Challenges and Opportunities with mm-Wave Communications in 5G

Tommy Svensson
Professor, PhD, Leader Wireless Systems
Department of Signals and Systems, Communication Systems Group
Chalmers University of Technology, Sweden
tommy.svensson@chalmers.se
www.chalmers.se/en/staff/Pages/tommy-svensson.aspx

CHALMERS

Gothenburg (Göteborg) in Brief

http://www.goteborg.com/en

- Located in the heart of Scandinavia
- Founded by Gustav II Adolf in 1621
- 2nd largest city in Sweden
  - 890,000 inhabitants

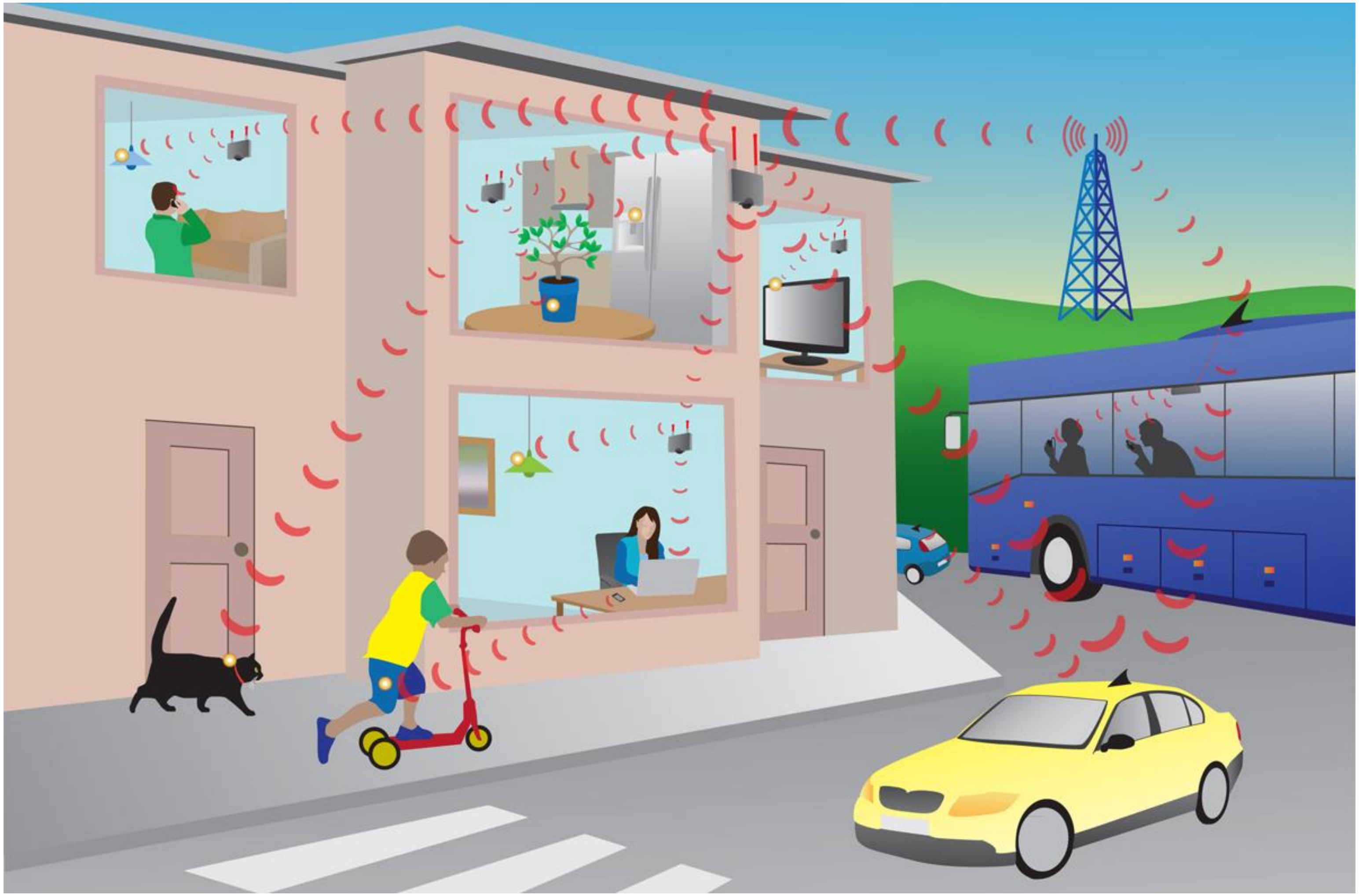
Knowledge and Industry

- Volvo, AstraZeneca, SAAB, SKF, Ericsson
- 2 universities / 61,000 students

Outline

- The European road to 5G:
  - METIS, 5GPPP
- Overview of EU H2020 mmMAGIC
- Some research highlights at Chalmers

Wireless Communications in Dense Heterogeneous Networks

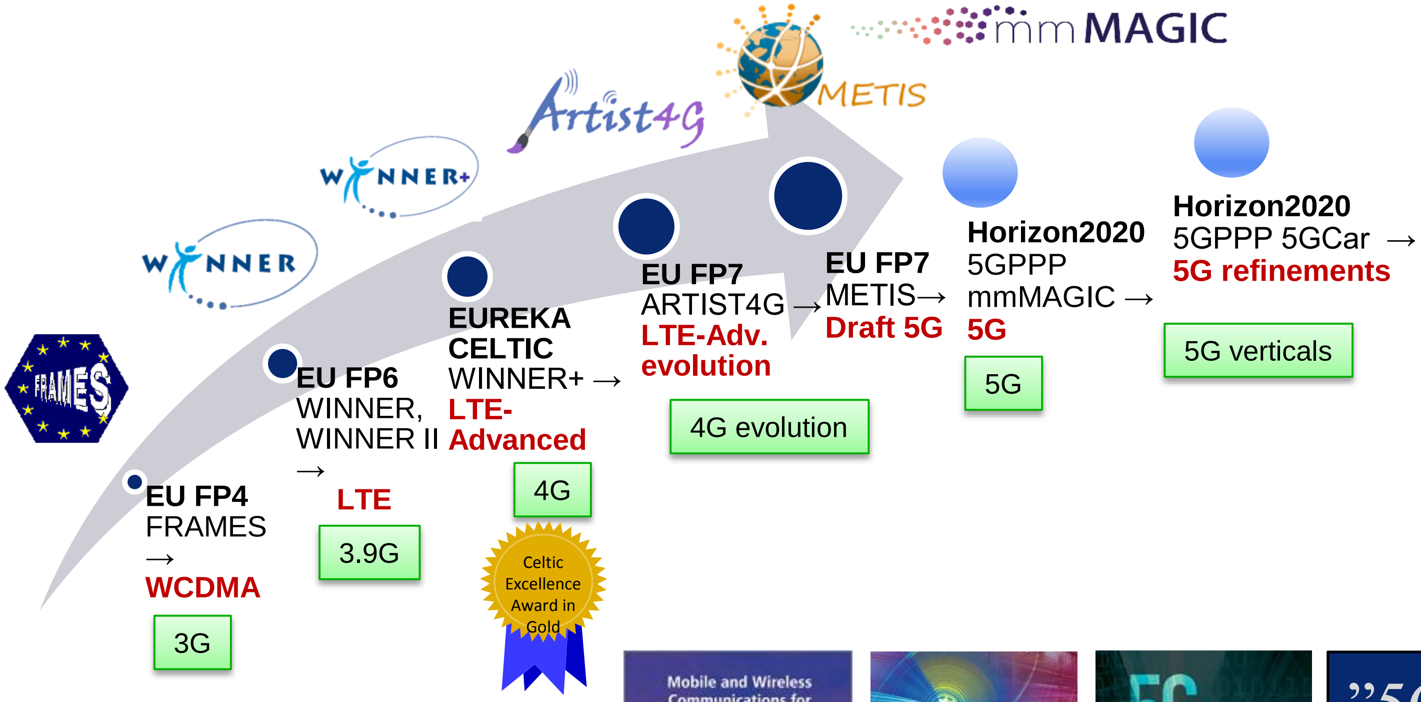


Active Research Topics and Collaborators in Wireless Systems Research Area

- Cooperative communications
  - CoMP with HARQ, HetNets, Relaying
  - Massive MIMO
  - D2D, Finite block length
- Moving networks
  - Backhaul links
  - Interference Coordination
- Internet of Things (IoT)
  - Waveforms
  - Architecture
- Satellite return link scheduling
- Ultra-dense wireless networks
  - mm-wave based access, backhaul and fronthaul
  - Hybrid RF-FSO
- Energy efficient/harvesting networks
- Cloud-RANs

Communications Systems group at Chalmers

Impacts Wireless Standards: 3G, 4G, 5G, and counting...



EU FP4
FRAMES
→
WCDMA

3G

EU FP6
WINNER,
WINNER II
→
LTE

3.9G

EUREKA CELTIC
WINNER+ →
LTE-Advanced

4G

EU FP7
ARTIST4G →
LTE-Adv. evolution

4G evolution

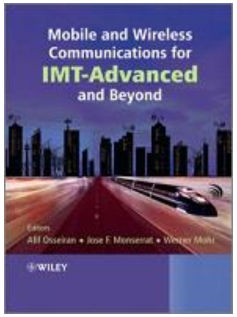
EU FP7
METIS→
Draft 5G

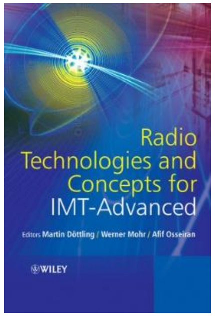
Horizon2020
5GPPP
mmMAGIC →
5G

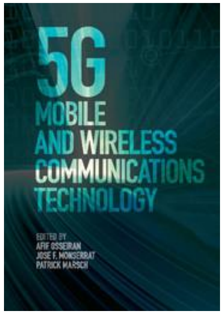
5G

Horizon2020
5GPPP 5GCar →
5G refinements

5G verticals


Mobile and Wireless Communications for
IMT-Advanced
and Beyond
Editors
Afif Osseiran • Jose F Monserrat • Werner Mohr
WILEY


Radio Technologies and Concepts for IMT-Advanced
Editors Martin Döttling / Werner Mohr / Afif Osseiran
WILEY


5G
MOBILE AND WIRELESS COMMUNICATIONS TECHNOLOGY
EDITED BY
AFIF OSSEIRAN
JOSE F. MONSERRAT
PATRICK MARSCH

”5G System Design”
Under preparation

https://www.metis2020.eu
https://ict-artist4g.eu
http://projects.celtic-initiative.org/winner+
http://cordis.europa.eu/infowin/acts/rus/projects/ac090.htm

METIS

Mobile and wireless communications Enablers for the 2020 Information Society (METIS)

ERICSSON
AALBORG UNIVERSITY DENMARK
Aalto University
BMW GROUP Forschung und Technik
Alcatel·Lucent
CHALMERS UNIVERSITY OF TECHNOLOGY
T · · ·
NTT docomo
Anite
orange™
Fraunhofer Heinrich Hertz Institute
HUAWEI
KTH VETENSKAP OCH KONST
National and Kapodistrian UNIVERSITY OF ATHENS
NOKIA Connecting People
nsn
UNIVERSITY of OULU
POLITECHNIKA POZNAŃSKA
RWTH AACHEN UNIVERSITY
MINES TELECOM INSTITUT Mines-Télécom
TELECOM ITALIA
Telefónica Investigación y Desarrollo
UNIVERSITÄT BREMEN
UNIVERSITÄT KAISERSLAUTERN
UNIVERSITAT POLITÈCNICA DE VALÈNCIA

METIS Scenarios and Test Cases

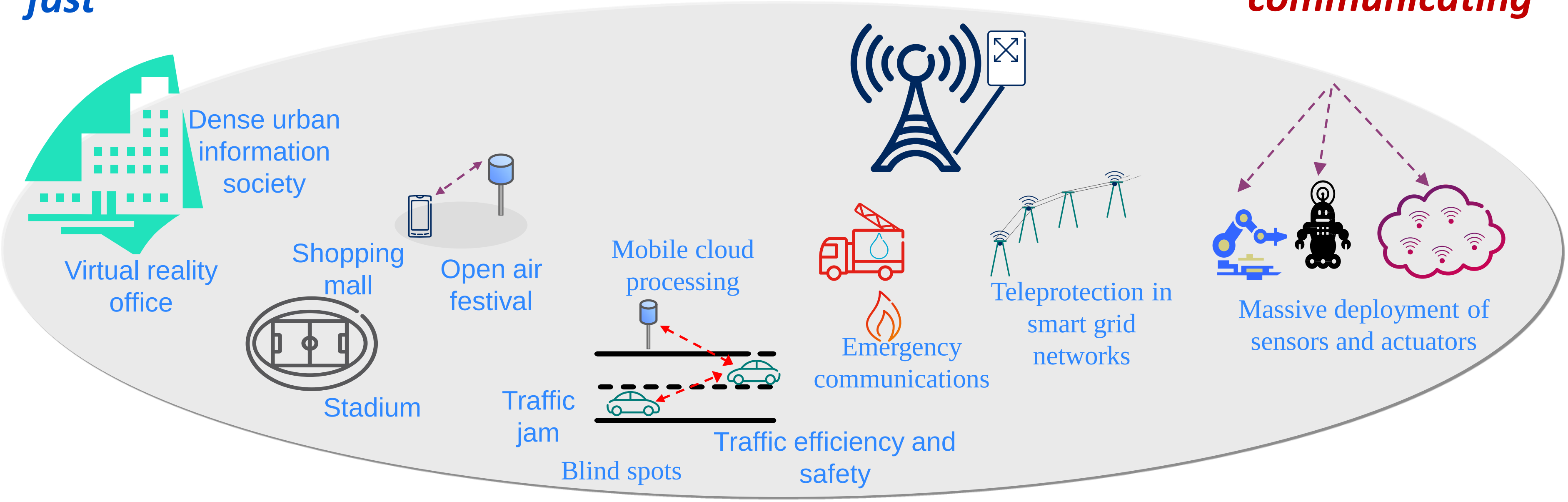
Amazingly fast

Great service in a crowd

Best experience follows you

Super real-time and reliable connections

Ubiquitous things communicating



Virtual reality office

Dense urban information society

Shopping mall

Stadium

Open air festival

Mobile cloud processing

Traffic jam

Blind spots

Traffic efficiency and safety

Emergency communications

Teleprotection in smart grid networks

Massive deployment of sensors and actuators

Source: METIS Deliverable D1.1 "Scenarios, requirements and KPIs for 5G mobile and wireless system", https://www.metis2020.com/

Additional use cases has been proposed by NGMN Alliance, 'NGMN White Paper,' Feb. 2015 (available online https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf)

METIS Overall Technical Goal

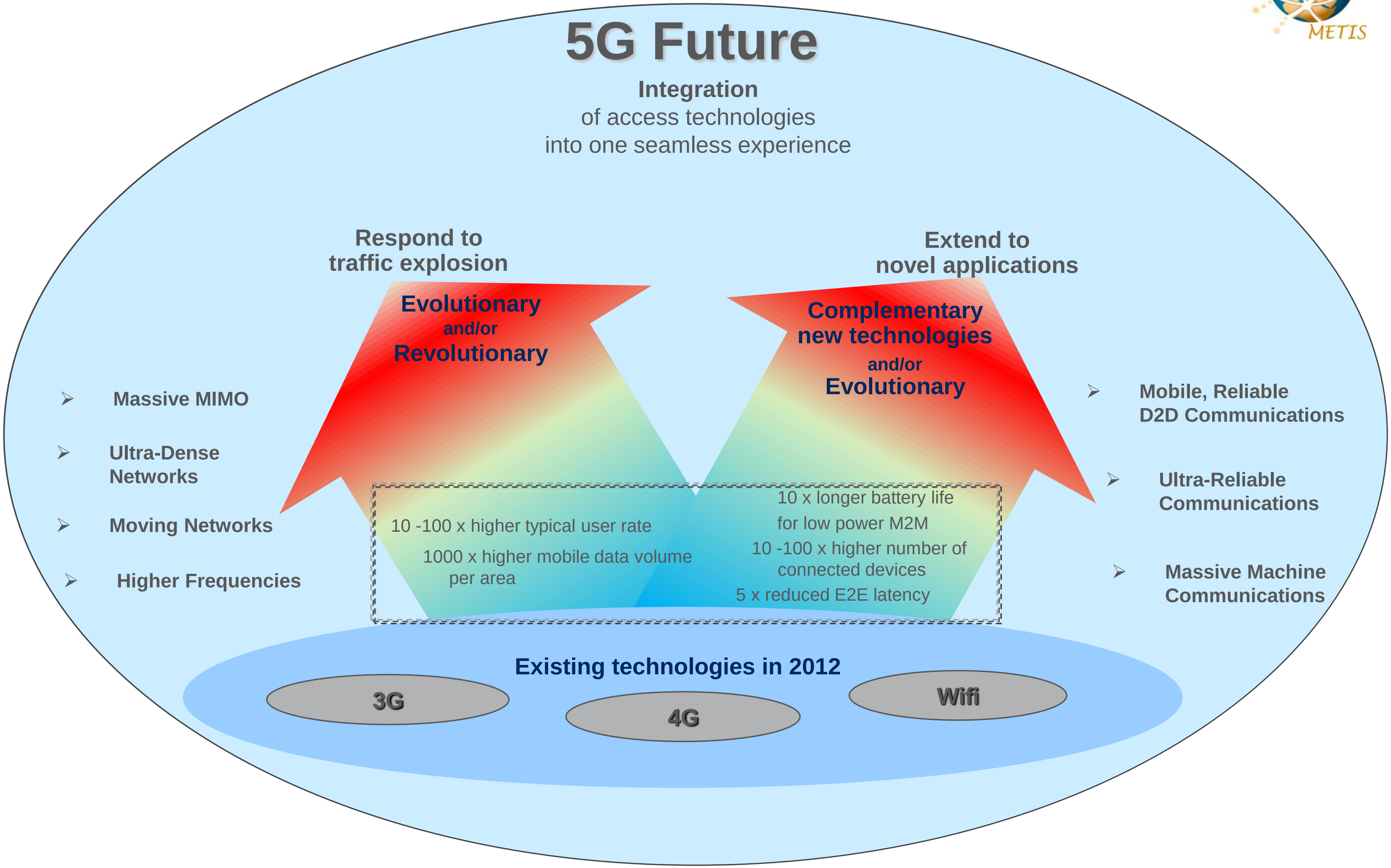
A system concept that, relative to today, supports:

- 1000 times higher mobile data volume per area,
- 10 times to 100 times higher number of connected devices,
- 10 times to 100 times higher typical user data rate,
- 10 times longer battery life for low power Massive Machine Communication (MMC) devices,
- 5 times reduced End-to-End (E2E) latency.

Source: METIS Deliverable D1.1 "Scenarios, requirements and KPIs for 5G mobile and wireless system", https://www.metis2020.com/

5G Future

Integration
of access technologies
into one seamless experience



Respond to traffic explosion

Evolutionary
and/or
Revolutionary

- **Massive MIMO**
- **Ultra-Dense Networks**
- **Moving Networks**
- **Higher Frequencies**

Extend to novel applications

Complementary new technologies
and/or
Evolutionary

- **Mobile, Reliable D2D Communications**
- **Ultra-Reliable Communications**
- **Massive Machine Communications**

10 -100 x higher typical user rate

1000 x higher mobile data volume per area

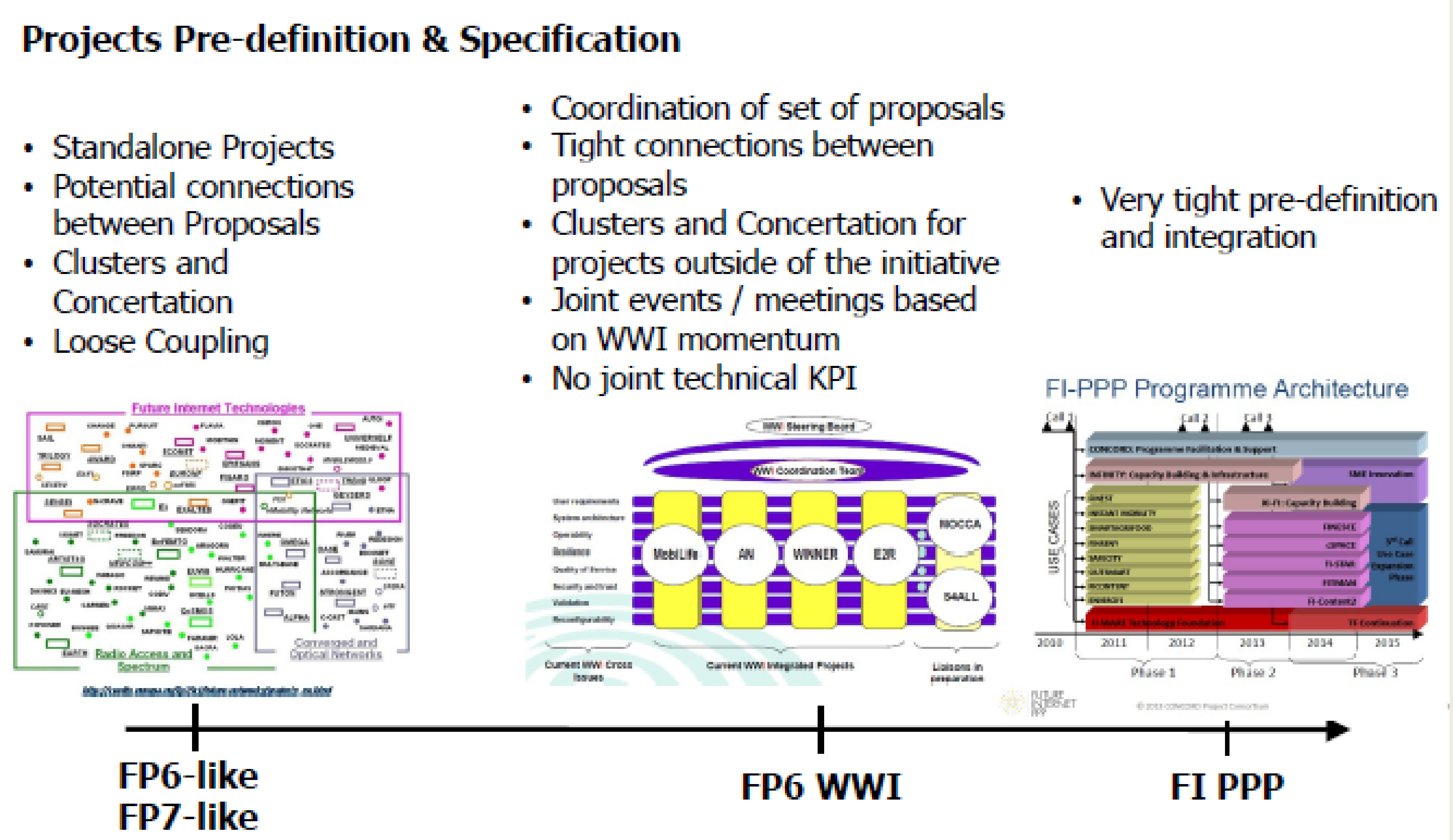
10 x longer battery life for low power M2M

10 -100 x higher number of connected devices

5 x reduced E2E latency

Existing technologies in 2012

The 5G Infrastructure Public Private Partnership



Projects Pre-definition & Specification

- Standalone Projects
- Potential connections between Proposals
- Clusters and Concertation
- Loose Coupling

- Coordination of set of proposals
- Tight connections between proposals
- Clusters and Concertation for projects outside of the initiative
- Joint events / meetings based on WWI momentum
- No joint technical KPI

- Very tight pre-definition and integration

FI-PPP Programme Architecture

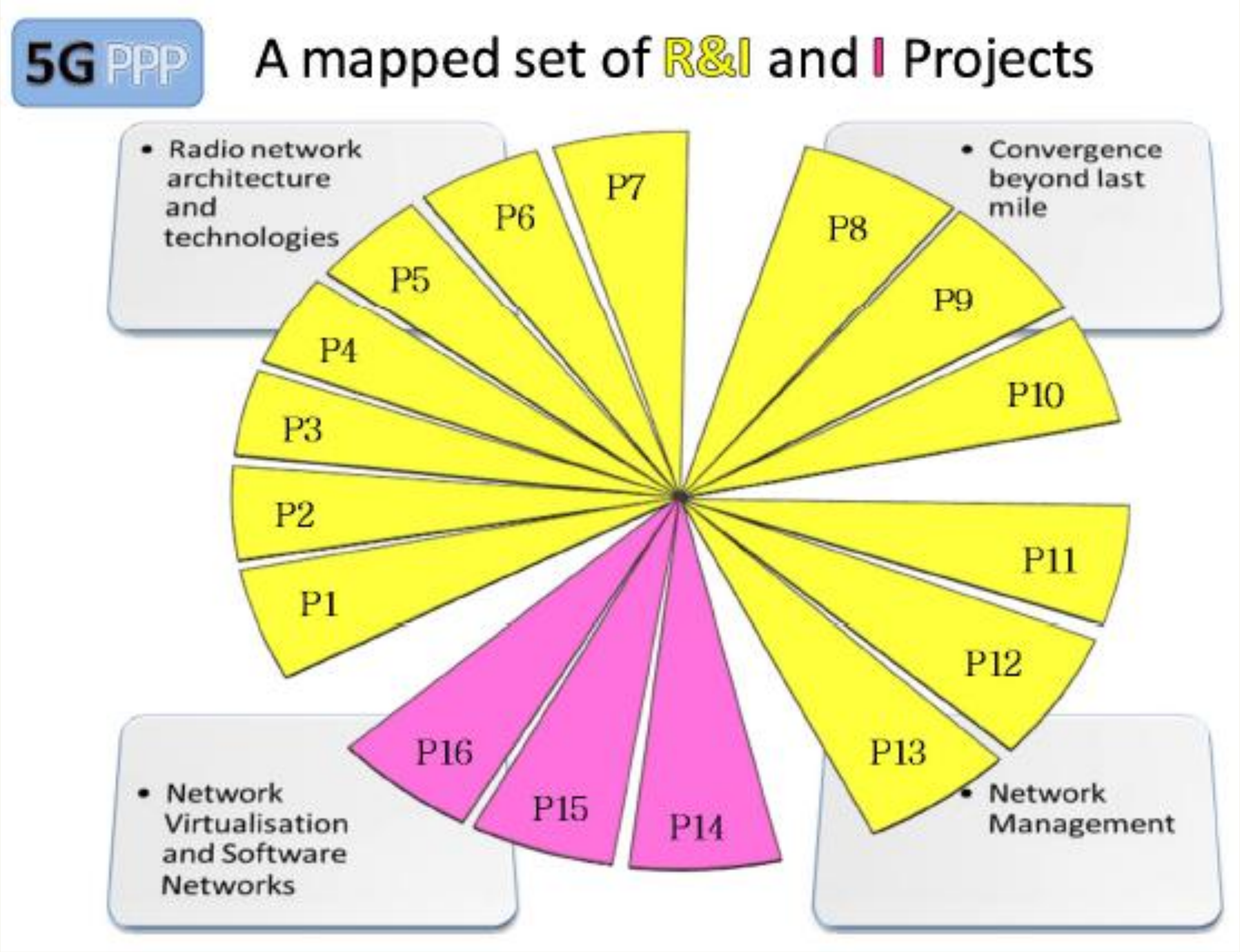
FP6-like
FP7-like

FP6 WWI

FI PPP

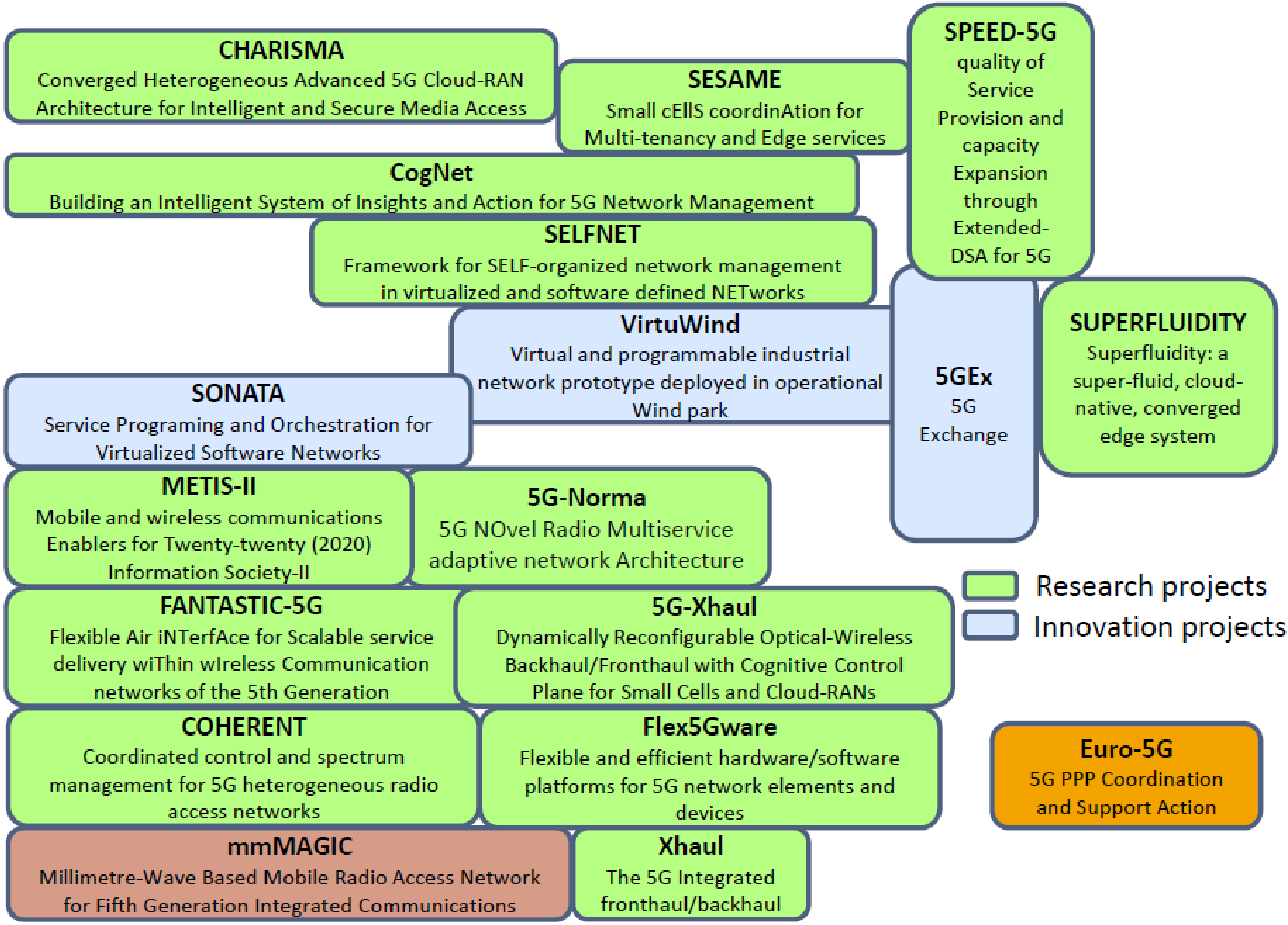
http://5g-ppp.eu/

Pre-structuring Model Approach



http://5g-ppp.eu/

Horizon 2020 5G PPP
Call 1 selected projects



CHARISMA
Converged Heterogeneous Advanced 5G Cloud-RAN Architecture for Intelligent and Secure Media Access

SESAME
Small cElls coordinAtion for Multi-tenancy and Edge services

SPEED-5G
quality of Service Provision and capacity Expansion through Extended-DSA for 5G

CogNet
Building an Intelligent System of Insights and Action for 5G Network Management

SELFNET
Framework for SELF-organized network management in virtualized and software defined NETworks

VirtuWind
Virtual and programmable industrial network prototype deployed in operational Wind park

5GEx
5G Exchange

SUPERFLUIDITY
Superfluidity: a super-fluid, cloud-native, converged edge system

SONATA
Service Programing and Orchestration for Virtualized Software Networks

METIS-II
Mobile and wireless communications Enablers for Twenty-twenty (2020) Information Society-II

5G-Norma
5G NOvel Radio Multiservice adaptive network Architecture

FANTASTIC-5G
Flexible Air iNTerfAce for Scalable service delivery wiThin wIreless Communication networks of the 5th Generation

5G-Xhaul
Dynamically Reconfigurable Optical-Wireless Backhaul/Fronthaul with Cognitive Control Plane for Small Cells and Cloud-RANs

COHERENT
Coordinated control and spectrum management for 5G heterogeneous radio access networks

Flex5Gware
Flexible and efficient hardware/software platforms for 5G network elements and devices

mmMAGIC
Millimetre-Wave Based Mobile Radio Access Network for Fifth Generation Integrated Communications

Xhaul
The 5G Integrated fronthaul/backhaul

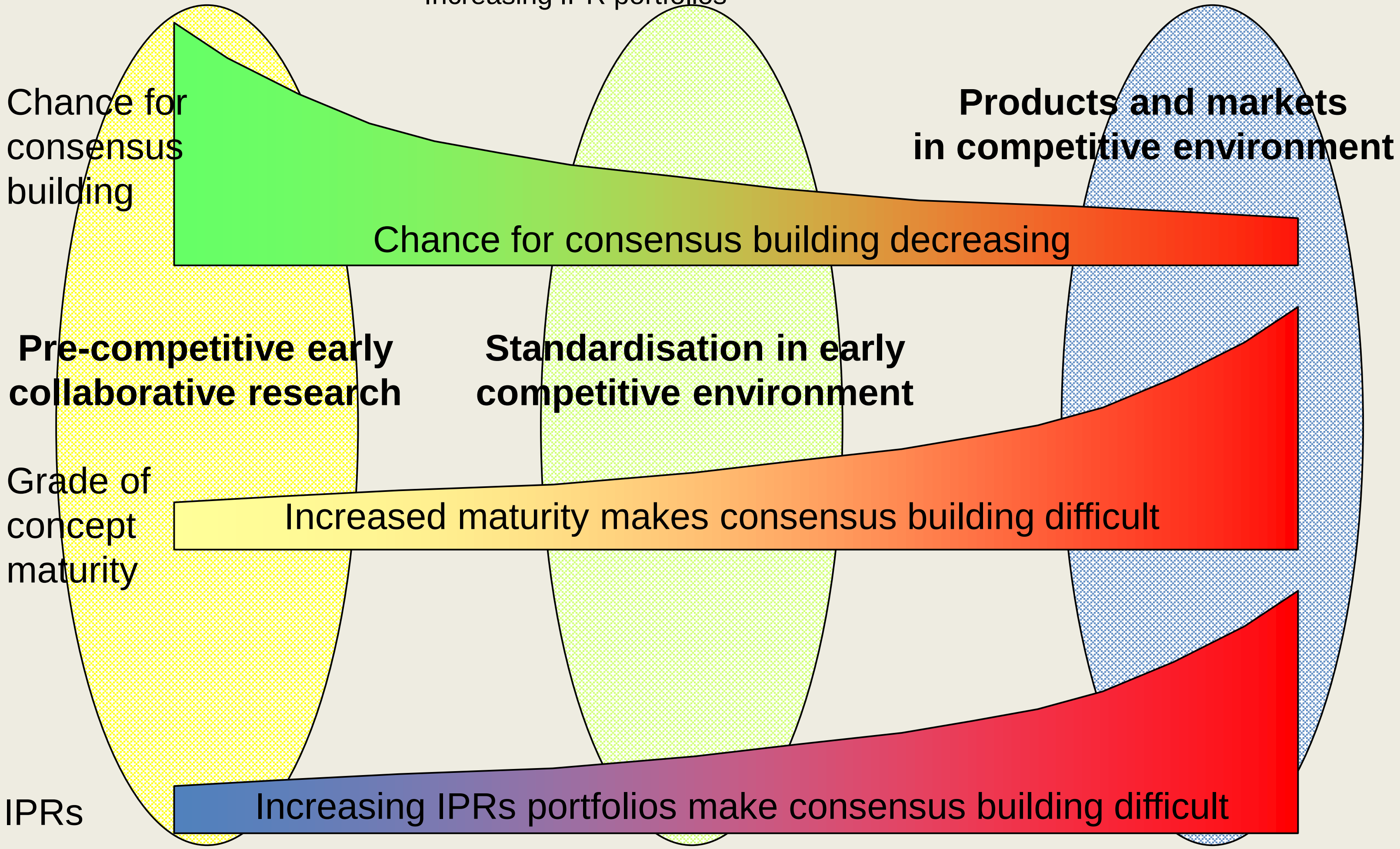
Euro-5G
5G PPP Coordination and Support Action

🟩 Research projects
🟦 Innovation projects

Source: 5G Infrastructure Association.

Why Competitive Organisations are Collaborating

- Increasing investment in solutions
- Increasing IPR portfolios



Chance for consensus building

Products and markets in competitive environment

Chance for consensus building decreasing

Pre-competitive early collaborative research

Standardisation in early competitive environment

Grade of concept maturity

Increased maturity makes consensus building difficult

IPRs

Increasing IPRs portfolios make consensus building difficult

- Thus, important to build international consensus building at an early stage!

mmMAGIC

Duration: 24 months
Budget: EURO 8.26M
Coordinator: Maziar Nekovee, Samsung
Technical Manager: Peter von Wrycza, Ericsson

https://5g-mmmagic.eu

mm-wave Based **M**obile Radio **A**ccess Network for Fifth **G**eneration (**5G**) **I**ntegrated **C**ommunications

Horizon 2020 Public Private Partnership Consortium

Coordinator: Samsung Electronics, Europe Ltd.
Technical Management: Ericsson AB

SAMSUNG
Alcatel·Lucent
intel
HUAWEI
NOKIA NETWORKS
orange
Telefonica

cea Leti
Fraunhofer Heinrich Hertz Institute
institute imdea networks

University of BRISTOL
CHALMERS UNIVERSITY OF TECHNOLOGY
TECHNISCHE UNIVERSITÄT DRESDEN

KEYSIGHT TECHNOLOGIES
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Advisory Board

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BNetzA
Viestintävirasto Kommunikationsverket Finnish Communications Regulatory Authority
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PTS

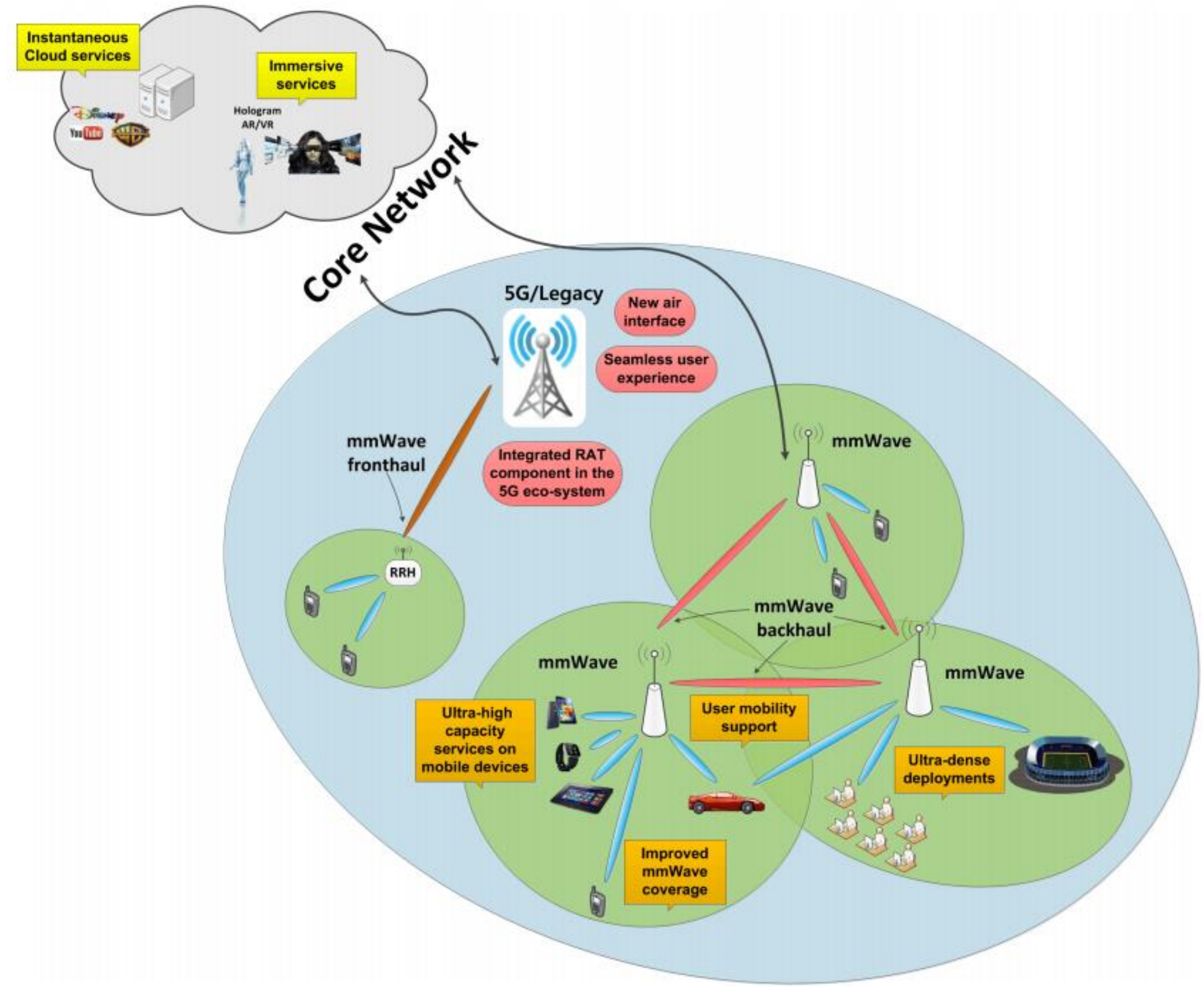
- UHD TV/streaming
- Immersive and interactive 3D services
- Ultra-responsive mobile cloud
- Ultra-dense deployment
- Multicast support
- Self-backhaul/front-haul support
- WRC'19 & 3GPP Head-start

3GPP A GLOBAL INITIATIVE
ITU

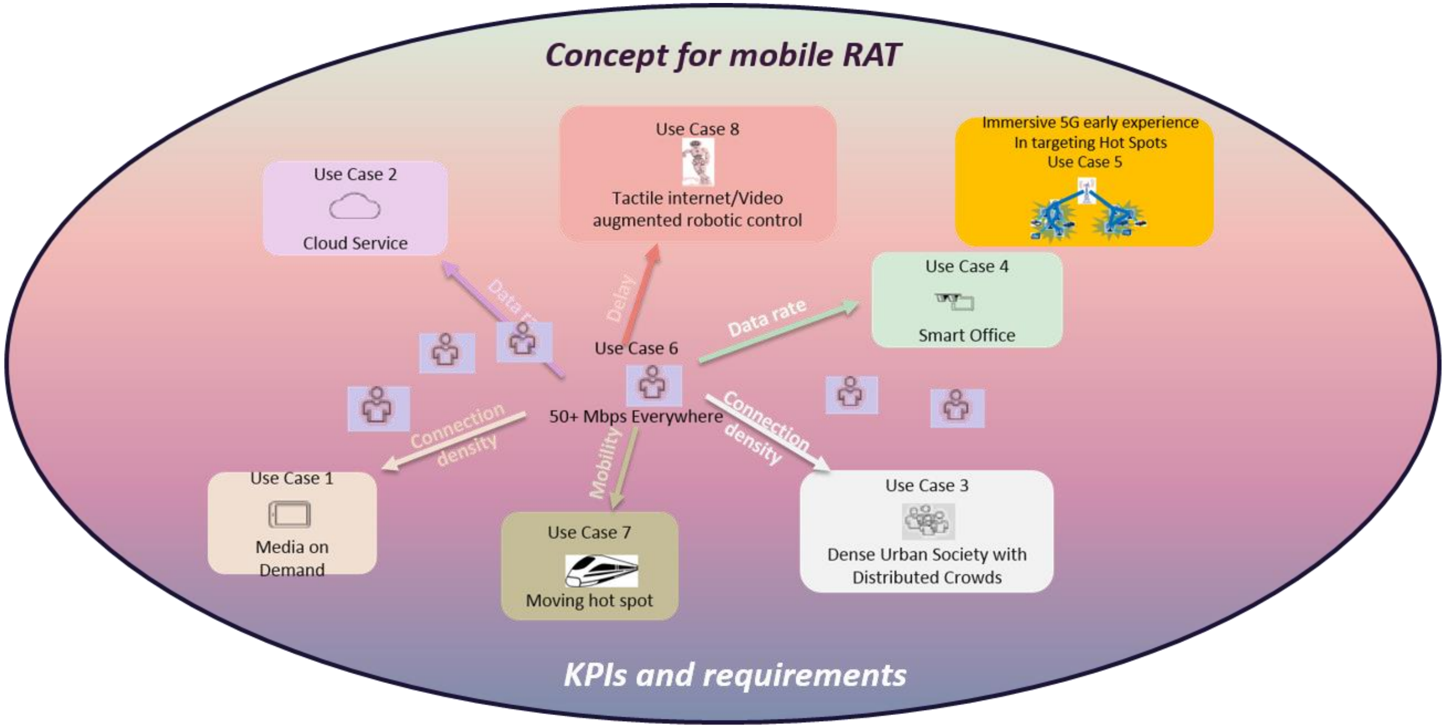
Project Objectives and Expected Outcome

- **Investigate** suitable frequency ranges (6-100 GHz) for extremely high capacity mobile broadband services
  - **Standards-ready** mobile radio interface operating in mm-wave frequencies (6-100 GHz), paving the way for a European head-start in 5G standards, including 3GPP and ITU-R
- **Conduct** measurements and develop accurate channel models for identified candidate frequency ranges
  - **Comprehensive** mm-wave channel models suited for regulatory and standards fora usage, ITU-R working groups and 3GPP
- **Develop** novel mobile radio access technologies for 5G systems in frequency above 6 GHz
- **Demonstrate** feasibility of the developed concepts
  - **Demonstrator** including advanced visualization of mm-wave based mobile broadband systems operating in **real-life** service provisioning scenarios & **hardware-in-the-loop** demonstrations
- **Interface/collaborate** with other 5G PPP projects, towards achieving a common set of 5G PPP KPIs
  - **Inputs** to the EC/5G-PPP Infrastructure Association in preparation of WRC 18/19 and contributing to the ITU-R evaluation work on IMT above 6 GHz

Objectives and Features



8 Use Cases in mmMAGIC



Concept for mobile RAT

Use Case 2
Cloud Service

Use Case 8
Tactile internet/Video augmented robotic control

Immersive 5G early experience
In targeting Hot Spots
Use Case 5

Use Case 4
Smart Office

Data r

Delay

Data rate

Use Case 6
50+ Mbps Everywhere

Connection density

Mobility

Connection density

Use Case 1
Media on Demand

Use Case 7
Moving hot spot

Use Case 3
Dense Urban Society with Distributed Crowds

KPIs and requirements

- Use cases describe *how, when and where end users can utilize a particular service*
  - Take into account end user perspective of a service
  - Identify KPIs and challenges
  - Are characterized by specific requirements
- The use cases, the corresponding KPIs and the requirements selected in mmMAGIC are used to derive directions to design a 5G multi RAT technology

Selected use Cases and Critical KPIs (mmMAGIC, METIS, NGMN)

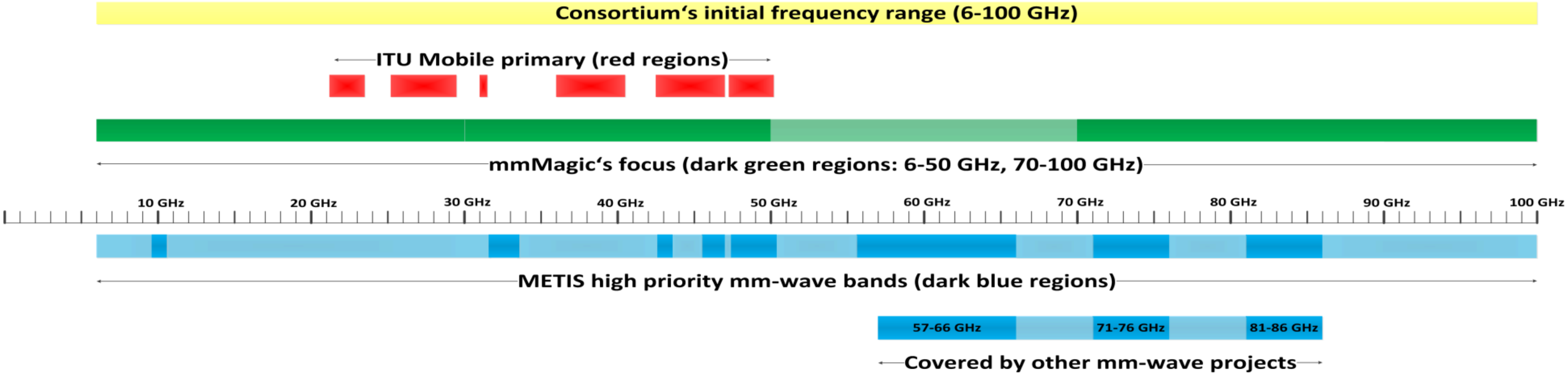
Use Case	Main Challenge (most critical KPIs)
Media on demand	Peak connection density (4000 users/km²)
Cloud services	DL traffic density (up to 750 Gbps/km²), mobility (up to 100 km/h)
Dense urban society with distributed crowds	Connection density (30000, up to 150000, users/km²), traffic density (7500 Gbps/km²), bandwidth
Smart offices	DL user data rate (1 Gbps), traffic density (15000 Gbps/km²)
Immersive 5G early experience in targeting hot spots	Data rate (x10 average, x20 peak) and cell densification (25 small cells/hotspot area)
50+Mbps everywhere	Coverage
Moving hot spot	Mobility (up to 500 km/h)
Tactile internet / video augmented robotic control and remote-robot manipulation surgery	Availability and reliability (99,999%), low latency (1 ms)

https://bscw.5g-mmmagic.eu/pub/bscw.cgi/d54427/mmMAGIC_D1.1.pdf

Advantages of mm-waves for Selected Use Cases

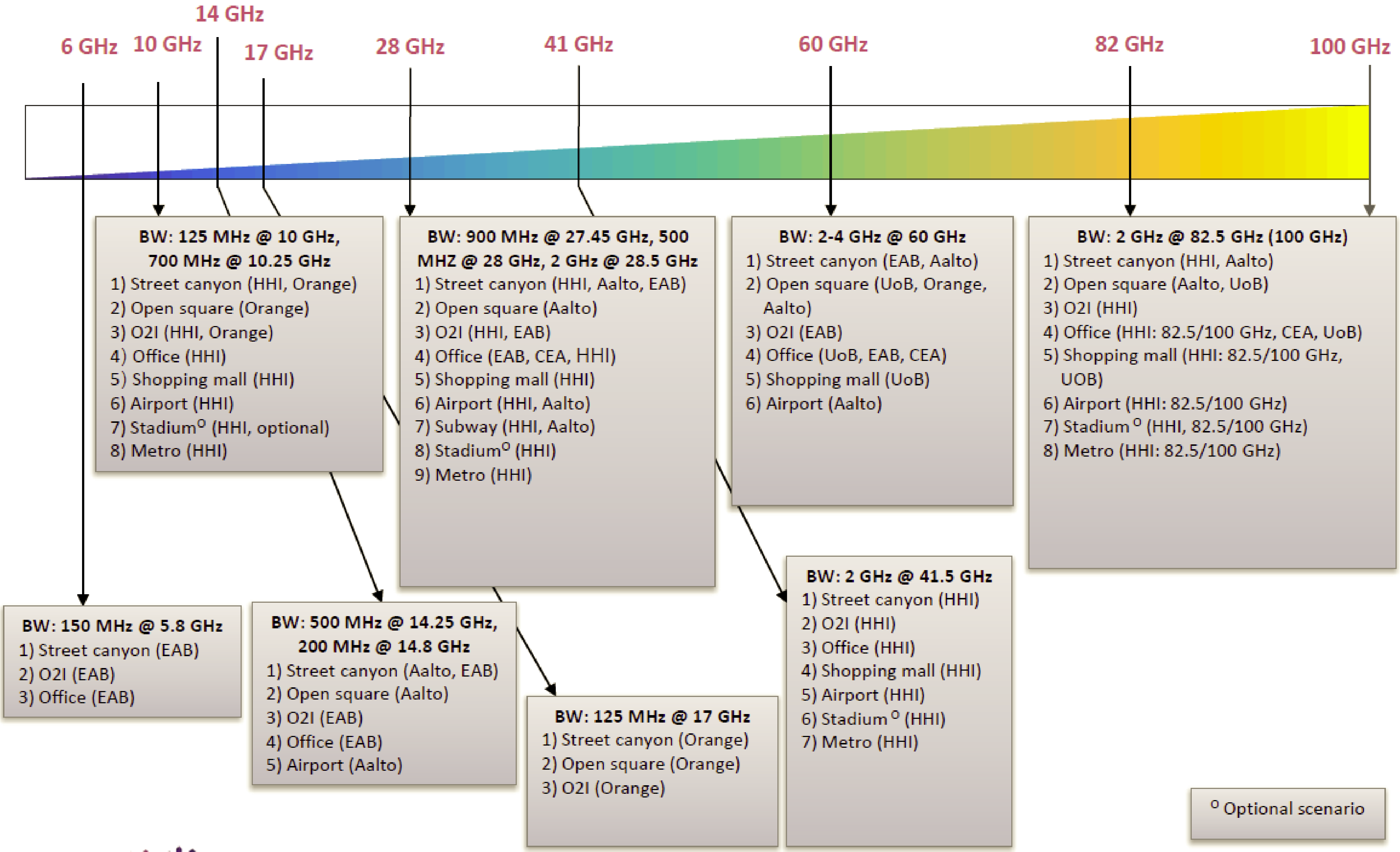
- Possibility to find wide contiguous bandwidth => potentially high data rate and low latency
- The high directionality of antennas needed for mmWave transmissions causes less interference to other systems
- Unfavourable propagation characteristics allows dense frequency reuse

Spectrum Considerations



- The analysis is conducted in the first instance to the 6-50 GHz frequency range, where mobile allocations already exists, and to the 70 - 100 GHz frequency range
- Factors included in the selection of the most suitable frequency bands for mm-wave communications
  - available technology hardware components
  - presence of incumbent systems and possible interference-mitigation techniques
  - potential for global harmonization
  - available and required contiguous bandwidth
  - transmit power, antenna characteristic and beamforming options
  - existing mobile-communication services
  - sharing and coexisting possibilities with other radio technologies and services,
  - …

mmMAGIC Measurement Bands and Scenarios



BW: 150 MHz @ 5.8 GHz
1) Street canyon (EAB)
2) O2I (EAB)
3) Office (EAB)

BW: 125 MHz @ 10 GHz, 700 MHz @ 10.25 GHz
1) Street canyon (HHI, Orange)
2) Open square (Orange)
3) O2I (HHI, Orange)
4) Office (HHI)
5) Shopping mall (HHI)
6) Airport (HHI)
7) Stadium° (HHI, optional)
8) Metro (HHI)

BW: 500 MHz @ 14.25 GHz, 200 MHz @ 14.8 GHz
1) Street canyon (Aalto, EAB)
2) Open square (Aalto)
3) O2I (EAB)
4) Office (EAB)
5) Airport (Aalto)

BW: 125 MHz @ 17 GHz
1) Street canyon (Orange)
2) Open square (Orange)
3) O2I (Orange)

BW: 900 MHz @ 27.45 GHz, 500 MHZ @ 28 GHz, 2 GHz @ 28.5 GHz
1) Street canyon (HHI, Aalto, EAB)
2) Open square (Aalto)
3) O2I (HHI, EAB)
4) Office (EAB, CEA, HHI)
5) Shopping mall (HHI)
6) Airport (HHI, Aalto)
7) Subway (HHI, Aalto)
8) Stadium° (HHI)
9) Metro (HHI)

BW: 2 GHz @ 41.5 GHz
1) Street canyon (HHI)
2) O2I (HHI)
3) Office (HHI)
4) Shopping mall (HHI)
5) Airport (HHI)
6) Stadium° (HHI)
7) Metro (HHI)

BW: 2-4 GHz @ 60 GHz
1) Street canyon (EAB, Aalto)
2) Open square (UoB, Orange, Aalto)
3) O2I (EAB)
4) Office (UoB, EAB, CEA)
5) Shopping mall (UoB)
6) Airport (Aalto)

BW: 2 GHz @ 82.5 GHz (100 GHz)
1) Street canyon (HHI, Aalto)
2) Open square (Aalto, UoB)
3) O2I (HHI)
4) Office (HHI: 82.5/100 GHz, CEA, UoB)
5) Shopping mall (HHI: 82.5/100 GHz, UOB)
6) Airport (HHI: 82.5/100 GHz)
7) Stadium° (HHI, 82.5/100 GHz)
8) Metro (HHI: 82.5/100 GHz)

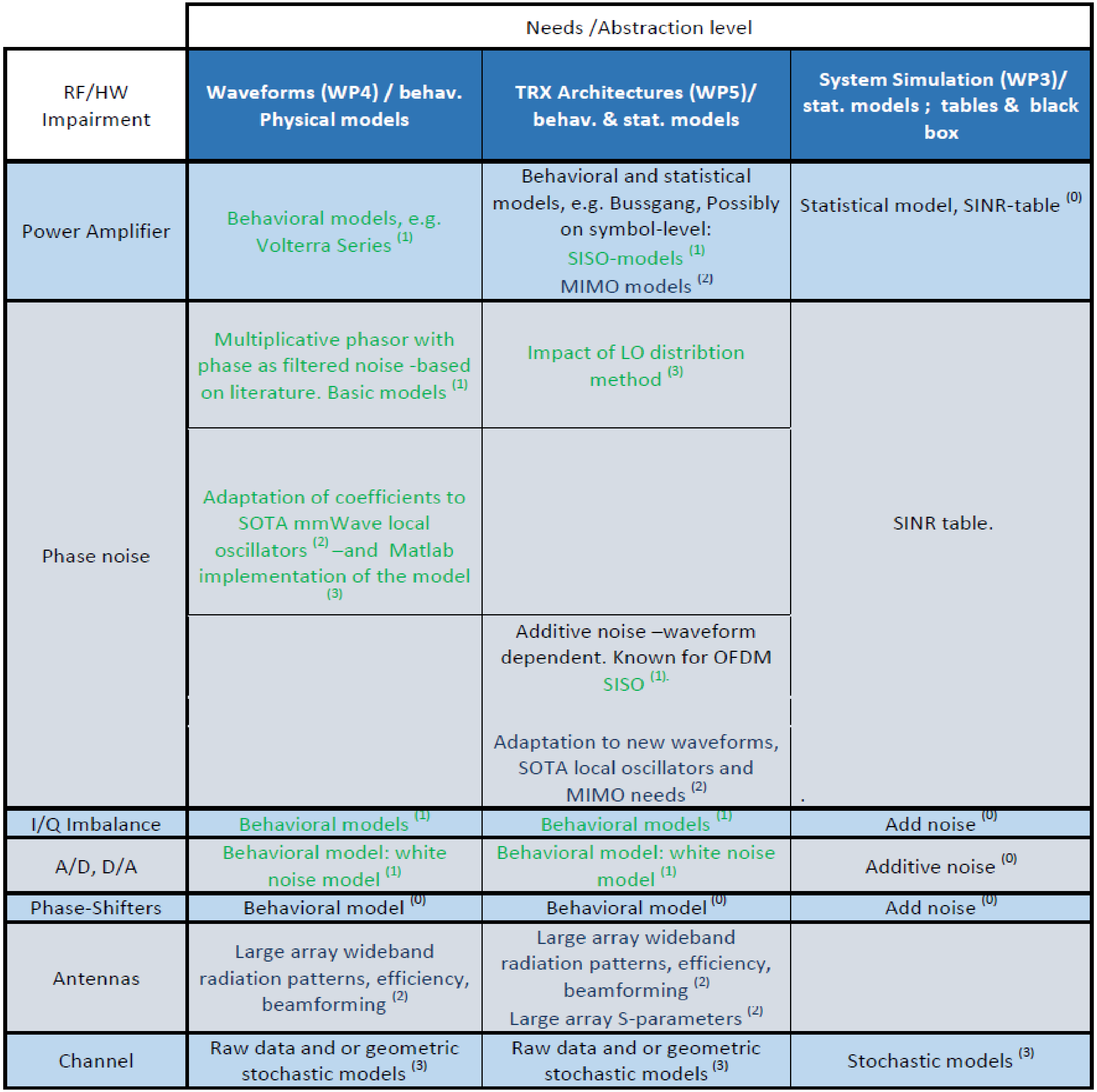
° Optional scenario

Need of Suitable HW Impairment Models

Behavioral/statistical models at various investigation levels

- Power amplifiers (HPA, LNA)
- Phase noise
- I/Q Imbalance
- A/D, D/A converters
- Phase shifters
- Antenna models

Effective models after Compensation techniques



RF/HW Impairment	Needs /Abstraction level Waveforms (WP4) / behav. Physical models	 TRX Architectures (WP5)/ behav. & stat. models	 System Simulation (WP3)/ stat. models ; tables & black box
Power Amplifier	Behavioral models, e.g. Volterra Series (1)	Behavioral and statistical models, e.g. Bussgang, Possibly on symbol-level: SISO-models (1) MIMO models (2)	Statistical model, SINR-table (0)
Phase noise	Multiplicative phasor with phase as filtered noise -based on literature. Basic models (1)	Impact of LO distribtion method (3)	SINR table.
	Adaptation of coefficients to SOTA mmWave local oscillators (2) –and Matlab implementation of the model (3)		
		Additive noise –waveform dependent. Known for OFDM SISO (1). Adaptation to new waveforms, SOTA local oscillators and MIMO needs (2)	
I/Q Imbalance	Behavioral models (1)	Behavioral models (1)	Add noise (0)
A/D, D/A	Behavioral model: white noise model (1)	Behavioral model: white noise model (1)	Additive noise (0)
Phase-Shifters	Behavioral model (0)	Behavioral model (0)	Add noise (0)
Antennas	Large array wideband radiation patterns, efficiency, beamforming (2)	Large array wideband radiation patterns, efficiency, beamforming (2) Large array S-parameters (2)	
Channel	Raw data and or geometric stochastic models (3)	Raw data and or geometric stochastic models (3)	Stochastic models (3)

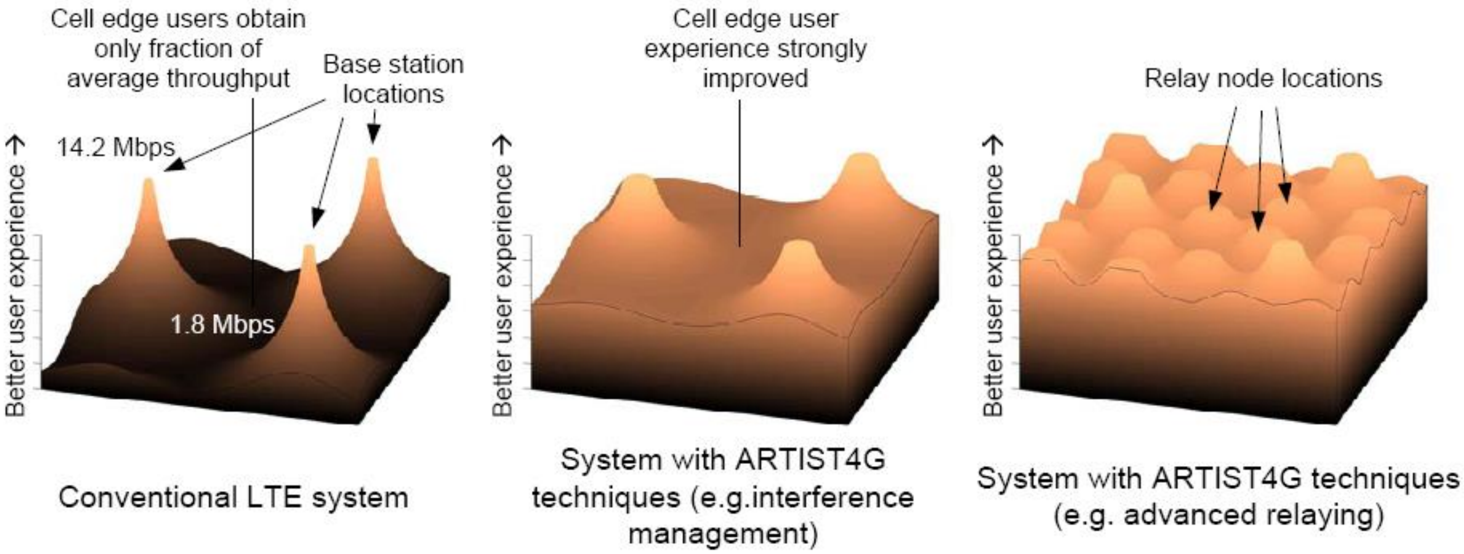
(0) Not available
(1) Existent
(2) Extension in mmMagic
(3) mmMagic contribution

https://bscw.5g-mmmagic.eu/pub/bscw.cgi/d95056/mmMAGIC_D5_1.pdf

Coordinated Multi-Point (CoMP)

Coordinated Multi-Point transmission (CoMP):

- Coordinated scheduling/beamforming over multiple cells has the potential to lower the interference levels in a frequency reuse one system
- Coordinated multi-cell transmission and reception has the potential to improve the outage capacity and to smoothen the capacity over the cell areas.



Relative Performance Gains (ideal CSI)

Main evaluation case: 4 Tx, 2 Rx antennas, 3 site (9 cell) CAs

	SINR [dB]		**Spectral efficiency** bits/s/Hz/cell	**SE gain** [%]
	cell edge	average		
Network wide CoMP (1)	-	-	**8 / 15**(2)	**160**
Network wide CoMP with nonlinear precoding(1)	-	-	**11 / 20**	**250**
3GPP MU-MIMO	-	-	**3.1**	**0** (reference)
3GPP JP-CoMP	-	-	**4.0**	**30**
9-cell CoMP (3)	**-2**	**12**	-	-
+ cover shift (3)	**4**	**17**	-	-
+ IF floor shaping (3)	**12**	**23**	-	-
+ 2-stage scheduler (4)	**5**	**15**	**7.5 / 13** (2)	**140**

SINRs [dB] for single UE per cell

Artist4G D1.4, *Interference Avoidance Techniques and System Design*, June 2012. https://ict-artist4g.eu

(1) Simulation conditions are not fully comparable; higher values are for nonlinear precoding
(2) Values after backslash ignore LTE overhead of 43%;
(3) SINR for single UE per cell and for 4x2;
(4) SINR for 2 to 3 out of 10 simultaneously scheduled UEs per cell and 4x2 configuration
Perfect transmitter CSI assumed in all evaluations above.

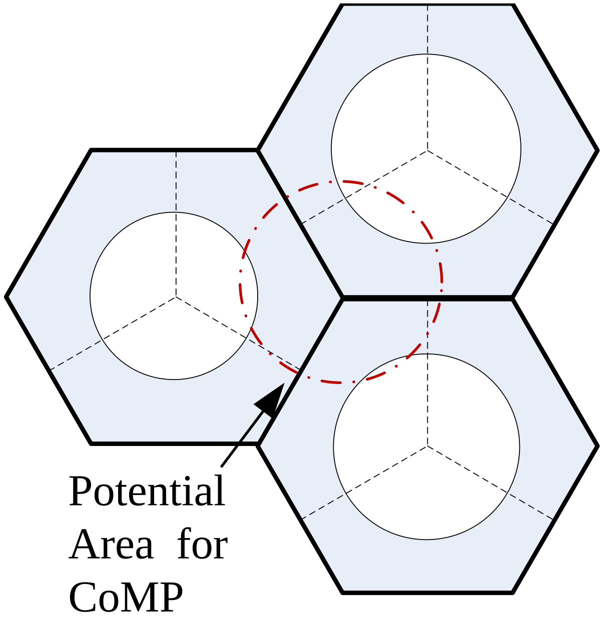
Revisit: Towards a Framework for Realistic CoMP

Based on

- Realistic channel knowledge, pilot overhead and feedback rates
- Backhaul awareness
- Application (QoS) aware performance metrics (KPIs)

Enablers

- Multi-link channel estimation/prediction schemes
- Robust metric-aware beamforming
- Adaptive (user centric) clustering
- Power control and resource allocation
- Inter-cluster interference coordination
- Backhaul limitations awareness
- User grouping and scheme/mode selection
- Dynamic multi-mode CoMP schemes



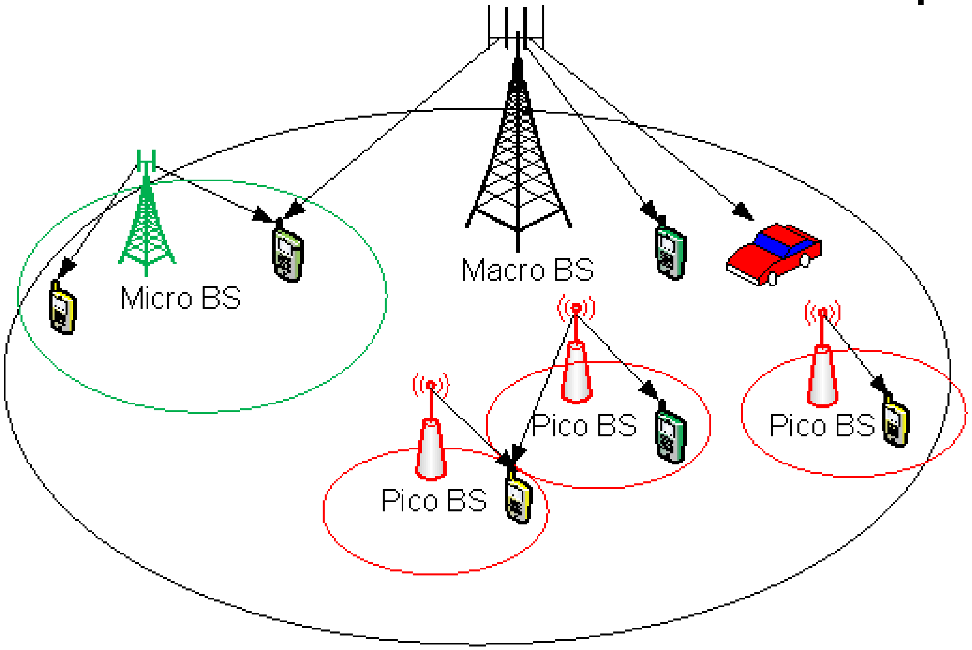
mm-wave: unstructured networks, unreliable backhauling, constrained/imprecise beamforming, smaller cells with more frequent handover, high requirement on energy efficiency…

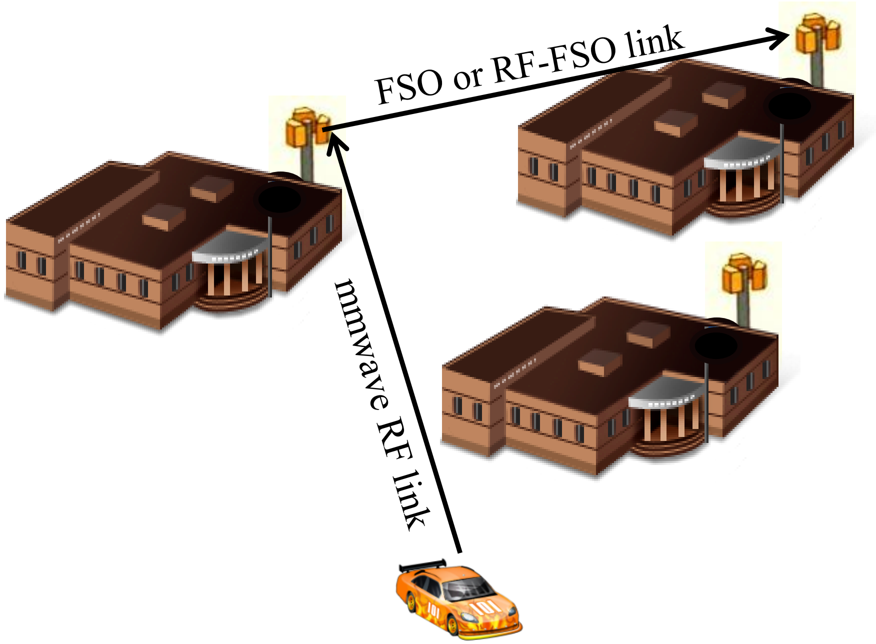
Potential of Multi-node Cooperation in mm-wave Systems

- With narrow beamforming mm-wave links, potentially less need for interference coordination(?), but also less knowledge of CSI
- Homogeneous
  - Macro-diversity gains towards shadowing/blocking
  - Power gains: potential EIRP limited
  - Increase multipath and thus (distributed) MIMO rank to better support (distributed) spatial multiplexing and massive MIMO gains at sparse mmWave channels
  - Spider handover
  - Load balancing
- Heterogeneous macro/mm-wave adds:
  - Low latency and robust out-of-band control
  - Coverage of mm-wave blind spots
  - Hybrid links for macro-diversity and rain fading diversity
- Integrated design of mm-wave backhaul and access can enable efficient user data delivery for cooperative communications

To assess the potential, angular dependency and spatial correlation in the channel models are critical.

Macro-BS/Small cell Cooperation and Hybrid Links



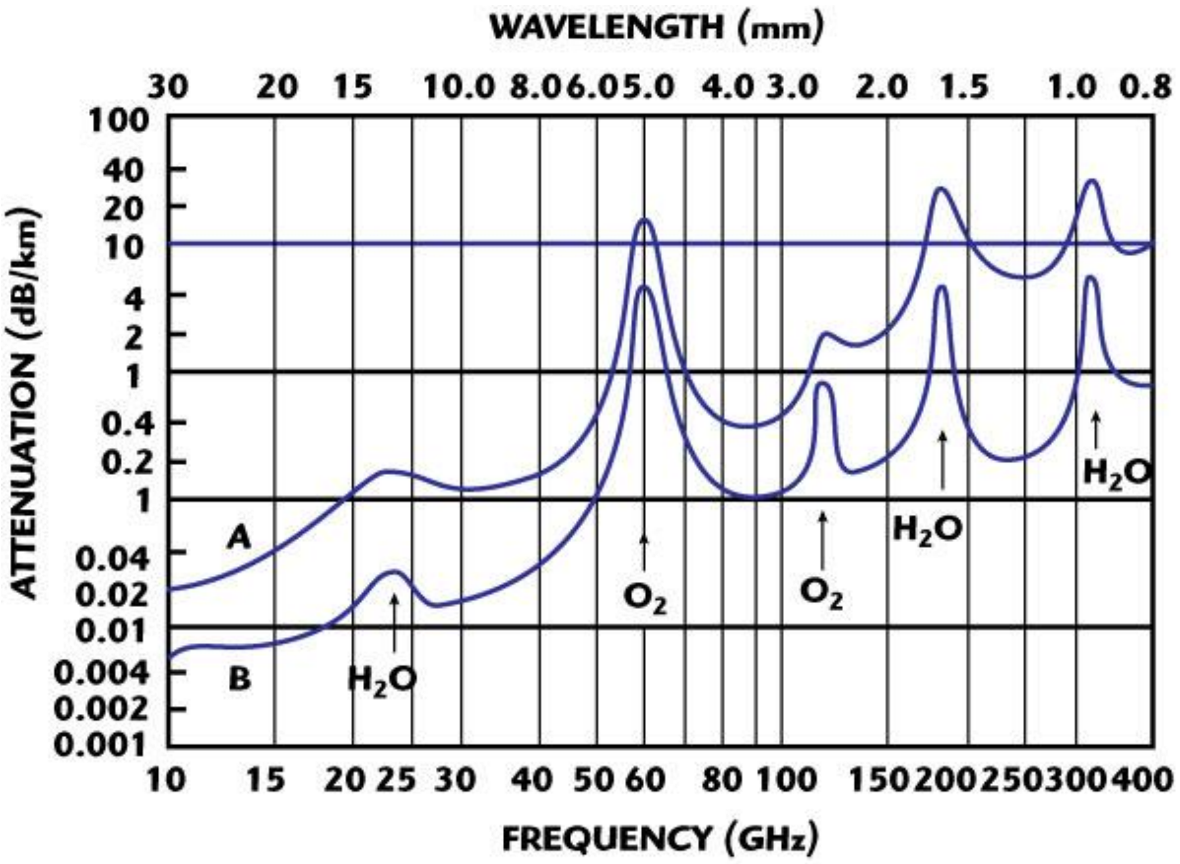


Jointly optimize the precoding, load balancing and BS operation modes for improving the network energy efficiency, using spatial multi-flow

- B. Makki, T. Svensson, T. Eriksson, and M..S. Alouini, “On the Performance of HARQ-based RF-FSO Links”, IEEE Globecom 2015

- J. Li, E. Bjornson, T. Svensson, T. Eriksson, M. Debbah, "Optimal design of energy-efficient HetNets: joint precoding and load balancing," in Communications (ICC), 2015 IEEE International Conference on , vol., no., pp.4664-4669, 8-12 June 2015 **Best paper award**
- J. Li, E. Bjornson, T. Svensson, T. Eriksson, M. Debbah, "Joint Precoding and Load Balancing Optimization for Energy-Efficient Heterogeneous Networks," in Wireless Communications, IEEE Transactions on , vol.14, no.10, pp.5810-5822, Oct. 2015

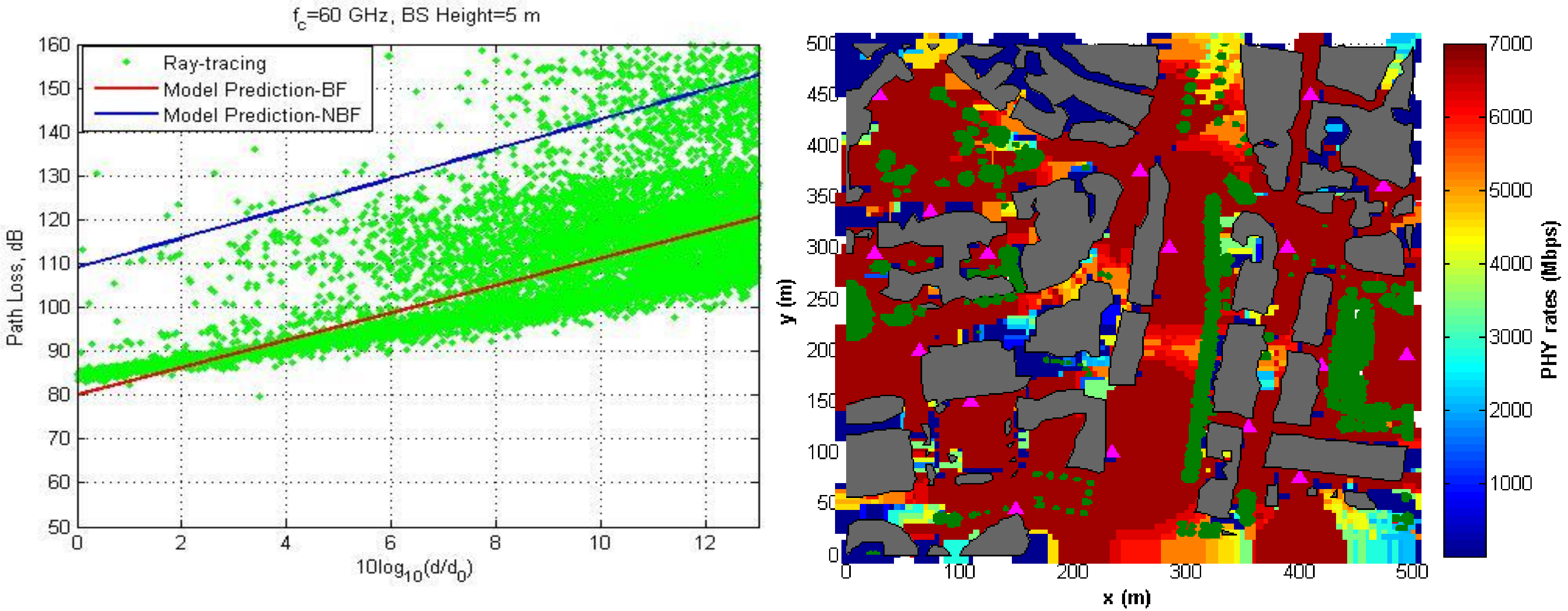
Attenuation at mm-wave Frequencies



Average atmospheric absorption of MMWs: (A) Sea Level: T = 20°C, P = 760mm, H_2O = 7.5 g/m^3 (B) 4 km altitude: T = 0°C H_2O = 1 g/m^3

Source: Microwave Journal: http://www.microwavejournal.com/legacy_assets/FigureImg/AR_4772_Fig02_L.jpg

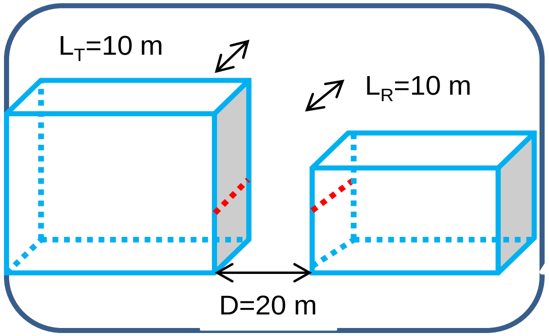
Coverage and Throughput Prediction at 60 GHz mm-wave using Ray Tracing



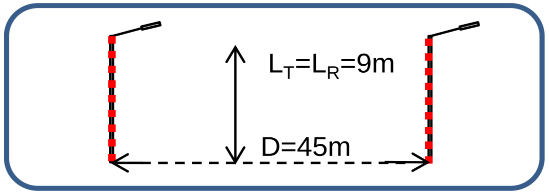
- Left: Path-loss with respect to distance for mm-wave outdoor system Right:Throughput estimation using 17 BSs [ABA+15].

- *D5.1 "Initial multi-node and antenna transmitter and receiver architectures and schemes" March 2016, https://5g-mmmagic.eu*
- *[ABA+15]: Abdullah, N.F.; Berraki, D.; Ameen, A.; Armour, S.; Doufexi, A.; Nix, A.; Beach, M., "Channel Parameters and Throughput Predictions for mmWave and LTE-A Networks in Urban Environments," inVehicular Technology Conference (VTC Spring), 2015 IEEE 81st , vol., no., pp.1-5, 11-14 May 2015*

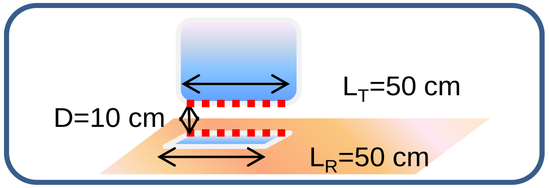
Massive MIMO at Both Tx, Rx (MMIMMO)



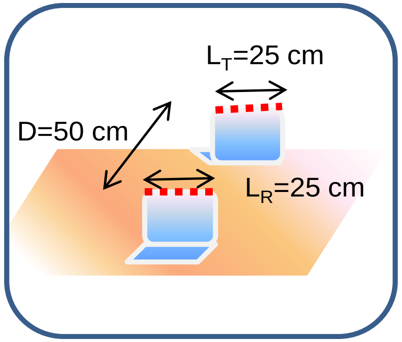
scenario 1: communicating buildings, **N=512, f=30.72GHz**



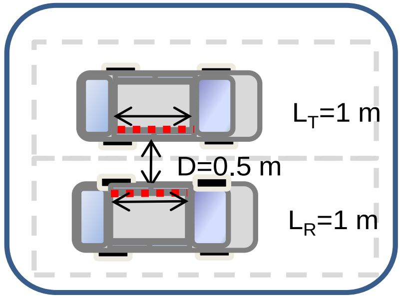
scenario 2: communicating lamp posts (these are heights and separations in France), **N=256, f=42.7GHz**



scenario 5: communicating laptop-screen, **N=512, f=61.4GHz**



scenario 3: communicating laptops, **N=32, f=76.8GHz**

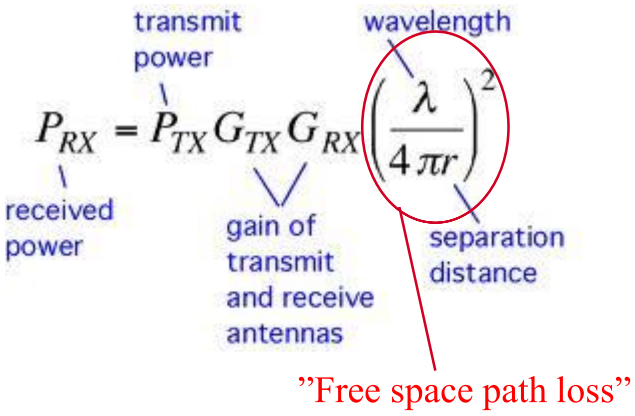


scenario 4: side-to-side communicating cars (non moving), **N=256, f=38.4GHz**

Legend:

▪▪▪▪▪ Uniform linear antenna array

Friis transmission equation



$$P_{RX} = P_{TX} G_{TX} G_{RX} \left(\frac{\lambda}{4\pi r} \right)^2$$

transmit power

wavelength

received power

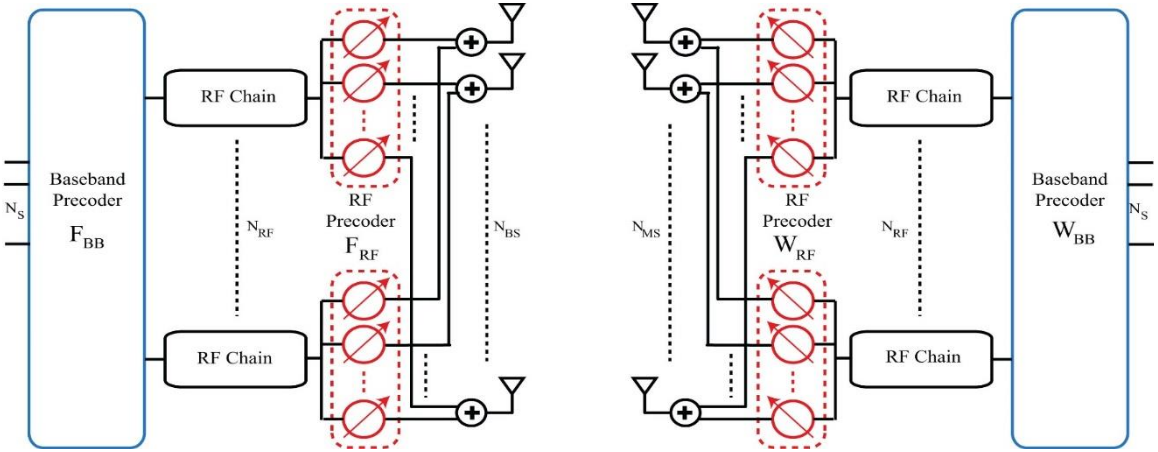
gain of transmit and receive antennas

separation distance

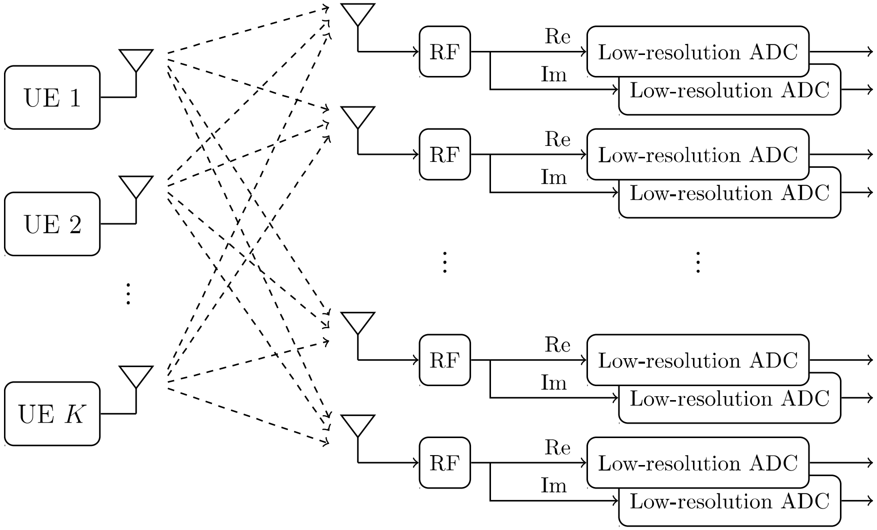
”Free space path loss”

Source: D5.1 ”Initial multi-node and antenna transmitter and receiver architectures and schemes” March 2016, https://5g-mmmagic.eu

Hybrid and Low-precision Beamforming for Massive MIMO



© O. El Ayach, S. Rajagopal, S. Abu-Surra, Z. Pi, and R. Heath, "Spatially sparse precoding in millimeter wave MIMO systems," IEEE Transactions on Wireless Communications, vol. 13, no. 3, pp. 1499–1513, March 2014



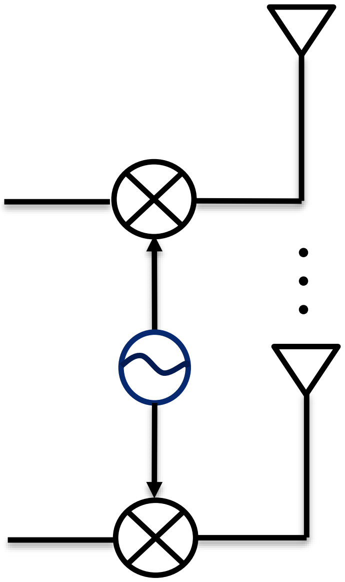
Also at transmitter?
However, might increase uncontrolled interference!

© C. Studer and G. Durisi, "Quantized massive MU-MIMO-OFDM uplink," Sep. 2015. [Online]. Available: http://arxiv.org/abs/1509.07928

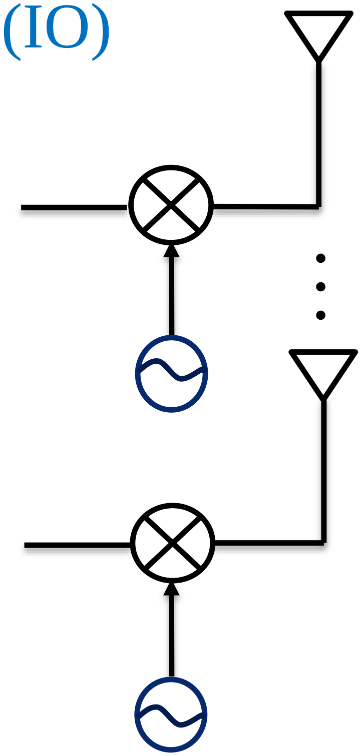
Impact of non-ideal oscillators

Phase noise effects for two alternative oscillator implementations

Common oscillator (CO)



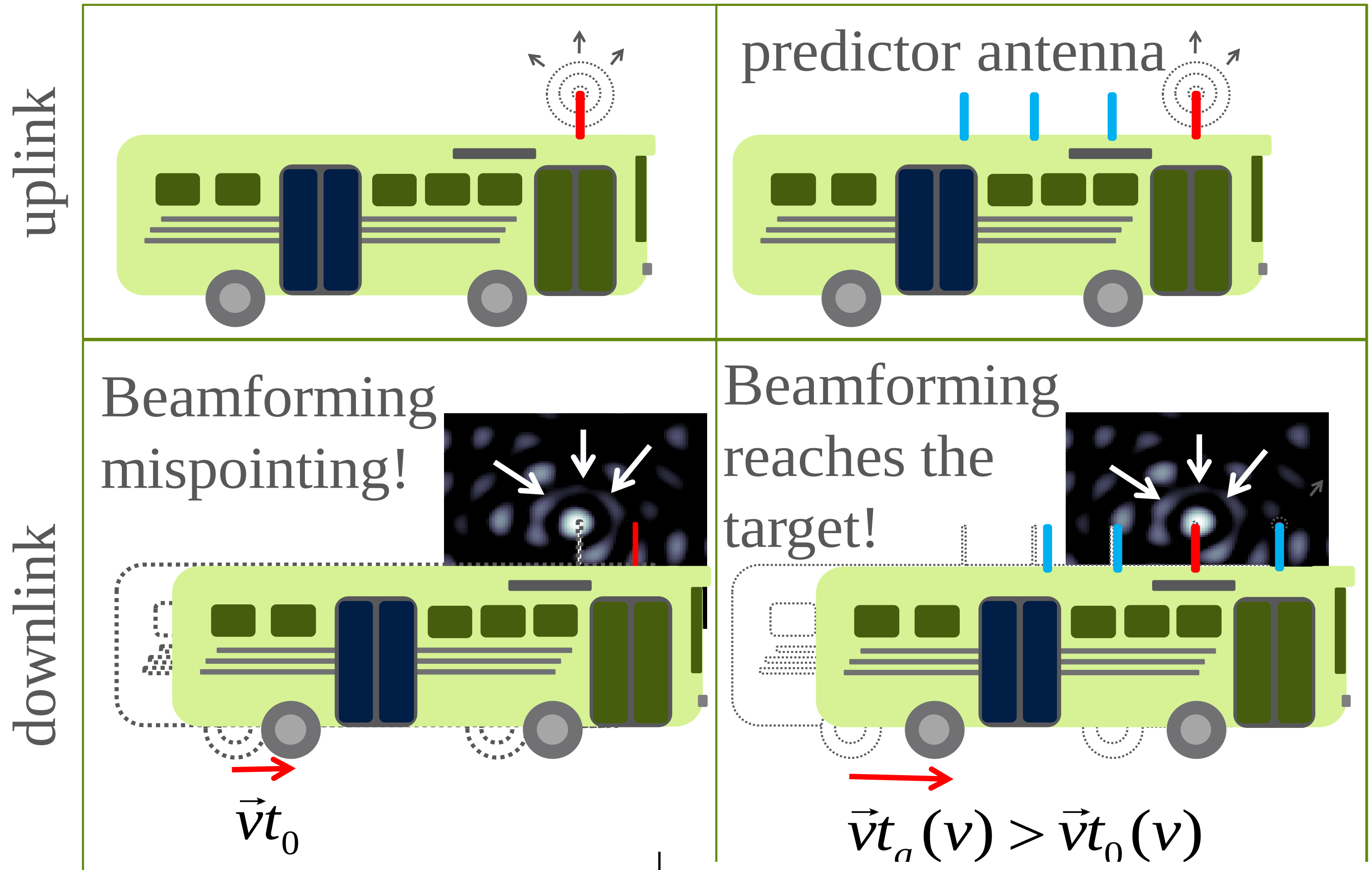
Independent oscillators (IO)



- Tx PN and Rx PN of CO have the same ICI influence on beamforming MIMO-OFDM.
- Tx PN and Rx PN of IO can have different influences depending on the number of Tx and Rx antennas.
- Unlike that of CO, PN of IO can be alliviated by having more antennas.
- It is easier to track the CO PN. Hence, with effective PN mitigation, the CO case outperforms the IO case.

X. Chen, F. Chao, Y. Zou, A. Wolfgang, T. Svensson, "Beamforming MIMO-OFDM Systems in the Presence of Phase Noises in Millimeter-Wave Frequencies", IEEE WCNC'2017 mmMAGIC workshop, Mar 2017, San Francisco, USA.

Moving BSs and Massive MIMO



uplink

downlink

predictor antenna

Beamforming mispointing!

Beamforming reaches the target!

$\vec{v}t_0$

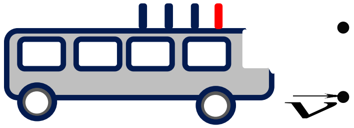
$\vec{v}t_a(v) > \vec{v}t_0(v)$

Reference System

Use of **predictor antenna**

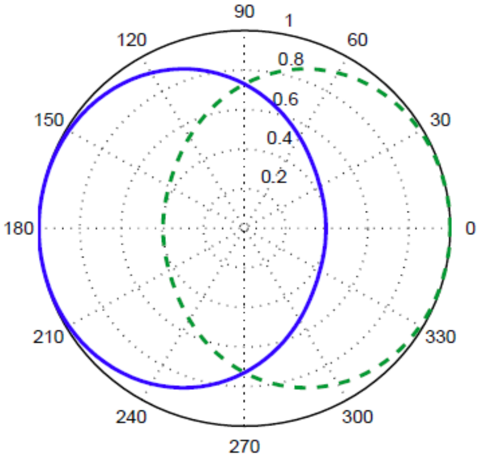
- *D. Thuy, M. Sternad and T. Svensson, "Adaptive Large MISO Downlink with Predictor Antenna Array for Very Fast Moving Vehicles," ICCVE'2013, Dec 2013, Las Vegas, USA.*

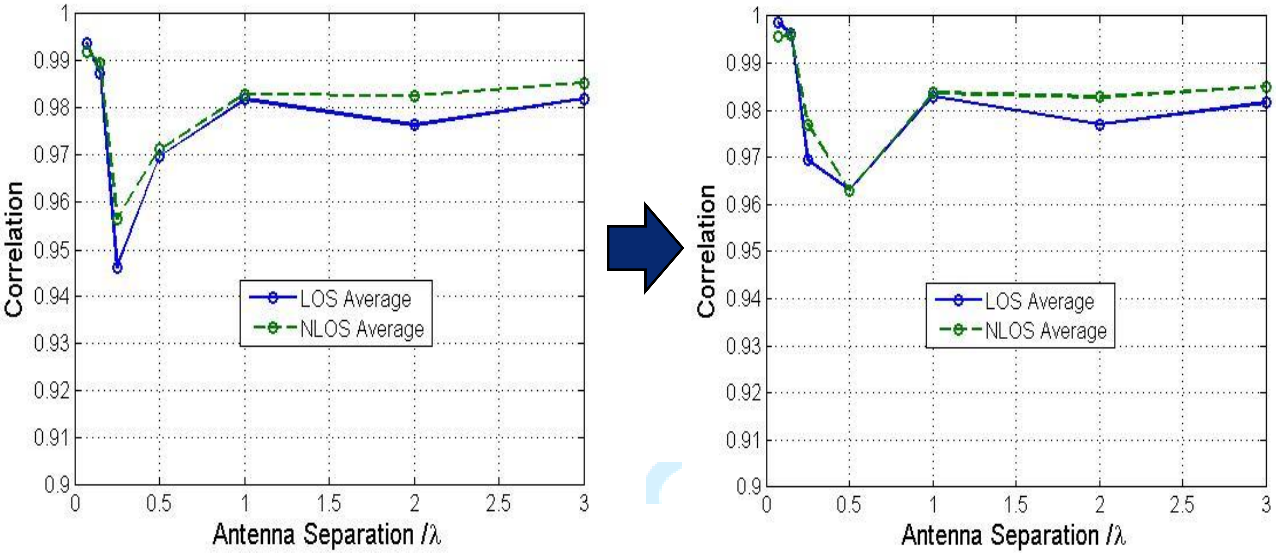
Predictor Antenna



- Two antennas in urban environment (line-of-sight, non-line-of sight).
- 20 MHz OFDM downlink at 2.68 GHz, measurements at 45-50 km/h

With Antenna embedded pattern compensation:

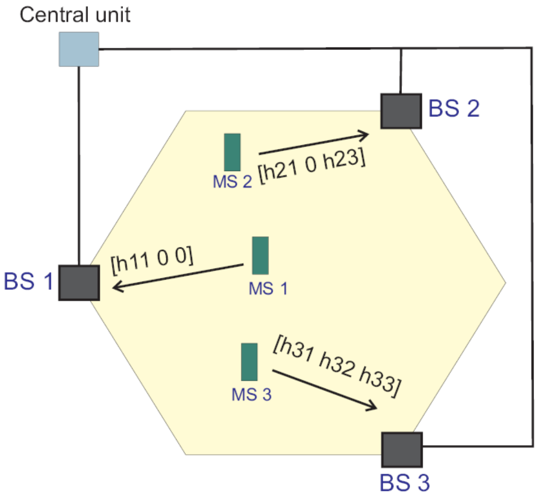




› Prediction horizon beyond **3λ** seems feasible => x10 better – enables closed loop schemes at high speed >1 GHz !

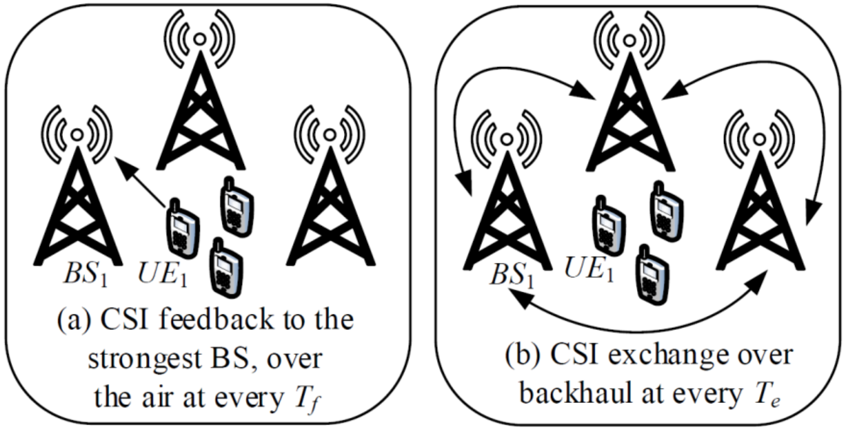
- *N. Jamaly, R. Apelfrojd, A. Belen Martinez, M. Grieger, T. Svensson, M. Sternad and G. Fettweis, ”Analysis and Measurement of Multiple Antenna Systems for Fading Channel Prediction in Moving Relays,” EuCAP’2014, April 2014, Haag, The Netherlands.*
- *M. Sternad, M. Grieger, R. Apelfrojd, T. Svensson, D. Aronsson, A. Belen Martinez “Using “Predictor Antennas” for Long-Range Prediction of Fast Fading for Moving Relays,” IEEE WCNC, Paris, 2012.*

Adaptive CoMP: Partial Joint Processing (PJP)



- *Sub-clusters* of base stations are defined for each user in the cluster, e.g. based on a channel gain *threshold mechanism*.
- Multiuser interference is introduced, but *less* requirements on *feedback* and *backhaul* are needed
- Possible to find *robust* close to optimum PJP schemes that lowers feedback and backhaul load

T. R. Lakshmana, A. Tölli, R. Devassy, T. Svensson, "Precoder Design with Limited Feedback and Backhauling for Joint Transmission", IEEE Transactions on Wireless Communications, vol.PP, no.99, pp.1-1



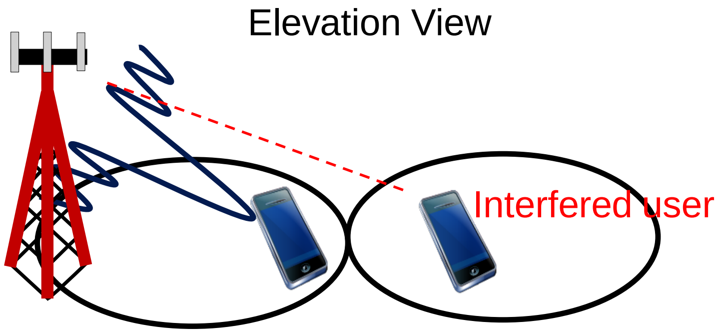
(a) CSI feedback to the strongest BS, over the air at every T_f

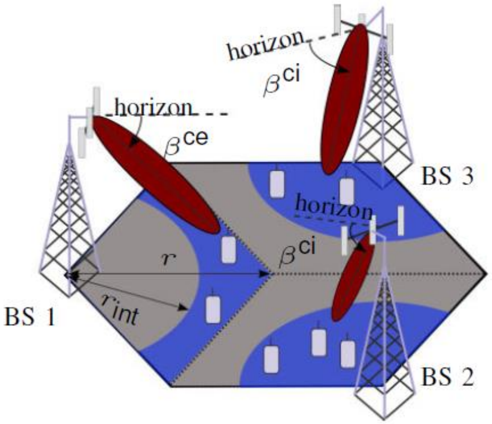
(b) CSI exchange over backhaul at every T_e

- User specific CSI update rate
- Possible to harvest a large part of the cooperation gains

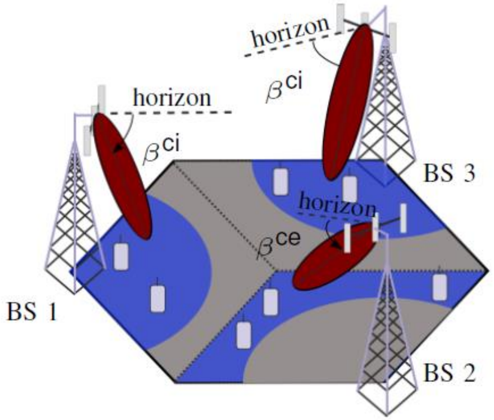
T. R. Lakshmana, A. Tölli, T. Svensson, "Improved Local Precoder Design for JT-CoMP with Periodical Backhaul CSI Exchange Corresponding Author: Mr. Tilak Rajesh Lakshmana", IEEE Communications Letters, To appear

Vertical Coordination



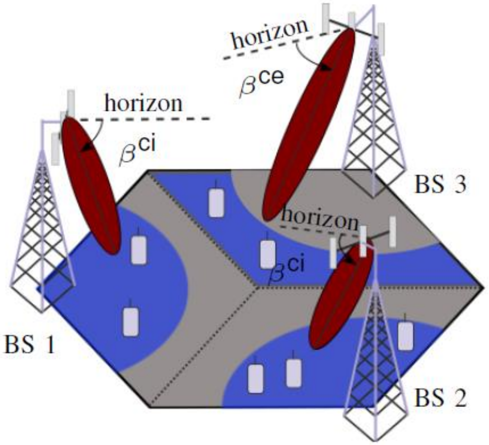


(a) Pattern 1



(b) Pattern 2

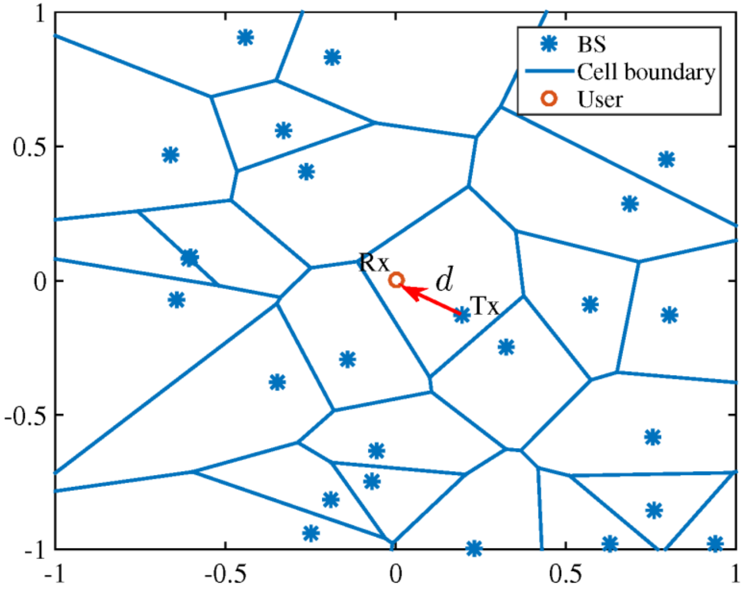
- No CSI exchange required



(c) Pattern 3

- *N. Seifi, M. Coldrey and T. Svensson, ”Elevation Plane Spatial Multicell Interference Mitigation With no CSI Sharing”, IEEE Globecom 2015 workshop on Emerging Technologies for 5G Wireless Cellular Networks, Dec 2015.*

Analysis of Unstructured Networks



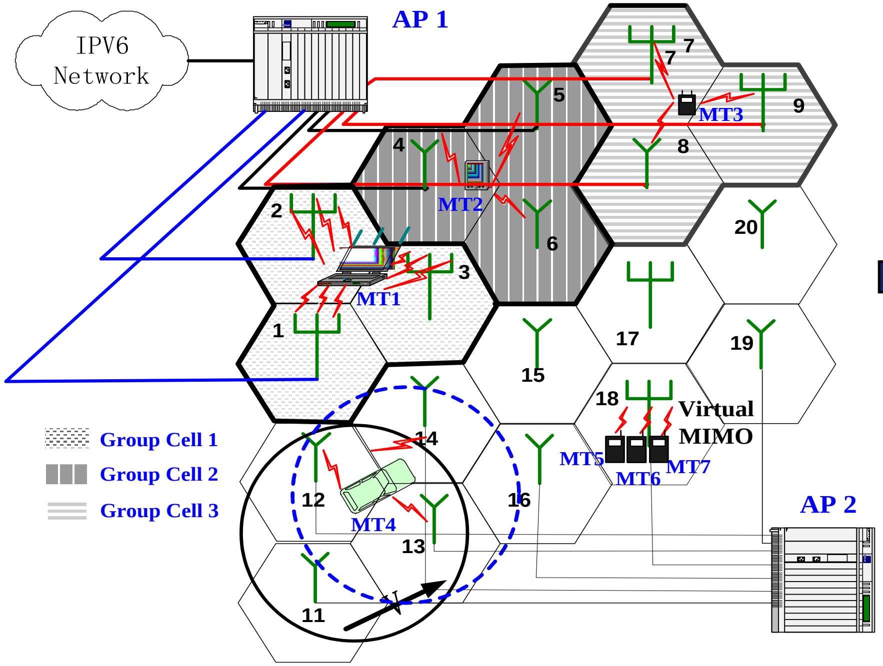
- Transmitter and/or receiver locations are modelled by a homogeneous Poisson point process (PPP) with density λ.
- Network-wide performance metrics can be analyzed
- User-specific performance metrics can also be analysed in case of moving networks

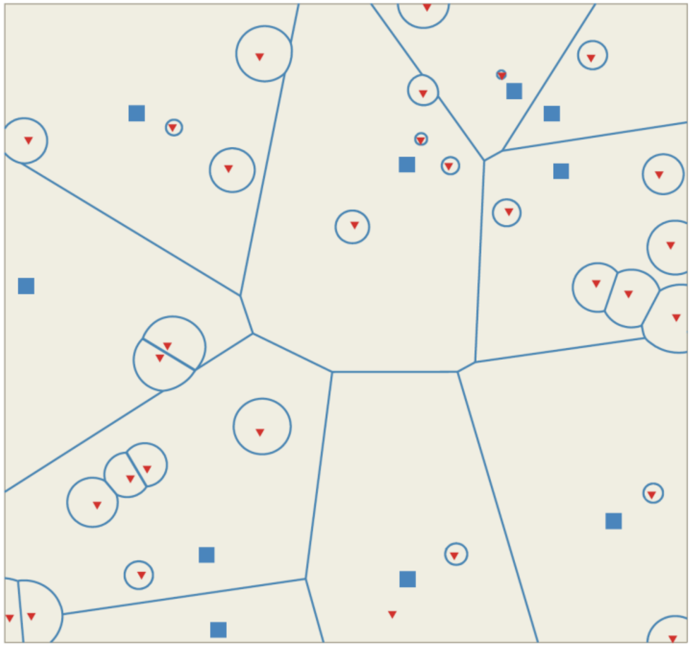
- C. Fang, B. Makki, T. Svensson, “HARQ in Poisson Point Process-based Heterogeneous Networks”, IEEE Vehicular Technology Conference (VTC2015-Spring), 2015, Glasgow, Scotland
- B. Makki, C. Fang, T. Svensson, M. Nasiri-Kenari, “On the performance of amplifier-aware dense networks: Finite block-length analysis”, International Conference on Computing, Networking and Communications (ICNC 2016), Workshop on Computing, Networking and Communications (CNC), Kauai, Hawaii, USA, Feb. 2016.
- Y. Hong, X. Xu, M. Tao, J. Li, T. Svensson, “Cross-tier Handover Analyses in Small Cell Networks: A Stochastic Geometry Approach”, ICC’2015
- C. Fang, B. Makki, T. Svensson, “"On the Performance of the Poisson-Point-Process-Based Networks with no Channel State Information Feedback”, submitted IET Communications
- C. Fang, B. Makki, X. Xu, T. Svensson, “Analysis of Equal Gain and Switch-and-stay Combining in Poisson Networks with Spatially correlated Interference”, submitted to IEEE Transactions on Wireless Communications

We plan to include also unreliable wireless backhauling, building on:

- Z. Mayer, J. Li, A. Papadogiannis, T. Svensson, “On the Impact of Control Channel Reliability on Coordinated Multi-Point Transmission”, EURASIP Journal on Wireless Communications and Networking, Feb 2014.
- Z. Mayer, J. Li, A. Papadogiannis, T. Svensson, “On the Impact of Backhaul Channel Reliability on Cooperative Wireless Networks”, IEEE International Conference on Communications, ICC 2013, Budapest, Hungary, June 2013.

CoMP with Mobility - in Unstructured Networks





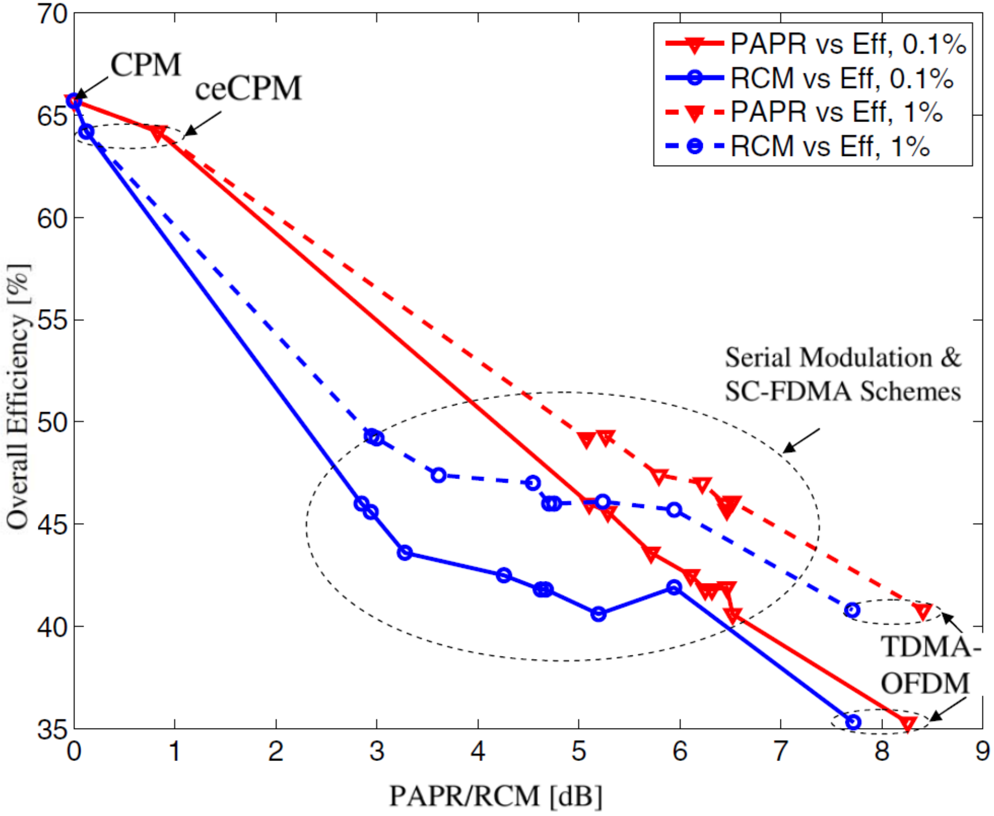
Equal long-term averaged biased DL-RSS coverage Boundaries (ESBs) in a two-tier small cell network with macro cells (blue squares) and small cells (red triangles).

- Fixed Group Cell: AP1 controls 3 fixed group cells of size 3
- Slide Group Cell: In AP2, the group cell serving MT4 is dynamically reconfigured in order to follow the movement of the user

Y. Hong, X. Xu, M. Tao, J. Li, T. Svensson, "Cross-tier Handover Analyses in Small Cell Networks: A Stochastic Geometry Approach", ICC'2015

High Power Amplifier (HPA) Overall Efficiency vs Envelope Metrics

- Maximum overall efficiency vs mean PAPR and Raw Cubic Metric with 1% and 0.1% clipping level



- › Low PAPR enables low cost HPAs
- › High HPA efficiency implies low heat dissipation enabling tight integration in transceiver in small form factor without cooling

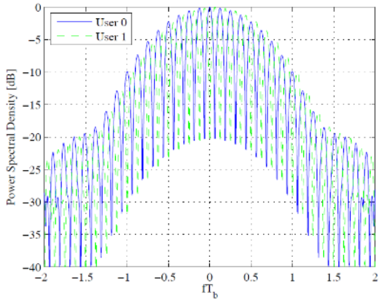
$$\eta_A = \frac{P_{Out}}{P_{DC} + P_{In}}$$

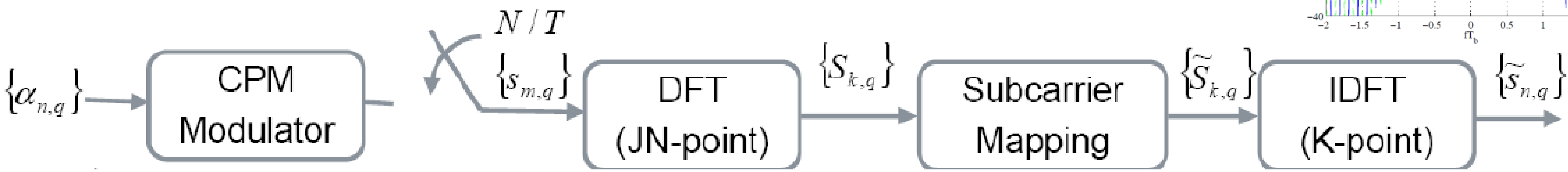
- › P_{In}: RF power at the input of the HPA
- › P_{Out}: resulting RF output power
- › P_{DC}: power at the DC input of the amplifier, $P_{DC} = V_{DC} \cdot I_{DC}$.

- HPA overall efficiency increases monotonically with decreasing Peak-to-Average-Power Ratio (PAPR) and Raw Cubic Metric (RCM)
- Constant (CPM) and constrained envelope (ceCPM) modulation schemes are substantially more efficient compared to OFDM, with serial modulation schemes in between.

T. Svensson, T. Eriksson, "On Power Amplifier Efficiency with Modulated Signals", VTC2010-Spring, May 2010, Taipei, Taiwan

Low PAPR wideband spread frequency interleaved waveform: Continuous Phase Modulation based Precoding of SC-FDMA (CPM-SC-FDMA)

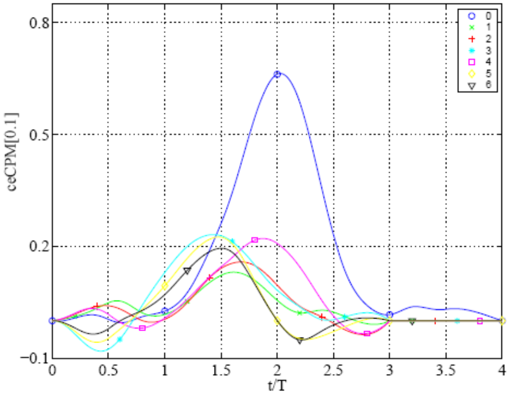


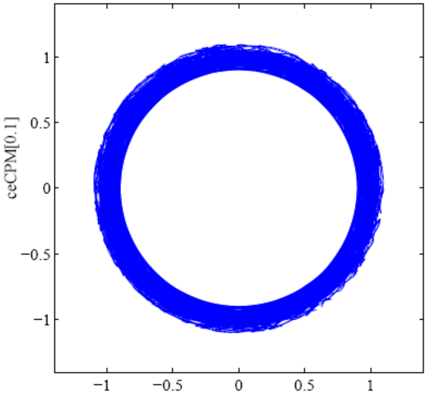


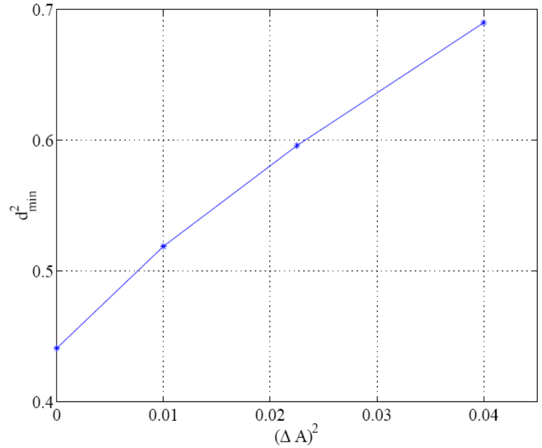
$\{\alpha_{n,q}\}$ → CPM Modulator → N/T $\{s_{m,q}\}$ → DFT (JN-point) → $\{S_{k,q}\}$ → Subcarrier Mapping → $\{\tilde{S}_{k,q}\}$ → IDFT (K-point) → $\{\tilde{s}_{n,q}\}$

M.P. Wylie-Green, E. Perrins, T. Svensson,"Introduction to CPM-SC-FDMA: A Novel Multiple-Access Power-Efficient Transmission Scheme," Communications, IEEE Transactions on , vol.59, no.7, pp.1904-1915, July 2011

Low PAPR narrowband: Constrained Envelope Continuous Phase Modulation (ceCPM)





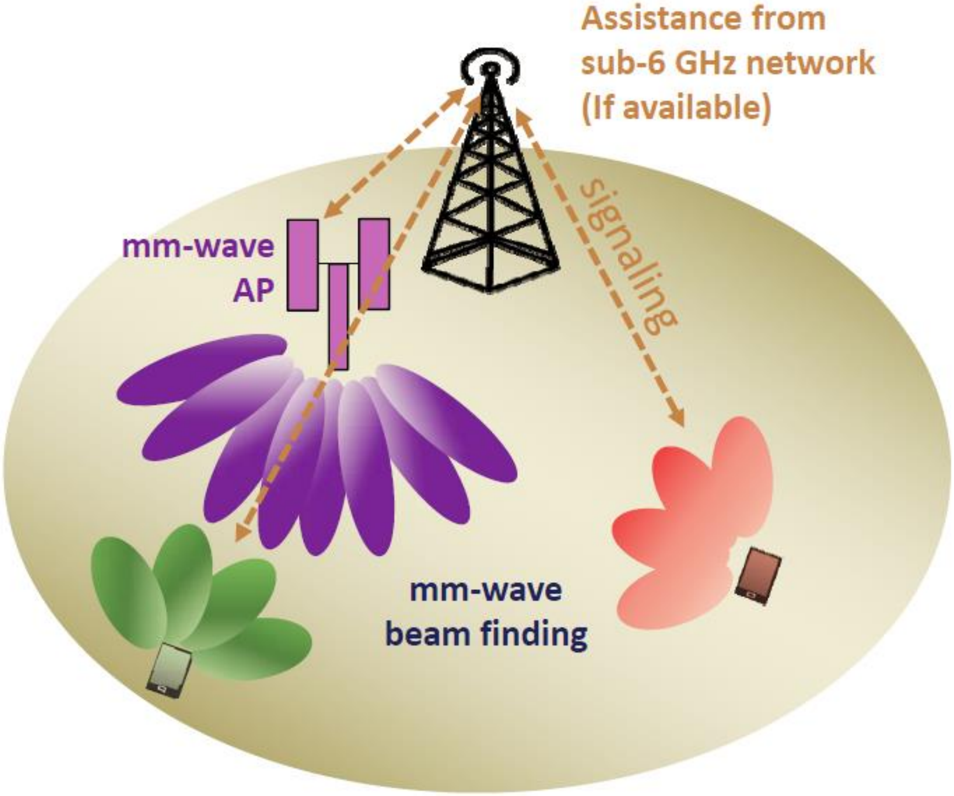


T. Svensson and A. Svensson, “Constrained envelope continuous phase modulation,” in Proc. IEEE Vehicular Technology Conference, vol. 4, Jeju, Korea, 2003, pp. 2623–2627.

T. Svensson, A. Svensson, “Design and Performance of Constrained Envelope Continuous Phase Modulation”, (Invited paper). Proceedings IEEE 4th International Waveform Diversity and Design Conference, Feb 2009, Orlando, Florida.

Initial Access

- **Design KPI's**
  - Access delay
  - Access ratio
  - Overhead
  - Complexity
  - Availability and accuracy of context information
  - Standalone/non-standalone operations support
  - Antenna configurations support

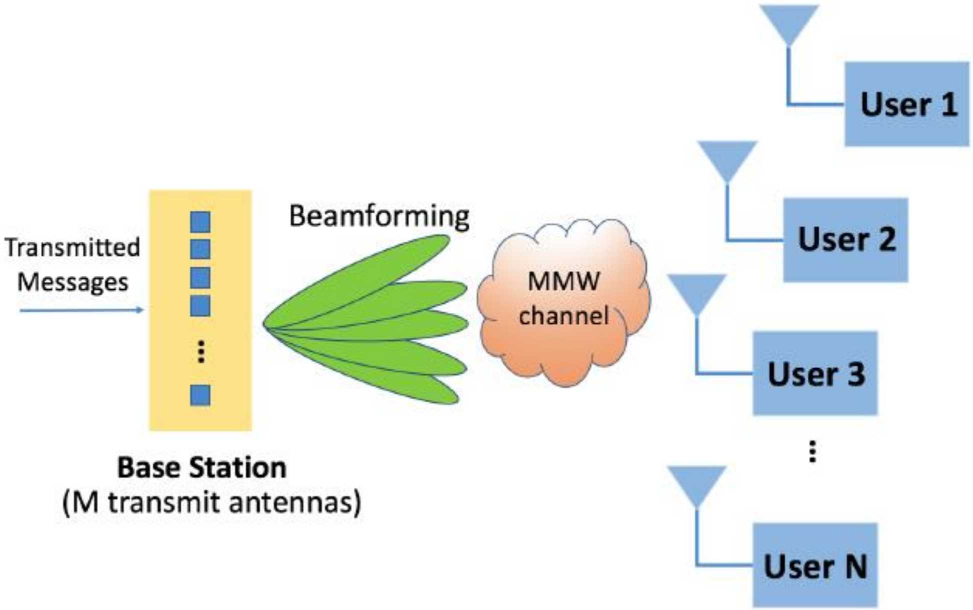


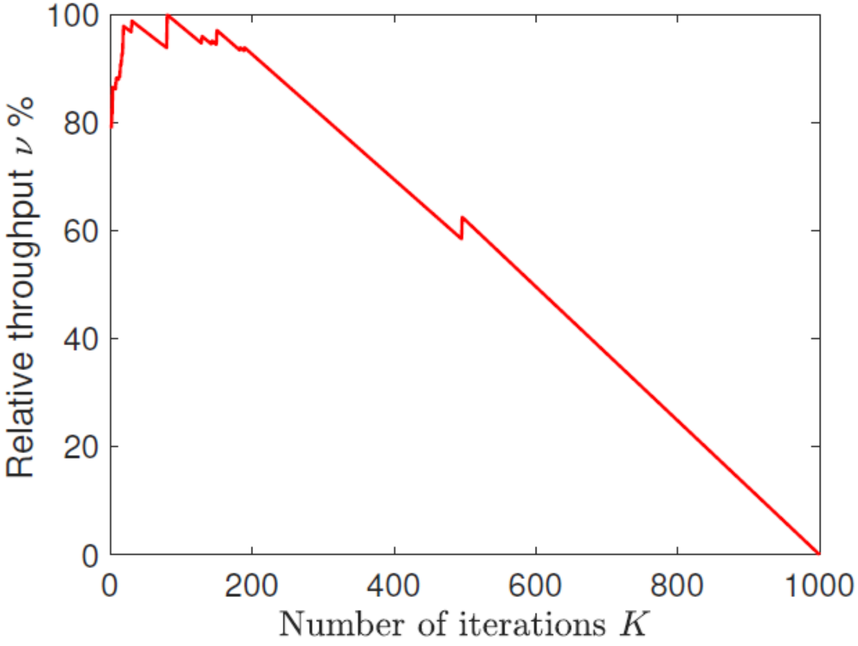
- Exploit sub-6 GHz coverage
- Exploit contexual information
- Coupling beamforming and initial access
- Support different transceiver/antenna configurations

Source: mmMAGIC WP4 presentation, ETSI workshop, Sophia-Antipolis, Jan 28, 2016

Beam finding/tracking – the key for enabling low latency mm-wave access!

Illustrative Initial Access Result

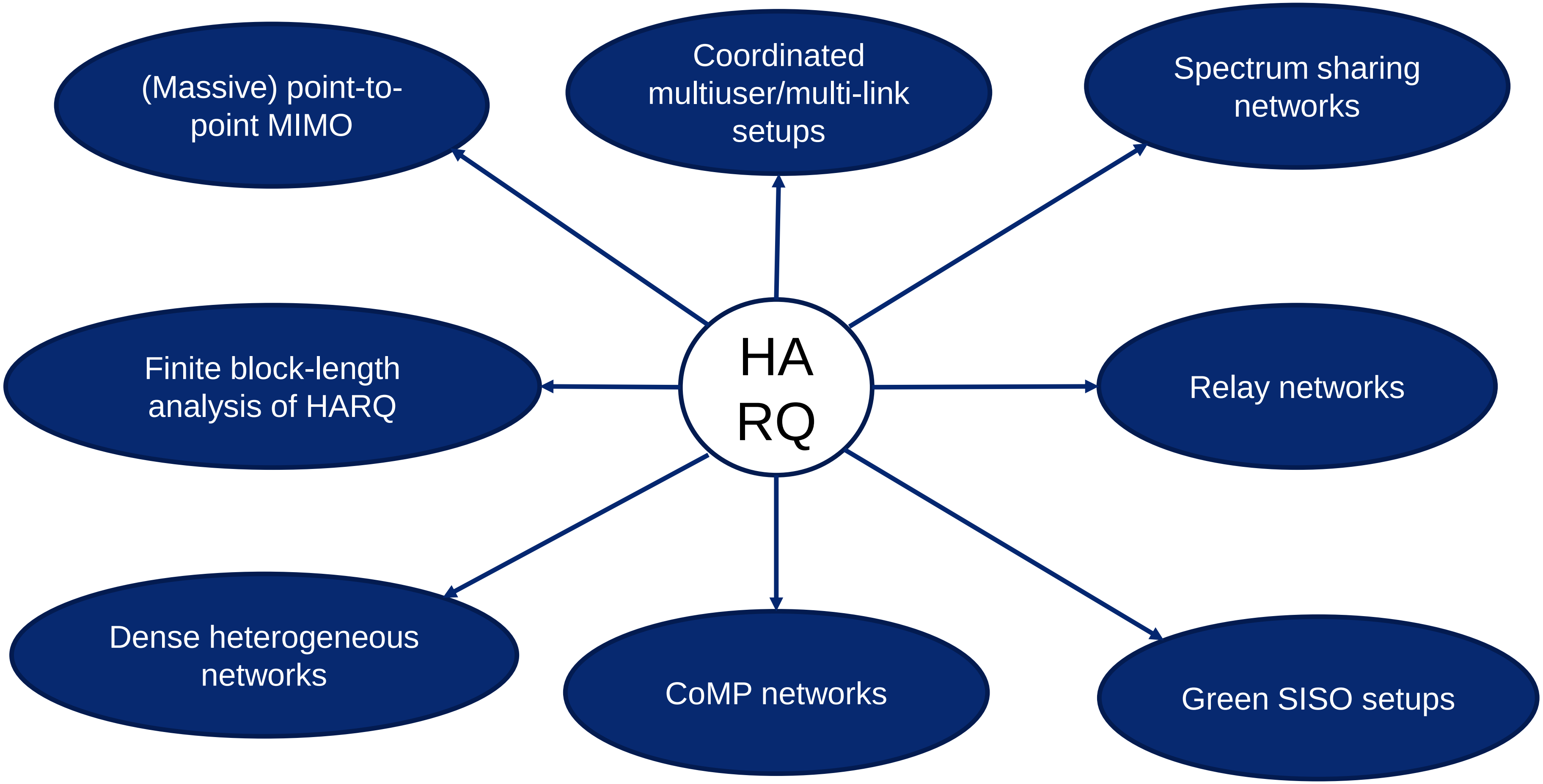




(a) System performance with delay ($\alpha = 0.001$)

H. Guo, B. Makki, T. Svensson, "A Genetic Algorithm-based Beamforming Approach for Delay-constrained Networks", IEEE WiOpt'2017, May 2017. To appear.

Hybrid Automatic Repeat request (HARQ)



HARQ

- (Massive) point-to-point MIMO
- Coordinated multiuser/multi-link setups
- Spectrum sharing networks
- Finite block-length analysis of HARQ
- Relay networks
- Dense heterogeneous networks
- CoMP networks
- Green SISO setups

Current focus: Fast HARQ protocols for delay constrained applications.

Summary

mm-wave for access/backhaul/fronthaul

- Access to mm-wave wide frequency bands is a key enabler for 5G access, backhaul and fronthaul to meet the requirements in key 5G scenarios
- Macro-assisted mm-wave *mobile* communication seems feasible
- Stand-alone is more challenging - cooperative multi-node mm-wave communications with limited CSI might be a crucial enabler
- Access-backhaul/fronthaul convergence is an opportunity
- Accurate channel models and HW-impairment models are important input to the design of mm-wave (cooperative) transceiver schemes
- Timely input to ITU is important for proper allocation of mm-wave frequency spectrum bands and definition of IMT-2020

The research leading to these results partly received funding from the European Commission H2020 programme under grant agreement no671650 (5G-PPP mmMAGIC project).

THANK YOU!

Find out more at https://5g-mmmagic.eu

Public deliverables: https://5g-mmmagic.eu/results/#deliverables

D1.1: “Use cases characterization, KPIs and preferred suitable frequency ranges for future 5G systems between 6 GHz and 100 GHz”, released 2015-11-30
D5.1 ”Initial multi-node and antenna transmitter and receiver architectures and schemes” released 2016-03-31
D4.1 ”Preliminary radio interface concepts for mm-wave mobile communications”, released 2016-06-30
D3.1 ”Initial concepts on 5G architecture and integration”, released 2016-03-31
D2.1 “Measurement campaigns and initial channel models for preferred suitable frequency ranges”, released 2016-03-31

mmMAGIC

Multiantenna wireless architectures for next-generation wireless systems — MANTUA (2017-2022)

Aim

- Develop advanced antenna systems and solutions for 5G and beyond 5G wireless communication networks

Objectives

- Determine the functionalities to be performed at each node of heterogeneous wireless networks for optimal performance in terms of capacity, coverage, latency, energy efficiency, and reliability
- Develop centralised/decentralised cooperative MIMO techniques approaching the optimal performance identified above
- Demonstrate the identified solutions on a hardware testbed

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IEEE ComSoc IEEE Communications Society IEEE

CONFERENCE VENUE:
MARINA BAY SANDS

6th Globecom’2017 Workshop on International Workshop on Emerging Technologies for 5G and Beyond Wireless and Mobile Networks (ET5GB)

Mon or Fri Dec 4 or 8, 2017, Singapore

Main topics:

- Novel radio access network (RAN) architectures
- Advanced radio resource management (RRM) techniques
- Emerging technologies in physical layer
- Novel services
- mmWave communications
- Energy efficiency
- Spectrum
- Prototype and test-bed for 5G and beyond technologies

Workshop Chairs:

- Wei Yu, University of Toronto, Canada
- Tommy Svensson, Chalmers U. of Technology, Sweden
- Lingjia Liu, University of Kansas, USA

Technical Program Chairs:

- Halim Yanikomeroglu, Carleton University, Canada
- Charlie (Jianzhong) Zhang, Samsung Electronics, USA
- Peiying Zhu, Huawei Technologies, Canada

http://wcsp.eng.usf.edu/5g/2017 (to appear) http://wcsp.eng.usf.edu/5g/2016

http://www.ieee-globecom.org/