The mmMAGIC Project

New Frontiers in 5G Mobile Communications and Networking in mm-Wave Bands

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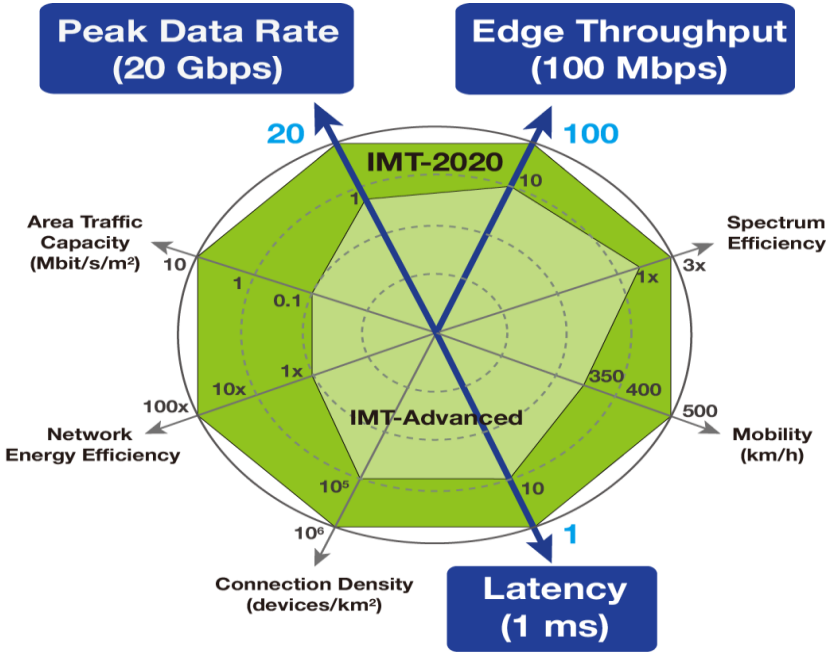
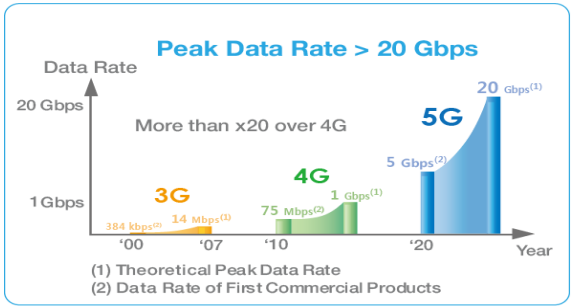
Agenda

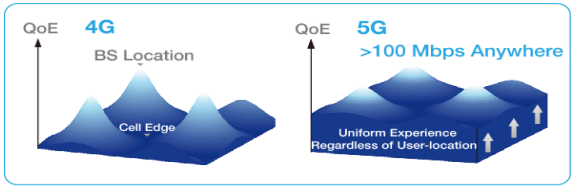
- 5G mm-Wave Spectrum – Standards Status
- Samsung 5G mm-Wave Focus Areas
- 5G PPP mmMAGIC
- What‘s next?

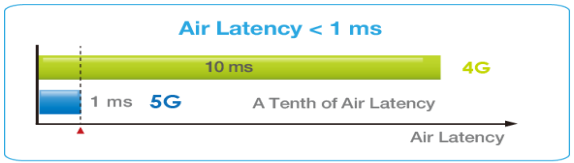
5G and 4G: Key Differences

ITU 5G Requirements









※ ITU-R document 5D/TEMP/625: ITU-R.M.[IMT.VISION] (June 2015)

※ ITU: International Telecommunications Union

5G Spectrum Status

Frequency Ranges Below/Above 6 GHz of by Region (WRC-15)

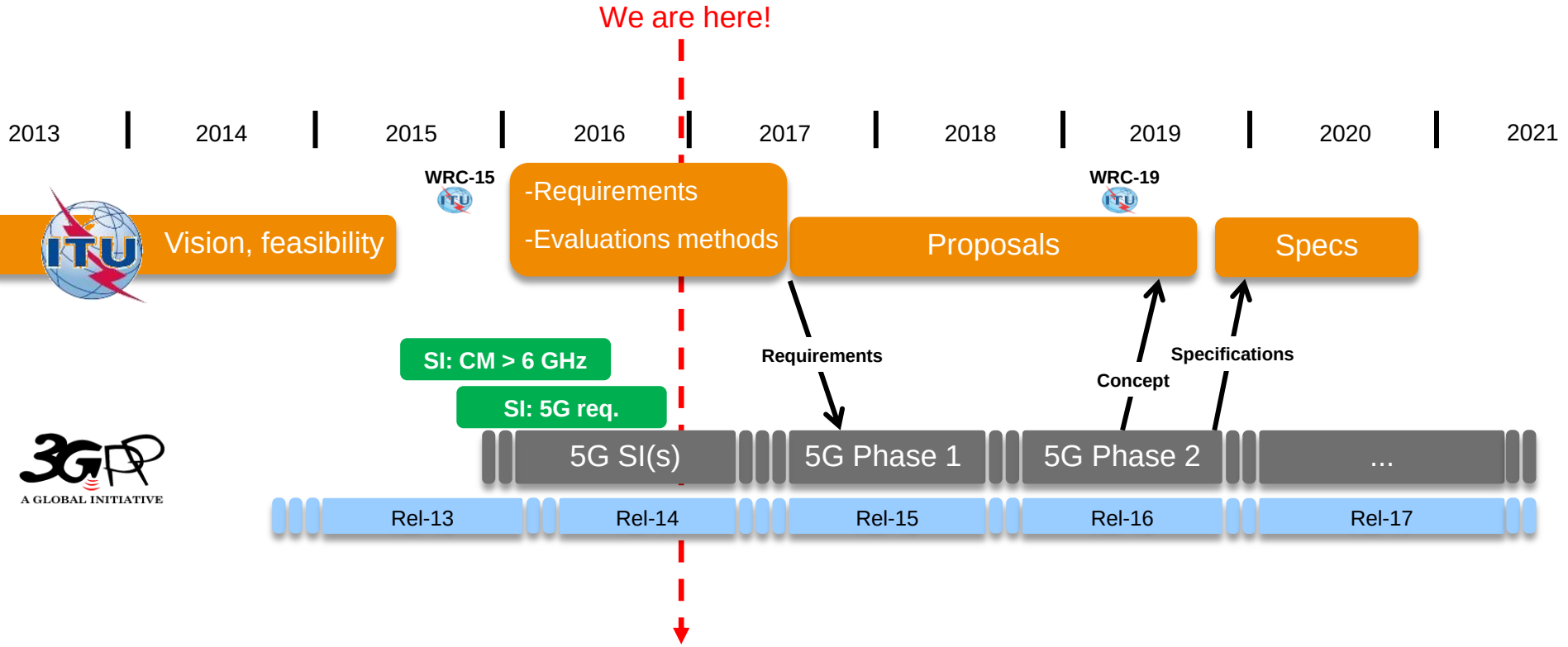
Below 6GHz ← → Above 6GHz/mm-Wave

	< 6GHz (MHz)	6-20	*20-30*	30-40	40-50	50-60	60-70	70-80	80-100
APAC *(APT)*	1427 – 1452 1492 – 1518		25.25 – 25.5	31.8 – 33.4	39 – 47 47.2 – 50.2	50.4 – 52.6	66 – 76		81 – 86
Europe *(CEPT)*	1427 – 1518 3400 – 3800		24.5 – 27.5	31.8 – 33.4	40.5 – 43.5 45.5 – 48.9		66 – 71 71 – 76		81 – 86
Americas *(CITEL)*	1427 – 1515 3488 – 3600	10 – 10.45	23.15 – 23.6 24.25 – 27.5 **27.5 – 29.5**	31.8 – 33 37 – 40.5	45.5 – 47 47.2 – 50.2	50.4 – 52.4	59.3 – 76		
Russia *(RCC)*	5925 – 6425		25.5 – 27.5	31.8 - 33.4 39.5 - 40.5	40.5 – 41.5 45.5 – 47.5 48.5 – 50.2	50.4 – 52.4	66 – 71 71 - 76		81 - 86
Mid. East *(ASMG)*	1452 – 1518 3400 - 3600			31 - 100					

※ APT : Asia-Pacific Telecommunity (APT)
CITEL : Inter-American Telecommunication Commission
ASMG : Arab Spectrum Management Group

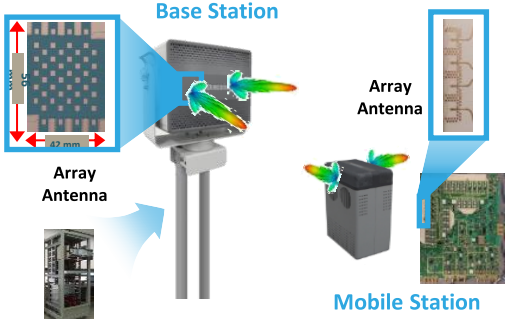
CEPT : European Conference of Postal and Telecommunications Administrations
RCC : Regional Commonwealth in the Field of Communications (Russia etc.)

Standardization and Spectrum Allocation Timelines



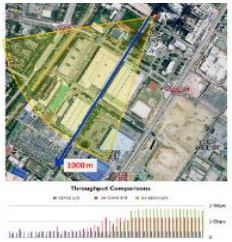
5G mmWave – Samsung's achievemnts

mmWave Testbed (2013/4)



Coverage Testing (2015)

3-Cell Coverage Map

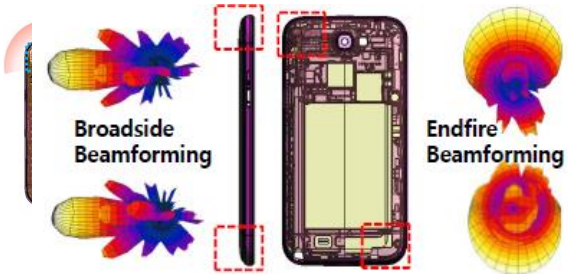


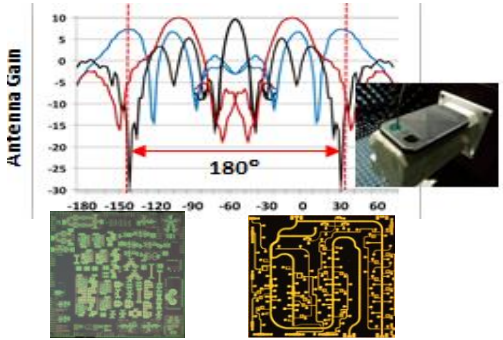
Range Testing

Handover Capability

LoS and NLoS Handovers
(<21ms with fast adaptive hybrid beamforming)

Devices/ Chipsets





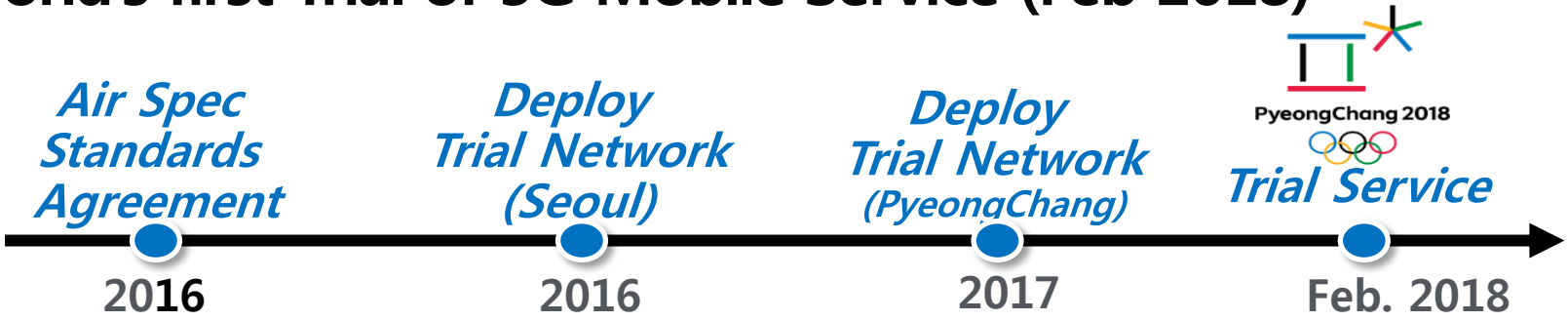
Beam-forming Radio Frequency Integrated Unit

Fixed wireless access

Commercial products 2018

KT 5G Mobile Trial Service @ PyeongChang, Korea

World's first Trial of 5G Mobile Service (Feb 2018)

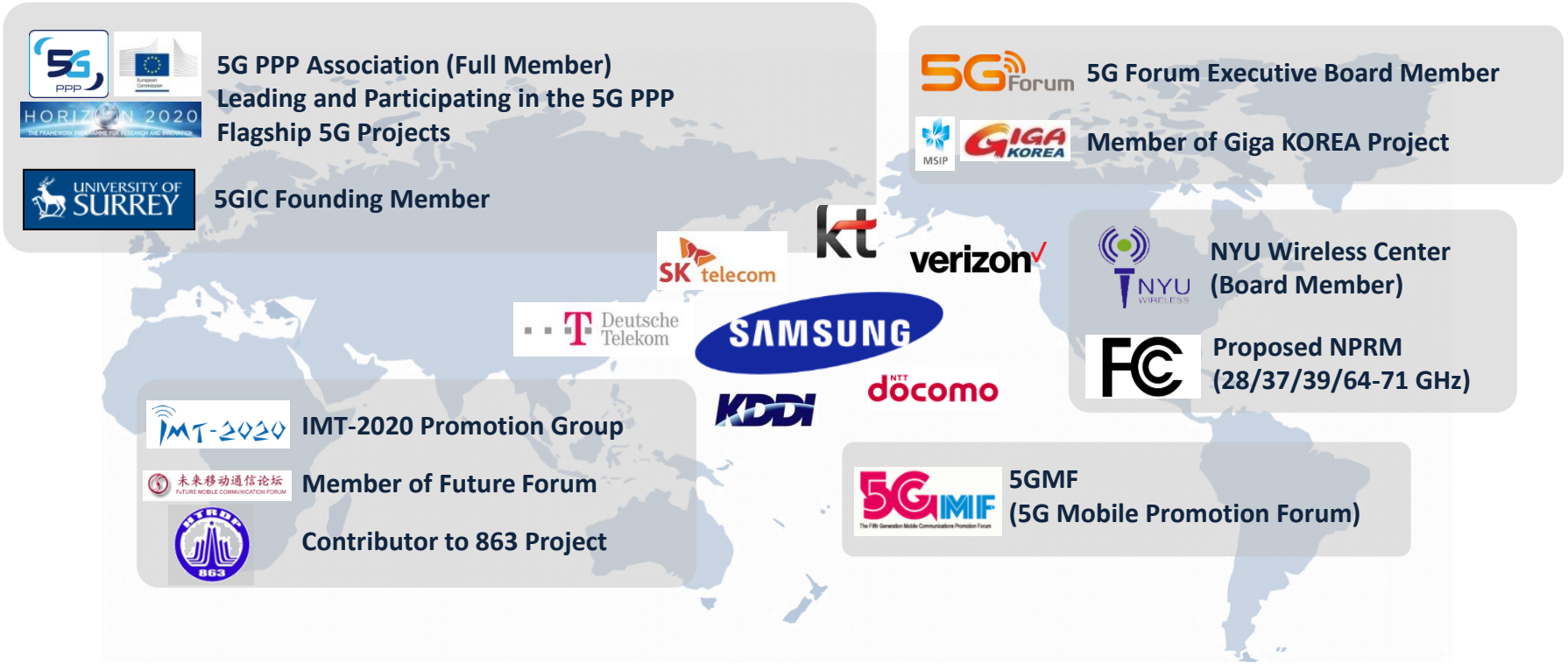


PyeongChang 5G Trial Scenarios
(Source : KT)

Sync View

5G Bus

Global 5G Initiatives with Samsung's Active Engagements



mmMAGIC Overview

Part of 5G PPP under the Horizon 2020 - Research and Innovation Framework Program

Partners: Samsung (Coordinator), Ericsson (Technical Manager), Huawei (WP3), Intel (WP1), Nokia (WP3), Orange, Telefonica,
CEA-LETI, Fraunhofer HHI (WP2), IMDEA Networks, Aalto University, University of Bristol, Chalmers University of Technology, TU D resden, Qamcom, Keysight Technologies, Rohde & Schwarz

Project Duration: July 2015-June 2017

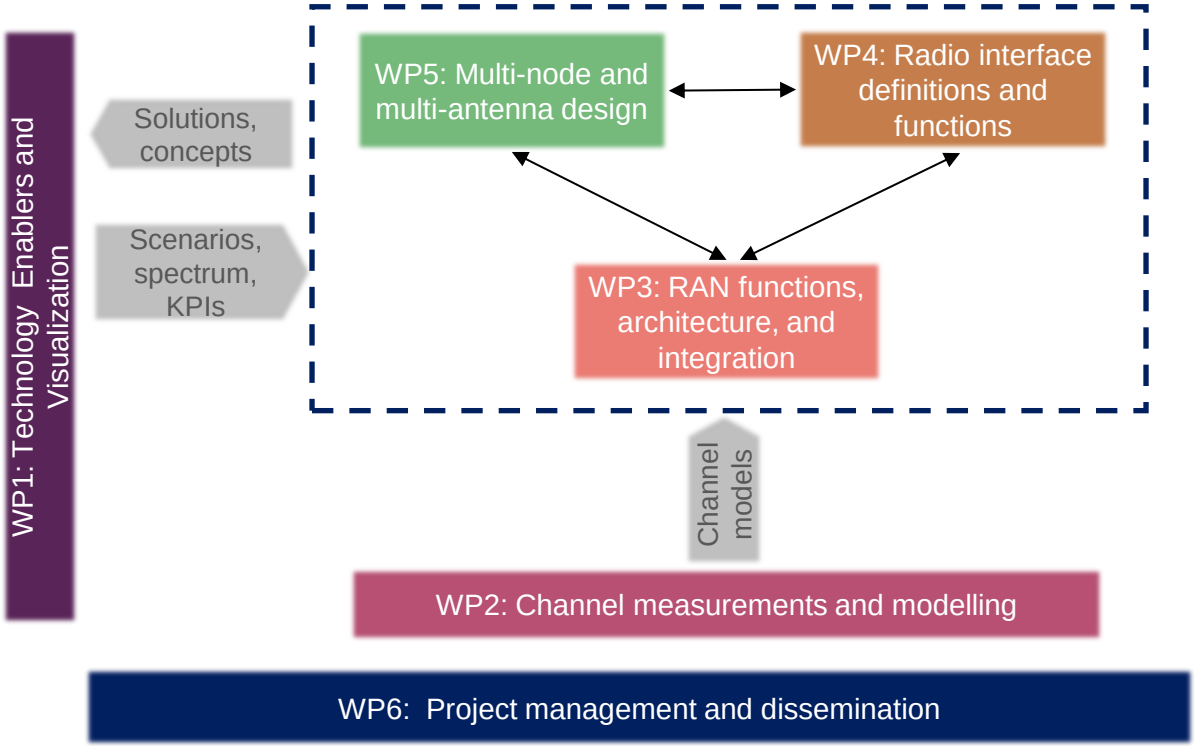
Advisory Board: ANFR, BNetZa, FICORA, Ofcom, PTS, ETSI, Sony Mobile, BMW, U. Illemenau

One of the largest EU-funded 5G project, focusing on key radio technologies, channel models and architecture component of 5G systems operating in mm-Wave frequencies

mmMAGIC's Achievements

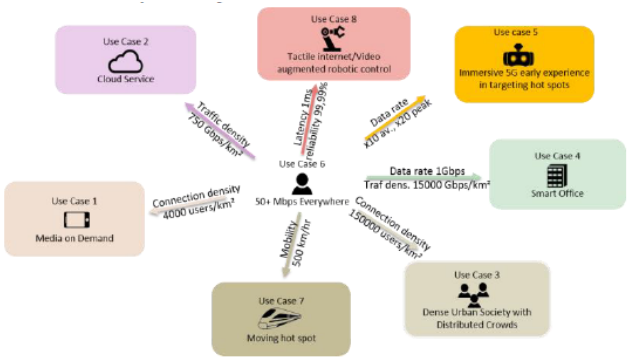
- ✓ **European Commission**: 8 high quality technical deliverables submitted on time to EC
- ✓ **Standards**: 15 contributions to 3GPP Study Item on 5G and counting
- ✓ **Spectrum** : 3 contributions to ITU-R SG3 and ramping up
- ✓ **Software :** 3D channel mode l (6-100 GHz), open source software, downloadable from mmMAGIC website
- ✓ **Hardware:** HW demos of 5G candidate waveforms. phased-array antenna beam –forming. channel sounders for 6-100 GHz
- ✓ **White Papers :** 2 white papers on mm-wave channel and 5G architecture
- ✓ **5G PPP** : WG Architecture, Spectrum, Evaluation, Vision contributor, Contributed to 5G PPP KPI achievement. Joint public workshops /panels with several other 5G PPP projects (METIS-II,F5G, 5G-NORMA, Flexware-5G) , Co-editor of 5G SRIA
- ✓ **Scientific publications :** 40+ research publications (accepted /submitted) including best paper award PIMRC
- ✓ **Dissemination :** 15+ keynote/panels/workshops at IEEE and European flagship conferences ; Strong presentence at ICT 2015, EUCNC, MWC'15 , Net future 2015 **,** 5G Global Event 2016
- ✓ **International Dimension /Visibility:** Brooklyn 5G Summit (USA) , IEEE 5G Summit (Europe), Global 5G Technology Summit (China) , WWRF (China), NGMN (Canada), European partner of NSF industry-academia collaboration on 5G mm-wave (USA); Brazil , Australia, Canada collaboration requests
- ✓ **mmMAGIC website** : Over 21000 hits (peaks at deliverable releases) and growing

mmMAGIC key components / interaction



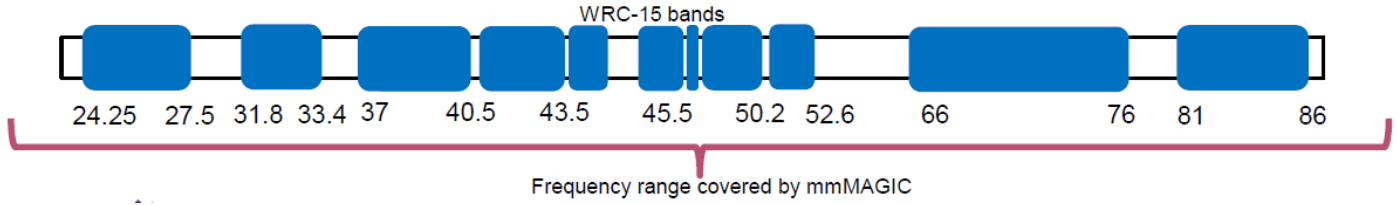
5G Use Case Characterization, KPIs and Frequency ranges

Use case families



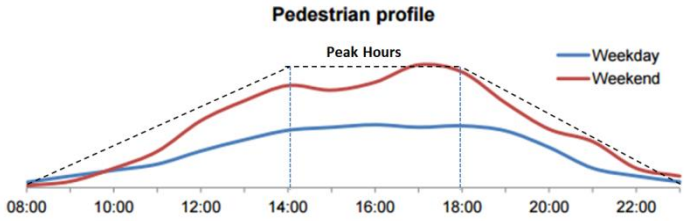
Estimated bandwidth

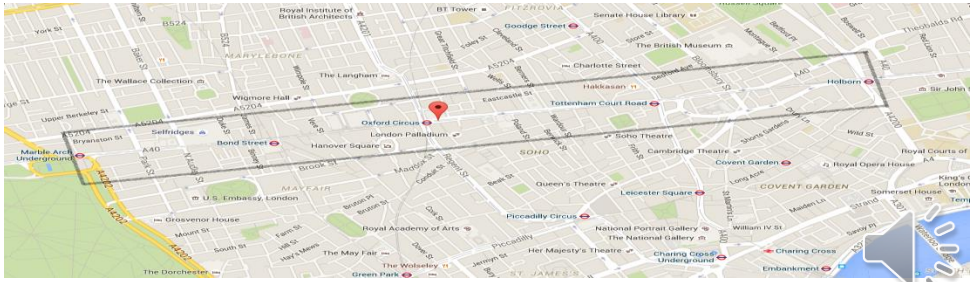
Use case	BW-DL (MHz)	BW-UL (MHz)
1	500	10
2	300	50
3	2250	1175
4	1000	270
5	1640	820
6	588	294
7a (Relay/cell in-vehicle)	100	50
7b (No in-vehicle cell/relay)	>5GHz	>2.5GHz
8a (Robotic control)	500	10
8b (Tactile internet)	10	10



Data Rate and BW Analysis of a 5G Use Case

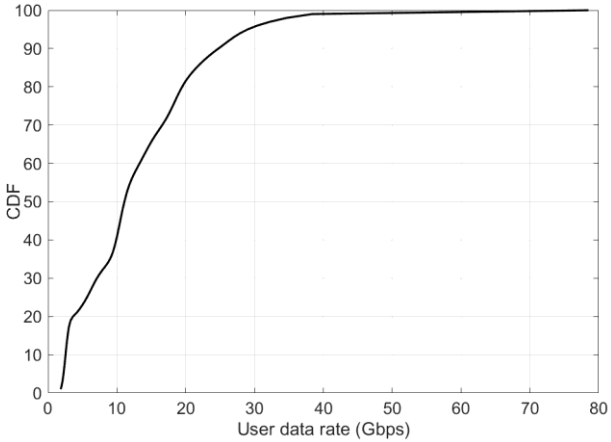
- 5G immersive experience use case
  - Applications of UHD, VR, mobile gaming to be supported.
  - 100Mbps base line data rate with up to 20Gbps peak rate.
  - Dense deployments in a 0.1km^2 area, with around 40 small cells supporting 1000 active users.
- The use case has been mapped to a real life scenario, Oxford St., London, the premier shopping area.

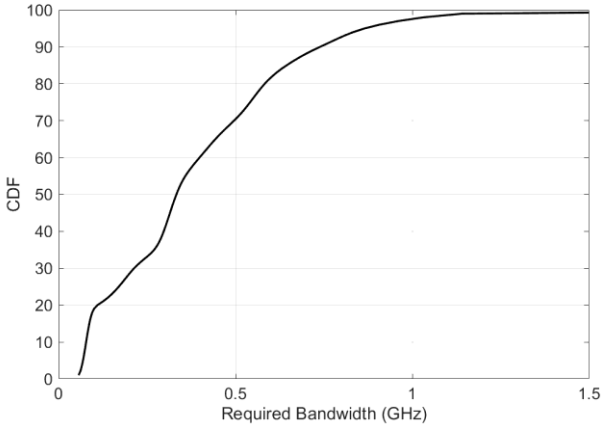




Results

- What would be the typical data distribution in the 5G small cell?
  - 4 user application types considered. Web browsing, content sharing, VR experience and UHD video.





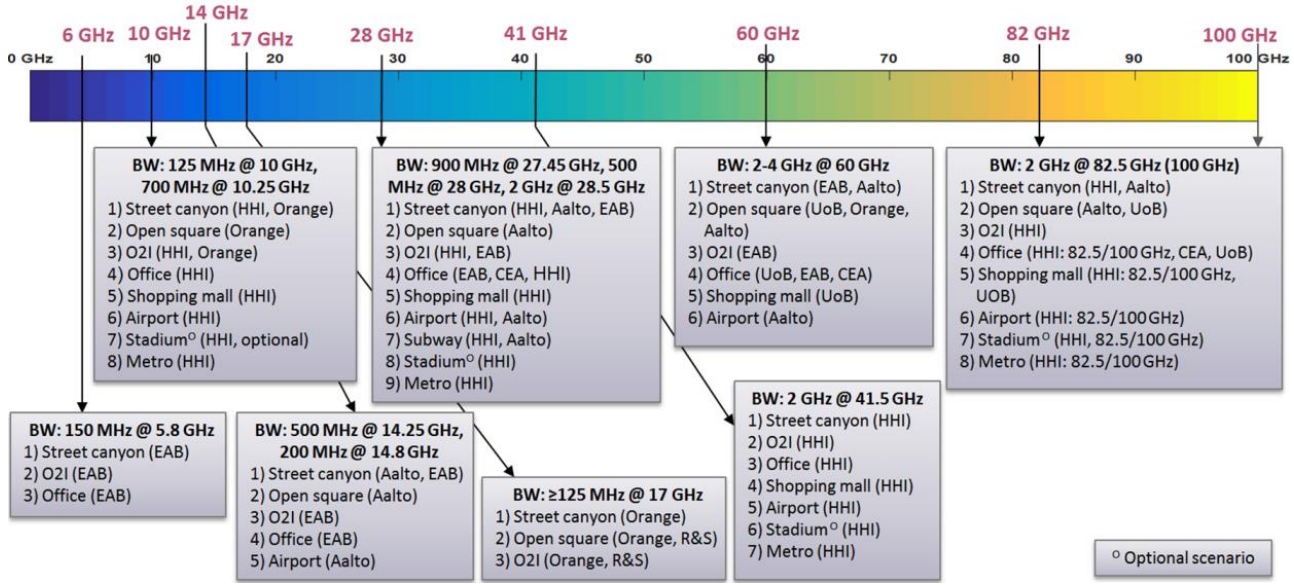
- The statistical analysis of data rate is converted to BW requirement.
  - Considering spectral efficiency=7.3, densification=4.
  - 1.15GHz BW needed to satisfy 99% of active users, 860MHz needed to satisfy 95% of active users.
  - The results are lower-bounds to requirements as low initial take-up of VR and UHD services are assumed in the study

Presented at IEEE ICC 2016 Workshop on 5G RAN Design, May 2016, KL, Malysia

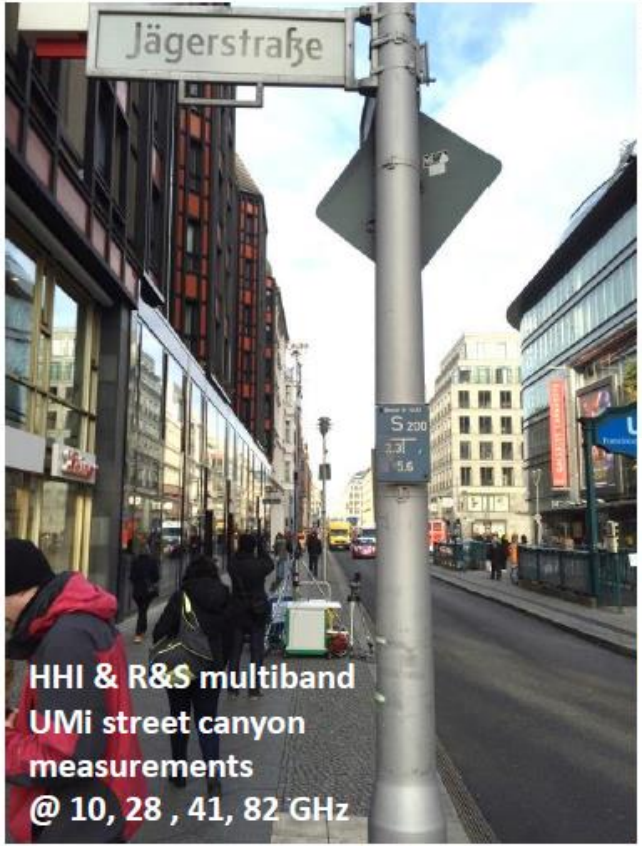
5G Channel Measurements and Modelling

- Measurement campaigns: over 20 measurement campaigns in more than 8 frequency bands from 6 to 100 GHz are ongoing across 5 European countries, and will continue till the end of the project.

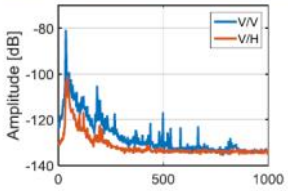
- Scenarios: UMi street canyon, UMi open square, indoor office, indoor shopping mall, indoor airport, outdoor to indoor (O2I), metro station and stadium.
- New channel model in line with the 3GPP-3D has been implemented supporting 10-80 GHz.



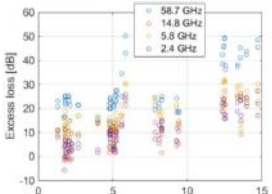
Measurement Campaigns (2)



Aalto's street canyon microcell measure-ments @ 28GHz, Finland

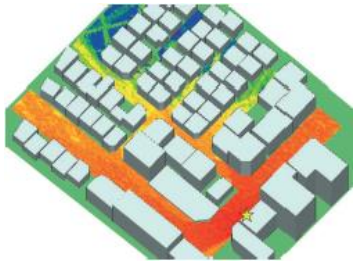


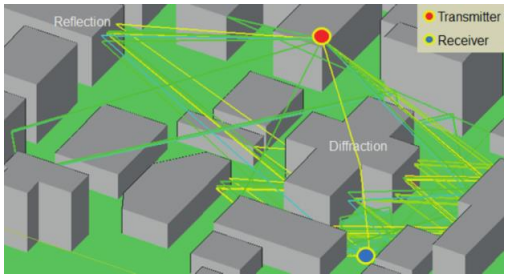
Ericsson's O2I measurements @ four frequencies, Sweden



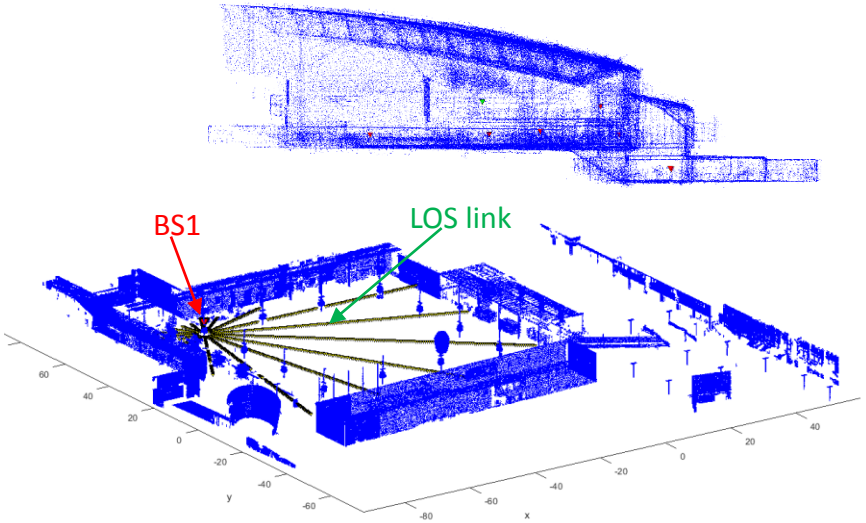
- Hybrid approach: Measurements and map-based simulations
  - combine measurements and prediction
  - measurement data for calibrating

Ray Tracing modelling (Samsung)





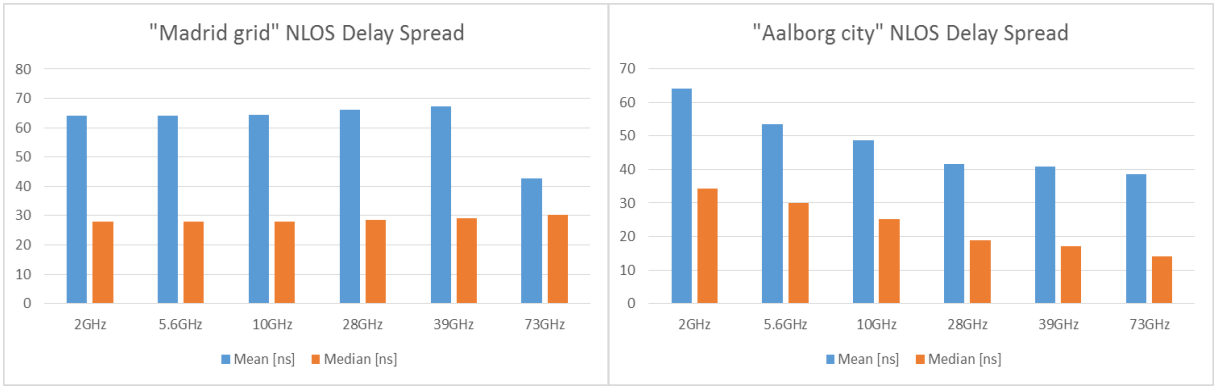
Map modelling (AALTO)



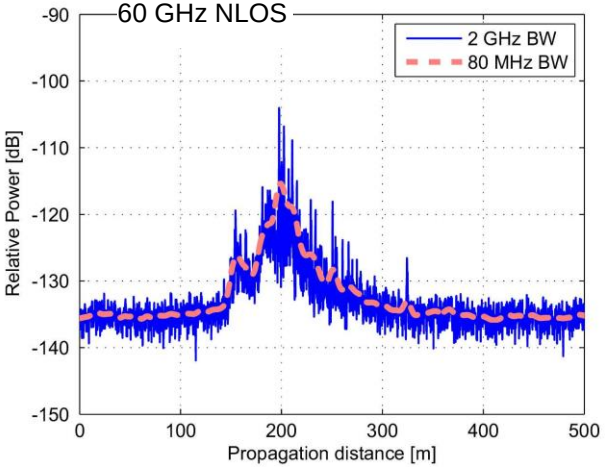
Analyzing trends in mm-wave propagation

- extracted and analyzed channel parameter from measurement & simulation data
  - e.g. bandwidth & frequency dependency

Frequency dependency

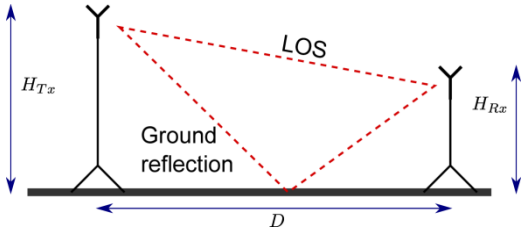


Bandwidth dependency

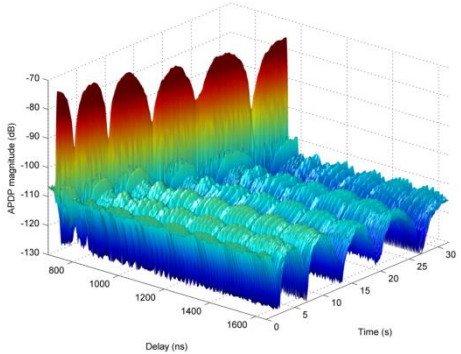


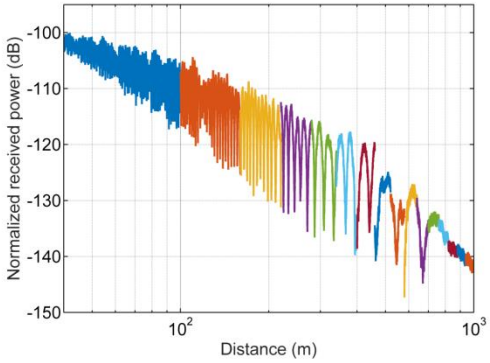
Analysis and interpolation of channel characteristics (1/3)

- Ground reflection

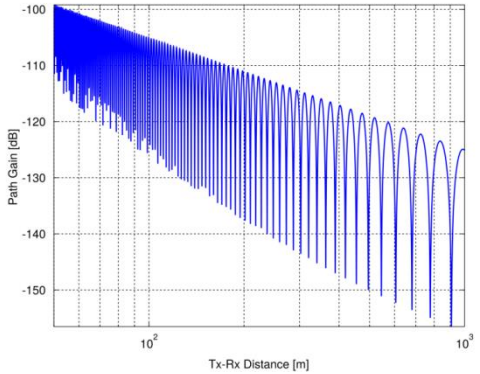


Measured ground reflection (HHI)



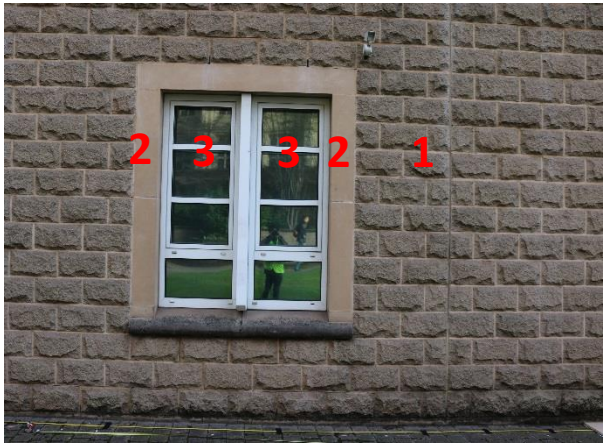


Modelled ground reflection

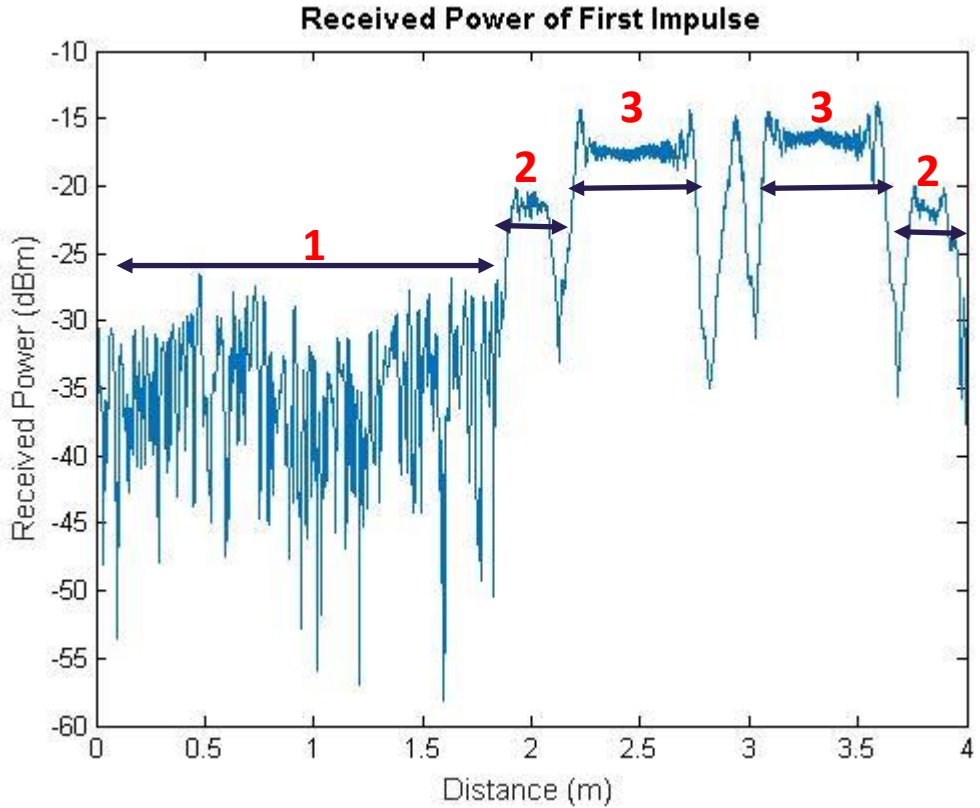


Analysis and interpolation of channel characteristics (2/3)

- Diffusive scattering



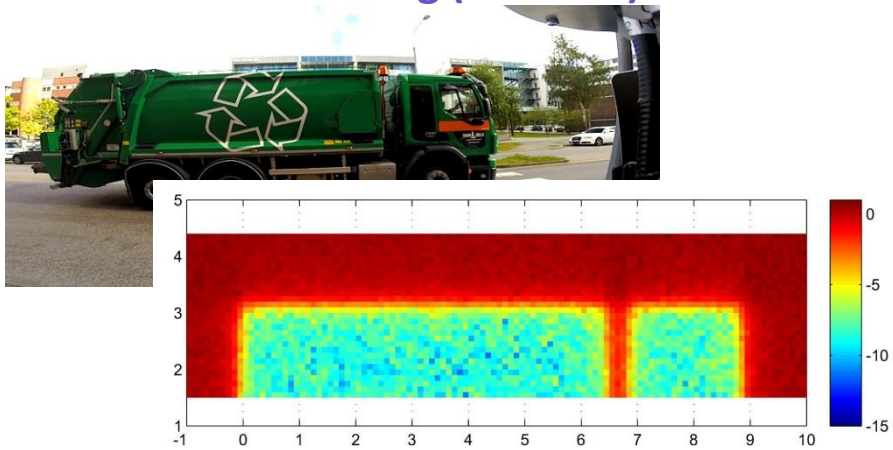
- Area 1: Rough wall
- Area 2: Smooth transition
- Area 3: Window (smooth surface)



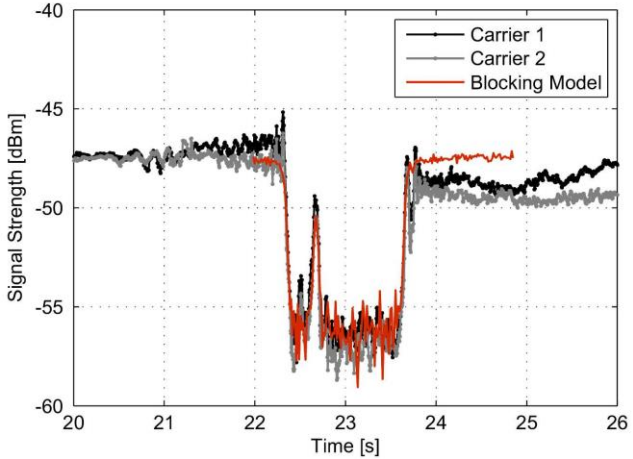
Analysis and interpolation of channel characteristics (3/3)

- Blocking model

Measured blocking (Ericsson)



Modelled blocking

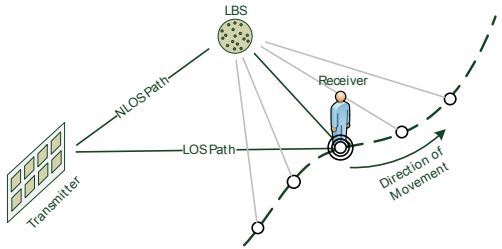


Channel models

- mmMAGIC channel model / QuaDRiGa reference implementation
  - Compatibility with 3GPP-3D (calibrated)
  - Full spatial consistency for single MT: tracking of paths, angles, delays, etc.; smooth scenario transitions
  - Initial mmMAGIC model implemented in QuaDRiGa version 1.4: parameter tables for 10–80 GHz (in addition to 0.45–6 GHz), up to 100 MHz bandwidth
  - Smooth time evolution of large-scale and small-scale channel parameters including the transition between different scenarios

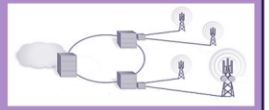
Quadriga
The Next Generation Radio Channel Model

Long-term time evolution



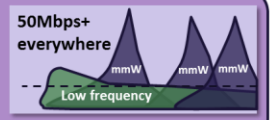
5G RAN Functions and Architecture Integration

Architectural enablers and deployment aspects



Provide cost and energy efficient architecture design and deployment requirements for 5G networks

Network integration for an edge-less mm-wave access



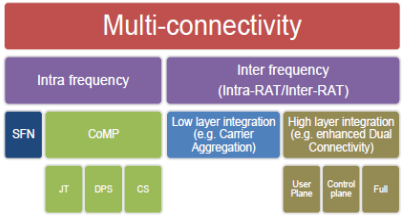
Design solutions for interworking of mm-wave nodes

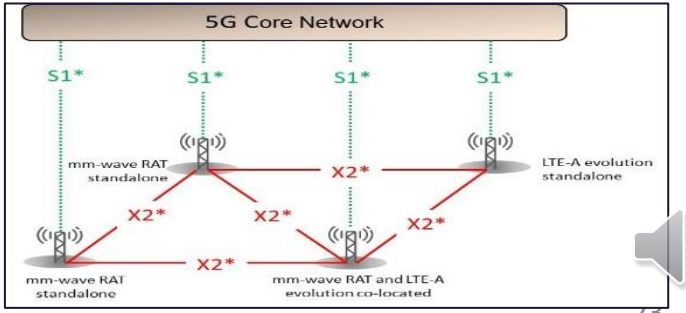
Methodologies for dynamic deployments

Provide backhaul connectivity and overall network planning, networks flexible both in structure and operation

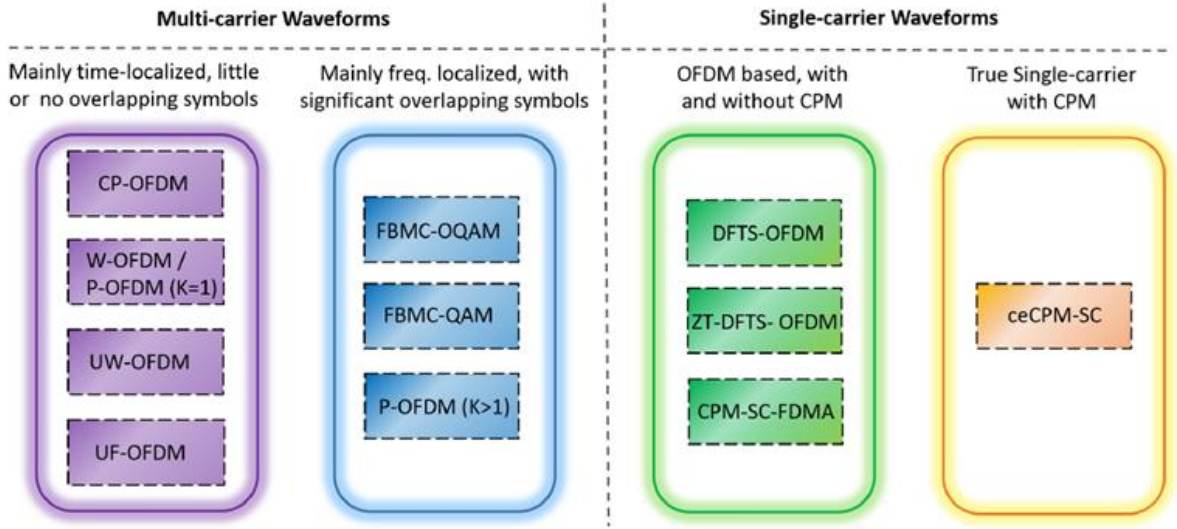
Concepts and solutions for 5G architecture.

* D3.1 Initial concepts on 5G architecture and integration.





Design of waveforms

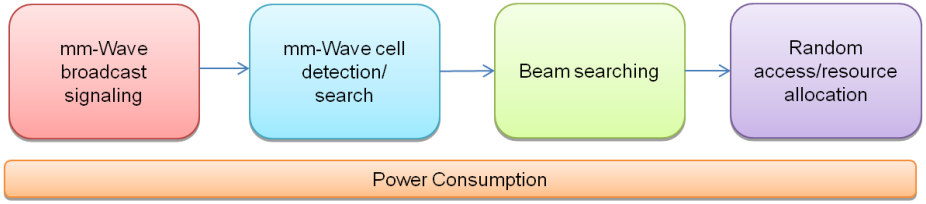


- Evaluated 10 waveform candidates according to 11 KPIs
- Based on both Simulation or analytical approaches
- **Current recommendation below 40 GHz**: OFDM-based waveform, incl. DFT-s version

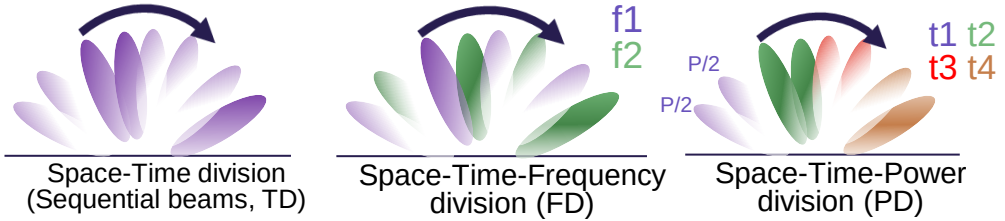
- KPI's defined for Evaluations (IR4.1)
  - Spectral efficiency
  - Robustness to hardware impairments and time/frequency selective channels
  - Power efficiency
  - Out-of-band emissions
  - Time localization
  - Implementation complexity
- Alignment on evaluation assumptions/parameters and common simulator (IR4.2, D4.1)
  - 2 common simulators developed in Matlab/ SystemVue

Initial Access Schemes

- Analyzed overall initial access procedure
- An analysis of beam-scanning based broadcast
  - Modelling of the broadcast signaling
  - Simulations to obtain optimal number of beam sectors at different system setups
- Sweeping sub-frames
  - A beam-based approach for common control is studied
  - Sweeping subframes for downlink have been introduced, carrying all required signals and channels for the UE to perform cell search and read essential system information.

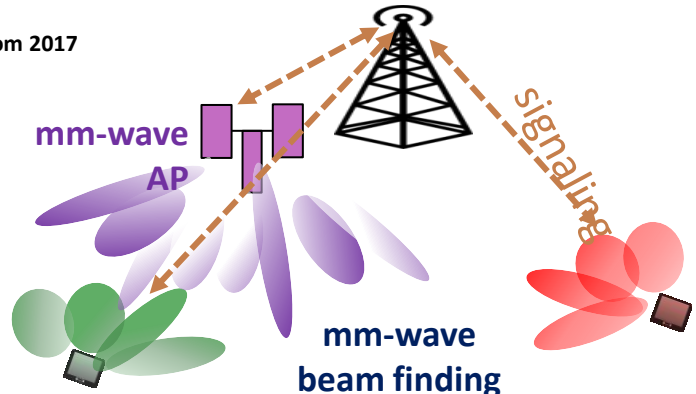


Components of mm-wave initial access



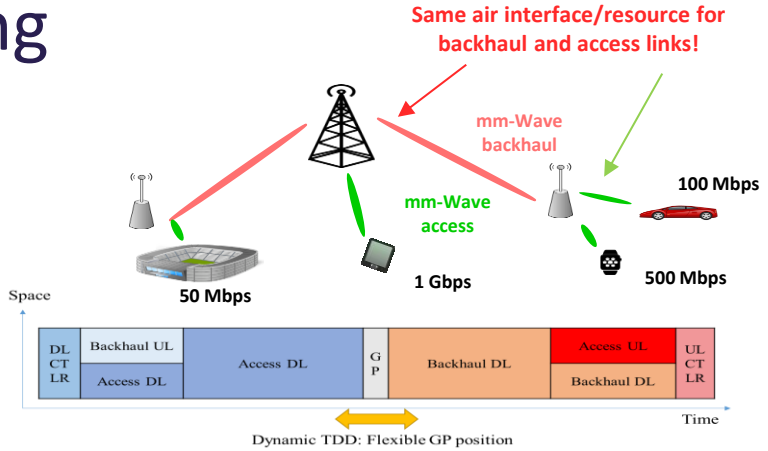
Different possible broadcast signaling

Fast beam-finding IEEE PIMRC Best Ppaer Award IEEE Infocom 2017

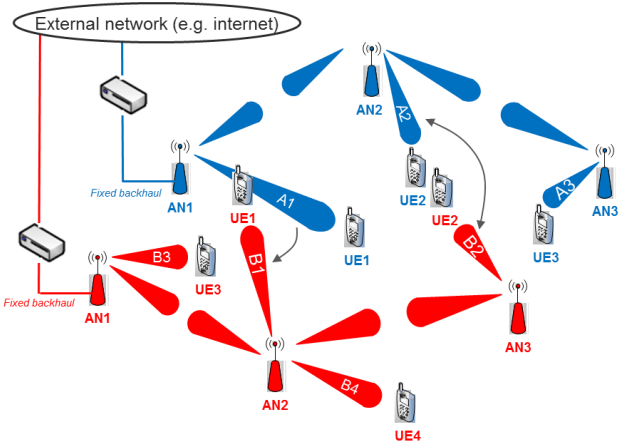


Multiple Access and Duplexing

- Joint backhaul and access optimization in mm-wave HetNets
  - Spatial Division Multiple Access
  - Dynamic TDD Duplexing
- Beam scheduling with periodic and aperiodic beam reporting
- Spectrum sharing among multiple operators
  - Spectrum pooling strategy which provides better resource utilization over traditional spectrum allocation schemes



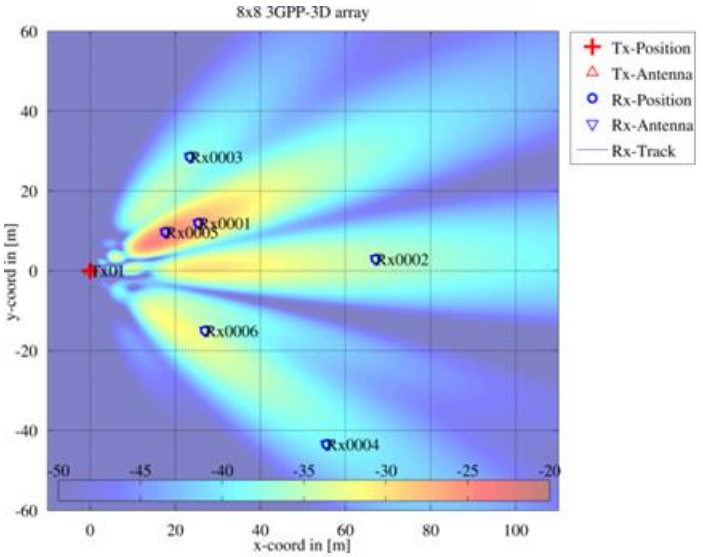
Joint backhaul and access optimization



Beam cooordination for mm-wave coexietence Nekovee et al, IEEE Infocom 2016

Multi-antenna and Multi-node design

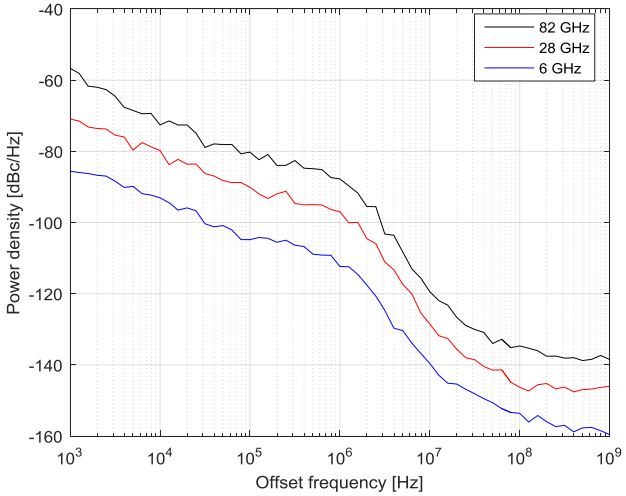
- Multi-antenna designs and schemes
  - A wideband , low complexity scheme for hybrid beamforming in mm-wave access
  - Multi-connectivity backhaul provision for moving hot-spots through macro cells and mm-wave small cells
  - Optimising complexity / performance trade-off for massive antenna M2M communications
- Multi-node designs and schemes
  - Multi-connectivity based joint mm-wave/free space optical links
  - Multi-node coverage analysis with ray tracing data and node positions
- Hardware imperfections/ models
  - Phase noise analysis and models (contributing to 3GPP)
  - Behavioural models for power amplifier non-linearities
  - Phased array distortion analysis for wider bandwidths

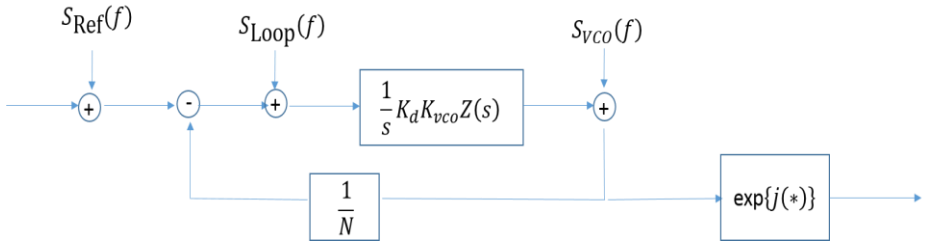


Phase noise (PN) model

- PLL-based oscillator with 3 main noise sources:
  - from reference oscillator S_{ref}
  - from phase-frequency detector, loop filter, etc S_{loop}
  - from VCO S_{VCO}
- Covering a wide frequency range and 'low' and 'high' modes for good/bad oscillators
  - Included in 3GPP R1-165685
- **Open-source code** in Matlab
  - Widely used by project partners and publically available from mmMAGIC

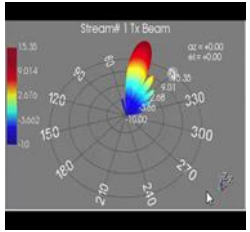
PSD of carrier phase noise in "low" mode

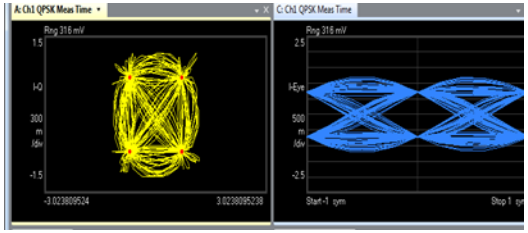


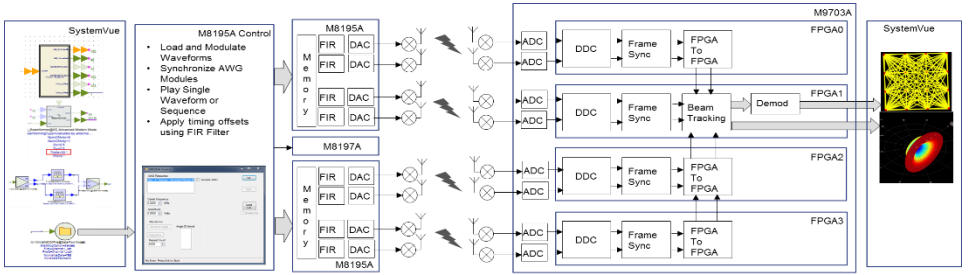


Hardware-in-the-Loop Demos

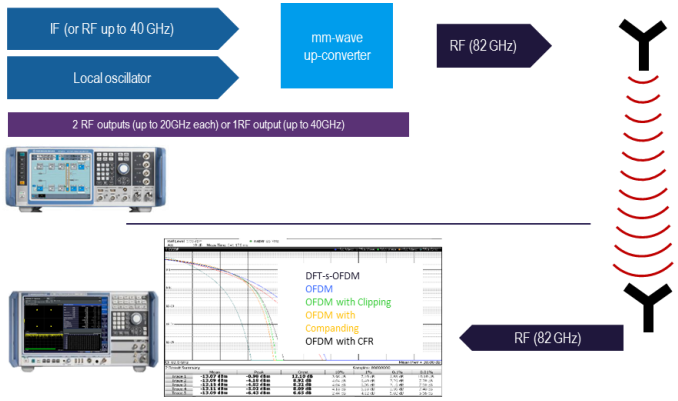
- PIMRC Workshop, Sept 2016, Valencia.
- Second Global 5G Event, Nov 2016, Rome.







Rapid prototyping for beamforming



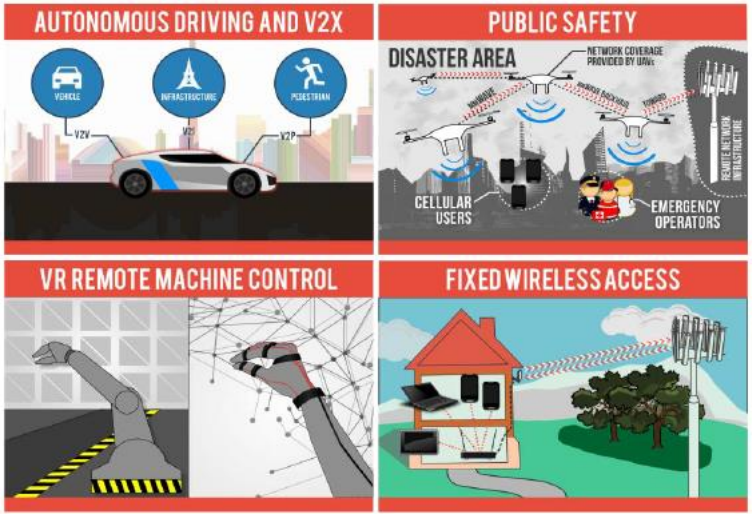
Waveform comparison at 82 GHz

Demo 1: **Rapid Prototyping for Real Time Beam Forming Systems**
Demo 2: **Waveform Comparison between OFDM and DFT-s-OFDM at 82 GHz**

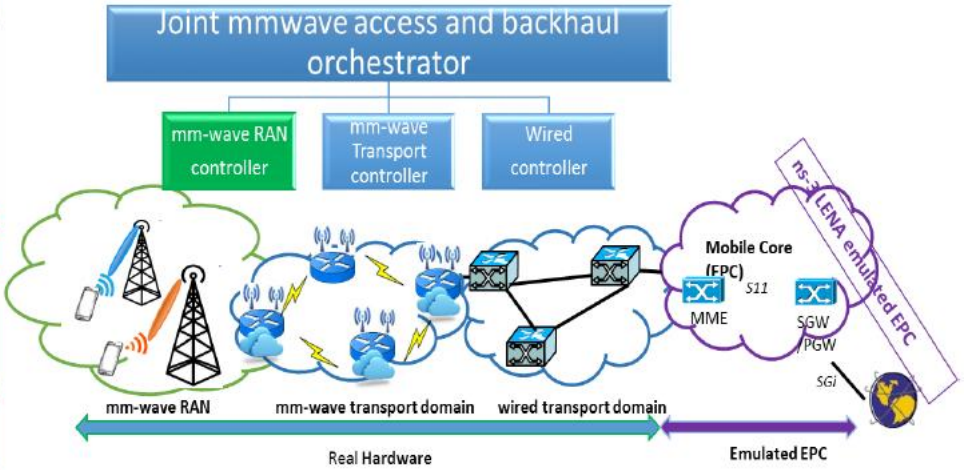
So, what's next? – mmMAGIC-II

17 Partners, 2 years, targeting 3GPP Rel-15 and beyond
Focusing on full system deployment and 5G verticals beyond eMBB

Vertical applications



End-to-End PoC



EC funding under Horizon 2020 5G PPP Program is acknowledged for work carried out in mmMAGIC

THANK YOU!

- ✓ Find out/ download docs & software at https://5g-mmmagic.eu
- ✓ Join mmMAGIC friends for exclusive updates

List of Deliverables (Completed)

Deliverable No.	Deliverable name	Planned Delivery Date
IR1.1	Use case characterization, KPIs and preferred suitable frequency ranges for future 5G systems between 6 GHz and 100 GHz	2015-07-31
IR3.1	Requirements, scenarios and use cases	2015-09-30
IR4.1	Requirements and general design principles for mm-wave radio interface	2015-09-30
IR5.1	Requirements analysis for multi-node and multiantenna transmitter and receiver architectures and schemes	2015-10-30
D1.1	Use case characterization, KPIs and preferred suitable frequency ranges for future 5G systems between 6 GHz and 100 GHz	2015-11-30
D2.1	Measurement Campaigns and Initial Channel Models for Preferred Suitable Frequency Ranges	2016-03-31
D3.1	Initial concepts on 5G architecture and Integration	2016-03-31
IR4.2	Preliminary concepts for waveform and frame structure	2016-03-31
D5.1	Initial multi-node and antenna transmitter and receiver architectures and schemes	2016-03-31
D4.1	Preliminary radio interface concepts for mm-wave mobile communications	2016-06-30
D6.2	Periodic report, first reporting period	2016-06-30
D6.4	1st Dissemination and exploitation report	2016-06-30
D1.2	Visualization of selected candidate radio interface functions	2016-09-30