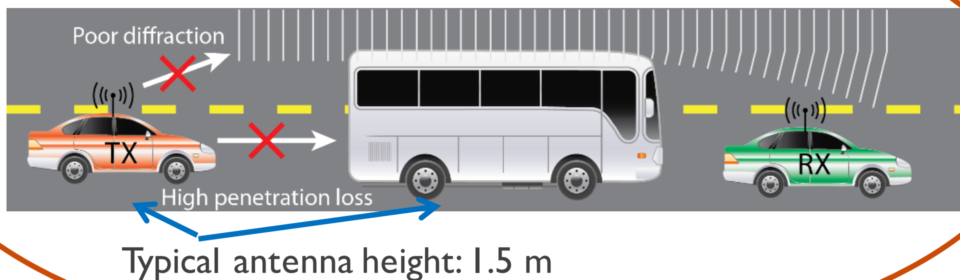
Less efficient access
Use of unlicensed band

5G is promising for mmWave connected cars

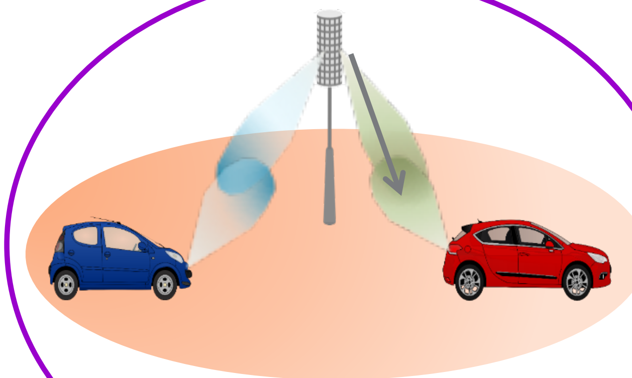
*Federal Communications Commission (FCC), "FCC 15-138," 2015

Challenges for mmWave in V2X

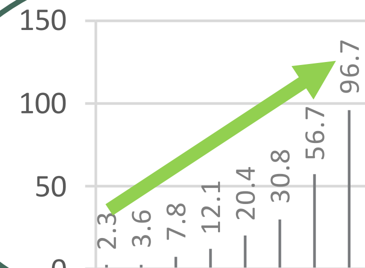
Lack of propagation channel models



More infrastructure



High penetration rate needed for most gains



Communication overhead

Junil Choi, Nuria Gonzáalez-Prelcic, Robert Daniels, Chandra R. Bhat, and Robert W. Heath Jr, "Millimeter Wave Vehicular Communication to Support Massive Sensing", submitted January 2016.

Implications of using mmWave in automotive

Increased sensing capability in the car

Joint automotive radar and communication is possible

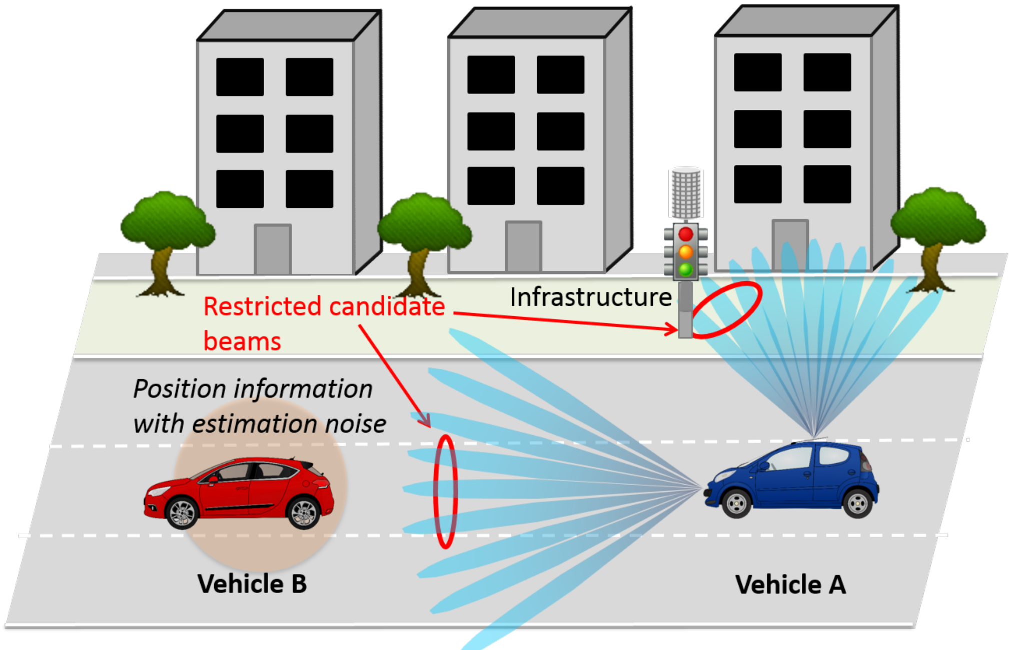
New kinds of infrastructure to be deployed near roads

Sensing technologies can be used to help establishing communications

MmWave V2X at UT

Some examples of current research work

Using position information to reduce beam alignment overhead in mmWave V2X



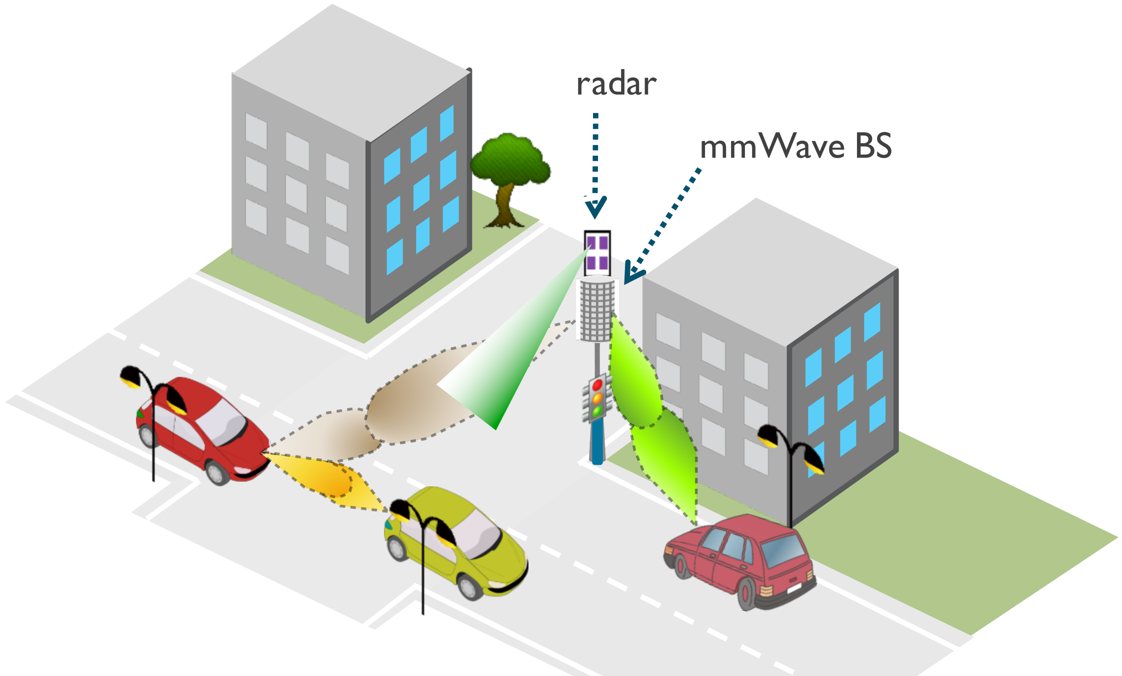
- Each vehicle decides candidate beams from other vehicles' position and size info

DSRC modules or automotive sensors can be used to reduce overhead

Junil Choi, Nuria Gonzáalez-Prelcic, Robert Daniels, Chandra R. Bhat, and Robert W. Heath Jr, "Millimeter Wave Vehicular Communication to Support Massive Sensing", submitted January 2016.

Adding radar to the infrastructure

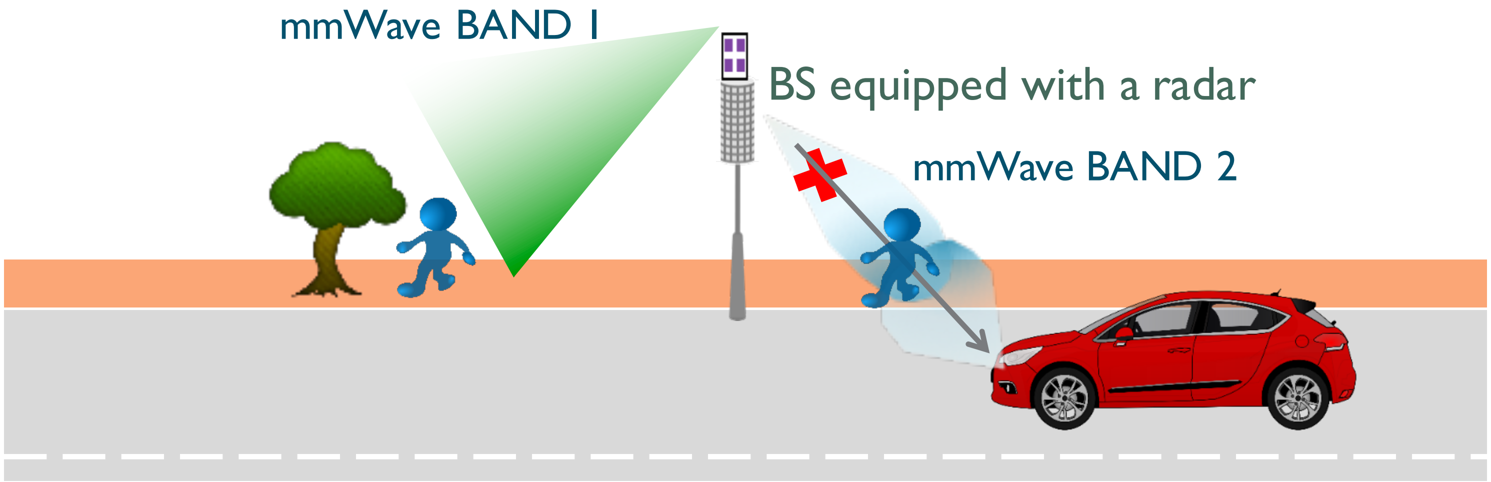
popsci.com



- A BS with a radar can capture information of the scattering environment
- Used to design multiuser beamforming, support remote car traffic control

Sensing at the infrastructure can help in establishing the communication links

Predicting blockage from out-of band sensing

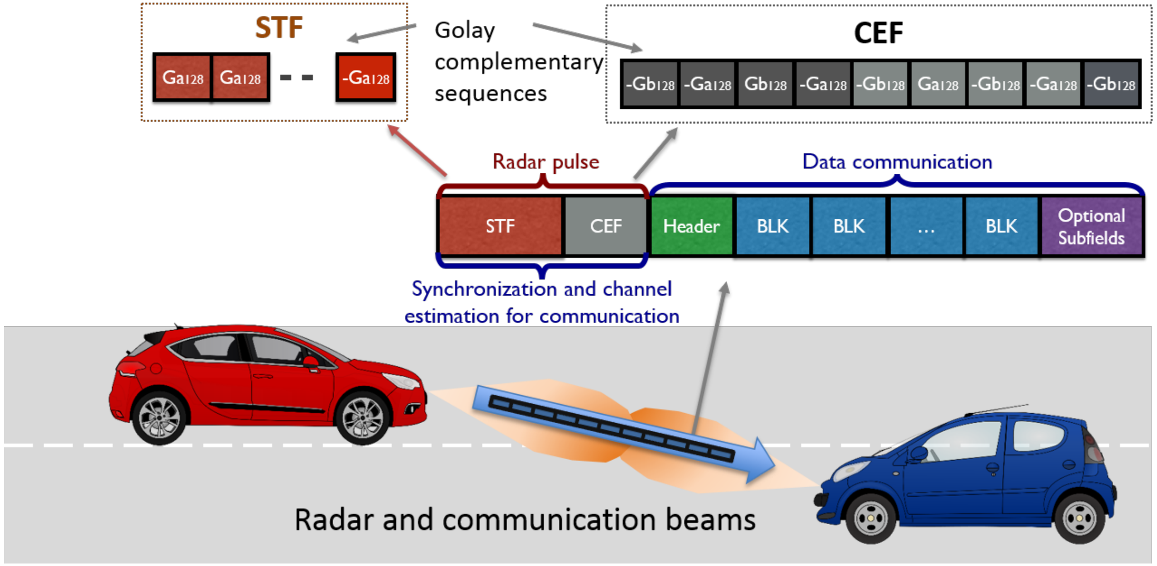


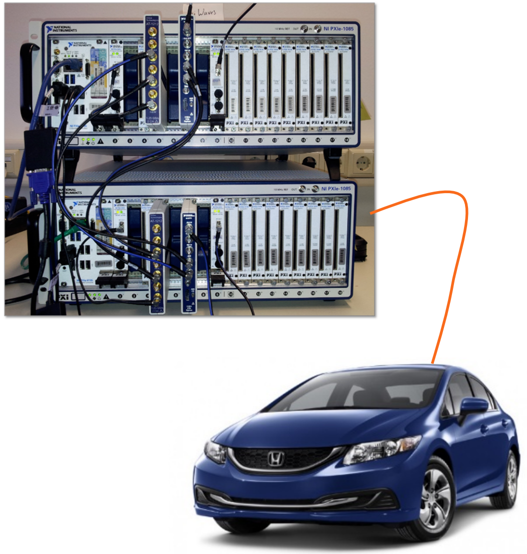
- Radar can detect potential obstacles and their associated mobility
- Machine learning can classify particular radar responses as blockages

Sensing & learning are symbiotic technologies

Junil Choi, Nuria Gonzáalez-Prelcic, Robert Daniels, Chandra R. Bhat, and Robert W. Heath Jr, "Millimeter Wave Vehicular Communication to Support Massive Sensing", to be submitted December 2015

Joint radar and communications based on 802.11ad





- IEEE 802.11ad mmWave waveform works well for radar
  - Special structure of preamble enables good ranging performance
  - Leverages existing WLAN receiver algorithms for radar parameter estimation
- Target vehicle information from 11ad radar can be directly used for communication

Joint system provides safety capabilities at lower cost

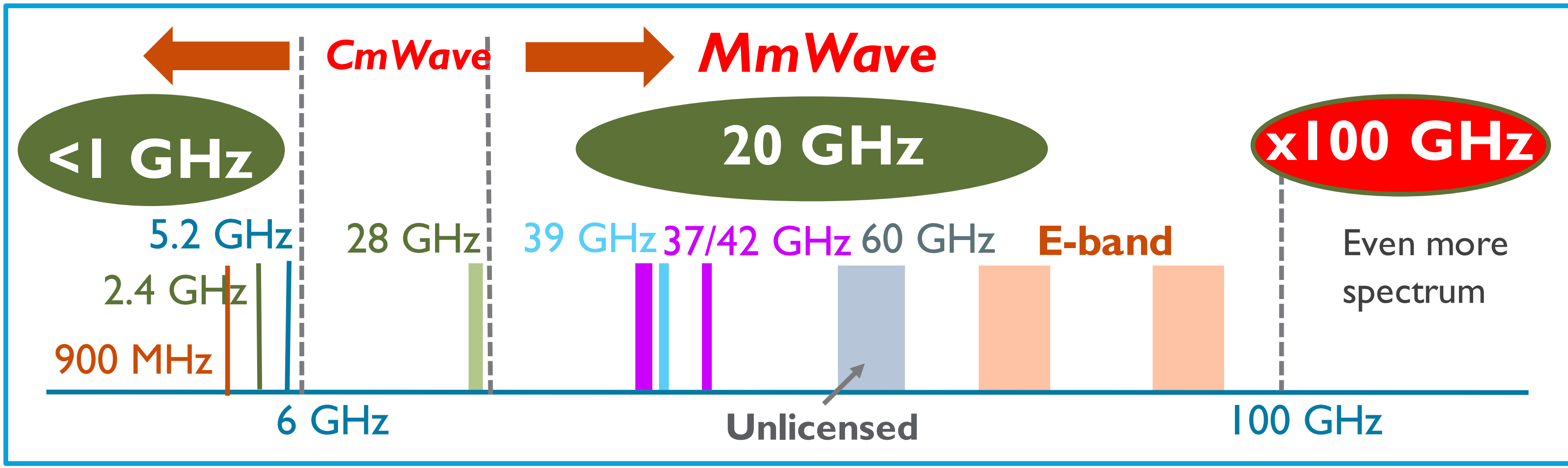
*P. Kumari, N. González Prelcic and R. W. Heath, Jr, ``Investigating the IEEE 802.11ad Standard for Millimeter Wave Automotive Radar," *IEEE VTC-Fall*, 2015.

Conclusions

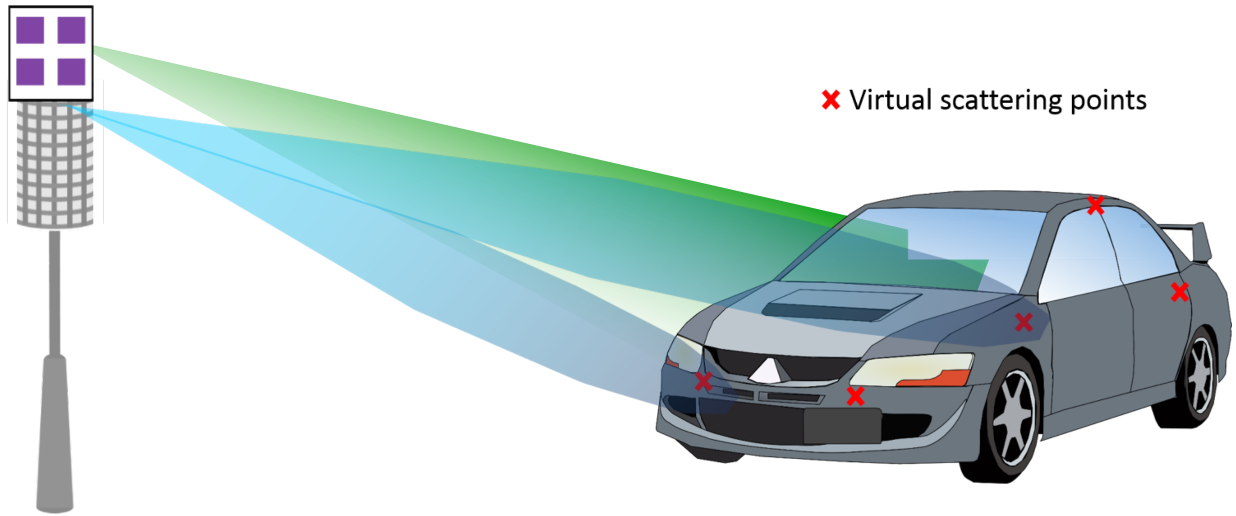
Why mmWave V2X?
- Provides the only high data rate solution for sensor exchange
- Already used in other automotive technologies

Why 5G?
- Already exploring a mmWave waveform
- Will operate in dedicated spectrum with heavy management
- Will support lower frequencies as a backup

MmWave V2X MmWave introduce new challenges
- Lack of propagation channel models
- New signal processing techniques need to be developed
- Infrastructure and penetration rate


CmWave
MmWave
<1 GHz
20 GHz
x100 GHz
5.2 GHz
2.4 GHz
900 MHz
28 GHz
39 GHz
37/42 GHz
60 GHz
E-band
Even more spectrum
6 GHz
Unlicensed
100 GHz

Antenna diversity to overcome blockage in V2I



- A BS with a radar is assumed at the infrastructure side
  - Antennas are assumed to be placed at the virtual scattering points in the car
  - Radar info is used to design a multi-beam pattern to track several antennas
- High mobility is considered and the positions of the antennas are predicted

Sensing at the infrastructure can help to manage blockage

* N. González-Prelcic, R. Méndez-Rial and R. W. Heath Jr., "Radar-aided multibeam directional beamforming for mmWave vehicle to infrastructure communications", in preparation.