Challenges and Techniques for Characterizing Massive MIMO Antenna Systems for 5G

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Outline

Massive MIMO

How to increase spectral and energy efficiency ?

Beamforming
MIMO

OTA Testing Technologies

Antenna Radiation Fields

Nearfield vs. Farfield Measurements

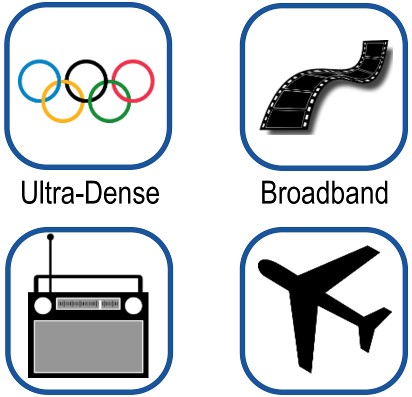
OTA Test Solutions:
- Spiral Scanner for Massive MIMO
- OTA Power Sensors

Channel sounding

Channel propagation measurements at mm-Waves

Channel measurements for Platooning

5G Vision: A union of spectral & energy efficiency becomes reality

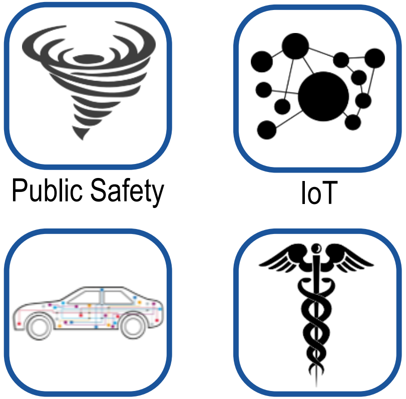


Ultra-Dense

Broadband

Broadcast

Mobility



Public Safety

IoT

Automotive

E-Health

Radio: Spectral Efficiency

Smart City Ecosystem

Advanced test equipment bridging between radio & virtualization

Virtualization: Energy Efficiency

Why Massive MIMO ?

Spectral efficiency: Why MIMO ?

Increased Capacity, Increased OPEX

Capacity (bits/second) → C

Number of Channels → N

$$C = W\,N\,log_2(1+SNR)$$

Signal BW (Hz) → W

Signal to Noise Ratio *(S/N)* → SNR

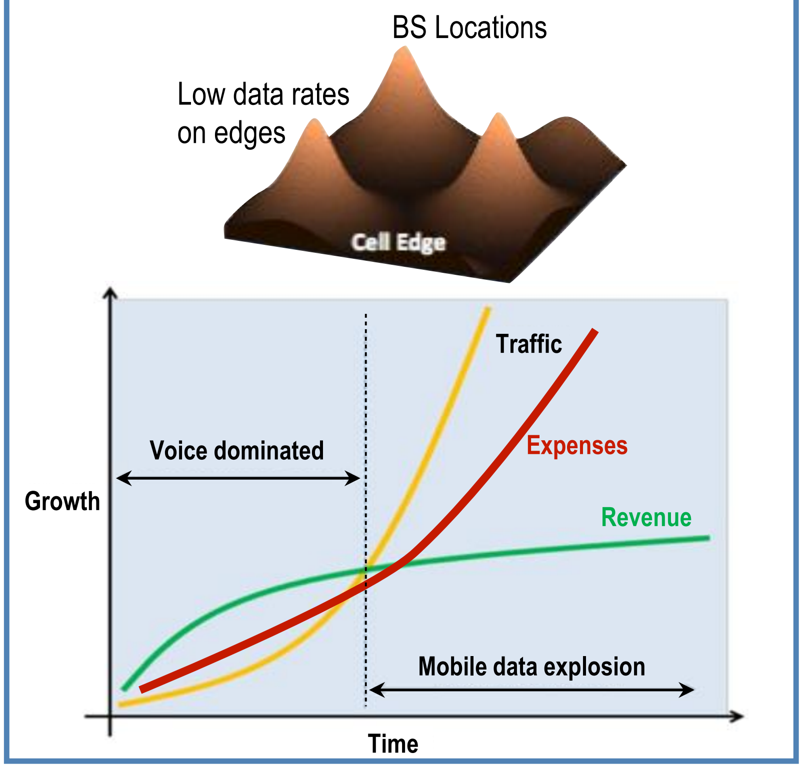
Solutions: mmWave & Massive MIMO

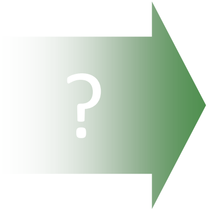
- Use additional frequency bands in **mmWave** spectrum (24 to 110 GHz) for increased **signal bandwidth** up to 2 GHz
- Increase **SNR** of 5G **waveforms** and multiple access
- Implement **Massive MIMO** with multiple **channels** and beamforming to improve SNR

Easiest ways to improve capacity: MIMO and Signal BW

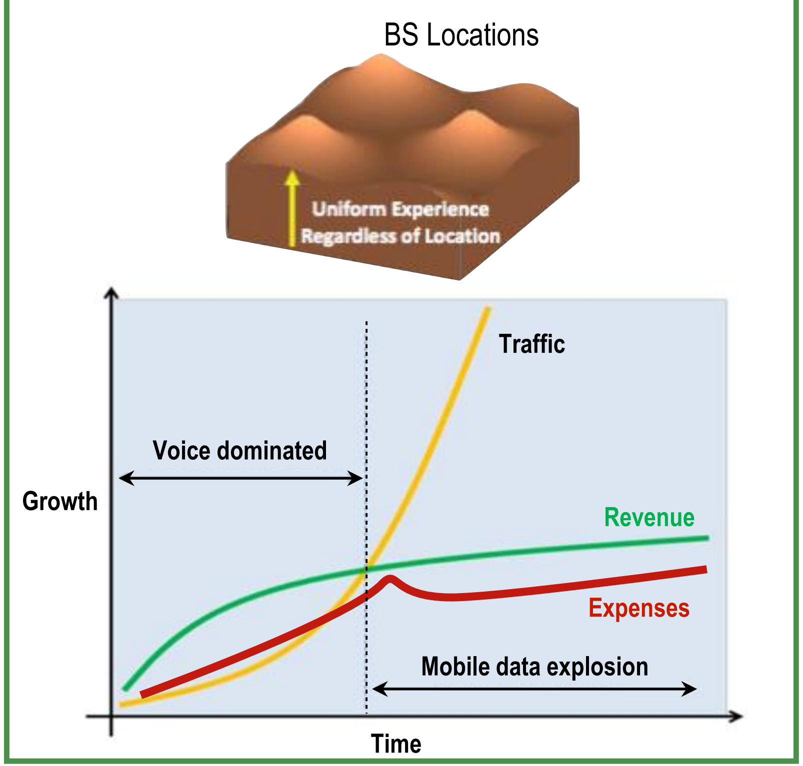
Why 5G?: Capacity vs. Revenue

Increased Capacity, Increased OPEX





Optimal Network



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Massive MIMO can increase capacity & reduce OPEX

Why 5G?: Power Consumption

Cellular Network Energy Consumption (China)

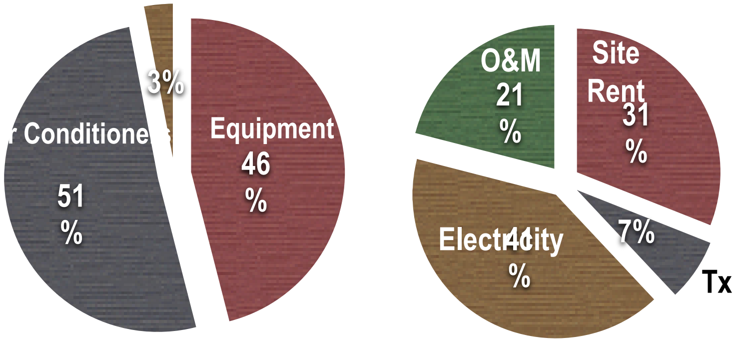
2G GSM
830,000 Basestations
80 GWH (96 KWH per BTx)

3G TD-SCDMA
350,000 Basestations
13 GWH (37 KWH per BTx)

WiFi Data Offloading
4.2 Million Access Points
2 GWH Power consumption

4G TD-LTE
800,000 Basestations
16 GWH (20 KWH per BTx)

Radio Access Network Energy Consumption



CAPEX

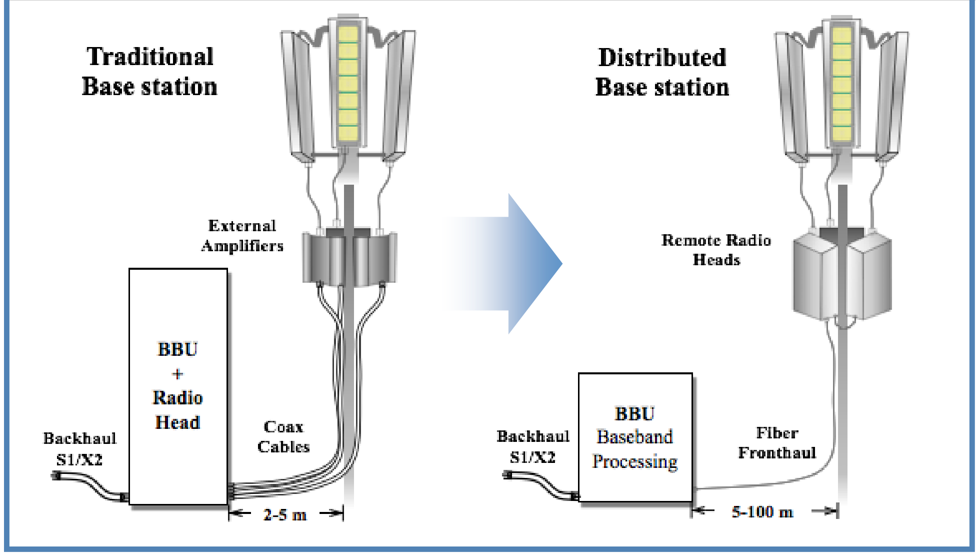
OPEX

Biggest CAPEX/OPEX Expense is Air Conditioning

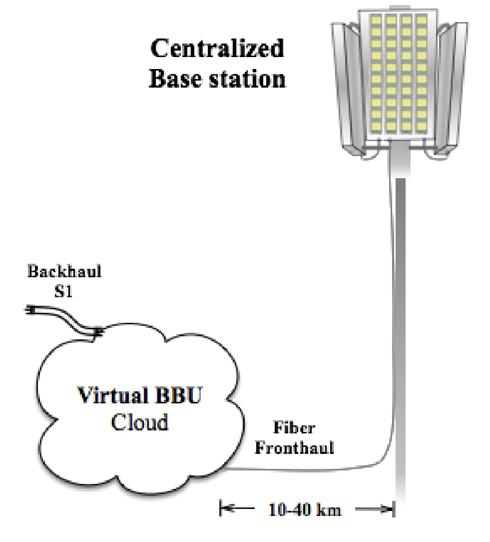
Example: China Mobile Network in 2014 consumed over 15 Billion KWH

Cellular Infrastructure Evolution to 5G

Passive Antennas & Separate Radio Transceivers

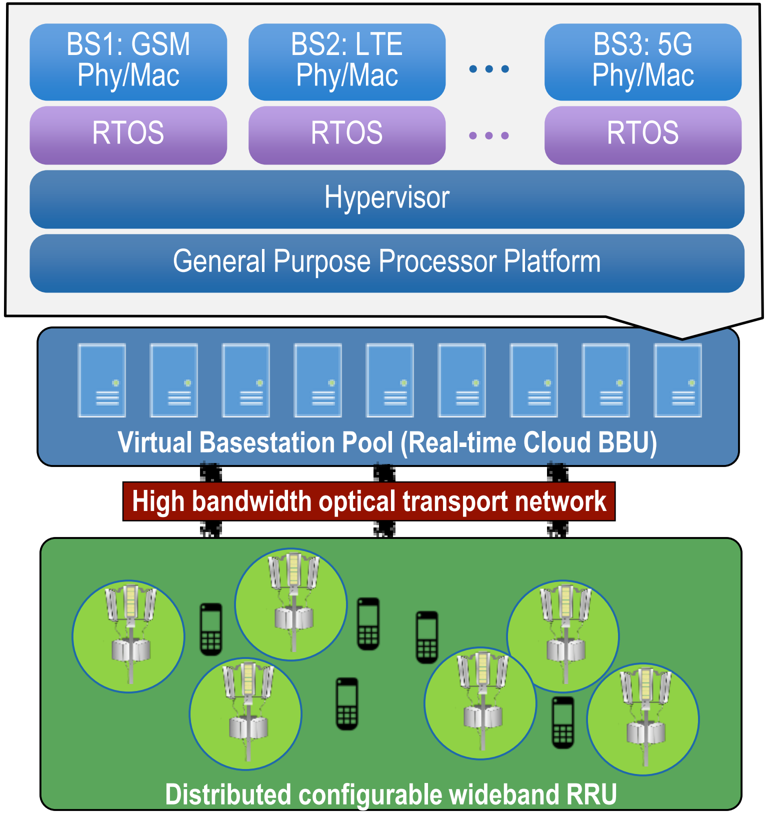


Active Antenna System Antenna + Integrated TRx



Traditional: 1G & 2G	Distributed: 3G & 4G	Centralized: 4.5G & 5G
0.45 to 1.9 GHz	0.7 to 3.6 GHz	3.4 to 6 GHz & 20-60 GHz
8 dual-polarized antennas	8+ dual-polarized passive antennas	128-512 active antennas
Peak Data Rate: 114 kbps	Peak Data Rate: 150 Mbps	Peak Data Rate: 10 Gbps

Energy Efficiency: C-RAN & Network Virtualization



Centralized Control/Processing
- Centralized processing resource pool that can support 10~1000 cells

Collaborative Radio
- Multi-cell Joint scheduling and processing

Real-Time Cloud
- Target to Open IT platform
- Consolidate the processing resource into a Cloud
- Flexible multi-standard operation and migration

Clean System Target
- Less power consuming
- Lower OPEX
- Fast system roll-out

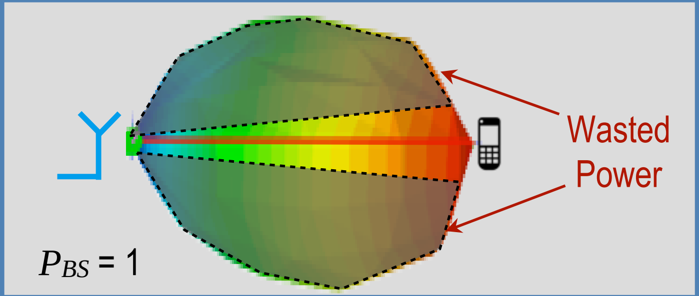
-15% Capital Costs
-50% Operating Costs
-70% Power Consumption

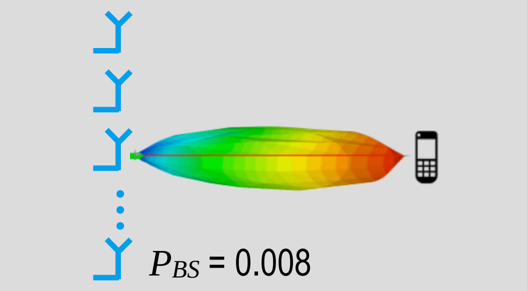
Architecture	Equipment	Air Con	Switching	Battery	Transmission	Total
Traditional	0.65 kW	*2.0 kW*	0.2 kW	0.2 kW	0.2 kW	3.45 kW
Cloud Radio	0.55 kW	*0.1 kW*	0.2 kW	0.1kW	0.2 kW	0.86 kW

CMRI, "C-RAN: The Road Towards Green RAN," Dec. 2013

Easiest way to improve energy efficiency: more virtualization

Energy Efficiency: Why Massive?





Number of Antennas = 1	
Number of BS Transmit Antennas	1
Normalized Output Power of Antennas	$P_{ant} = \frac{1}{M_t} = 1$
Normalized Output Power of Base Station	$P_{total} = \sum_{i=1}^{M_t} P_{ant}^{i} = 1$

Number of UEs: 1 120 antennas per UE
120
$P_{ant} = \frac{1}{M_t^2}$
$P_{total} = \sum_{i=1}^{M_t} P_{ant}^{i} = 0.008$

Source: IEEE Signal Processing Magazine, Jan 2013

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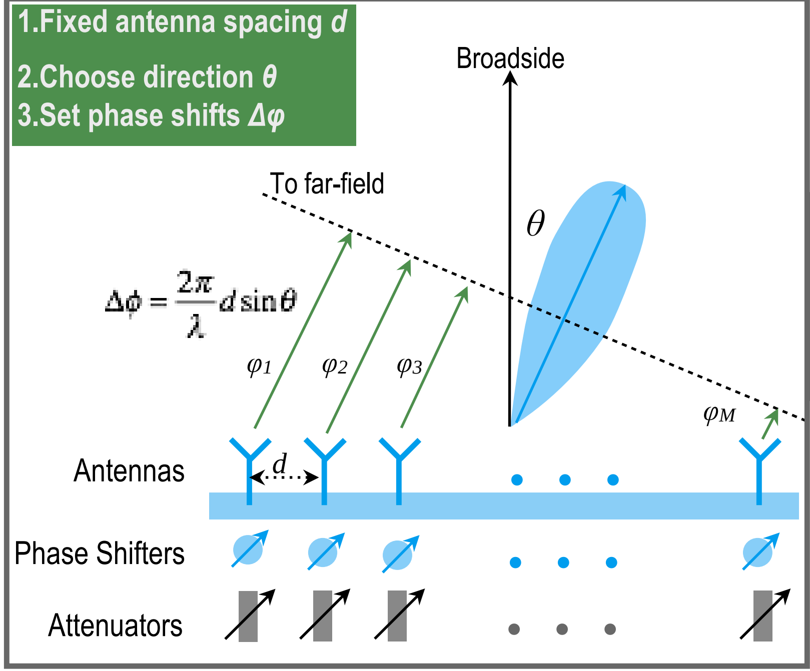
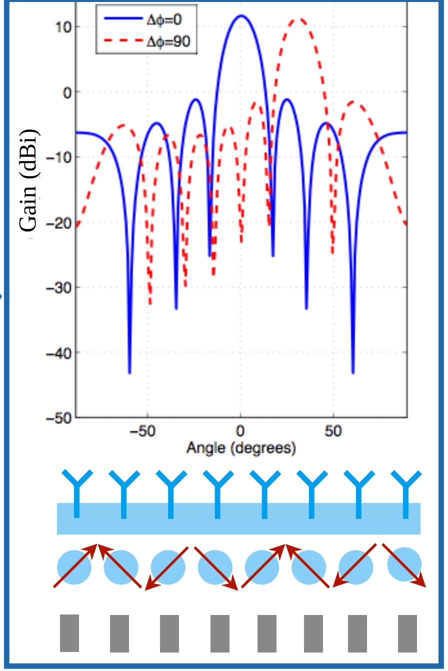
Easiest way to improve energy efficiency: more antennas

How to Steer Beams? 8 Element Dipole Array Example

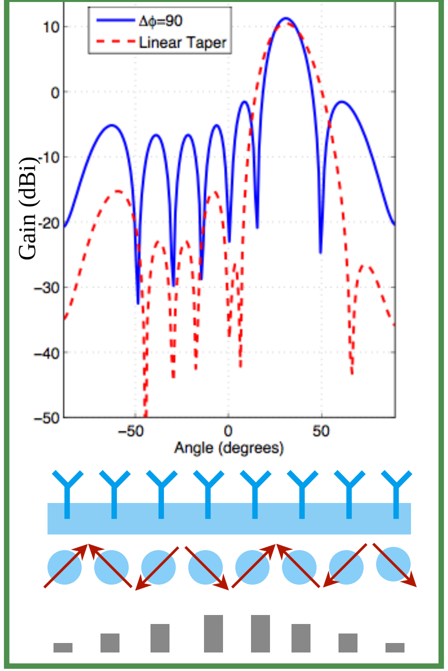
Principle of Beamforming & Beamsteering



Beamsteering (Phase Shift)

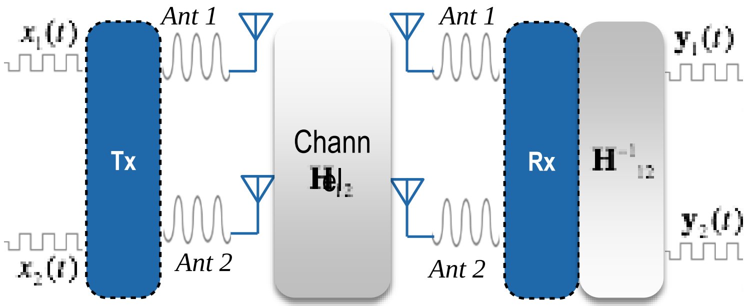


Sidelobe Suppression



System Perspective: From MIMO to MU-MIMO

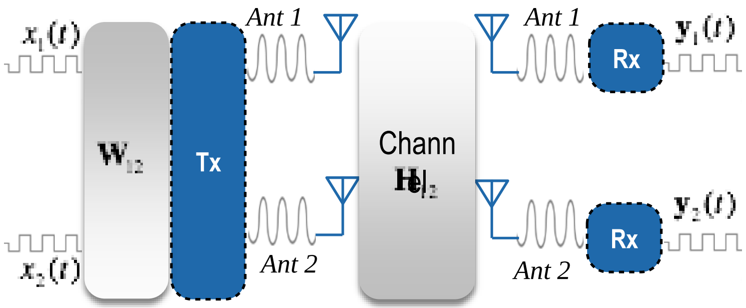
Single User MIMO



1. Tx transmits multiplexed data streams with pilot signals
2. Rx determines channel matrix H from pilot signals
3. Rx calculates inverse channel matrix to recover data

Complexity at Receiver (UE)

Multi-User MIMO



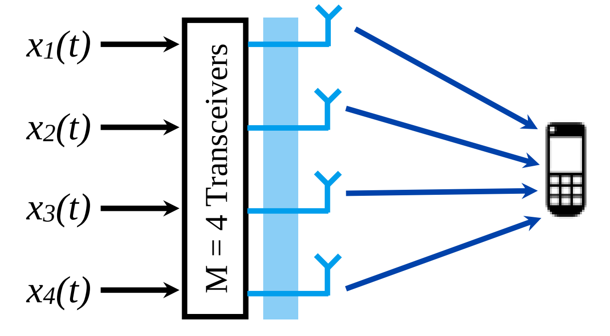
$W_{12} = H^*_{12}\left(H_{12}H^*_{12}\right)^{-1}$ **H***: complex conjugate

1. Tx precodes with weights based on inverse channel matrix with multiplexed data streams
2. Rx receives in-phase waves from Tx
3. Interference is out-of-phase

Complexity at Transmitter (Basestation)

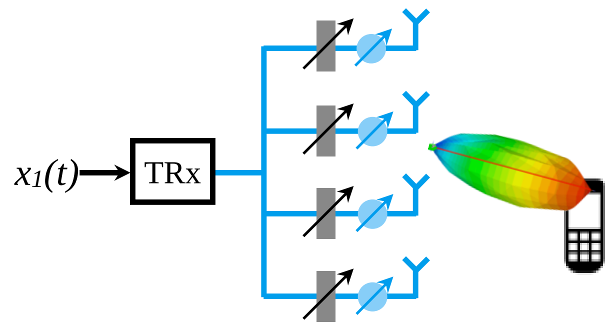
Hardware Perspective: Massive MIMO = Beamforming + MIMO

MIMO Array: *M* Data Streams

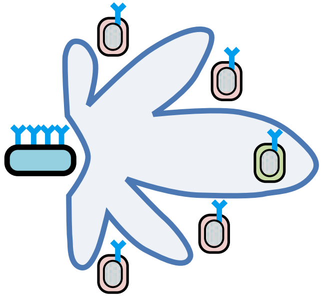


+

Beamforming Array: *1* Data Stream



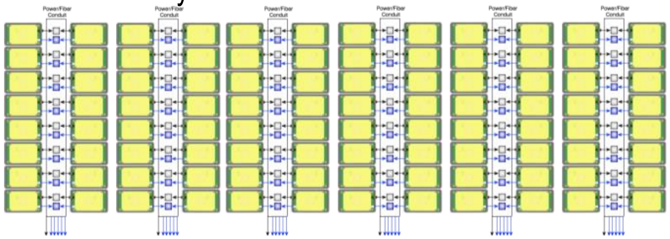
Massive MIMO: Combine Beamforming + MIMO = MU-MIMO with M antennas >> # of UEs



Multi User-MIMO

Increase SINR and capacity for each user
i.e. UE1: 16 ant BF with 16x2 MIMO
UE2: 32 ant BF with 8x2 MIMO

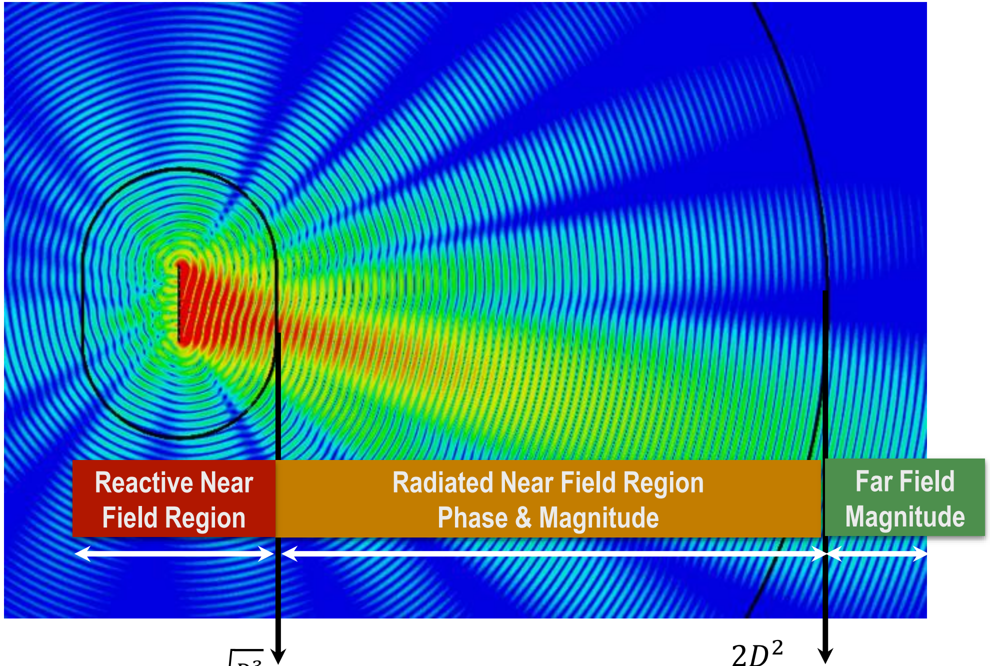
Massive arrays of 128-1024 active antenna elements



Background on over-the-air (OTA) testing technologies

Fundamental Properties: Electromagnetic Fields

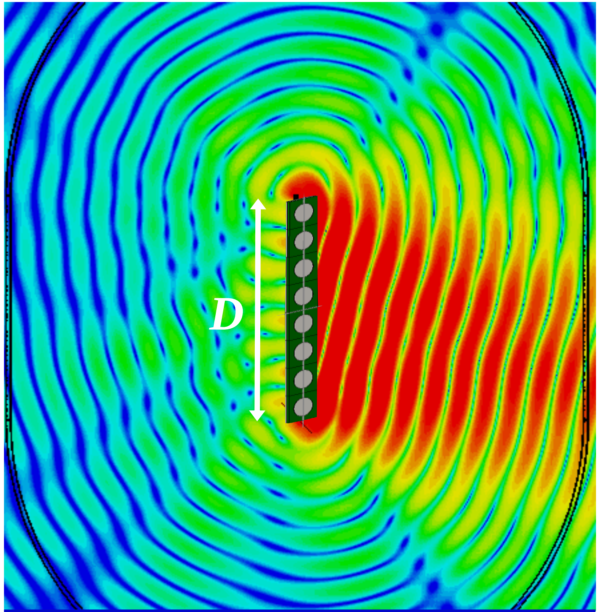
Basestation 8 Element Array at 2.7 GHz



$0.62\sqrt{\frac{D^3}{\lambda}} = 0.6 \text{ m}$

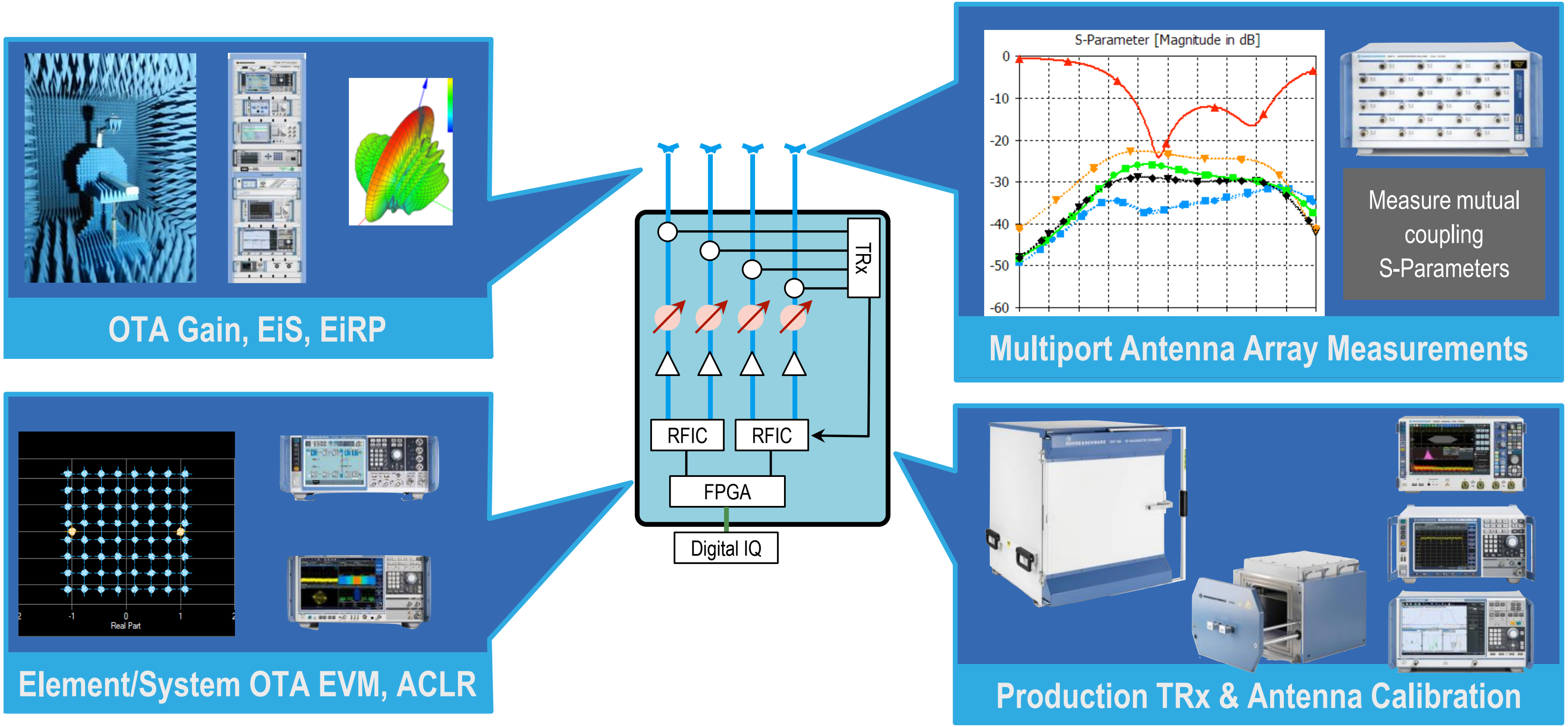
$\frac{2D^2}{\lambda} = 4.5\ m$

Reactive Near Field Region (< $0.6m$)



Any object in this region becomes part of antenna system & interferes with the measurements

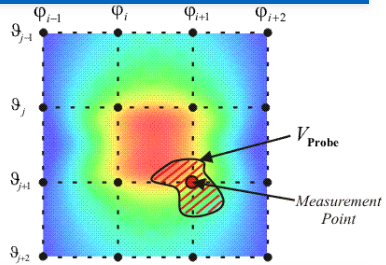
Measuring 5G mmWave & Massive MIMO Systems



Near-field to Far-field Transformation – FIAFTA

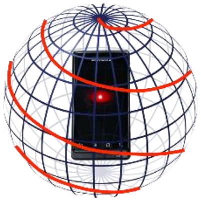
Features

Equivalent Sources



Probe Compensation

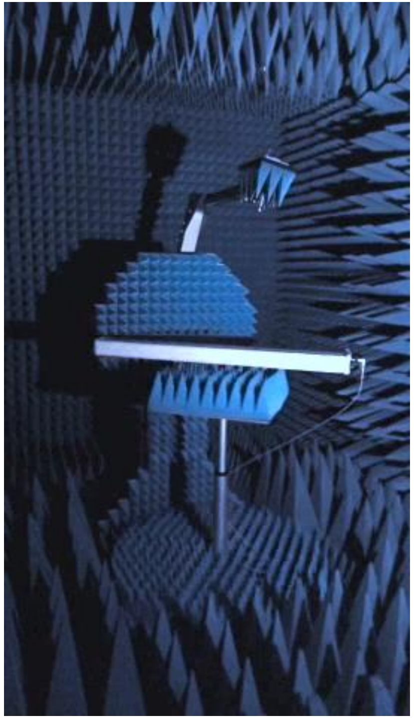
vs.



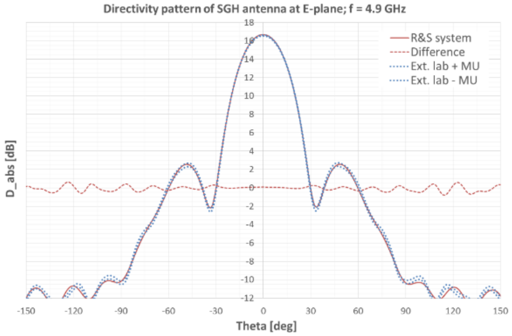
220 minutes

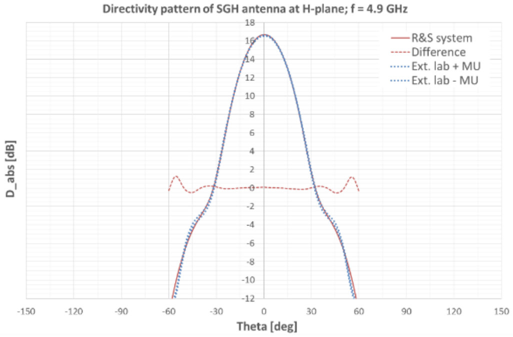
6 minutes

Arbitrary Grids

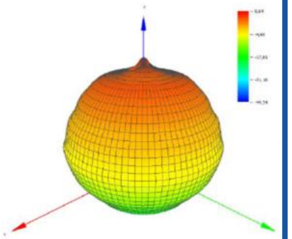


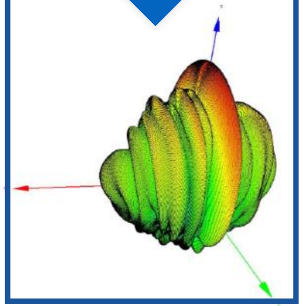
Performance Comparison





Transformation



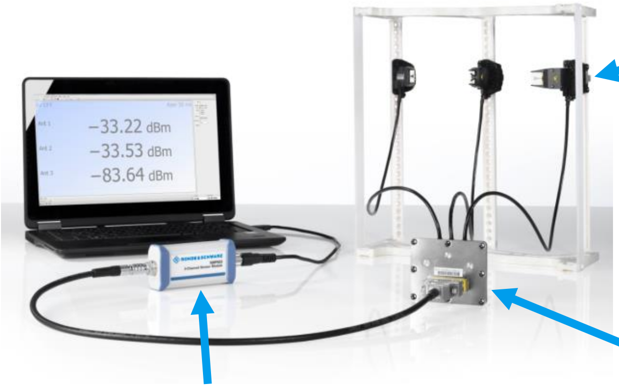


mmWave & 802.11ad test setup in the TS7124

- TS7124 shielded chamber+multiple OTA Power sensors
- OTA power sensor: Vivaldi antenna with integrated diode detector

  No compensation of mmWave cable loss required
- Frequency range 27.5 GHz to 75 GHz
- Power measurements

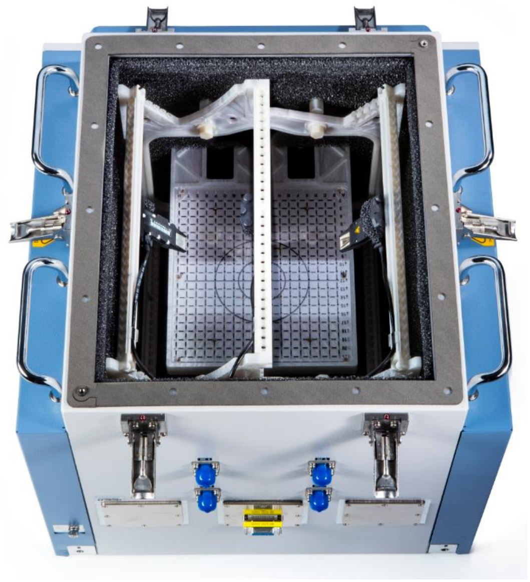
Monitoring PC with Power Viewer Plus



NRPM-A66 Antenna module

NRPM-ZD3 Interface to TS7124

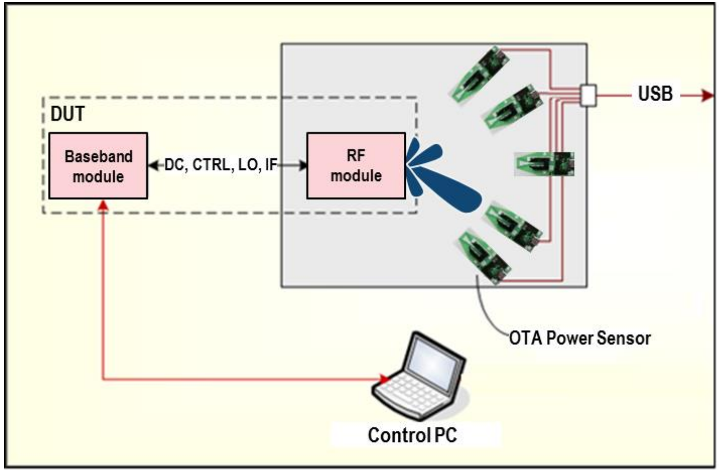
NRPM3 3 channel power sensor

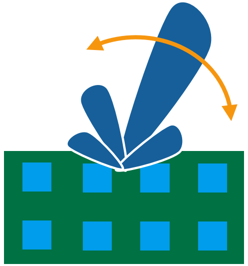


Antenna Array Beamsteering
Magnitude Only

mmWave DUTs will not have antenna connectors

OTA Measurements will be mandatory for production





RF antenna array

Measurement Equipment

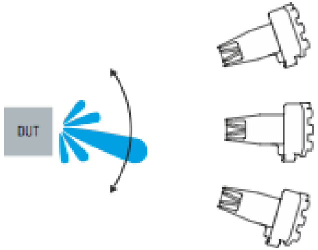
R&S®TS7124

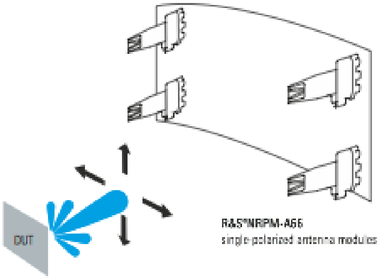
R&S®NRPM

Shielded chamber (TS7124)

Vivaldi Probe 28-77 GHz

Measurement Scenarios





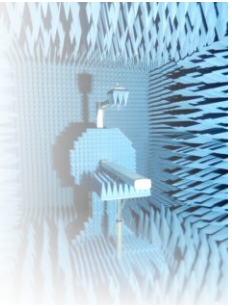
2D Beam-Steering

3D Beam-Steering

R&S Antenna Test Solutions Summary

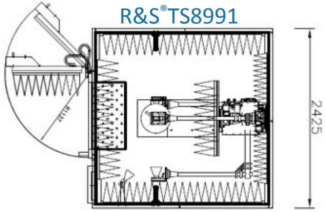
Massive MIMO

R&S®TS8991



CTIA Radiation Patterns

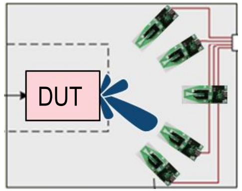
R&S®TS8991



R&S®FSV

R&S®NRP

mmWave Beamsteering



R&S®NRPM

R&S®NRPM-A66

RF Conformance

R&S®TS7380

R&S®ATS1000

mmWave

R&S®ATS1000

R&S®ZVA

R&S®FSW

R&S®SMW200A

Multiport Testing

R&S®SMW200+
6x R&S®SGT100

R&S®ZNBT

- Phase-coherent RF generation
- Multi-port VNA for Active Return Loss

Production & Benchtop

R&S®DST200

R&S®TS7124

R&S®RTO

R&S®FSV/FSP

R&S®ZVC/D

Outline

Channel sounding

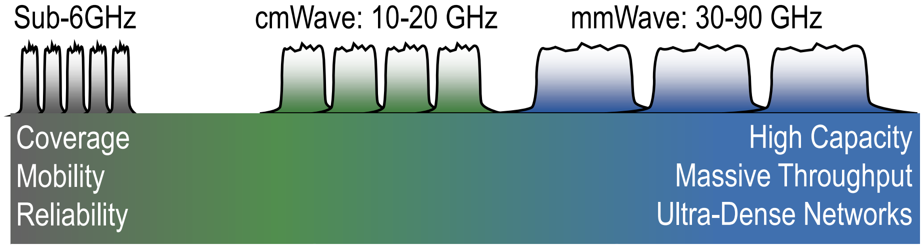
Channel propagation measurements at mm-Waves

Channel measurements for Platooning below 6 GHz

Conclusion from WRC-15 related to 5G frequency candidates

- Considered frequency ranges and bands for 5G at cm- and mm-Waves:
  - 24.25 to 27.5 GHz
  - 31.8 to 33.4 GHz
  - 37.0 to 43.5 GHz
  - 45.4 to 50.2 GHz
  - 50.4 to 52.6 GHz
  - 66 to 76 GHz
  - 81 to 86 GHz.

- 27.5 to 29.5 GHz band is not listed, but is still expected to play an important role for anticipated 5G deployments.



Carrier BW	*n* x 20 MHz	*n* x 100 MHz	1-2 GHz
Cell Size	Macro	Small	Ultra-small
Waveform	Multi-Carrier (OFDM)	Multi-Carrier (OFDM)	Multi-Crrier? Single Carrier?

Recommended Bands < 6GHz (Europe)

Sub 700MHz 470-694 MHz	TD-LTE 2.7-2.9 GHz
L-Band 1350-1400 MHz 1427-1517 MHz	C-Band 3.4-3.8 GHz 3.8-4.2 GHz

Total available bandwidth: **1.3 GHz**

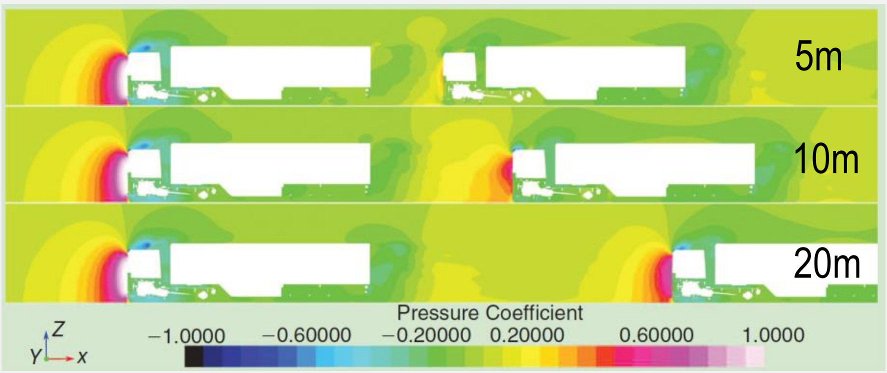
Platooning

„road train“ with „electronic link“ to reduce aerodynamic drag and thus fuel consumption

Platooning: A cooperative method to enhance safety and efficiency

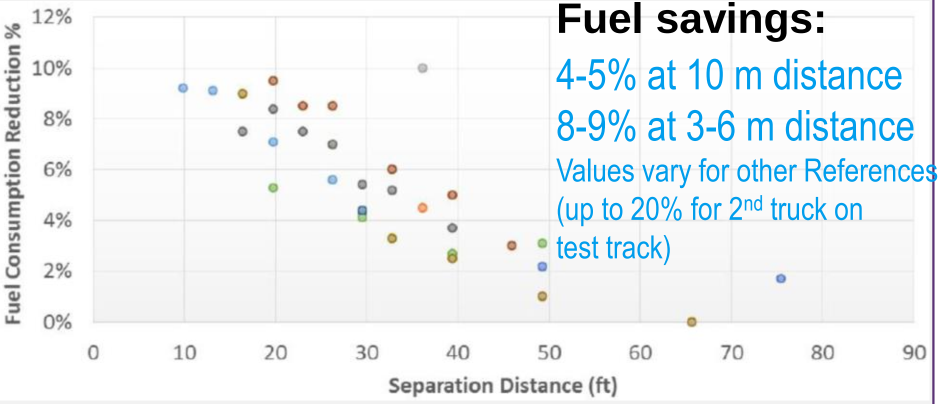
Technologies: radar, stereometric camera, V2X

Aerodynamics (pressure coefficient)



The pressure field for a two-vehicle platoon with a spacing of 5, 10, and 20 m. The pressure coefficient represents a scaled deviation from the nominal air pressure.
Reference: *A. Alam et. al. “Heavy-Duty Vehicle Platooning for Sustainable Freight Transportation”,* In: IEEE Control Systems Magazine, Dec 2015

Fuel Consumption Reduction



Fuel savings:

4-5% at 10 m distance

8-9% at 3-6 m distance

Values vary for other References (up to 20% for 2nd truck on test track)

Reference: 2016 North American Council for Freight Efficiency
CONFIDENCE REPORT: Two-Truck Platooning

⇒ The distance is crucial for fuel reduction (even 1-2m if possible)

⇒ 5G URLLC

3GPP 5G Standardization: RAN#74 (Dec 2016)

Platooning: a 5G use case

NR: New Radio
SA: Standalone
NSA: Non Standalone

TOKYO 2020

2015 | 2016 | Today | 2017 | 2018 | 2019

LTE Advanced Pro | 5G NR Phase 1 | 5G NR Phase 2

Release 13 | Release 14 | Release 15 | Release 16

A GLOBAL INITIATIVE

TR 22.886, December 2016:

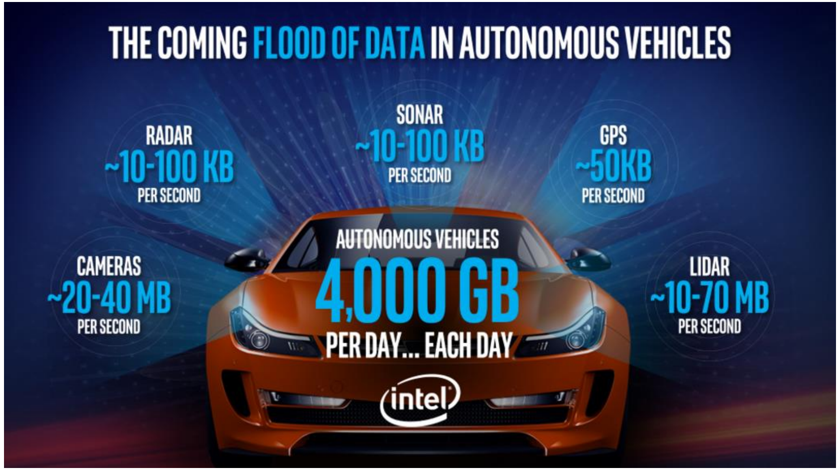
- safe platooning requires reliable wireless communication
- current discussion in 3GPP towards 5G involves long-term development (eV2X) including automated driving

- TR 22.886 V15.0.0 (2016-12)
- Technical Specification Group Services and System Aspects
- Study on enhancement of 3GPP support for 5G eV2X Services
- Important use case “Information exchange within platoon”

- complementary technologies: 11p, LTE-V

5GAA Automotive Association

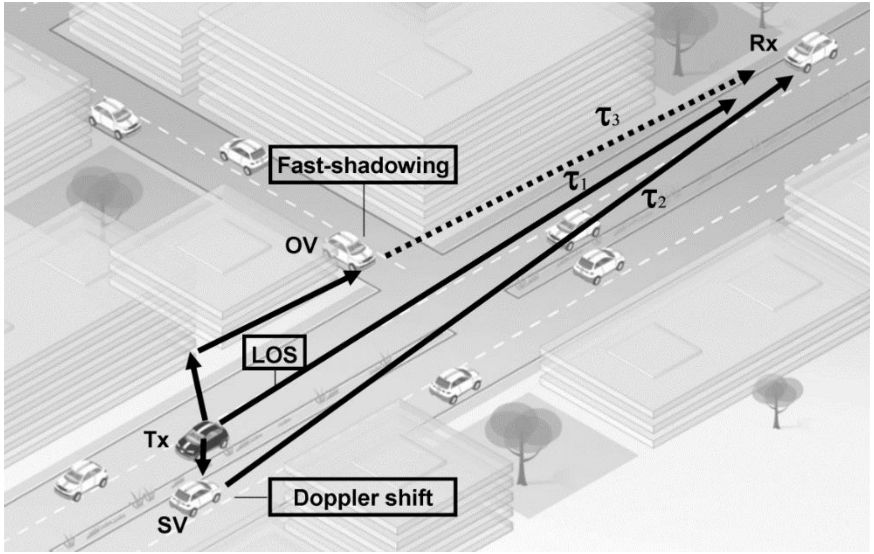
Requirements for eV2X for Platooning



- Exchange of (raw) sensor data (1 Gbps)
- Ultra Reliable and Low Latency (URLLC)
- Could only be accomplished with 5G mmW V2X

- Raw Sensor data enable
  - Cooperative perception
  - 3D real time perception (need to transmit the video from first truck, otherwise truck drivers in truck 2, truck 3 etc. will fall asleep)
  - Satellite view
  - Redundancy
  - Security against attacks
  - Increased sensor accuracy
  - Increased sensor reliability

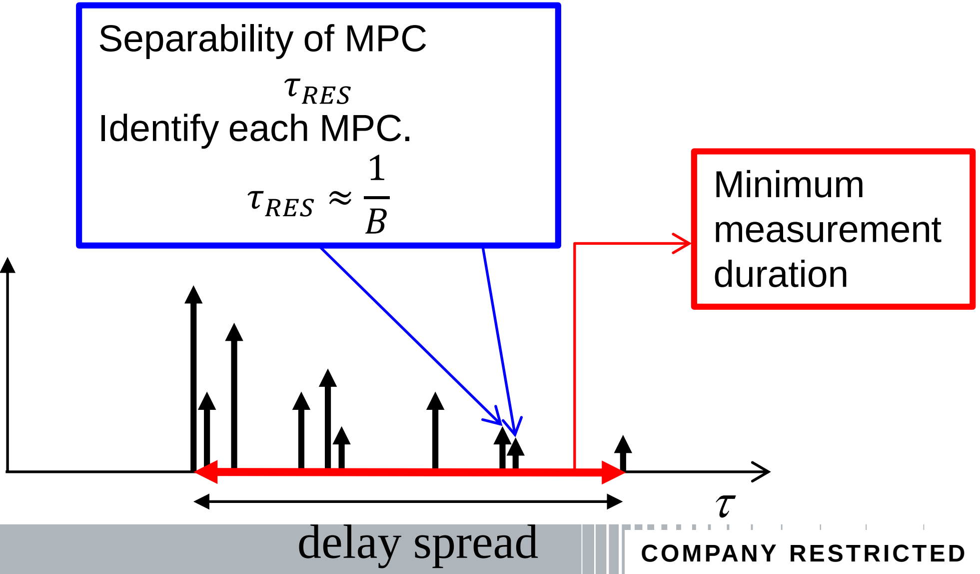
Theoretical review: multipath propagation



Channel impulse response CIR is a theoretical measure to describe the wave propagation: Idea is to excite the channel with a Dirac impulse and to measure the arrivals of that impulse at the receiver. Due to multipath each pulse response is attenuated, delayed and phase shifted.

$$h(\tau,t)=\sum_{i=0}^{L-1} a_i(t)\,e^{j\phi_i(t)}\,\delta(\tau-\tau_i)$$

path attenuation | path phase | path delay

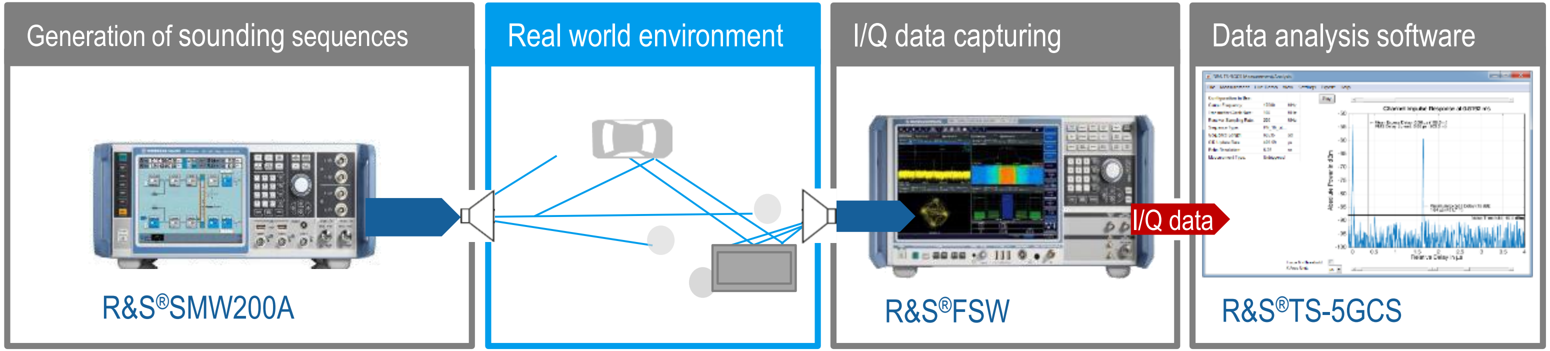


Setup for Channel Propagation Measurements

Channel Impulse Response in the time domain

Channel Sounding Solution

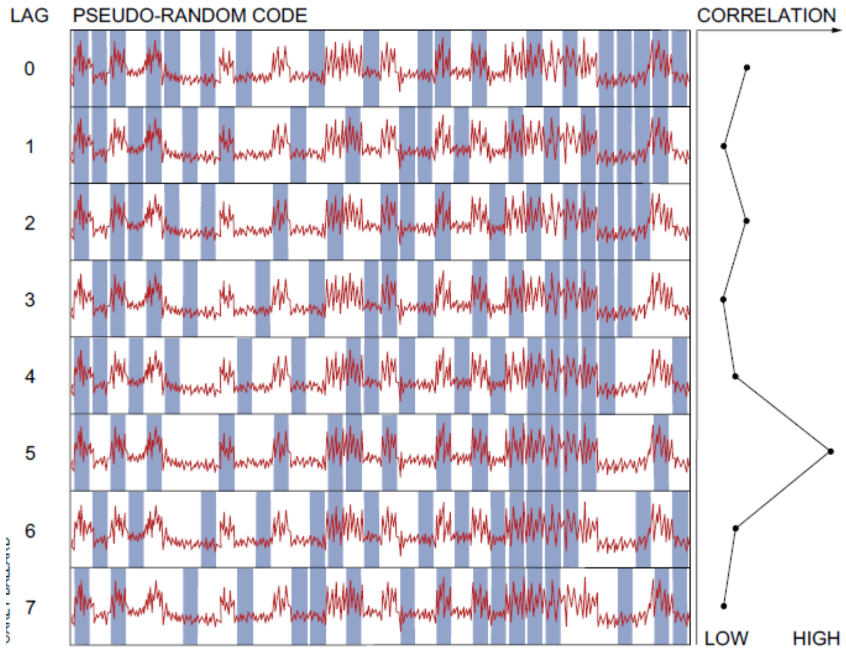
Channel sounding is a process that allows a radio channel to be characterized by decomposing the radio propagation path into its individual multipath components.

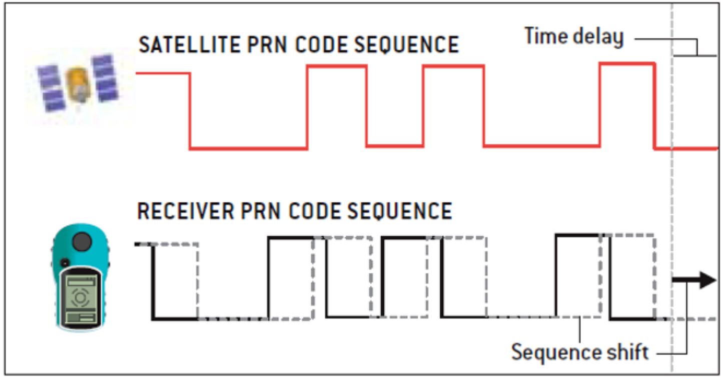


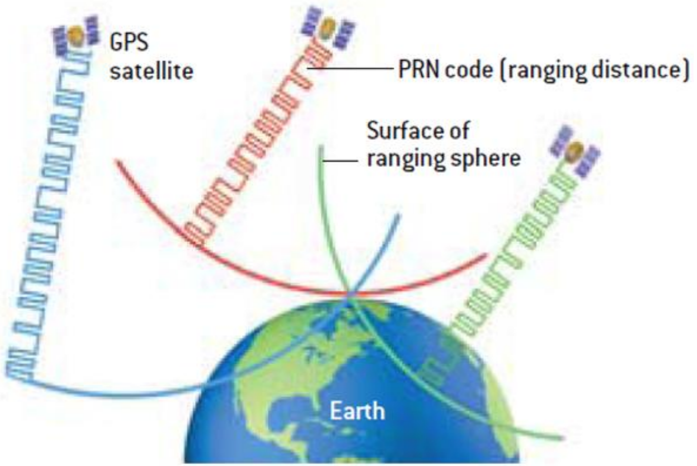
- fast measurement in time domain
- support for in- and outdoor sounding
- very high dynamic range
- Time and frequency reference

Correlation for time delay measurement

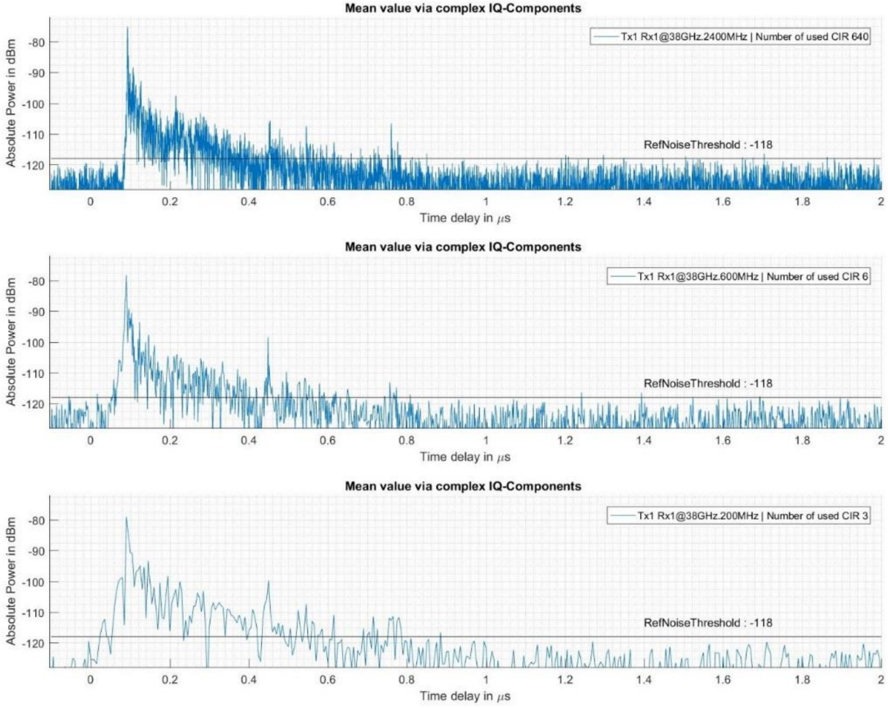
Analogy to GPS (each satellite distinctive PRN "song")



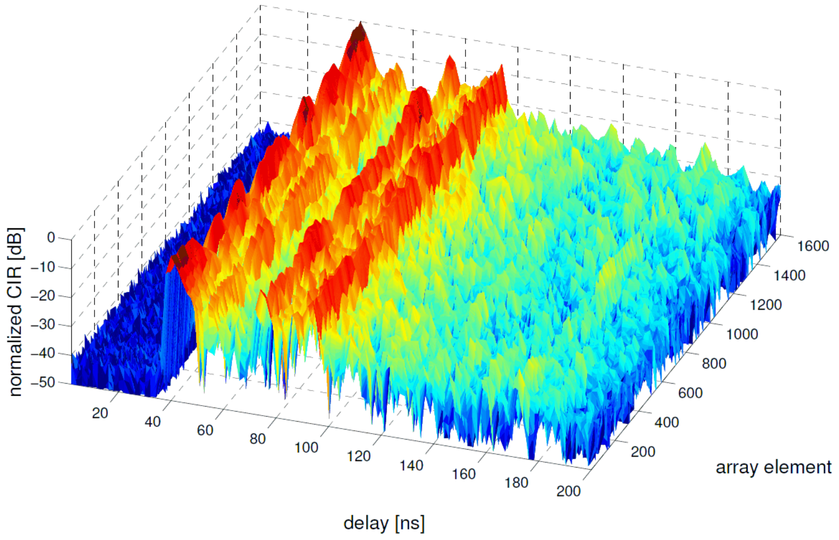




Channel Sounding Measurement Examples



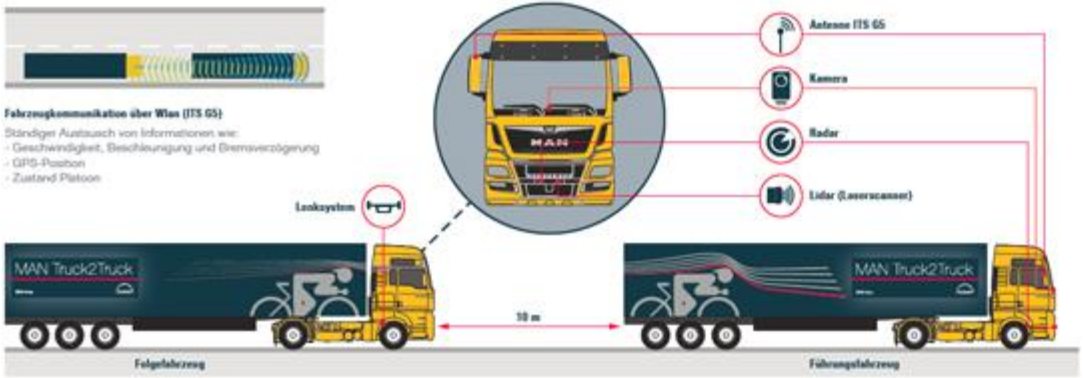
- Industry 4.0: R&S conducted own channel sounding campaigns in industrial surrounding

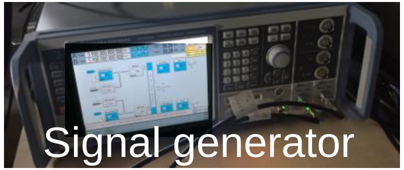


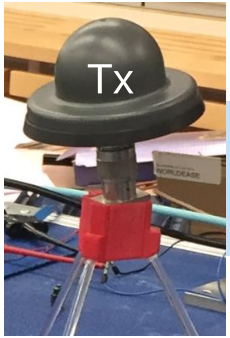
Power delay profile measurements in the factory
Frequencies: 38GHz with 160MHz 500MHz and 2GHz bandwidth (path resolution)

V2X Channel Propagation Measurements at 5.9 GHz (24.11.2016)

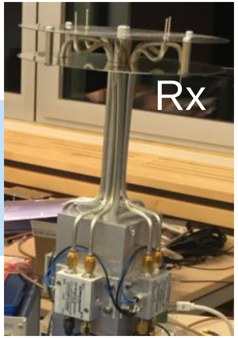
MAN Truck2Truck (Project RoadArt / Platoon)







2x8 MIMO channel measurement



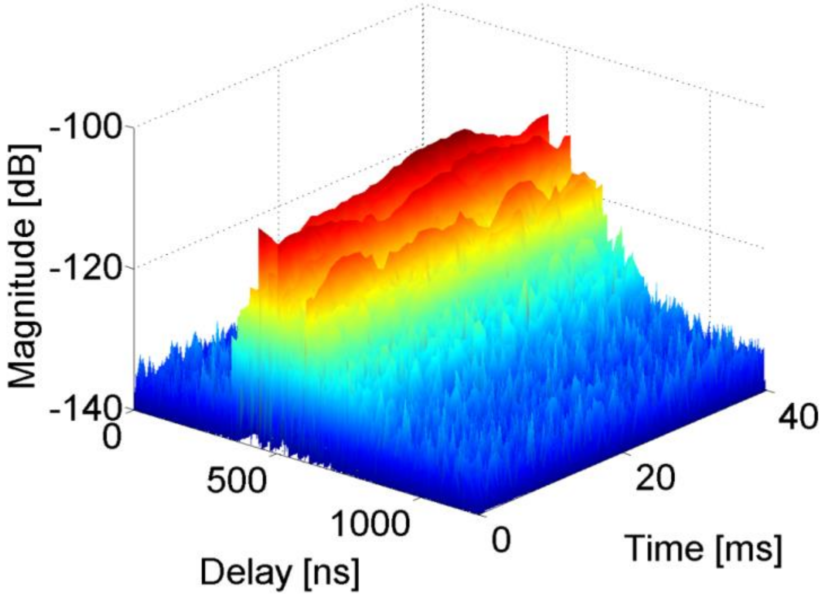
IMST MAN Fraunhofer Heinrich-Hertz-Institut

V2X Channel Propagation Measurements at 5.9 GHz

Various drive Scenarios (highway, intersection, roundabout, tunnel) with 3 trucks

Tunnel Scenario

Typical CIR measurement between moving vehicles



Tunnel scenario

- Direct outcome of measurement
- Line-Of-Sight Path (LOS) and reflected components (multipath contributions: MPC)
- Channel length: 1µs
- Large-scale fading of MPCs due to RX movement

Thank you for your attention !