Rate maps for V2X communication at mmWave

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mmWave and 5G supporting V2X use cases

V2X scenarios are an important part of 5G NR

Platooning

Vehicles form a group travelling together

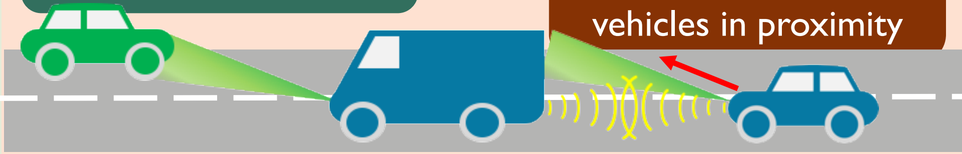
Vehicles in the platoon receive periodic data from the leading vehicle

Distance between vehicles can become extremely small

Advanced driving

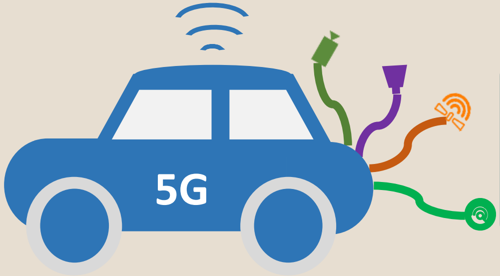
Sharing sensing data to coordinate maneuvers

Sharing driving intentions with vehicles in proximity



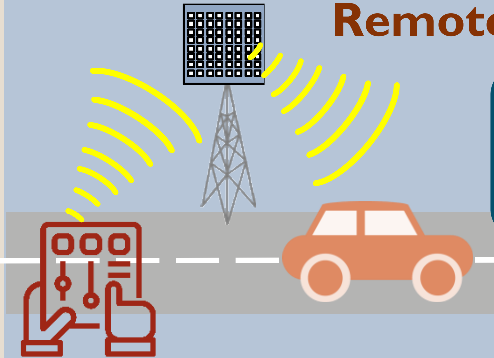
Benefits are collision avoidance and traffic efficiency

Extended sensors



Exchange of raw/processed data to enhance perception of the environment

Remote driving



Remote driver or a V2X application operates a remote vehicle

5G Release 16 has support for V2X and more detailed on use cases

[1] 3GPP TS 22.186 V15.3.0: Service requirements for enhanced V2X scenarios (Release 15), 3GPP Std., July 2018.

Summary of requirements select cases

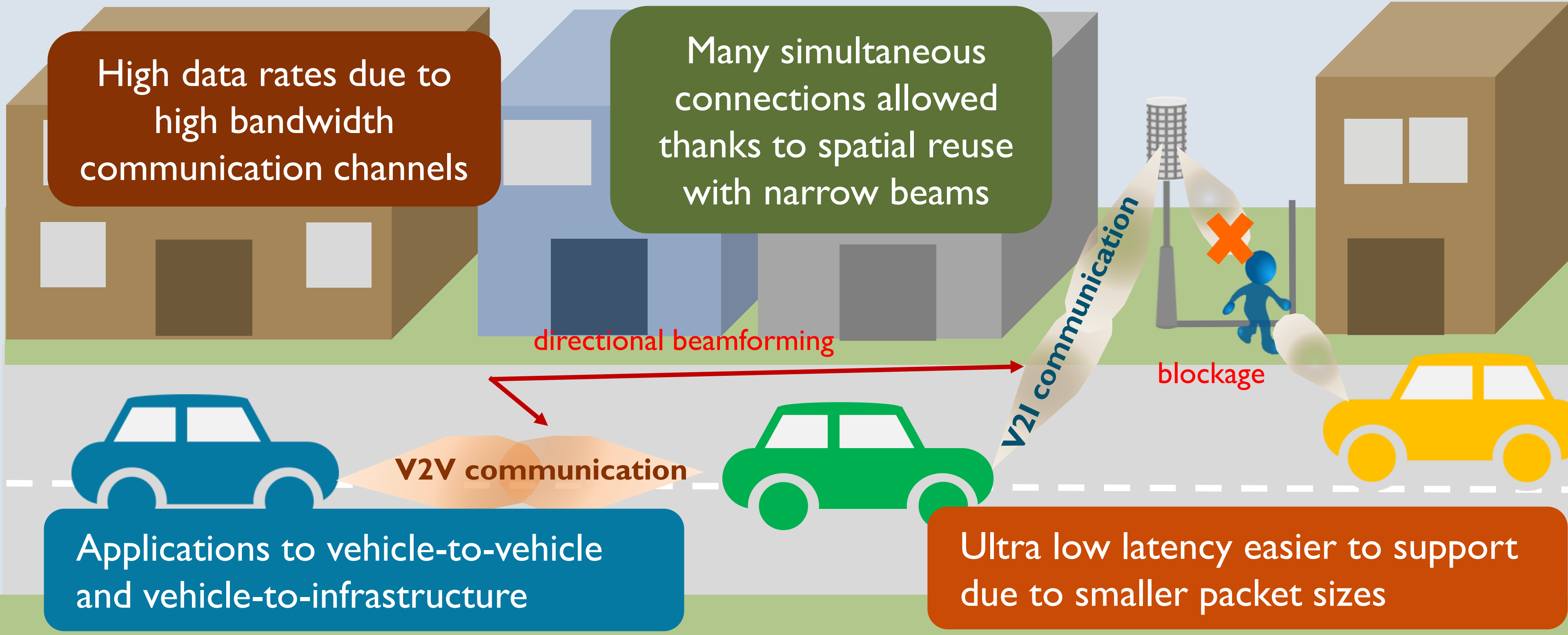
Use case	Latency	Reliability	Data rate
Vehicle platooning	< 25 ms	>90%	Low
Remote driving	< 5 ms	> 99.99%	> 10 Mbps DL, >20 Mbps UL
Collective perception of environment	< 3 ms	> 99%	1 Gbps for a single UE
Cooperative collision avoidance	< 10 ms	> 99.99%	> 10 Mbps
Info sharing for level 2/3 aut.	< 100 ms	> 90%	> 0.5 Mbps
Info sharing for level 4/5 aut.	< 100 ms	> 90%	> 50 Mbps
Video data sharing for improved automated driving	< 10 ms	>99.99%	100-700 Mbps

Rate requirements heavily depend on use case

[1] 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; “Study on enhancement of 3GPP Support for 5G V2X Services (Release 16)”, Technical Report 3GPP TR 22.886 V16.2.0 (2018-12)

Millimeter wave MIMO systems

mmWave will enable high data rate V2X use cases



Key question: How much rate can be achieved at a given location?

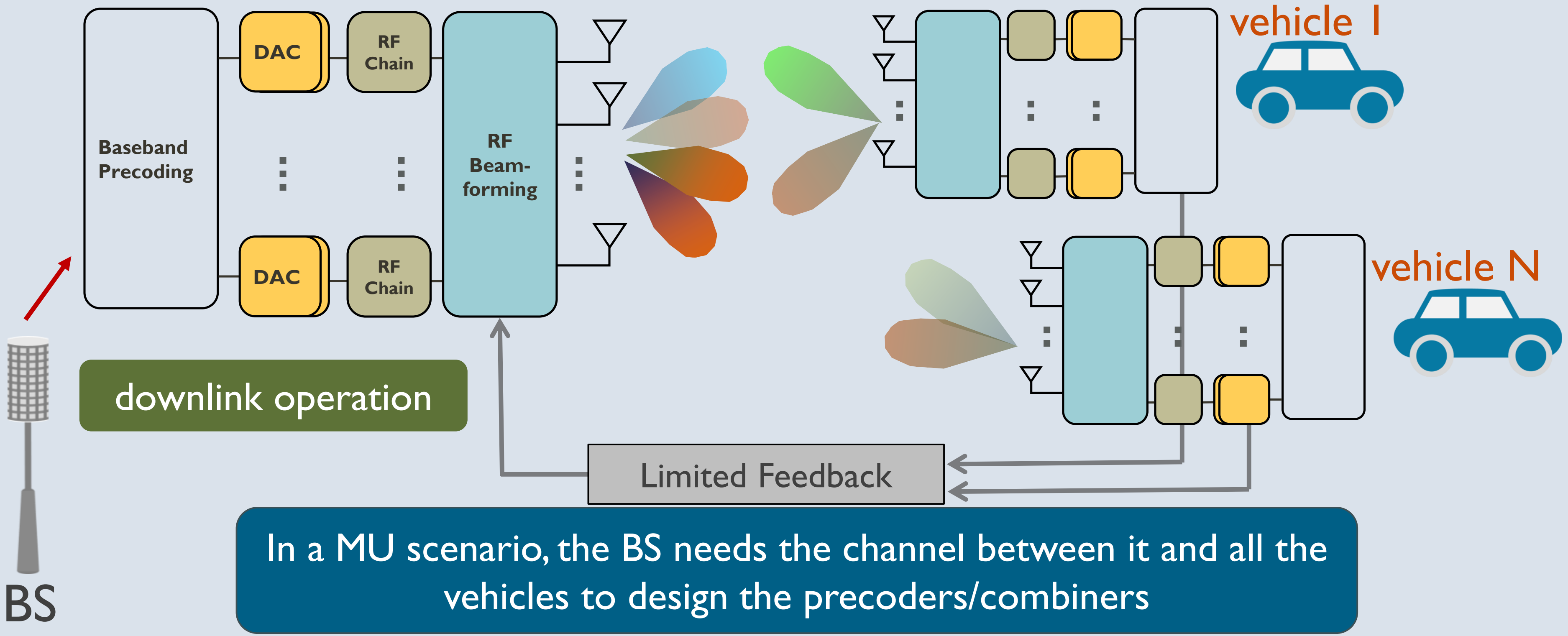
[1] Junil Choi, Vutha Va, Nuria González-Prelcic, Robert Daniels, Chandra R. Bhat, and Robert W. Heath Jr, “Millimeter Wave Vehicular Communication to Support Massive Sensing”, IEEE Communications Magazine, vol. 54, no. 12, pp. 160-167, December 2016.

V2X will support multiple users simultaneously

multiple streams

multiple users

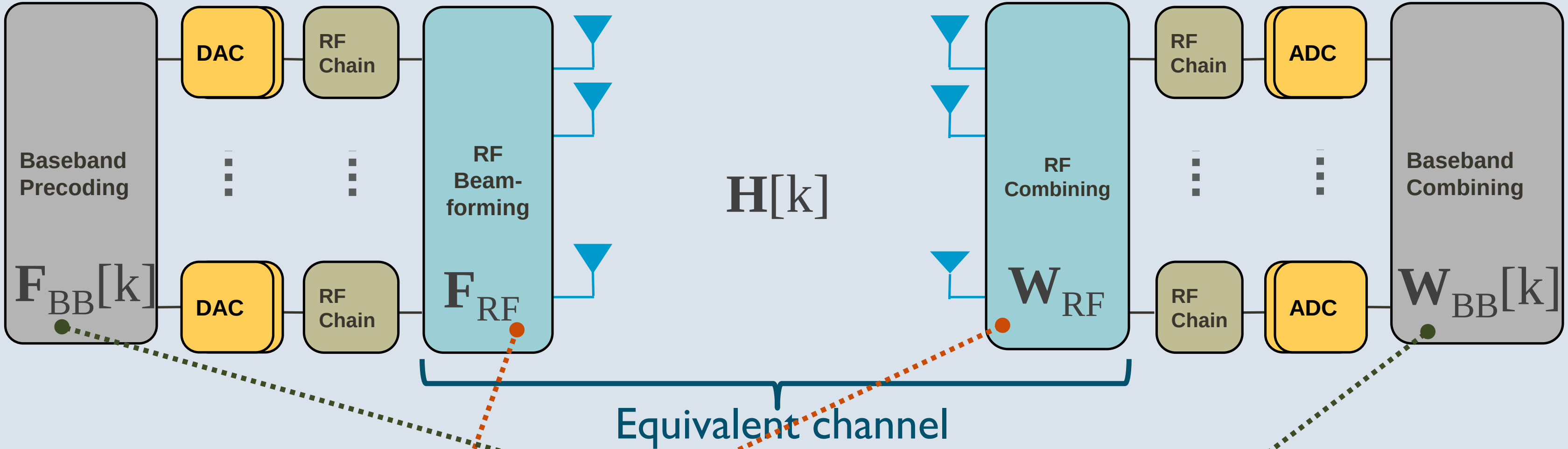
different possible architectures at UE



downlink operation

In a MU scenario, the BS needs the channel between it and all the vehicles to design the precoders/combiners

Hybrid precoding allows training



RX signal →

STAGE 1

Beam training aided by sub-6 GHz [1] to configure analog precoder/combiner

→

STAGE 2

Least squares estimation of equivalent channel

→

STAGE 3

Design of digital precoder/combiners based on ZF

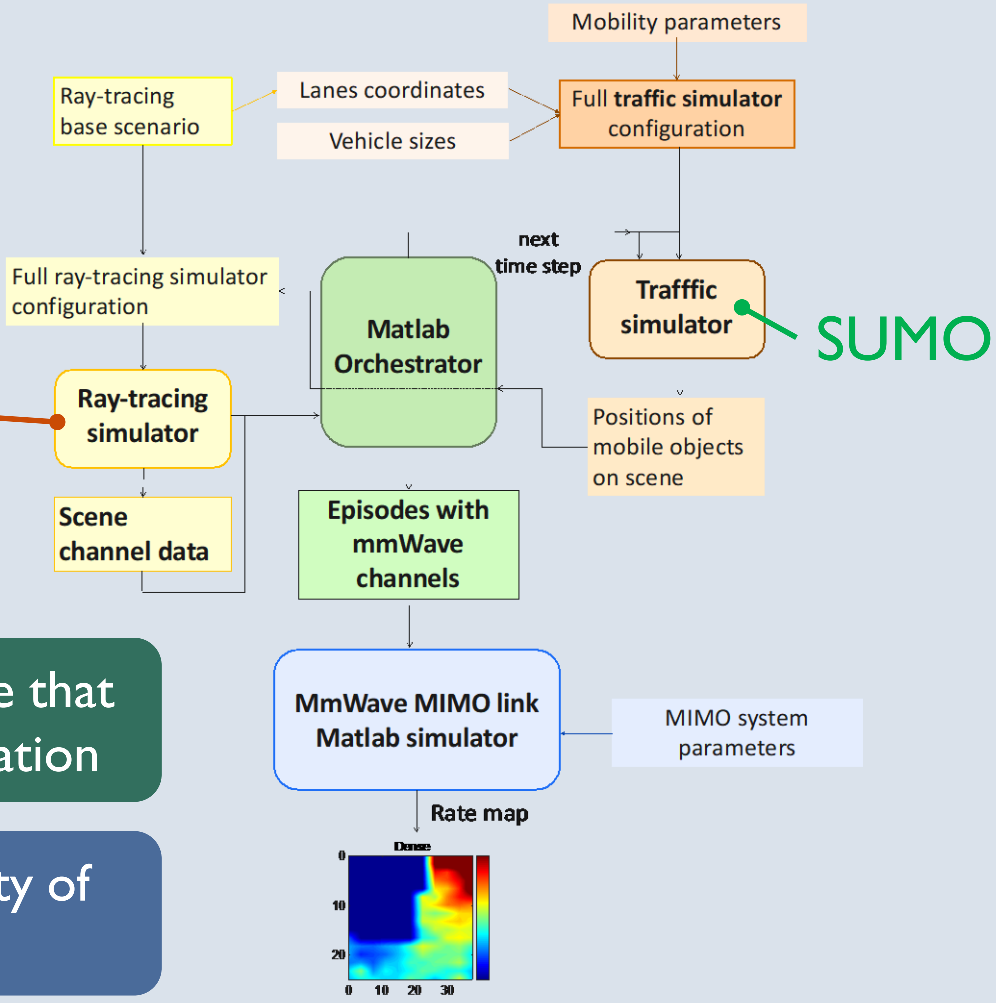
→ Hybrid precoders

[1] A. Ali, N. González-Prelcic, and R. W. Heath Jr., “Millimeter Wave Beam-Selection Using Out-of-Band Spatial Information”, IEEE TWC, 2018

Building rate a rate map

Computation methodology

Ray tracing using REMCOM Wireless Insite [1]



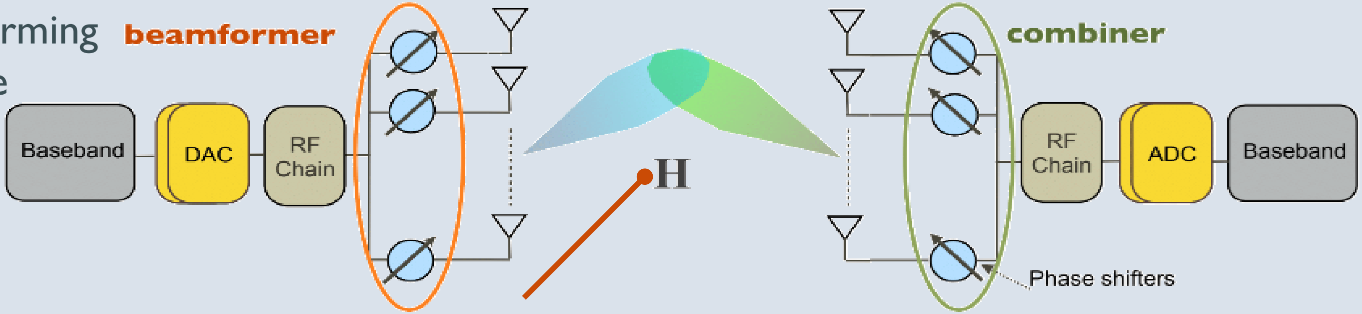
A rate map specifies the average rate that can be achieved as a function of location

Useful for understanding the viability of high rate sensor data sharing

[1] https://www.remcom.com/wireless-insite-em-propagation-software

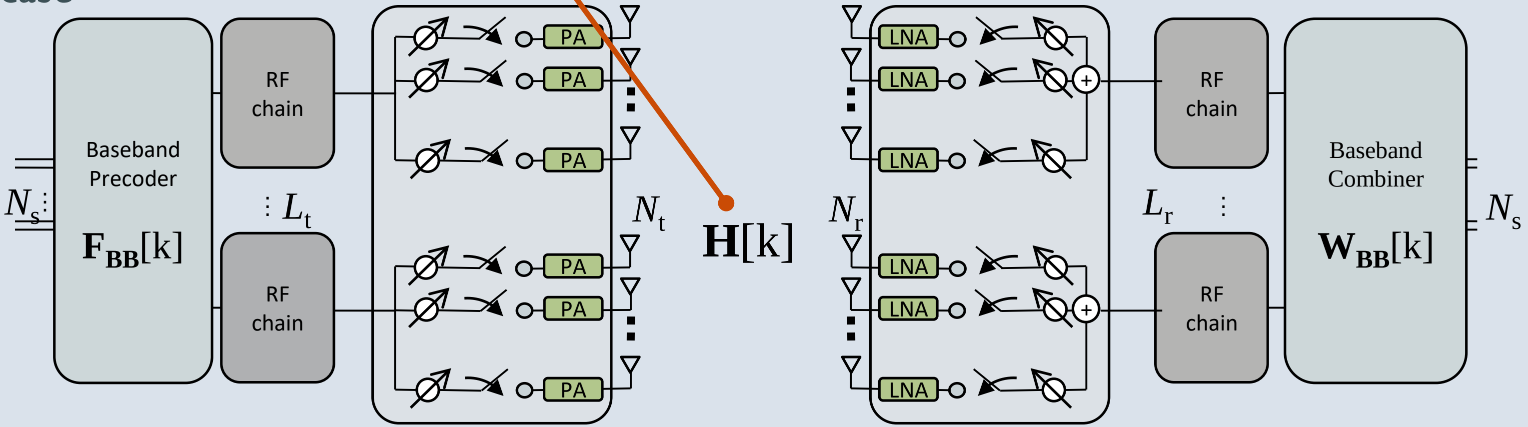
Compute the precoders and combiners given channel info

Analog beamforming
for the SU case



Vehicular channels generated by ray tracing

Hybrid beamforming
for the MU case



Estimate the rate of the high bandwidth channel

rate per user at a grid point indexed by g

bandwidth

Number of subcarriers

transmit power

channel at grid point indexed by g and subcarrier k, channel also includes pathloss

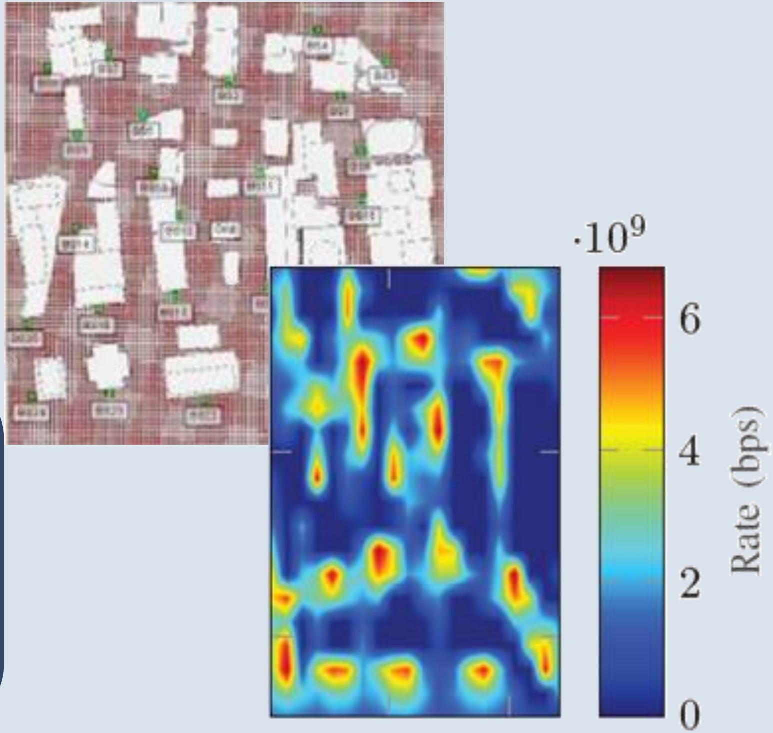
$$R_g = B \sum_{k=0}^{K-1} \log_2 \left(1 + \frac{P}{\sigma^2} |\mathrm{w}_g \mathrm{H}_g[k] \mathrm{f}_g|^2 \right)$$

noise power

$$\sigma^2[\mathrm{dBm}] = -173.8 + 10 \log_{10}(B)$$

Must compute rate for the broadband channel, the entire reason for mmWave

Computing a rate map



1. Define spatial grid with a given resolution

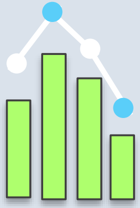
2. Define BS deployment and place MIMO TX at the BS locations

3. Run the ray tracing simulation with the MIMO RX in each possible position of the spatial grid (G) considering different traffic conditions (N_{tra}) and obtain the corresponding communication channels ($G x N_{tra}$)

4. For each one of the points in the grid and traffic realization, run the Matlab simulation to design the MIMO link and compute the associated rates

5. Average the rate for each spatial point among the different traffic realizations

Rate statistics



Average rate in the coverage area

Percentage of spatial slots where the rate is larger than a target rate R

Standard deviation

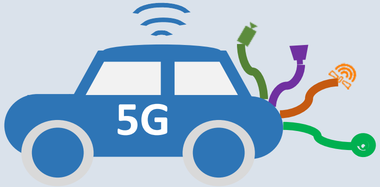
Statistics will be obtained for different types of scenarios

Statistics for each scenario are averaged among N_{scn} environments

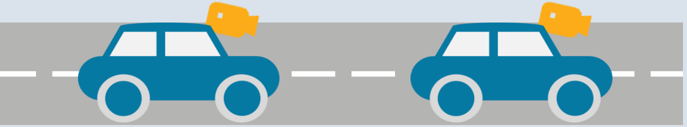
Statistics also depend on the specific BS deployment

Optimization of the BS deployment is out of the scope of the project

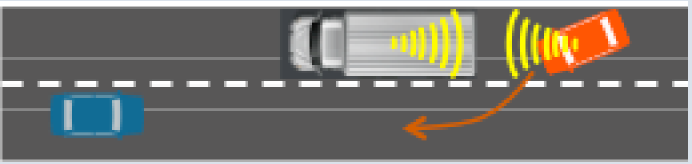
Choosing target rates R



R **= 50 Mbps** to enable info sharing for level 4/5 automation



R = 500 Mbps to enable video data sharing



R = 1 Gbps to enable collective perception of the environment

R is chosen as a function of the use case

Simulation results

System parameters

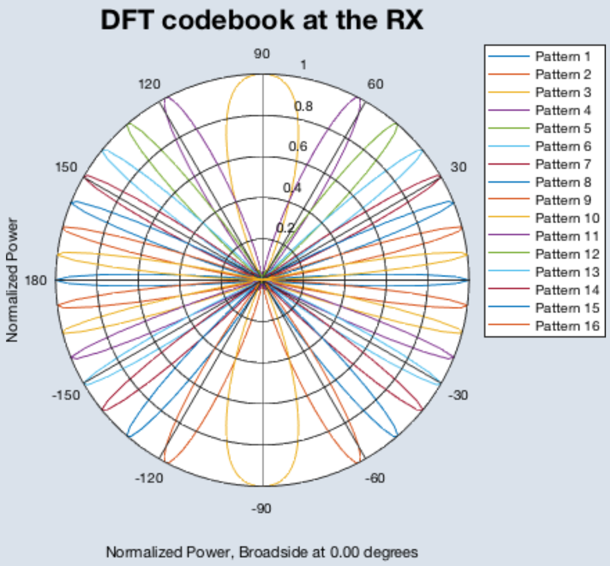
SU and MU MIMO-OFDM system operating at mmWave; U= 4 users in the MU scenario

Analog architecture for the SU case; fully and partially connected hybrid architectures for the MU case

UPAs at the BS and UEs:
16x16 at BS
4x4 at UE

DFT codebook

4 RF chains in hybrid



Carrier frequency:
28 GHz [1]

Bandwidth:
850 MHz [1]

Ntra: 5

Nscn: 5

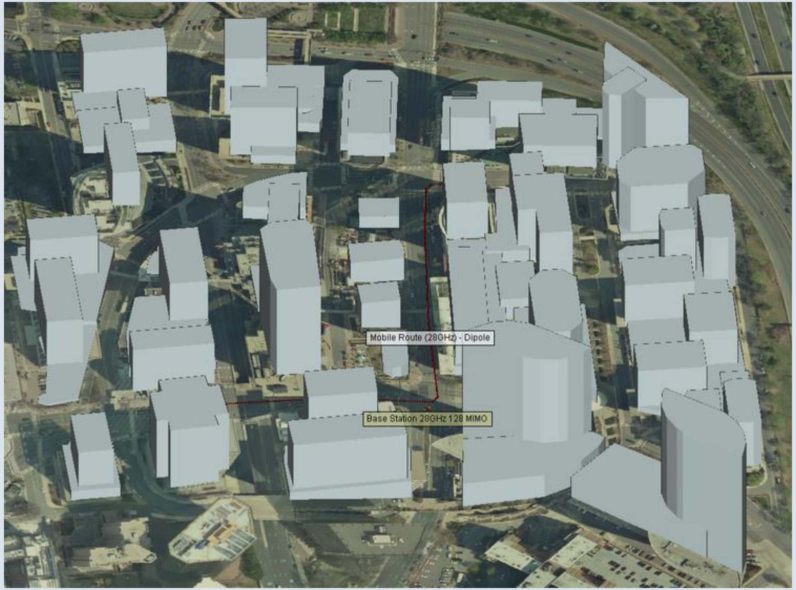
[1] The WRC Series – 26 GHz and 28 GHz , https://www.gsma.com/spectrum/wp-content/uploads/2019/07/26-and-28-GHz-for-5G.pdf

Environment parameters

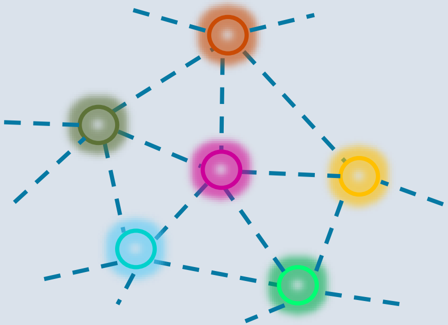
Heavy and light traffic conditions considered in the ray tracing simulations

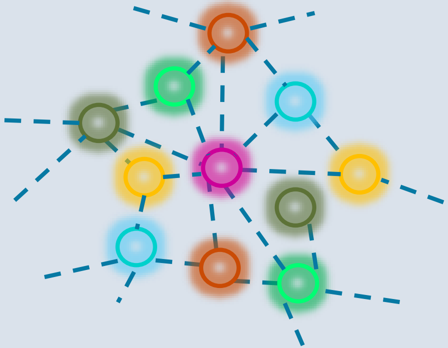
Heavy traffic: intervehicle distance in the range 3-5 m

Light traffic: intervehicle distance in the range 50-100m



Urban environments taken from an electromagnetic model of a real city: Rossylyn, VA



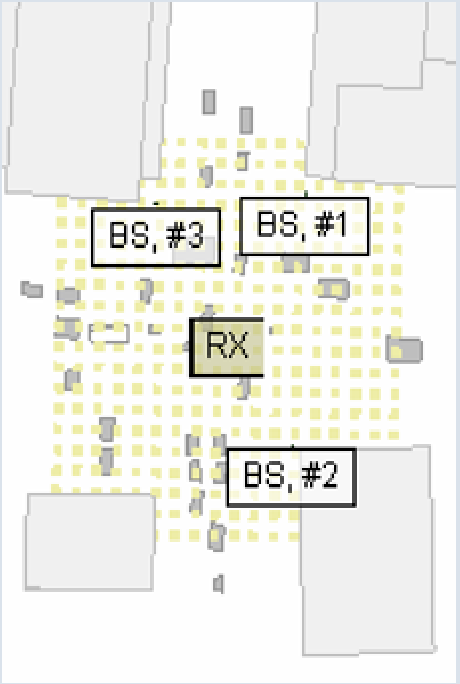


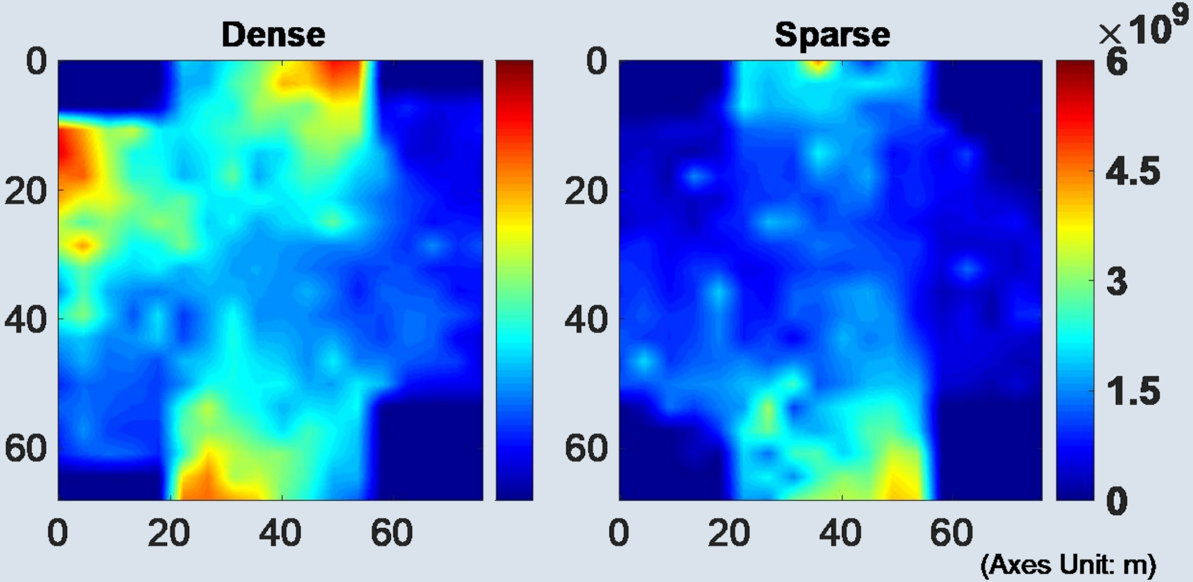
Sparse and dense BS deployments are considered

Dense deployment: average distance between BSs: 50 m

Sparse deployment: average distance between BSs: 150 m

Example of rate map for intersections, SU case





Parameters: Grid size: 2.5m / Interpolation factor: 16

BS Layouts

For this particular example, most of the points in the map are above 1 Gbps for a dense BS deployment

Rate statistics for intersections, SU case

Results after averaging among 5 intersections and 5 different traffic realizations

	Sparse deployment		Dense deployment	
	Light traffic	Heavy traffic	Light traffic	Heavy traffic
Average rate (Gbps)	1.511	1.495	1.834	1.805
Standard deviation	0.119	0.102	0.101	0.129

Percentage of locations above target rate without optimization of BS deployment

	1 Gbps	500 Mbps	50 Mbps
Intersections	75.70	94.08	99.44

Average rate and outage is better in intersections than in corners because of the spacious radio environment and less blockages

Conclusions

We developed a software tool to design the 5G compatible MIMO link at mmWave frequencies given a particular time varying vehicular channel and considering the MIMO architectures in the standard

We devices a means to compute average rate maps based on electromagnetic models of real environments and traffic simulation

We analyzed the rate maps and obtained rate statistics for 5G supported vehicular communications at mmWave

These tools can be used to understand if the KPIs assumptions for different 5G use cases provided by the 5GAA and 3GPP working groups can be achieved under different system and environment parameters

Comments

Presented results are based on a pseudorandom deployment, so they can be considered as a lower bound for the system performance

Optimization of the BS and relays deployment heavily contributes to improve the rate statistics as shown in some examples

Results without deployment optimization are very close to the 5G use cases requirements, so it is expected that the improvement coming from the network optimization can fill the gap

Thank you!