The mmMAGIC Project

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

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Agenda

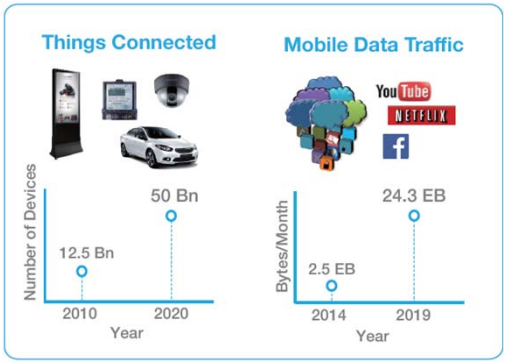
- 5G mm-Wave Spectrum – Standards Status
- Samsung 5G mm-Wave Focus Areas
- 5G mmMAGIC
- What‘s next?

Future cellular networks - *more than just phones*

Source: Samsung 5G Vision, white paper

5G Vision

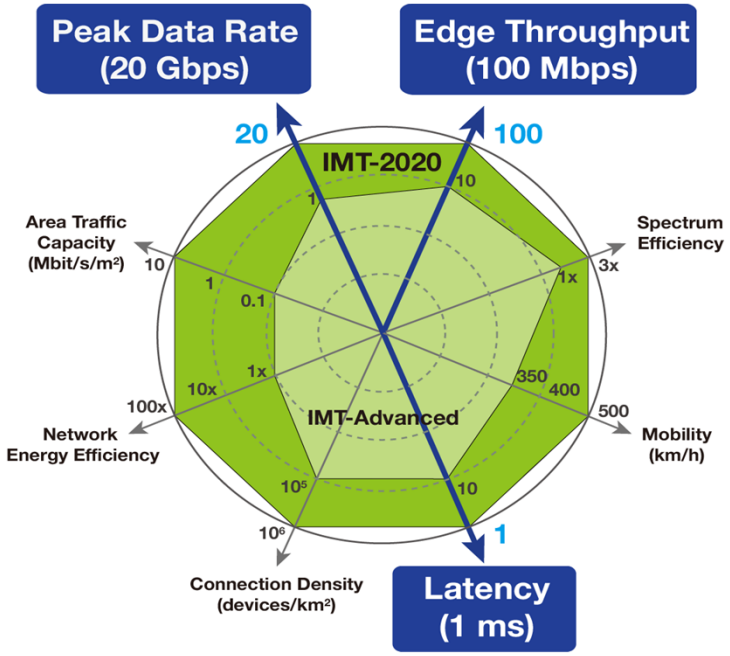
- **Massive number of connected devices**
- **A large versatile type of mobile services (eMBB, URLLC, mMTC) and terminals (handsets, cars, drones, robots, etc.)**
- **Different requirements**
  - very high data rates
  - low complexity and low power
  - High reliability and low latency

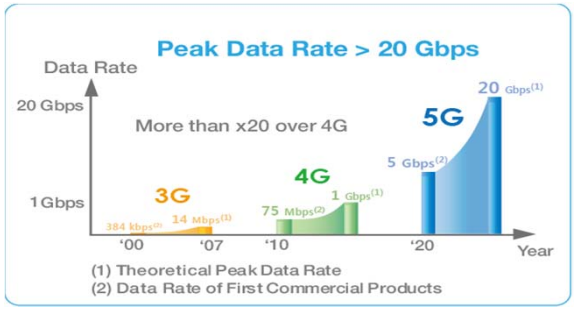


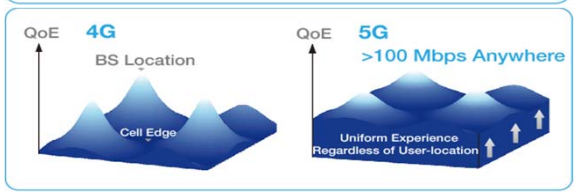
Source: Samsung 5G white paper

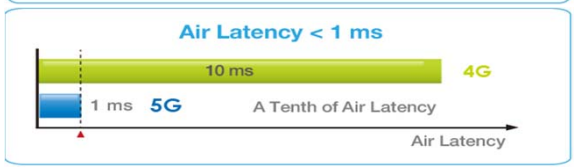
5G Vision

ITU 5G Requirements









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

※ ITU: International Telecommunications Union

The need for mm-wave in 5G

- Sub-6GHz spectrum is already heavily utilized
- The mm-wave spectrum (denoted as 6-100GHz) offers much wider bandwidths for mobile services

※ **WRC-15 Results**

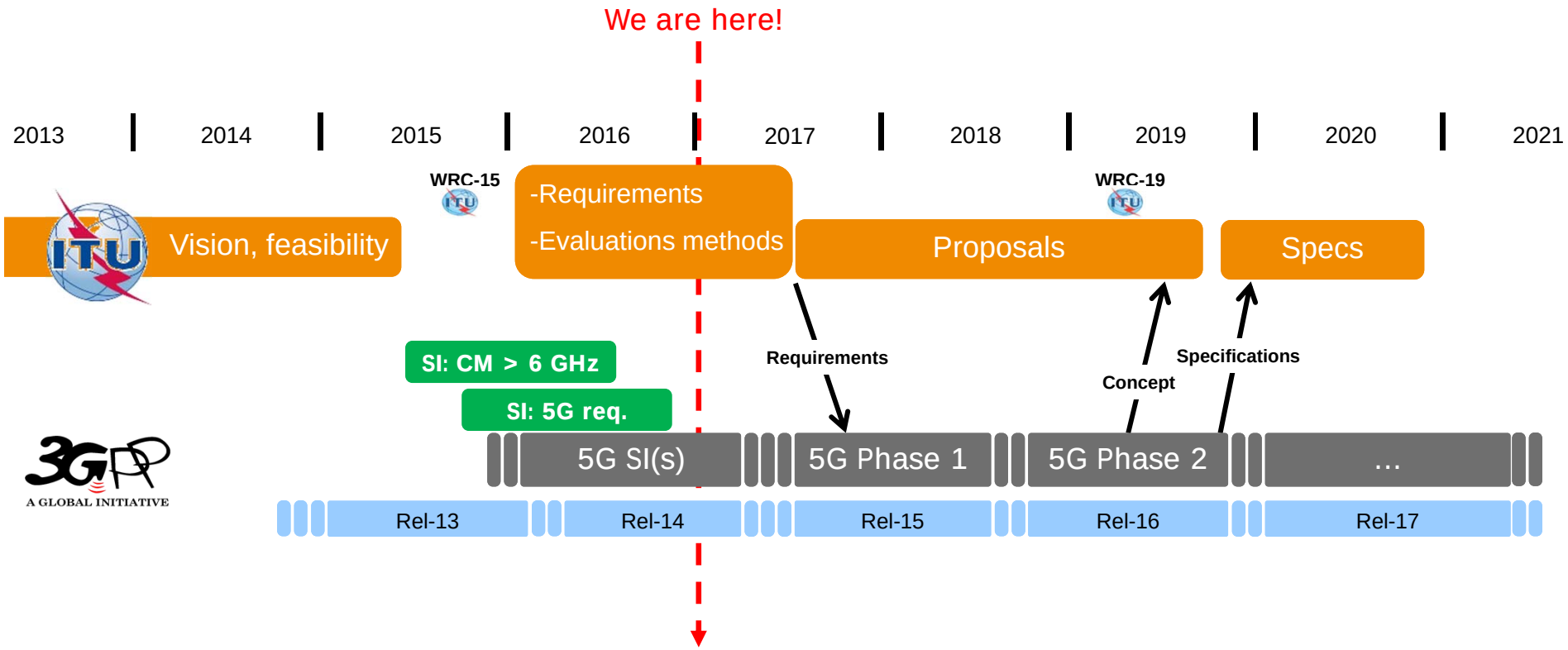
- Above 6 GHz : [WRC-19 Candidates] (24.25-27.5), (31.8-33.4), (37-40.5), (40.5-42.5), (42.5-43.5), (45.5-47), (47-47.2), (47.2-50.2), (50.4-52.6), (66-76), (81-86)GHz

- Below 6 GHz : [IMT Spectrum] (1.427-1.518)GHz, (3.4-3.6)GHz

← Below 6GHz → ← Above 6GHz/mm-Wave →

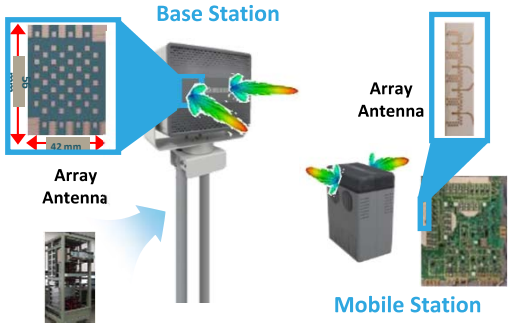
	< 6GHz (MHz)	6-20	20-30	30-40	40-50	50-60	60-70	70-80	80-100
APAC *(APT)*	1427 – 1452 1492 – 1518		25.25 – 25.5	31.8 – 33.4	39 – 47 47.2 – 50.2	50.4 – 52.6	66 – 76		81 – 86
Europe *(CEPT)*	1427 – 1518 3400 – 3800		24.5 – 27.5	31.8 – 33.4	40.5 – 43.5 45.5 – 48.9		66 – 71 71 – 76		81 – 86
Americas *(CITEL)*	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					

Standardization and Spectrum Allocation Timelines



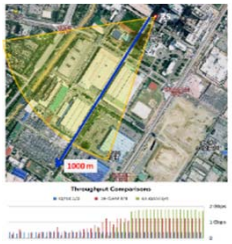
5G mmWave – Samsung's achievements

mmWave Testbed (2013/4)



Coverage Testing (2015)

3-Cell Coverage Map

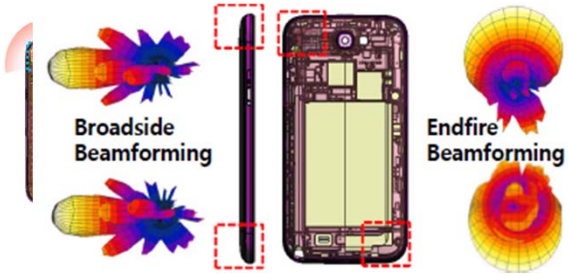


Range Testing

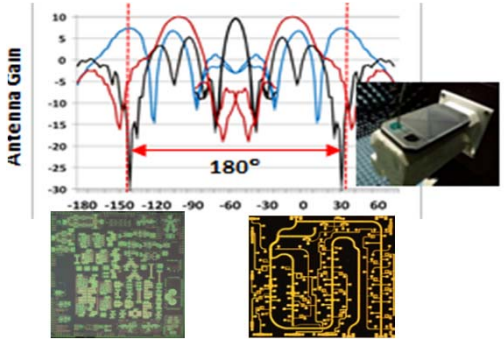
Handover Capability

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

Devices/ Chipsets



Beam-forming Radio Frequency Integrated Unit

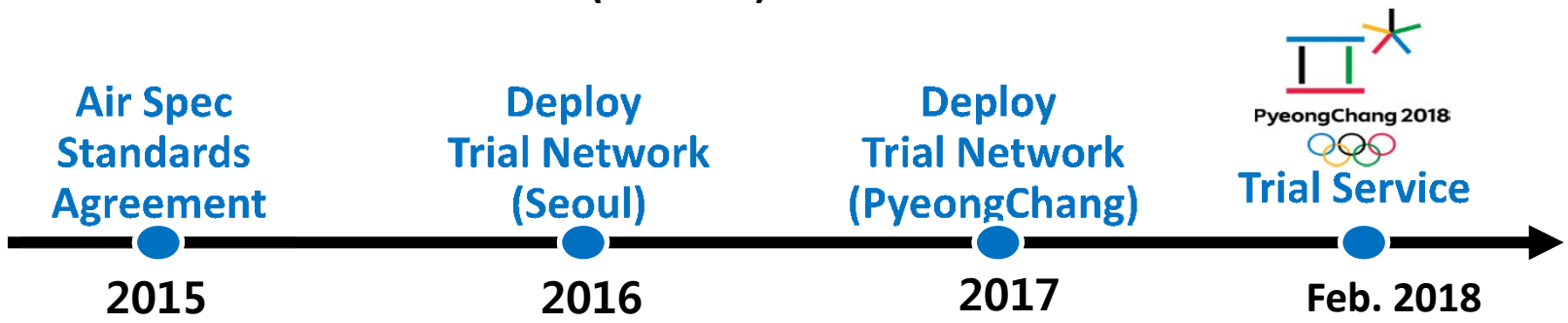


Fixed wireless access

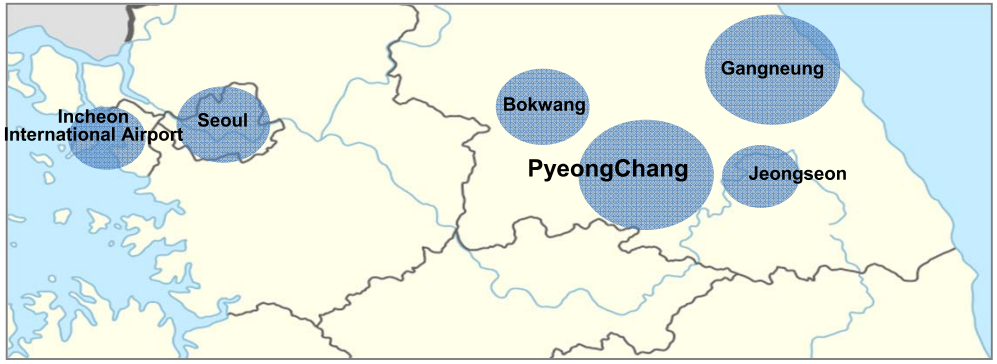
Commercial products 2018

KT 5G Mobile Trial Service @ PyeongChang, Korea

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



PyeongChang 5G Trial Scenarios (Source : KT)

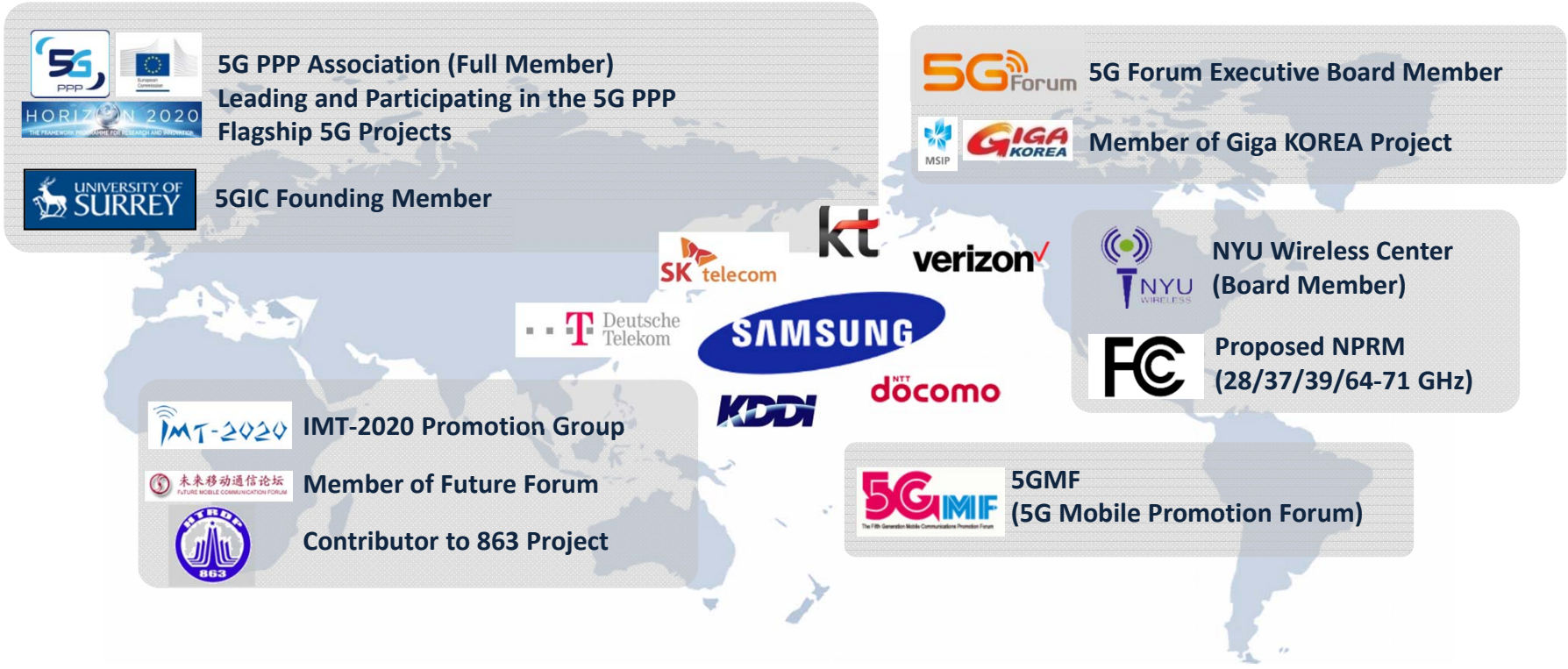


Sync View

5G Bus

Global 5G R&D Activities

Global 5G Initiatives with Samsung's Active Engagements



The mmMAGIC Project

https://5g-mmmagic.eu

Project Overview

Co-funded by Horizon 2020, part of 5G PPP Portfolio
Project coordinator: Samsung
Technical manager: Ericsson
Project runtime: July 2015 – July 2017

19 partners:
Vendors: Samsung, Ericsson, (Alcatel-Lucent), Huawei, Intel, Nokia
Operators: Orange, Telefonica
Research institutions: CEA-LETI, Fraunhofer HHI, IMDEA Net works
Universities: Aalto University, University of Bristol, Chalmers University of Technology, TU Dresden
SME: Qamcom
Test equipment manufacturers: Keysight Technologies, R&S

Advisory Board: ETSI, ANFR, BNetZa, OFCOM, PTS, FICORA, BMW, U. Illemenau, SONY mobile

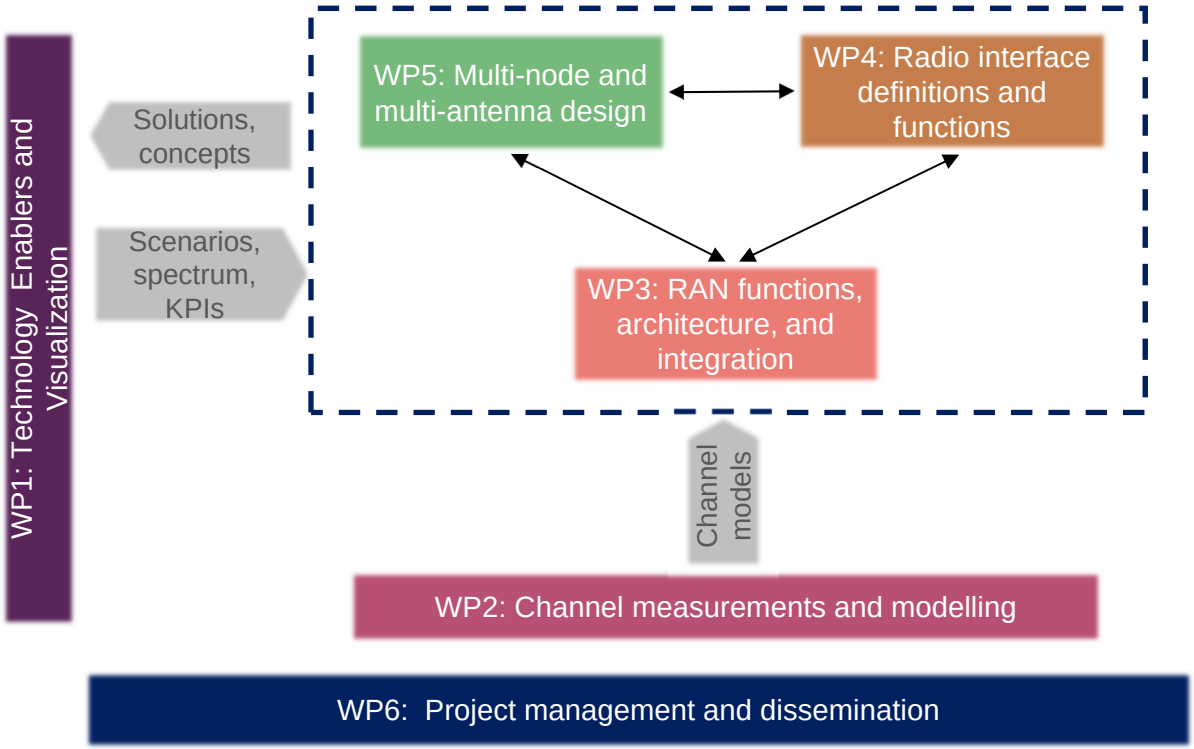
The main objective is to deliver key concepts and components for mobile radio access technology (RAT) in the 6-100 GHz range

- Spectrum, Use Cases, KPI requirements
- massive channel measurements and channel model
- Architecture components and integration
- Air interface for access and self-backhaul
- Multi-node and Multi-antenna

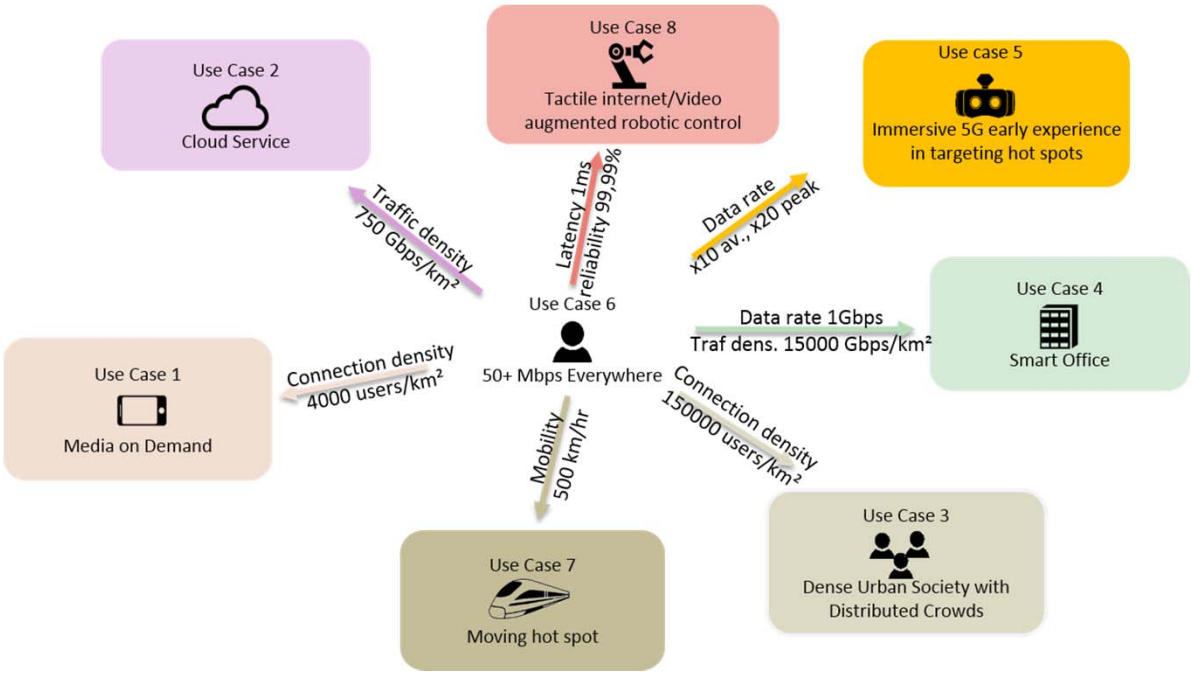
mmMAGIC's Achievements

- ✓ **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 model (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)
- ✓ **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 Cases, KPIs and Frequency Ranges

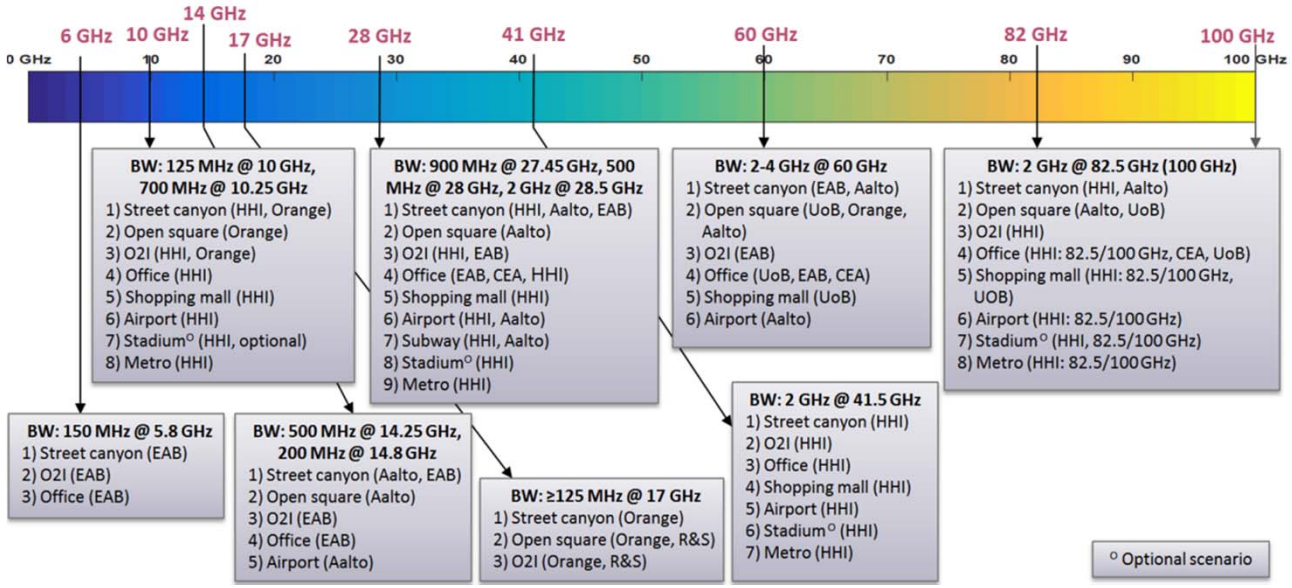


Estimated bandwidth

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

5G mm-Wave Channel Measurements and Modelling

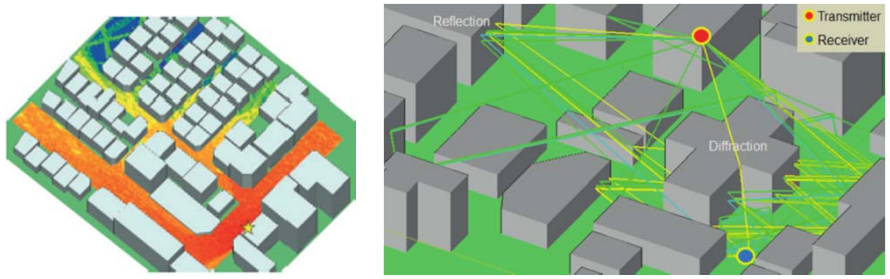
- Measurement campaigns: over 20 measurement campaigns in more than 8 frequency bands from 6 to 100 GHz are ongoing across 5 European countries, and will continue till the end of the project.
- Scenarios: UMi street canyon, UMi open square, indoor office, indoor shopping mall, indoor airport, outdoor to indoor (O2I), metro station and stadium.
- New channel model in line with the 3GPP-3D has been implemented supporting 10-80 GHz.



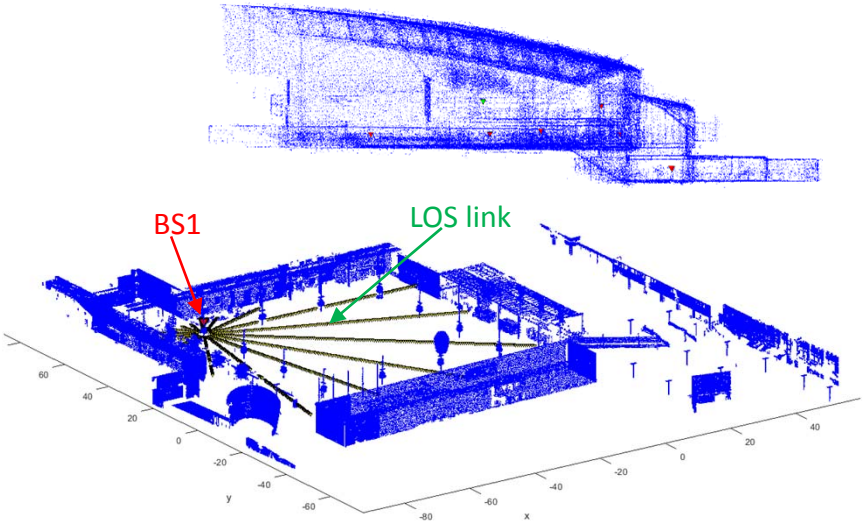
5G mm-Wave Channel Measurements and Modelling

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

Ray Tracing modelling (Samsung)



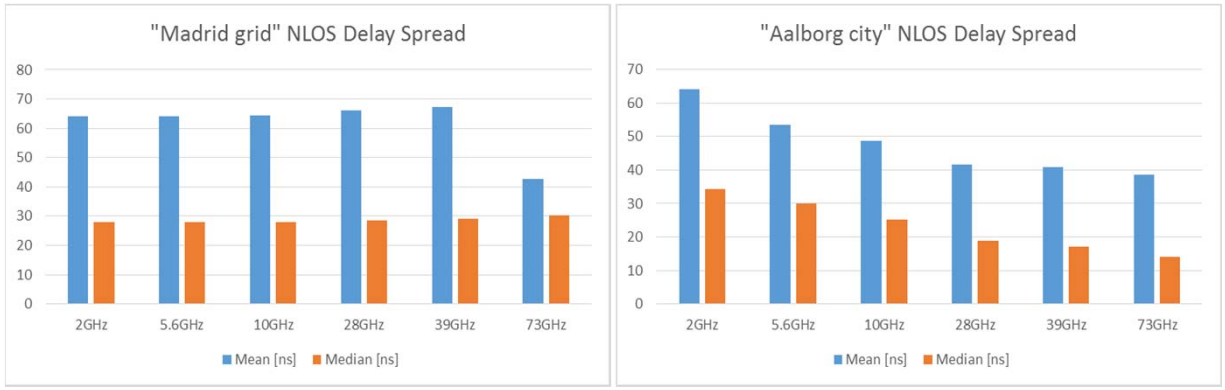
Map modelling (AALTO)



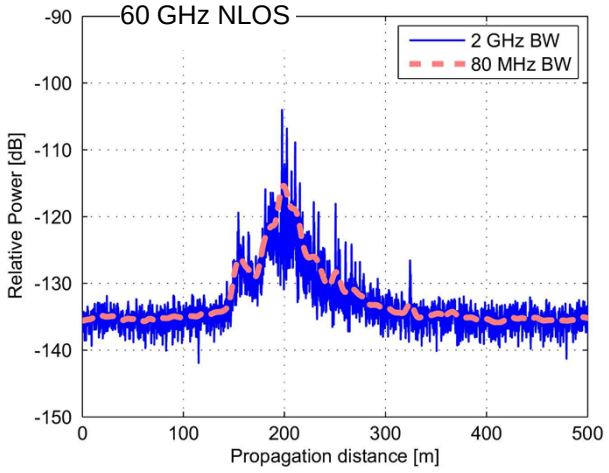
Analyzing trends in mm-wave propagation

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

Frequency dependency



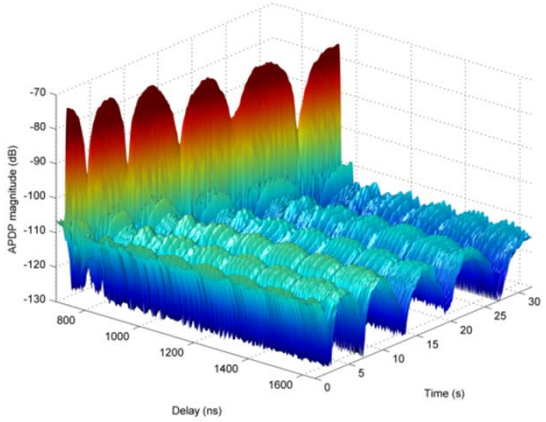
Bandwidth dependency

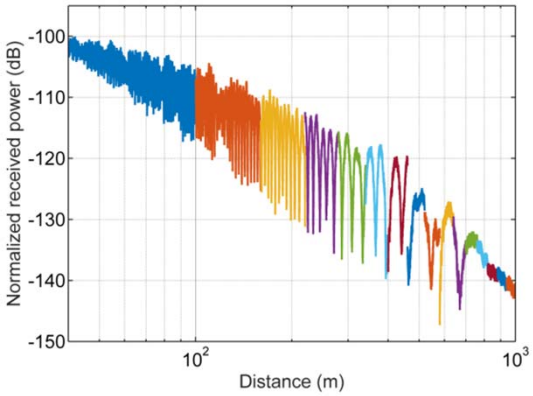


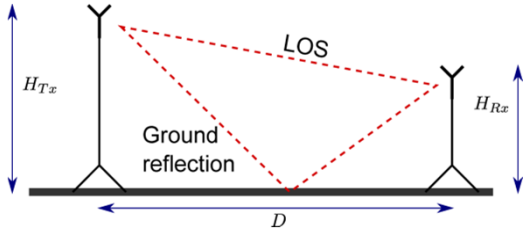
Analysis and interpolation of channel characteristics (1/3)

- Ground reflection

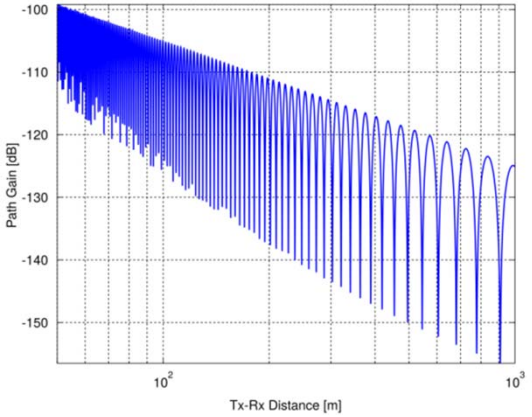
Measured ground reflection (HHI)





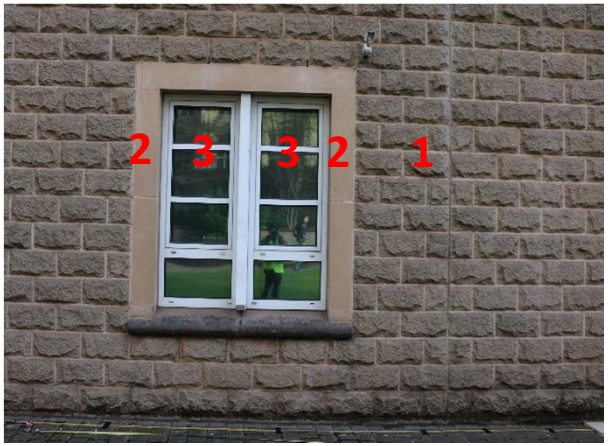


Modelled ground reflection

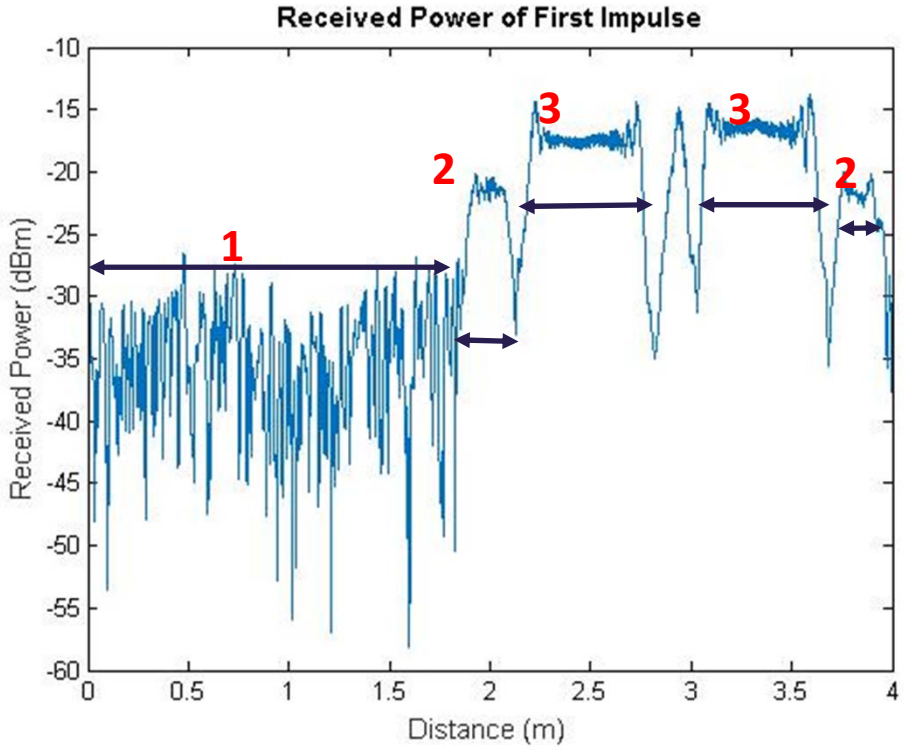


Analysis and interpolation of channel characteristics (2/3)

- Diffusive scattering



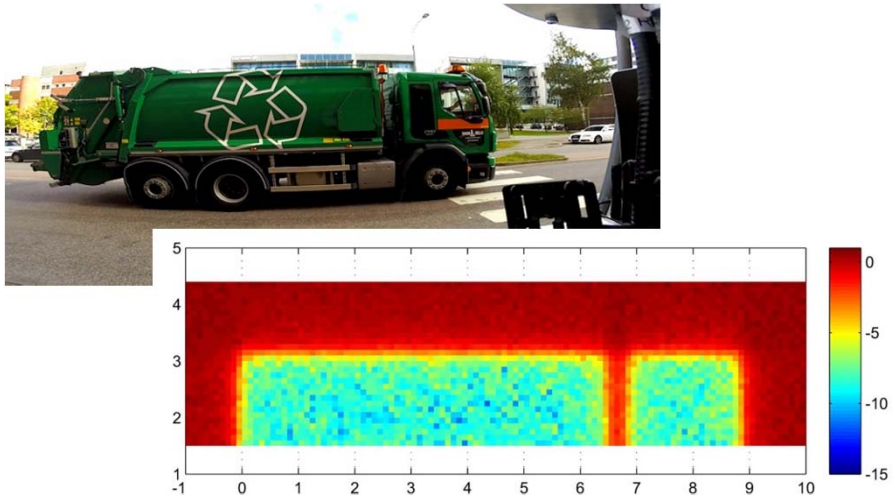
- Area 1: Rough wall
- Area 2: Smooth transition
- Area 3: Window (smooth surface)



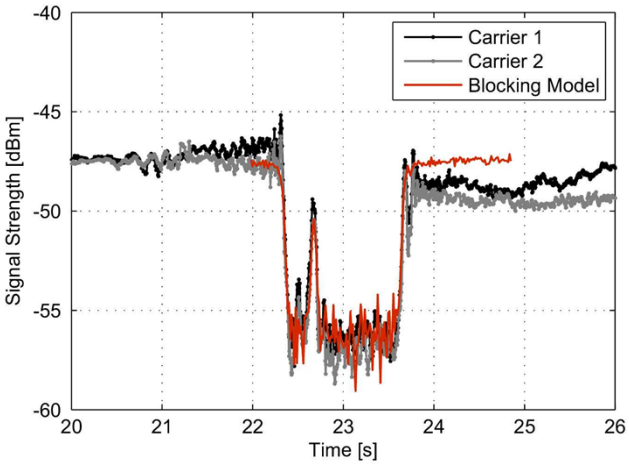
Analysis and interpolation of channel characteristics (3/3)

- Blocking model

Measured blocking (Ericsson)



Modelled blocking

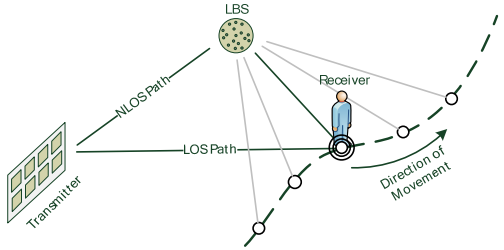


Channel models

- mmMAGIC channel model / QuaDRiGa reference implementation
  - Compatibility with 3GPP-3D (calibrated)
  - Full spatial consistency for single moving terminal: 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
  - **First channel model software released (open source to public)**

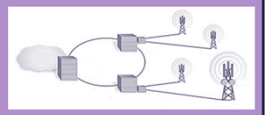
Quadriga
The Next Generation Radio Channel Model

Long-term time evolution



5G RAN Functions and Architecture Integration

Architectural enablers and deployment aspects

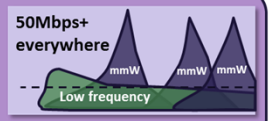


Provide cost and energy efficient architecture design and deployment requirements for 5G networks

Network Slicing
Multiple logical networks as independent business operations on a common infrastructure.

Multi-layer/ Multi-RAT management
Abstracting logical functions at different layers in a unified structure.

Network integration for an edge-less mm-wave access



Design solutions for interworking of mm-wave nodes

Multi-connectivity
Providing a given UE with radio resources from two or more radio links.

Agile Mobility
Providing agile and low-overhead mobility via mm-wave cell clustering and new radio control states.

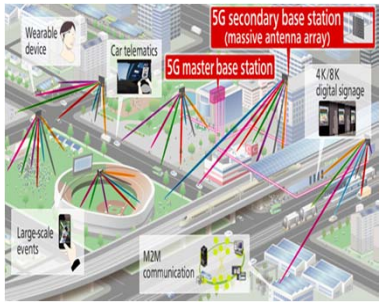
Methodologies for dynamic deployments

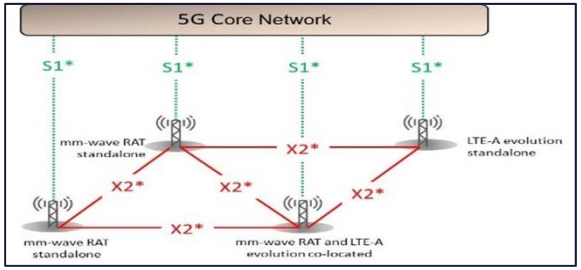
Provide backhaul connectivity and overall network planning, networks flexible both in structure and operation

Self-backhauling
Coverage/capacity extension by means of utilizing the same radio resources used by users.

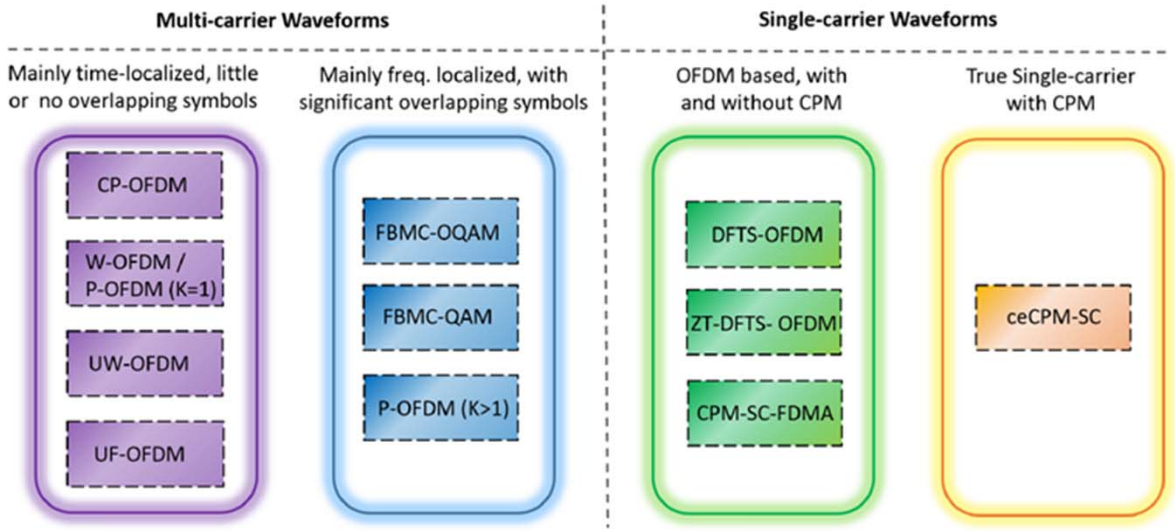
Low-band integration
Supporting some control signals via greater reliability over the lower frequency RAT.

- ✓ White Paper on architecture and integration with 5G multi-RAT
- ✓ 5G PPP WG Architecture White Paper





Design of waveforms

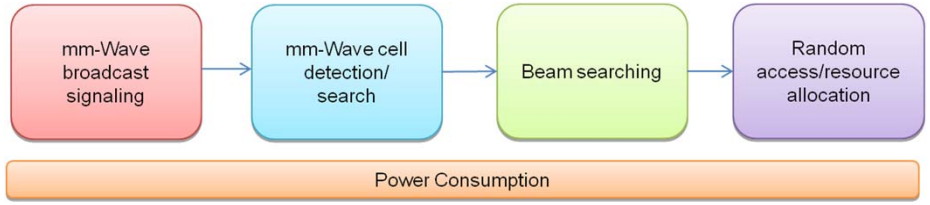


- Evaluated 10 waveform candidates against 11 KPIs
- Based on both Simulation or analytical approaches

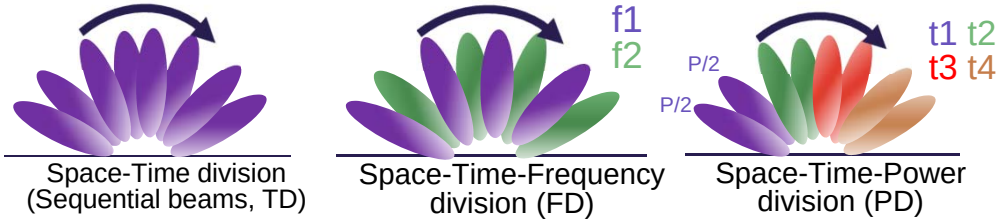
- KPI's defined for Evaluations
  - Spectral efficiency
  - Robustness to hardware impairments and time/frequency selective channels
  - Power efficiency
  - Out-of-band emissions
  - Time localization
  - Implementation complexity
- Alignment on evaluation assumptions/parameters and common simulator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

Initial Access Schemes

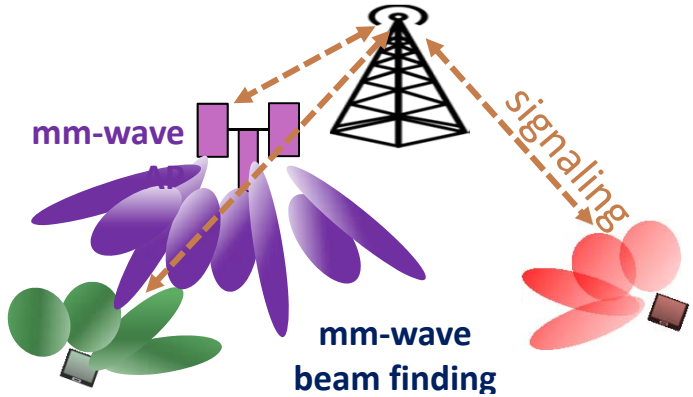
- Analyzed overall initial access procedure
- An analysis of beam-scanning based broadcast
  - Modelling of the broadcast signaling
  - Simulations to obtain optimal number of beam sectors at different system setups
- Sweeping sub-frames
  - A beam-based approach for common control is studied
  - Sweeping 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

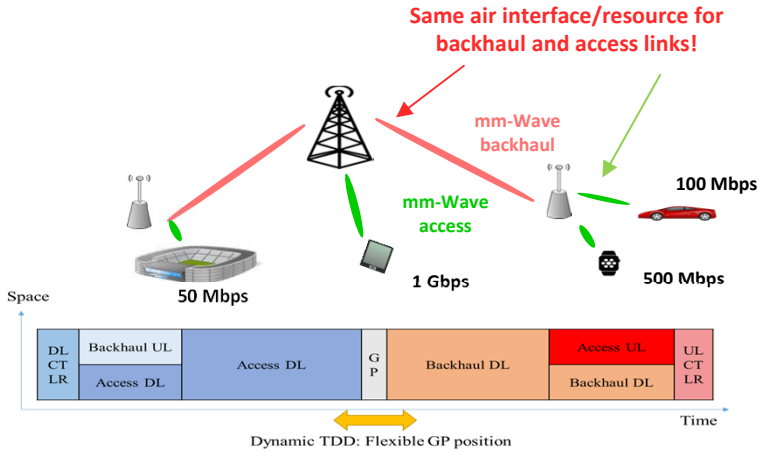


Different possible broadcast signaling

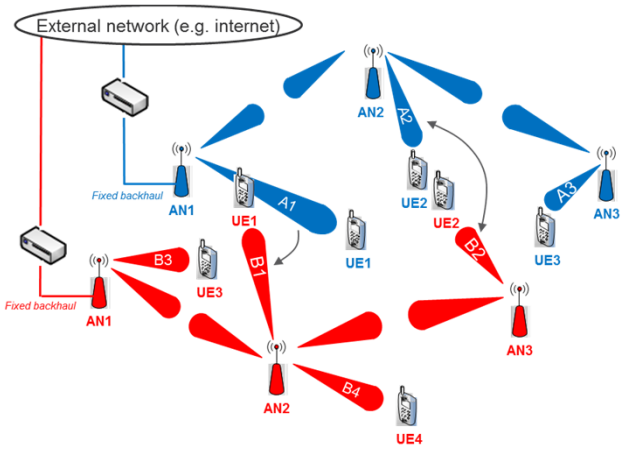


Multiple Access and Duplexing

- 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



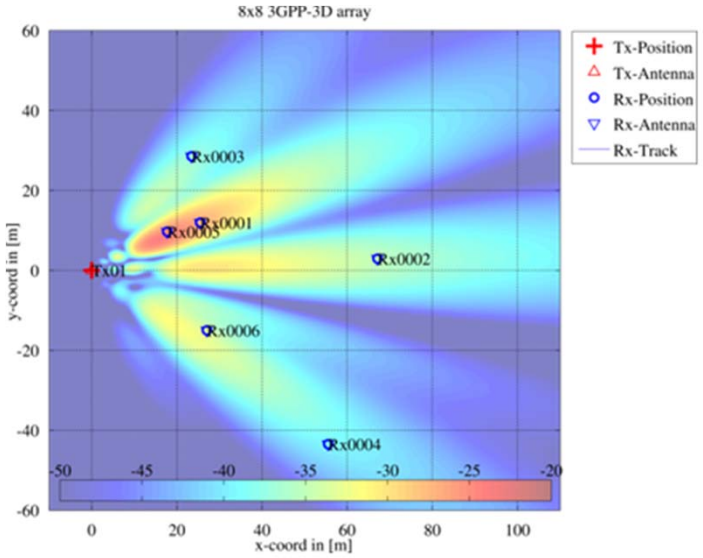
Joint backhaul and access optimization



Beam cooordination

Multi-antenna and Multi-node design

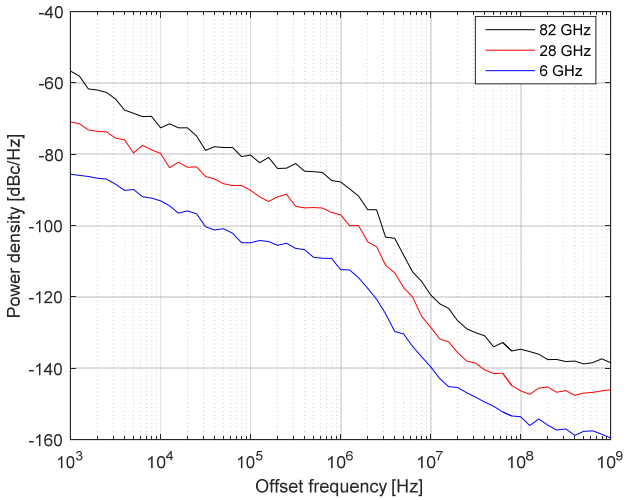
- Multi-antenna designs and schemes
  - A wideband, low complexity scheme for hybrid beamforming in mm-wave access
  - Multi-connectivity backhaul provision for moving hot-spots through macro cells and mm-wave small cells
- Multi-node designs and schemes
  - Multi-connectivity based joint mm-wave/free 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

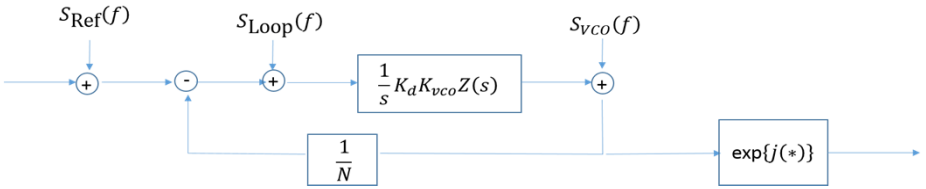


Phase noise (PN) model

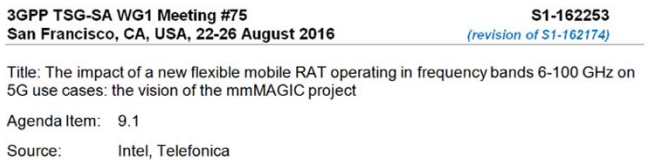
- PLL-based oscillator with 3 main noise sources:
  - from reference oscillator S_{ref}
  - from phase-frequency detector, loop filter, etc S_{loop}
  - from VCO S_{VCO}
- Covering a wide frequency range and 'low' and 'high' modes for good/bad oscillators
  - Included in 3GPP R1-165685
- **Open-source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

PSD of carrier phase noise in "low" mode





mmMAGIC Impact



3GPP TSG-SA WG1 Meeting #75 S1-162253
San Francisco, CA, USA, 22-26 August 2016 *(revision of S1-162174)*

Title: The impact of a new flexible mobile RAT operating in frequency bands 6-100 GHz on 5G use cases: the vision of the mmMAGIC project

Agenda Item: 9.1

Source: Intel, Telefonica

- **Standard:**
  - Coordinate dissemination of results to 3GPP via industrial partners, 15 3GPP contributions
- **Regulatory bodies:**
  - Coordinate dissemination of results to regulatory bodies, ITU-R, CEPT, FCC, etc. via industrial partners
- **5GPPP:**
  - Organize dissemination of results to appropriate Working Groups (WG) of 5G Infrastructure Association
- **Wider community:**
  - Coordinate dissemination of mmMAGIC results to a wider scientific community via all partners
  - Showcase and demonstrate mmMAGIC proof-of-concept to wider industry community and policy makers

mmMAGIC Demos

ICT 2015

MWC 2016

EUCNC 2016

WCNC 2016

PIMRC 2016

Yet a lot more to come!

What's next

- 5G PPP Workshop on "5G RAN Architecture and Integration", London (hosted by Samsung), 30-31 of March. Open day on March 31.
- mmW5G workshop, co-located with WCNC 2017, 1:45-5:00pm, Sunday 19th March.
  - Bring together the leading names in industry, academia and research institutes, including Prof. Akbar Sayeed of Wisconsin Madison Univ. and Prof. Robert Heath of University of Texas at Austin.
  - The panel will include Nada Golmie (NIST, US), Nuria Gonzalez Prelcic (University of Vigo, Spain), Sundeep Rangan (NYU, US), David Michelson (UBC, Canada), Gia Khanh Tran (Tokyo Inst. of Tech).

What's next – mmMAGIC-II

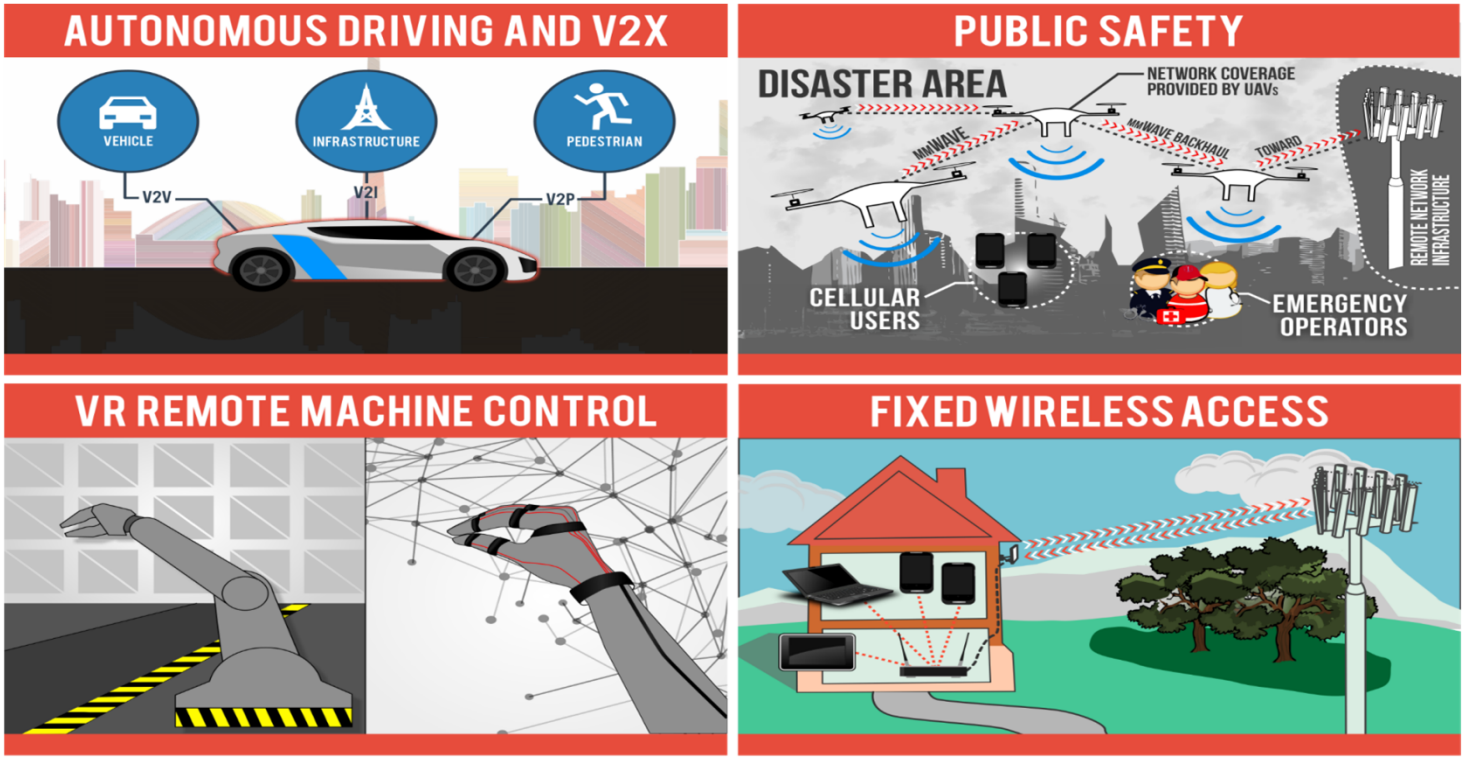
- 18 Partners, 2 years, targeting at 3GPP Rel-15 and beyond
- Vertical applications
- Proof-of-Concept

mmMAGIC-II will design and validate a forward compatible Radio Access Network (RAN) operating in the mm-wave frequency range (as identified in WRC'15). The mmMAGIC-II system will be capable of delivering a diverse set of disruptive 5G's services, including vertical applications, which requires an inter-leaving of ultra high (Gbps and higher) data rate, extended coverage, exceptional quality of experience, low and high mobility and ultra low latency.

The project will validate and proof the feasibility of developed solutions through full protocol stack system simulations, hardware Proof-of-Concepts (PoCs) development, and initial field trials.

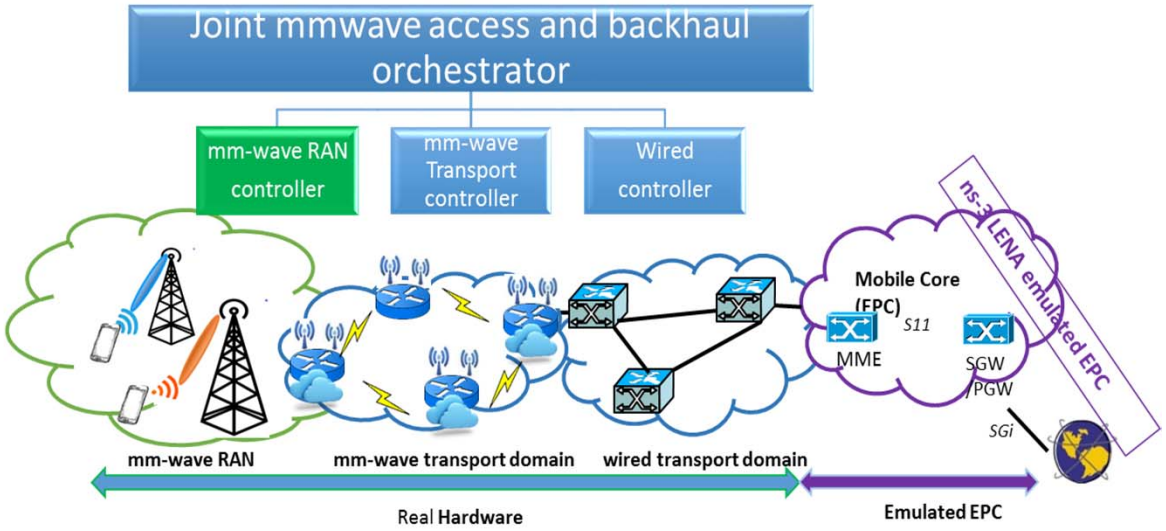
Making mm-wave based 5G services a Reality

mmMAGIC-II Services



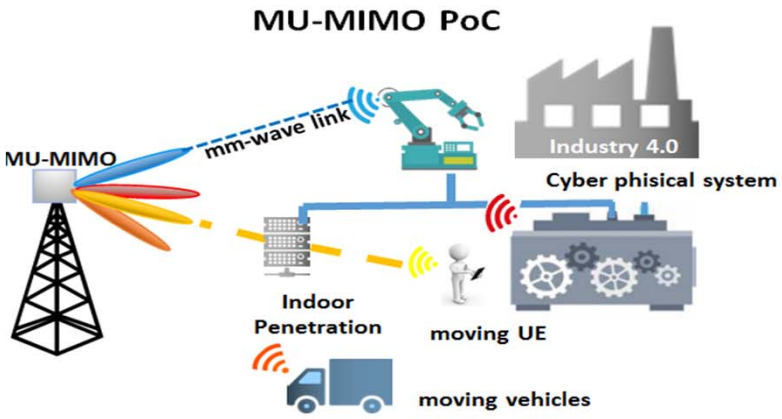
mmMAGIC-II PoCs

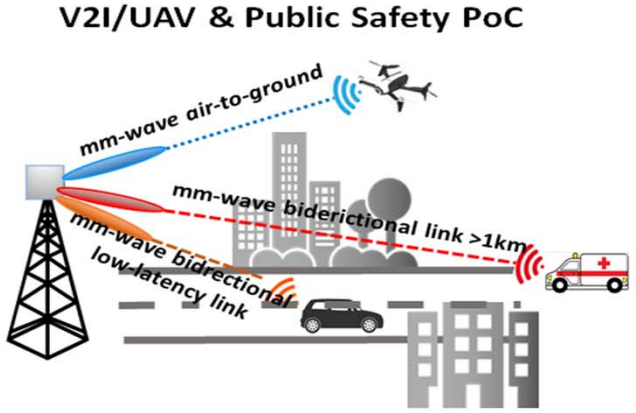
- **End-to-end PoC**
  - An end-to-end network including access and transport parts operating at real-time mm-wave bands



mmMAGIC-II PoCs

- **MU-MIMO**
  - Implement multiuser multi-input multi-output (MU-MIMO) techniques and will mainly target at remote controlled machines in industry applications
- **V2X/UAV**
  - Driven by Thales, a partner from the Public Safety sector, this PoC will target at demonstrating the feasibility of using mm-wave for the mission critical services.
- **CoMP PoC**
  - show the feasibility of mm-wave coordinated multipoint (CoMP) schemes developed within this project





Thank you!

- ✓ Find out/ download docs & software at https://5g-mmmagic.eu
- ✓ Join mmMAGIC friends for exclusive updates
- ✓ Questions? yue2.wang@samsung.com

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