Vehicle-to-X communication for 5G - a killer application of millimeter wave

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See vehicular initiative
http://www.utsaves.org

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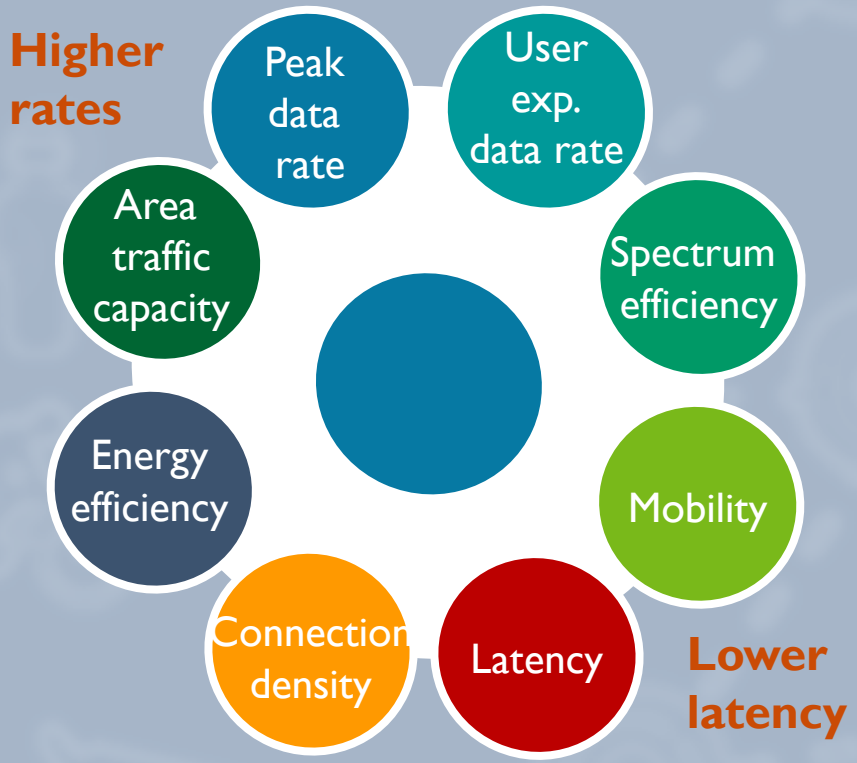
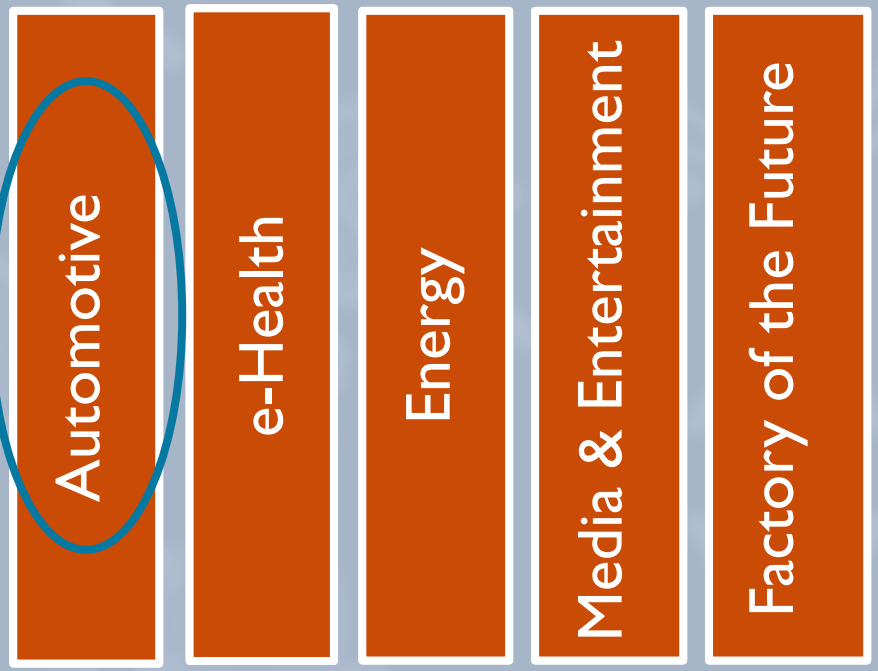
Fifth generation (5G) cellular communication

Multidimensional objectives*



New industry verticals**



Automotive industry is provinding key requirements for the development of 5G

* Recommendation ITU-R M.2083-0, "IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond," September 2015

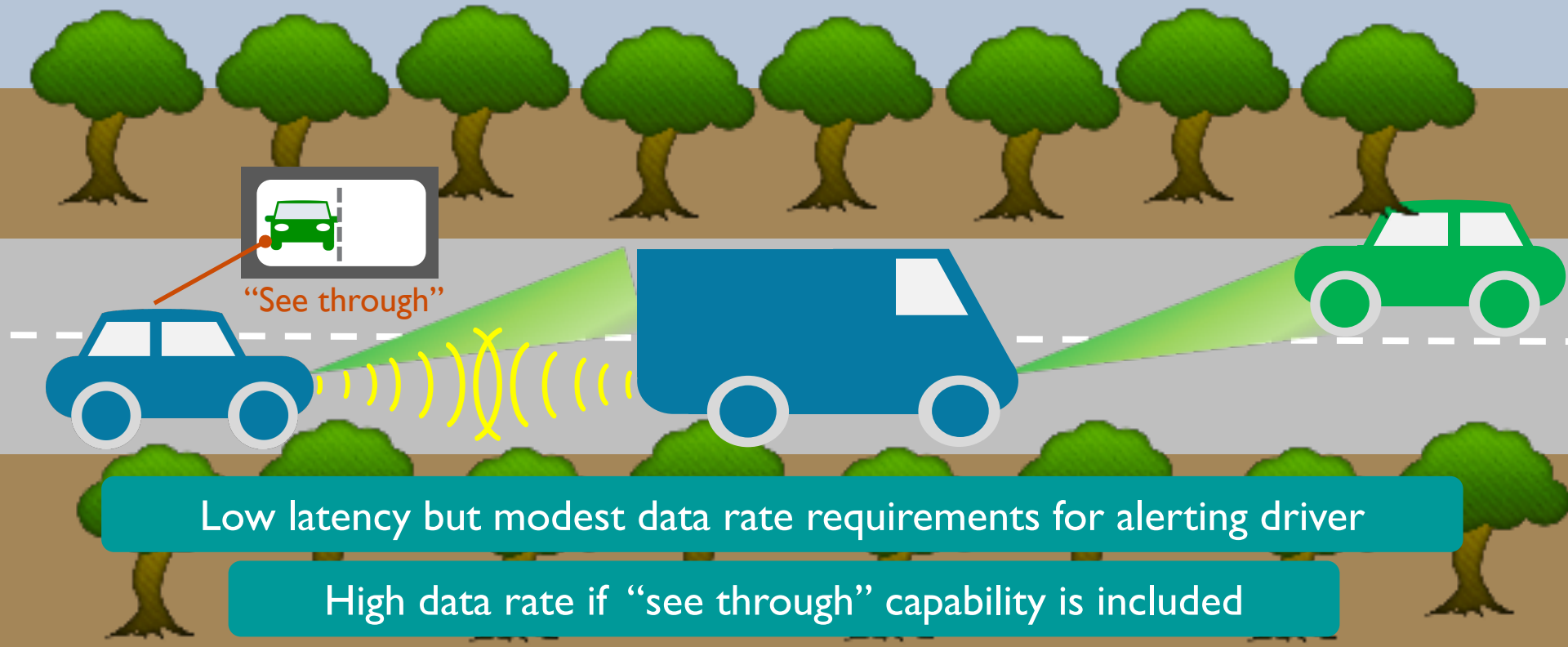
** "5G empowering vertical industries," 5GPPP White Paper, Feb. 2016

V2X for advanced driver assistance systems

Sensors require line-of-sight

Communication can expand sensing range

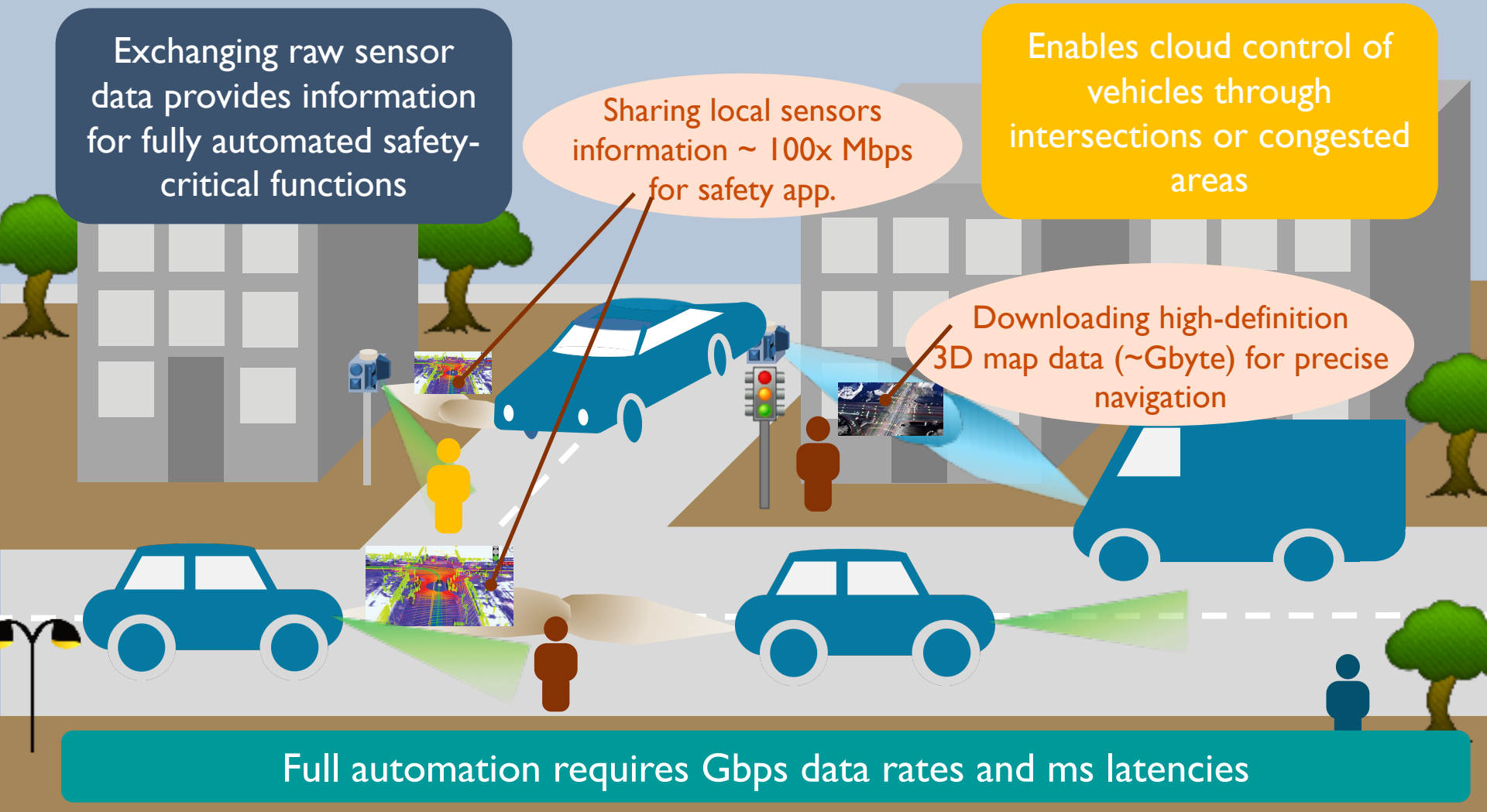
Both communication and automotive sensors are useful for collision avoidance



Low latency but modest data rate requirements for alerting driver

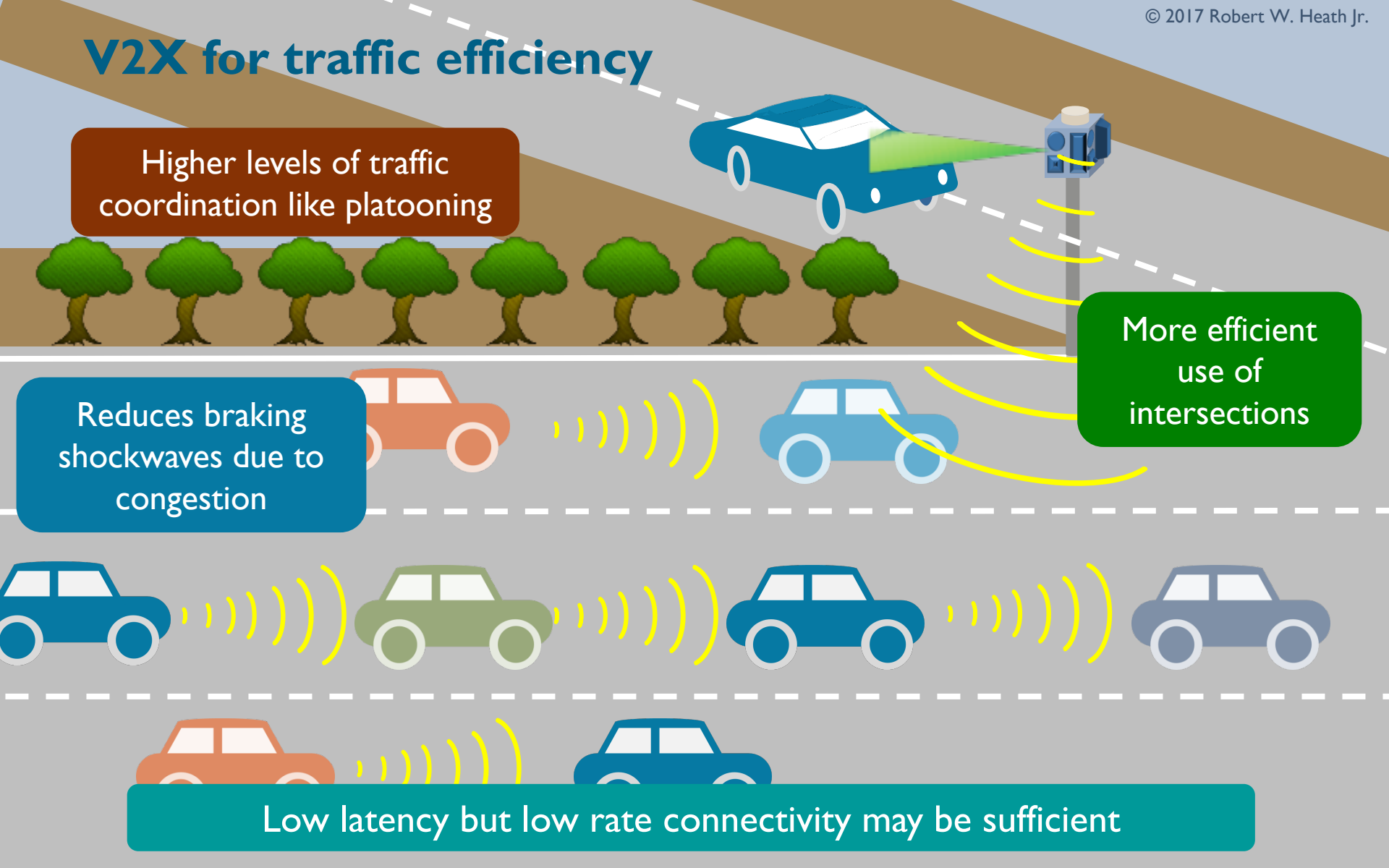
High data rate if "see through" capability is included

V2X for fully automated driving



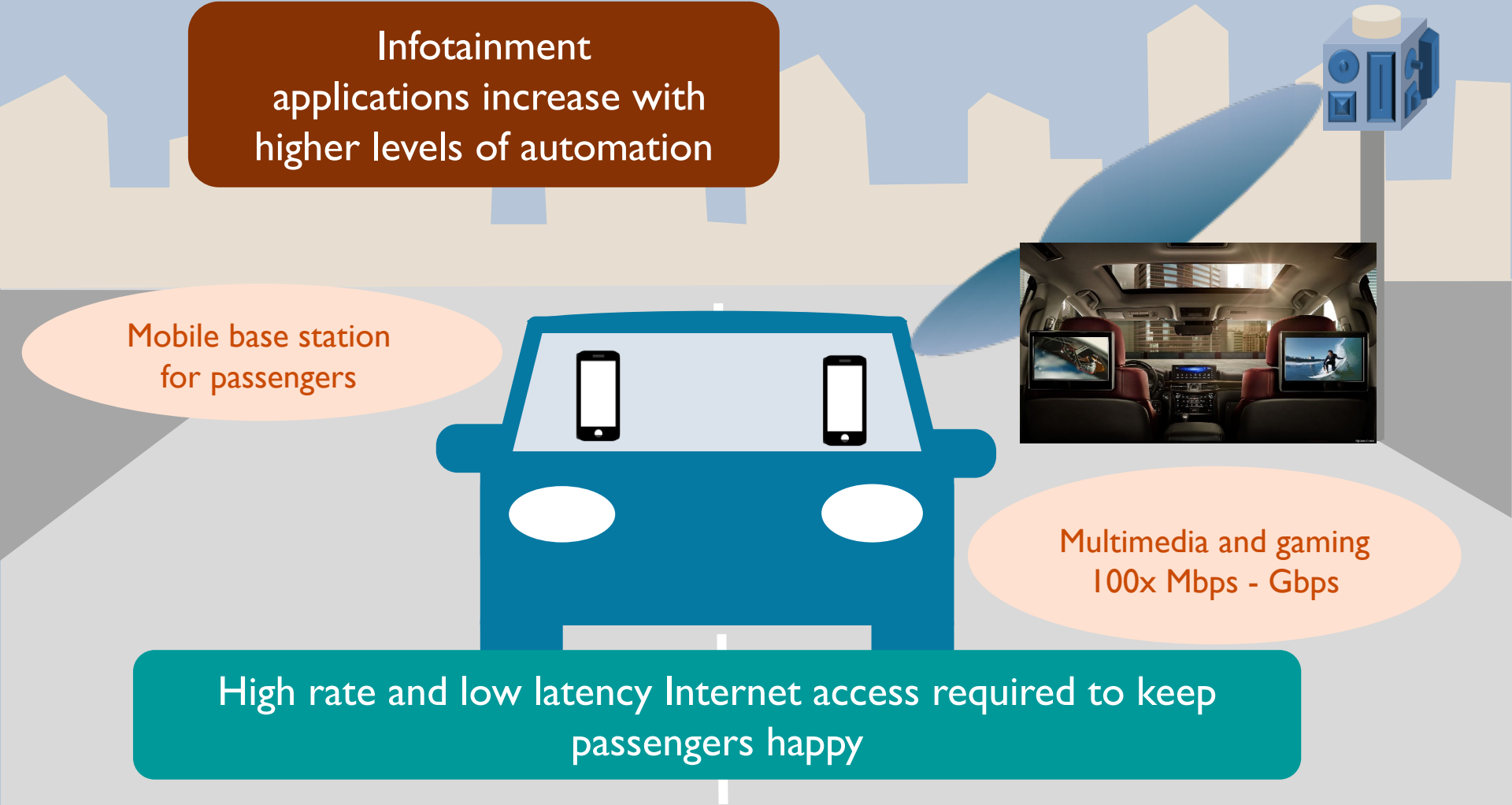
Full automation requires Gbps data rates and ms latencies

V2X for traffic efficiency



V2X for infotainment

Infotainment applications increase with higher levels of automation



Mobile base station for passengers

Multimedia and gaming
100x Mbps - Gbps

High rate and low latency Internet access required to keep passengers happy

Summary of current technologies for V2X

Features	DSRC	D2D LTE-V2X	Cellular LTE-V2X
Channel width	10 MHz	Up to 20 MHz	Up to 20 MHz
Frequency Band	5.9 GHz	5.9 GHz	450 MHz-3.8 GHz
Bit Rate	3–27 Mb/s	Up to 44 Mb/s	Up to 75 Mb/s
Range	~ 100s m	~ 100s m	Up to a few km
Spectral efficiency	0.6 bps/Hz	0.6 bps/Hz (typical)	0.6 bps/Hz (typical)
Coverage	Ubiquitous	Ubiquitous	Inside cell only
Mobility support	High speed	High speed	High speed
Comm. fee	Free	?	?
Latency	x ms	x10-x100 ms	X10 ms

Low latency and Gbps data rates are not supported

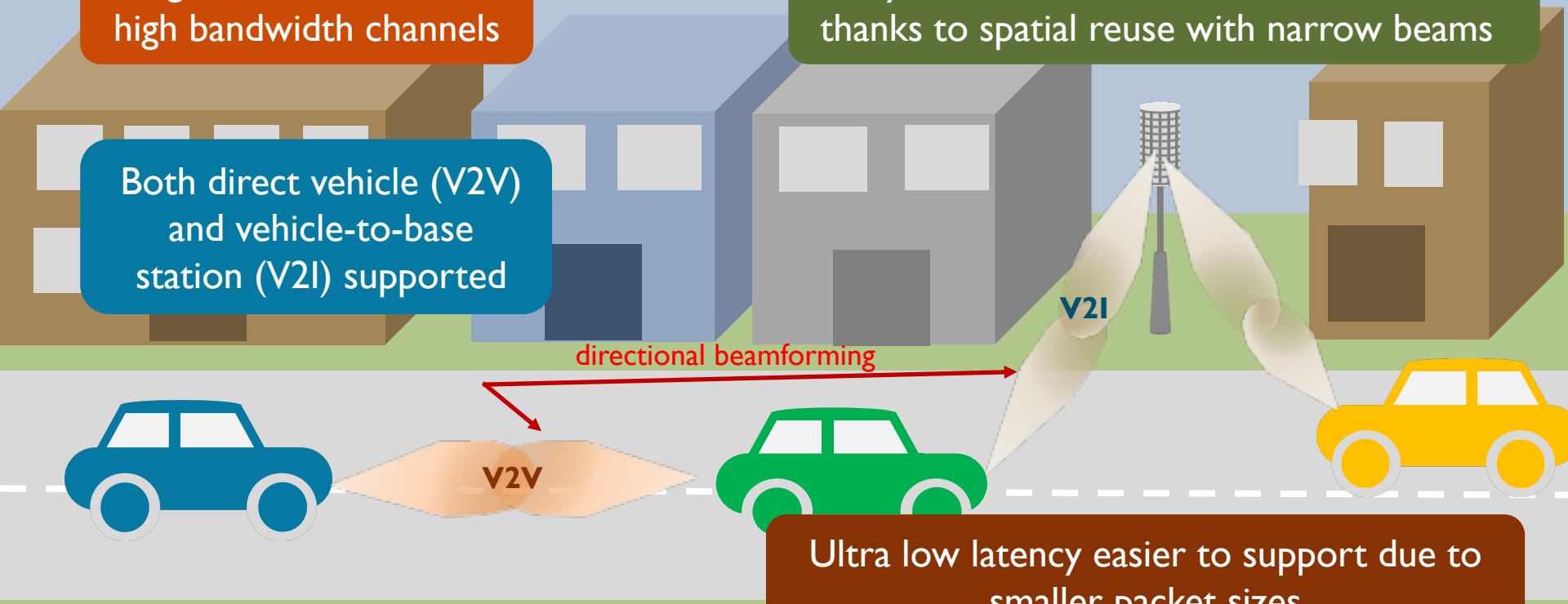
*Giuseppe Araniti *et al.*, "LTE for Vehicular Networking: A Survey", *IEEE Commun. Mag.*, May 2013

mmWave 5G will enable Gbps V2X data rates

High data rates due to high bandwidth channels

Many simultaneous connections allowed thanks to spatial reuse with narrow beams

Both direct vehicle (V2V) and vehicle-to-base station (V2I) supported



Ultra low latency easier to support due to smaller packet sizes

MmWave is the only viable approach for high bandwidth connected vehicles*

*Junil Choi, Vutha Va, Nuria González-Prelcic, Robert Daniels, Chandra R. Bhat, and Robert W. Heath Jr, "Millimeter Wave Vehicular Communication to Support Massive Sensing", IEEE Communications Magazine, vol. 54, no. 12, pp. 160-167, December 2016.

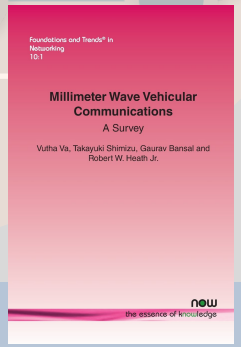
Can mmWave really work with high mobility?

Many misconceptions surround mmWave communications in mobile channels

Doppler is too high

Beams are too hard to configure

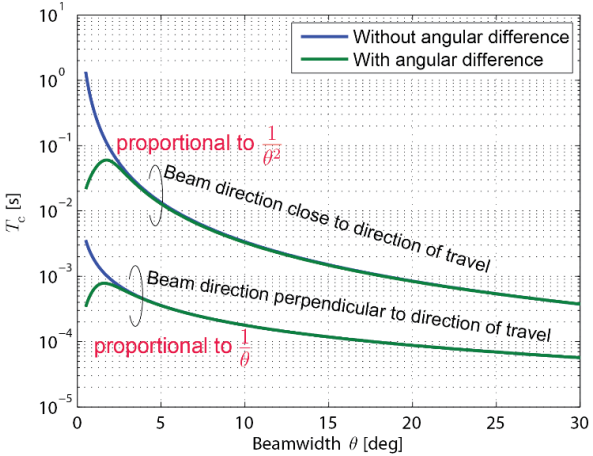
Nothing is known about the channel

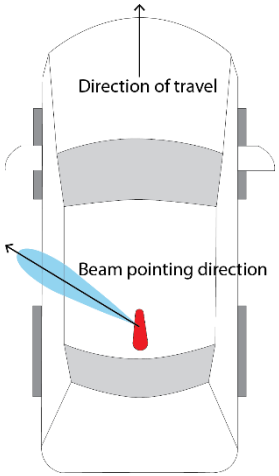


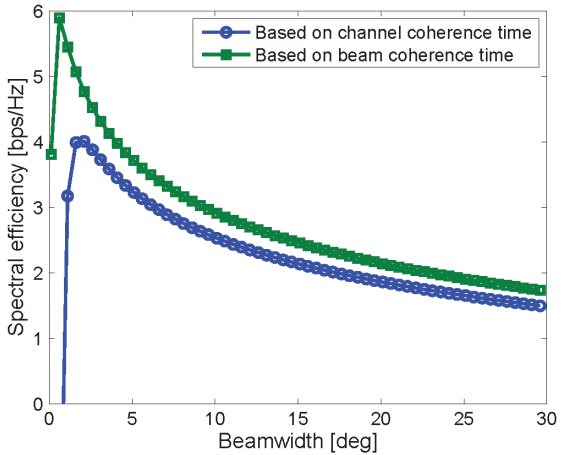
Channel and beam coherence times

Narrow beams increase the channel coherence time, if beams can be pointed

Optimum beamwidth is a tradeoff between pointing error and Doppler







Beams should be narrow but not too "pointy"

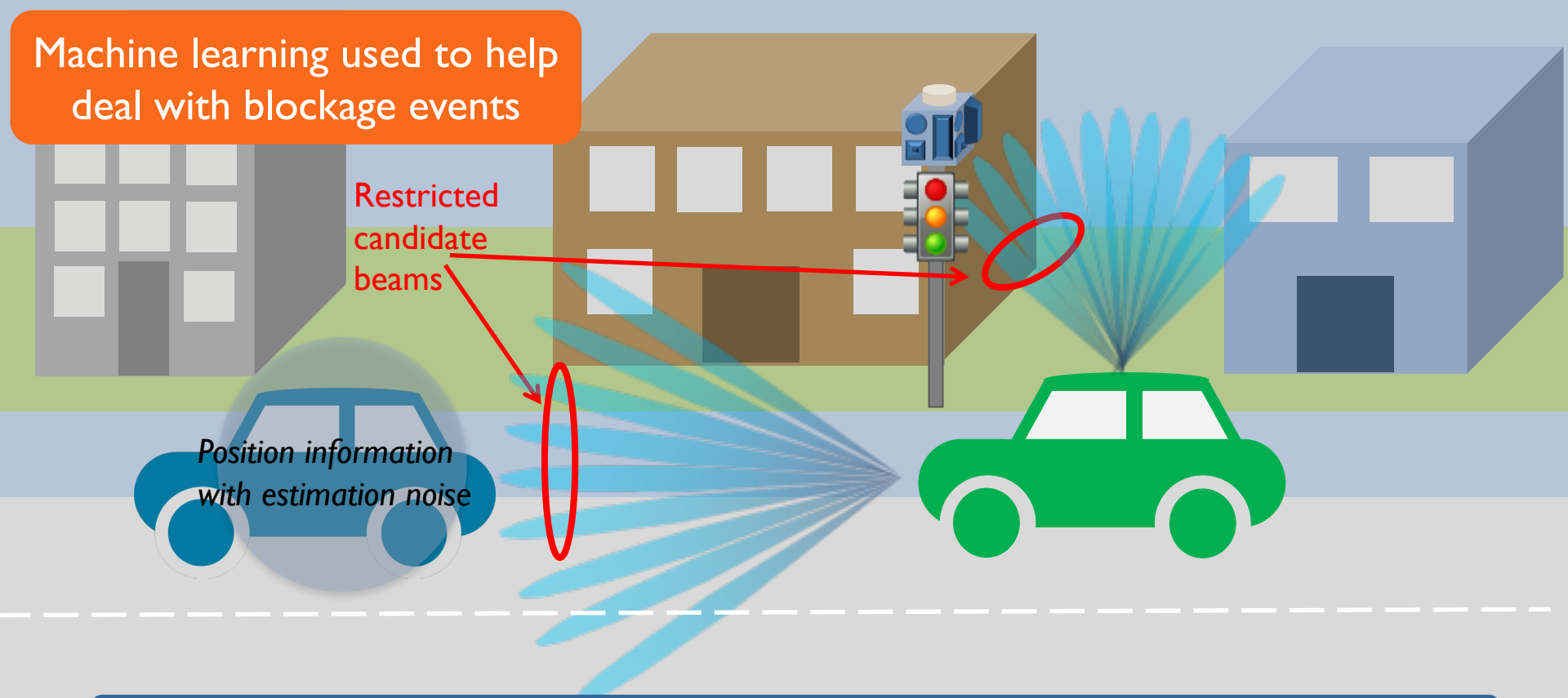
Long term beamforming can be used

Doppler does not have to be significant in a mmWave system

*V. Va, J. Choi, and R. W. Heath Jr. The impact of beamwidth on temporal channel variation in vehicular channels and its implications. to appear in IEEE TVT, previous version available on arXiv.

Position aided beam training in mmWave V2X

Machine learning used to help deal with blockage events

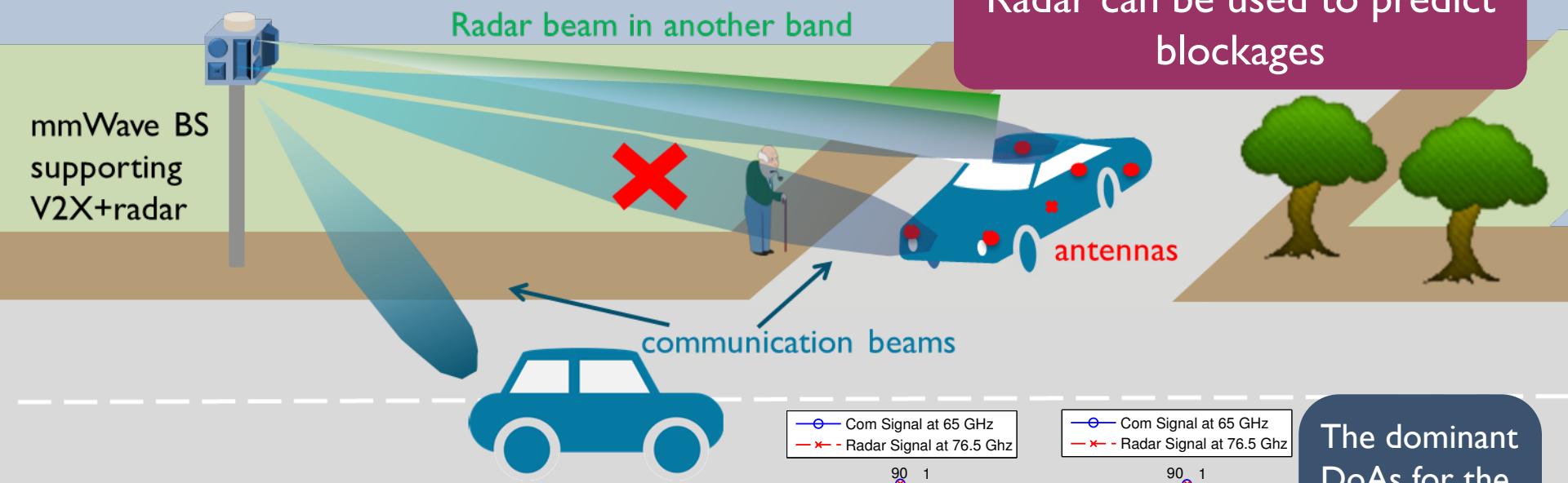


GPS derived location information can reduce beam training overhead

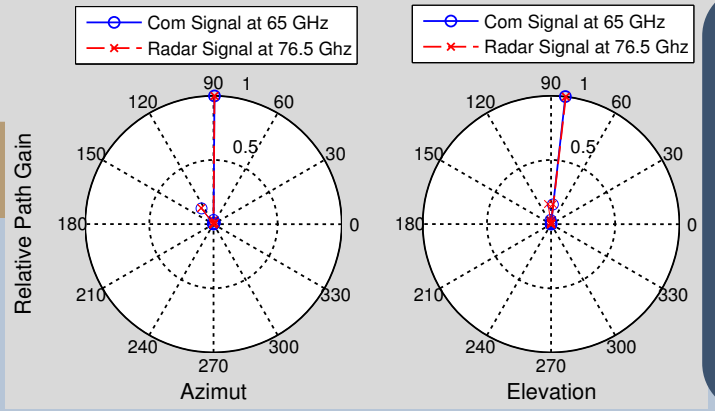
* Vutha Va,J. Choi, Takayuki Shimizu, Gaurav Bansal, and R. W. Heath, Jr., " Inverse Fingerprinting for Millimeter Wave V2I Beam Alignment," submitted to IEEE Trans. on Veh. Tech., May 2017. Available at ArXiv.

Radar-aided millimeter wave V2X

Radar can be used to predict blockages



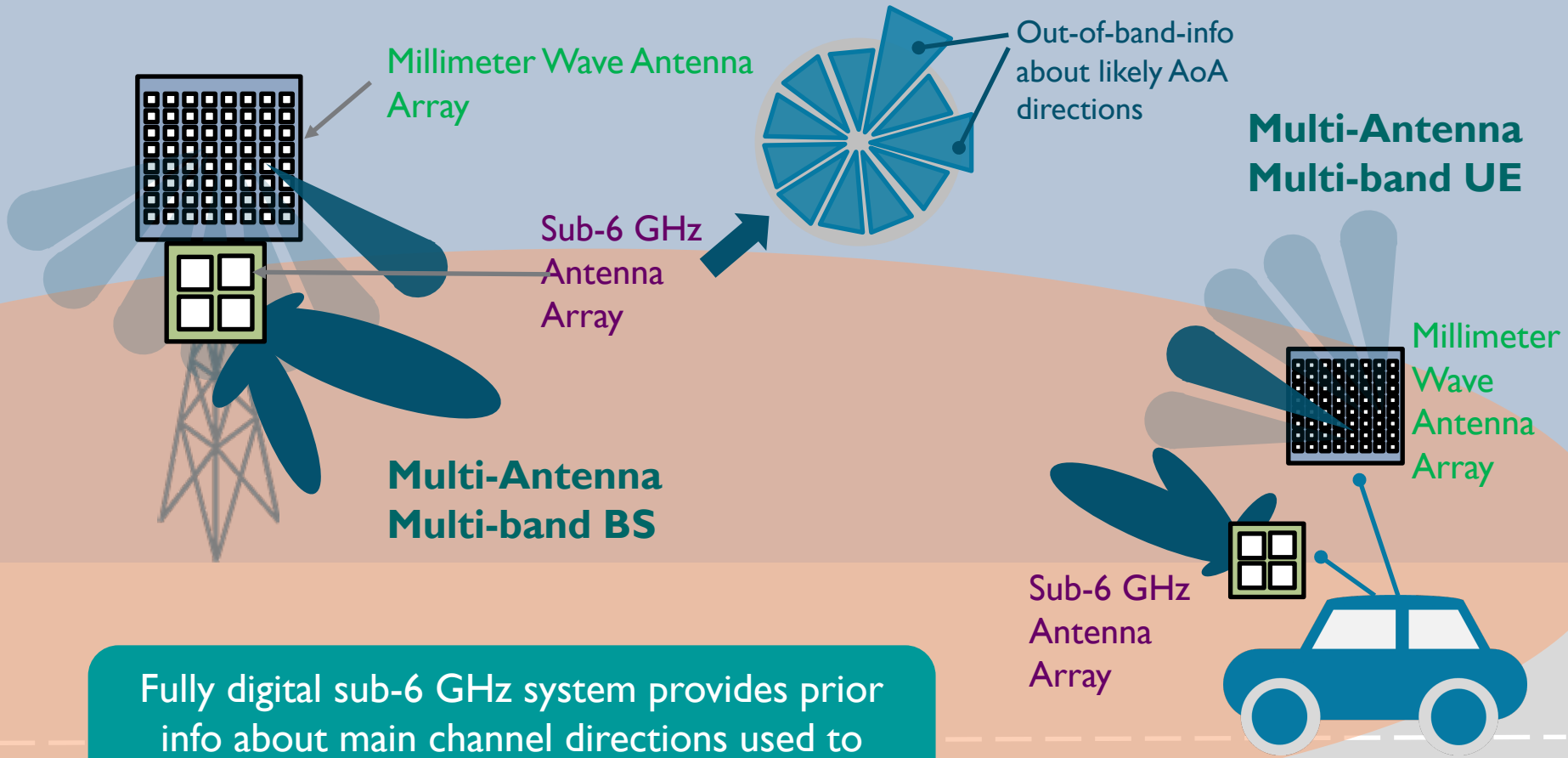
Radar can be used to track vehicles



The dominant DoAs for the communication signal also appear at the radar echo in a different band

* N. González-Prelcic, Roi Mendez-Rial, and R. W. Heath Jr., "Radar aided beamforming in mmWave V2I communications supporting antenna diversity," Proc. of Inf. Th. and App. Workshop, 2016 .

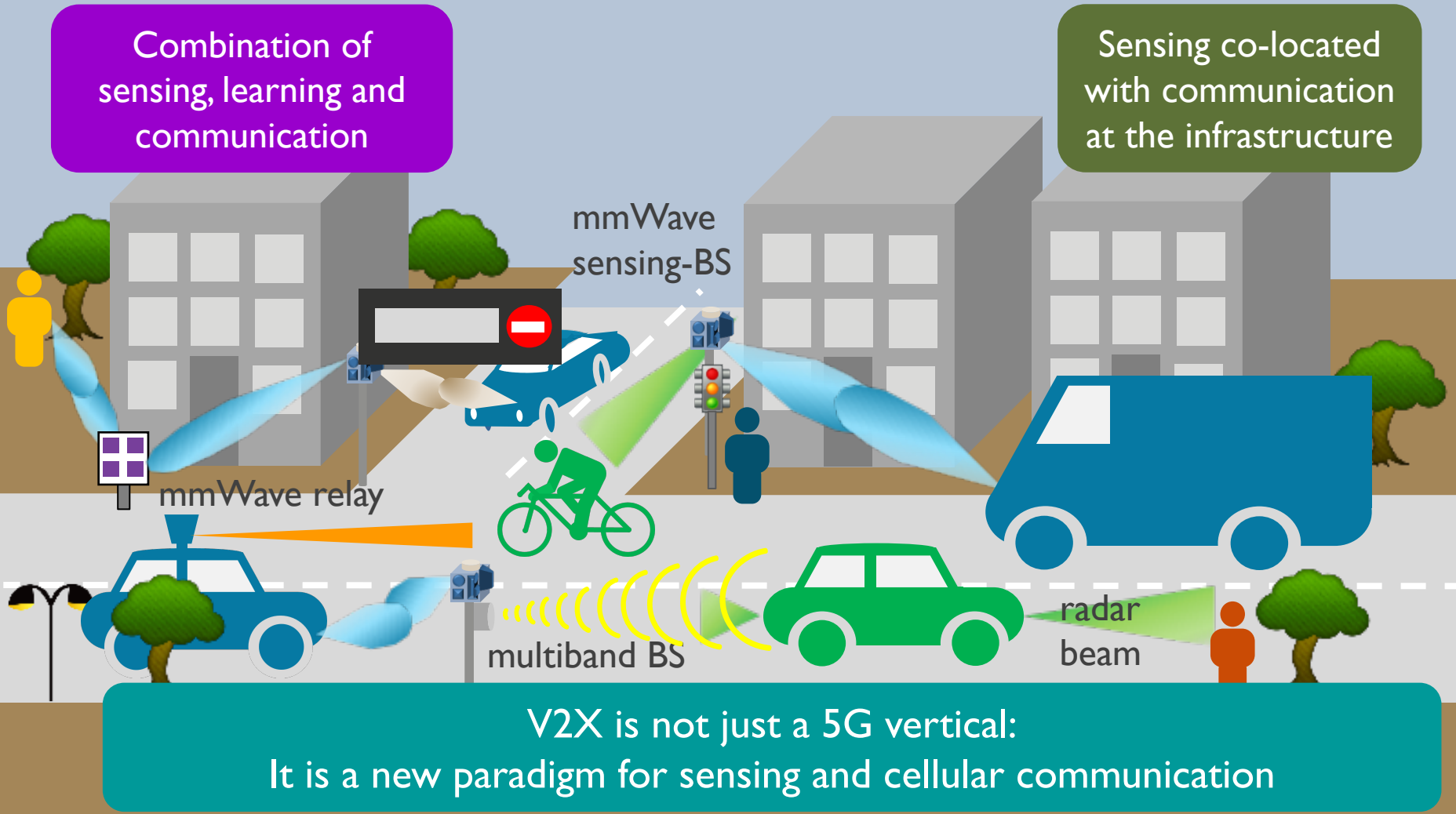
Beam-selection in mmWave V2I aided by sub-6GHz info



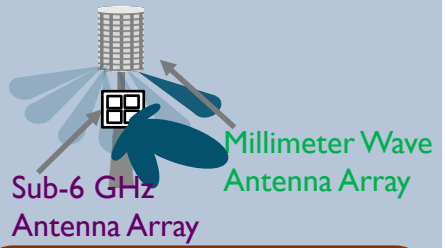
Fully digital sub-6 GHz system provides prior info about main channel directions used to reduce training length at mmWave

A. Ali, N. González-Prelcic, and R. W. Heath Jr., "Millimeter Wave Beam-Selection Using Out-of-Band Spatial Information", submitted to IEEE TWC, available arXiv.

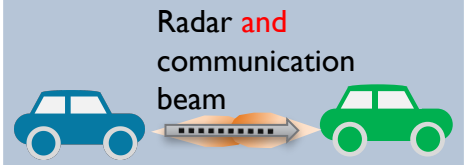
Creating a new cellular infrastructure in 5G for V2X



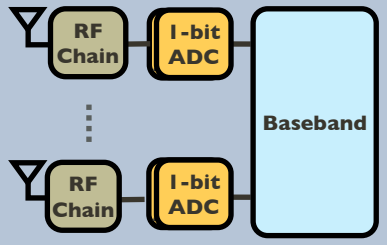
V2X is not just a 5G vertical:
It is a new paradigm for sensing and cellular communication



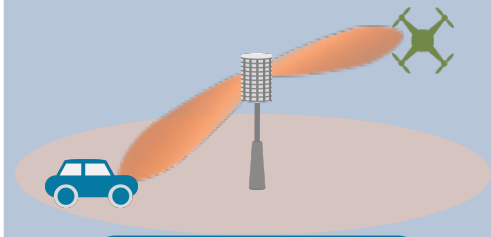
Efficient array configuration using out-of-band info



Joint vehicular comm. and radar



Low power V2X

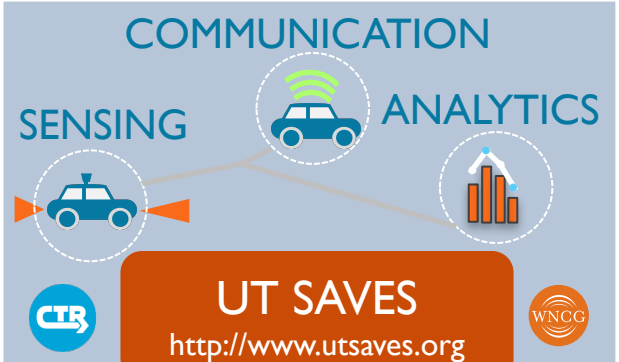


Coverage and rate analysis

WNCG @ UT maintains a top position on research on mmWave communications and V2X

Texas Department of Transportation · HUAWEI · TOYOTA InfoTechnology Center, U.S.A., Inc. · FUJITSU · NATIONAL INSTRUMENTS · HONDA Honda R&D Americas

Collaborations with DOT, TxDOT, automotive and wireless companies



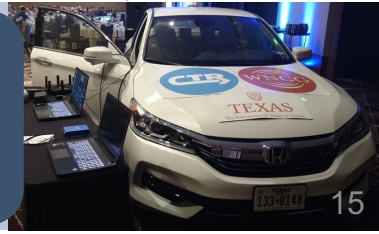
UT SAVES
http://www.utsaves.org

Platform by National Instruments for BB prototype

24 elements phased array donated by NI

mmWave communicati algorithms developed In CAR STOP

Prototyping mmWave for V2X



In summary

Millimeter wave is a key technology for connected vehicles in 5G

Thank you!

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