Towards Making 5G a Reality

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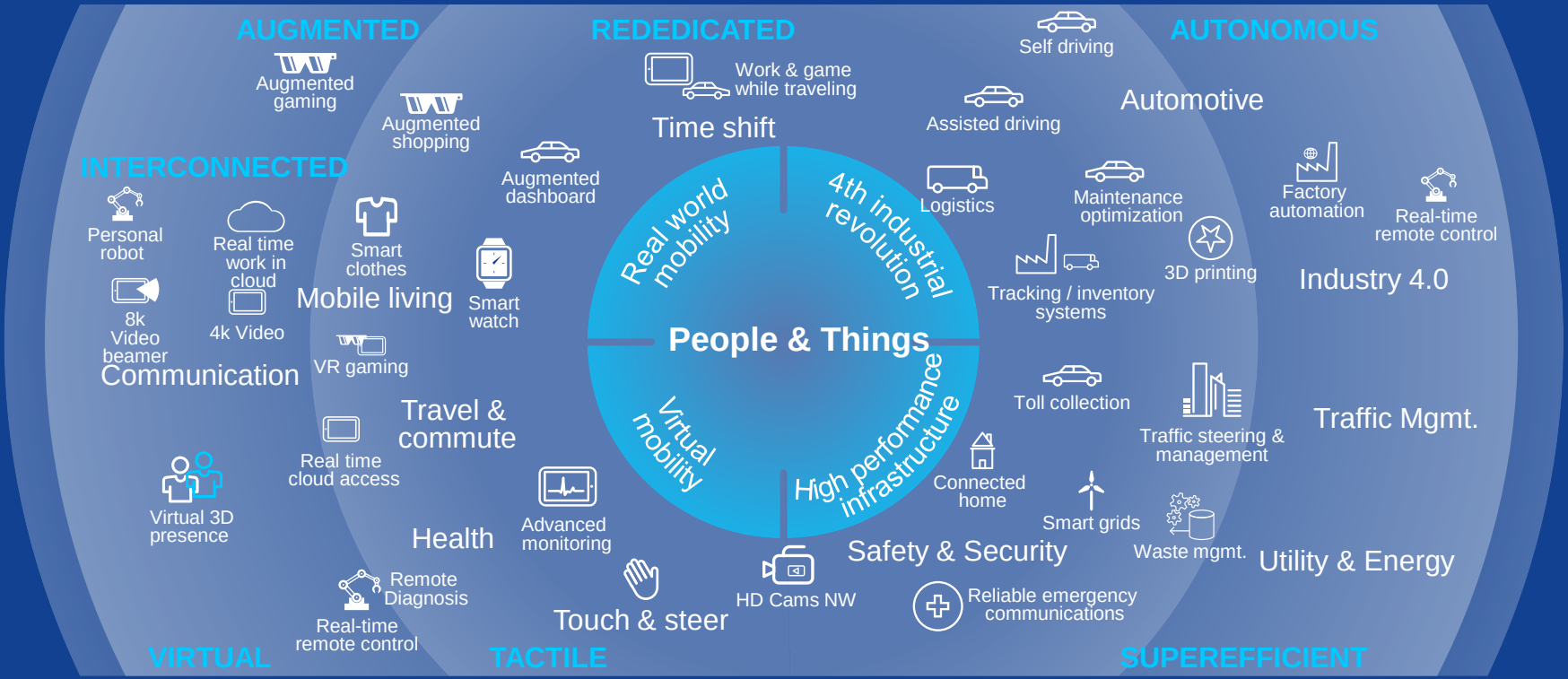
5th Nov, 2016

Small Cells Research

Nokia Bell Labs

NOKIA

Explosion of possibilities: new performance levels of people and things



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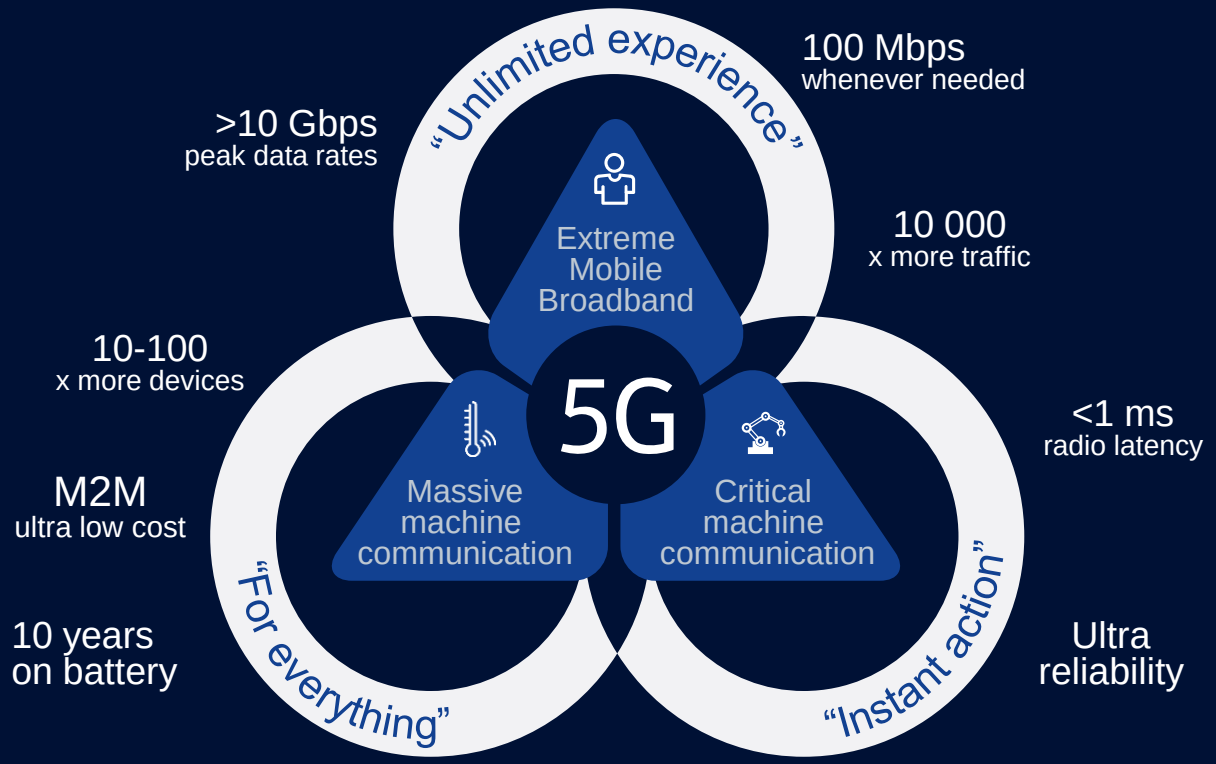
Heterogeneous use cases – diverse requirements



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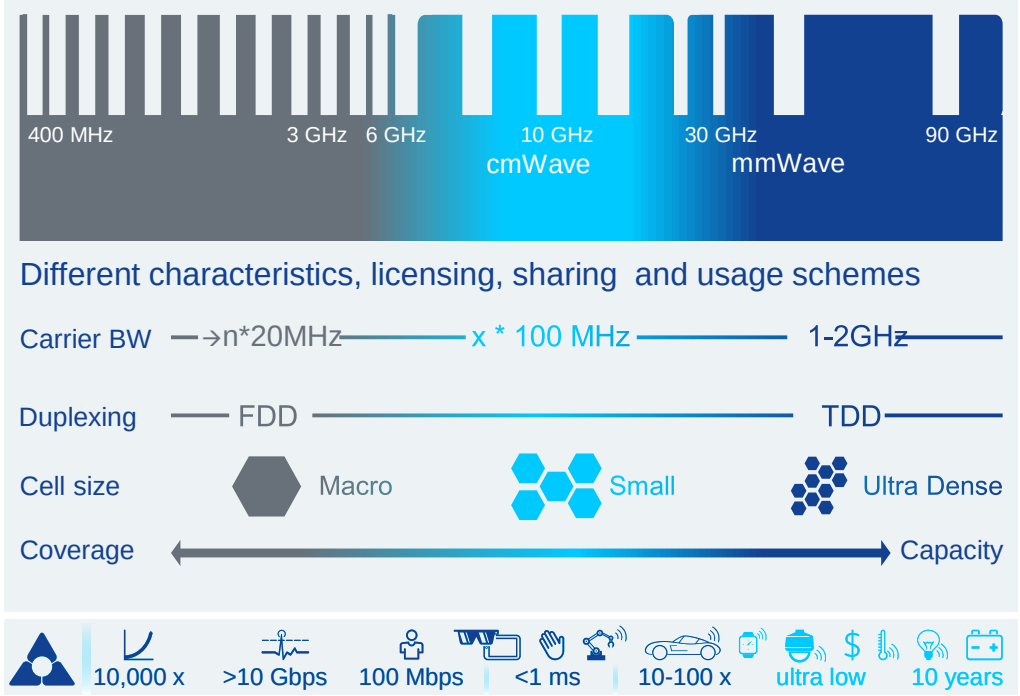
Unlocking new spectrum assets | The Foundation for 5G

FutureWorks



Lower frequencies translate into continuous coverage for high mobility and reliability cases

Higher frequencies translate into higher capacity and massive throughput

Leading channel modeling know-how
Channel measurements from 2-73GHz

Leading METIS I & II spectrum work package

METIS II

Worlds 1st

Wide Area Single Frequency Network trial in UHF band

Worlds 1st

Licensed Shared Access demos/trial

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Possible 5G Bands (before year 2020)

GHz			
600 MHz	LTE/5G	US, Can	
700 MHz	LTE/5G	APAC, EMEA, LatAm	
3.3-3.4	LTE/5G	APAC, Africa, LatAm	
3.4-3.6	LTE/5G	**Europe**	(Global)
3.55-4.2	LTE/5G	US	
3.6-3.8	5G	Europe	
4.5	5G	**Japan**	China
28	5G	**US, Korea**	Japan
37/39	5G	US	
24.25-27.5	5G	WRC-19 band	
31.8-33.4	5G	WRC-19 band (Fra, UK)	
~40,~50,~70	5G	WRC-19 bands	

- If availability of bands 600MHz and 700MHz is delayed, 5G is a valid option
- After year 2020, when IMT-2020/5G specification is ready, all existing IMT spectrum can be used for 5G, based on market demand

Expected kick-start

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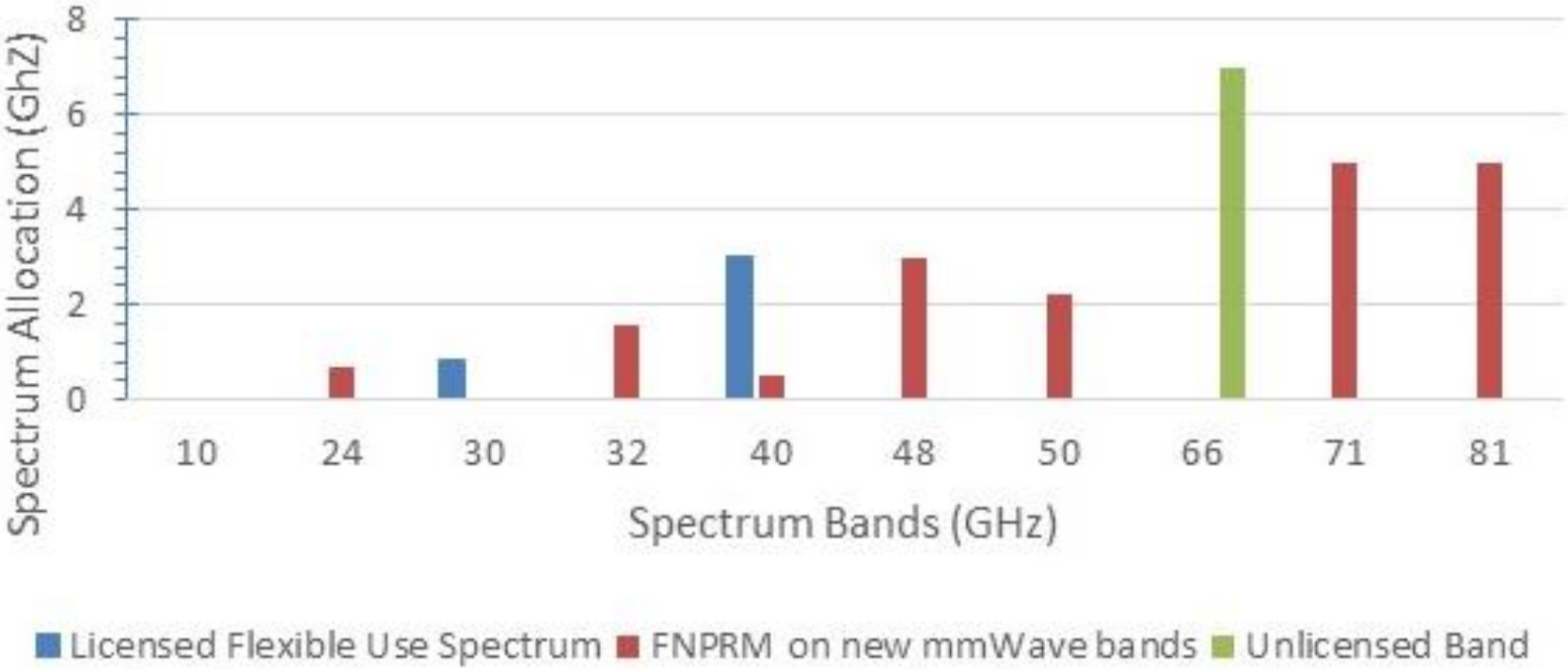
FCC mmWave Spectrum Allocation



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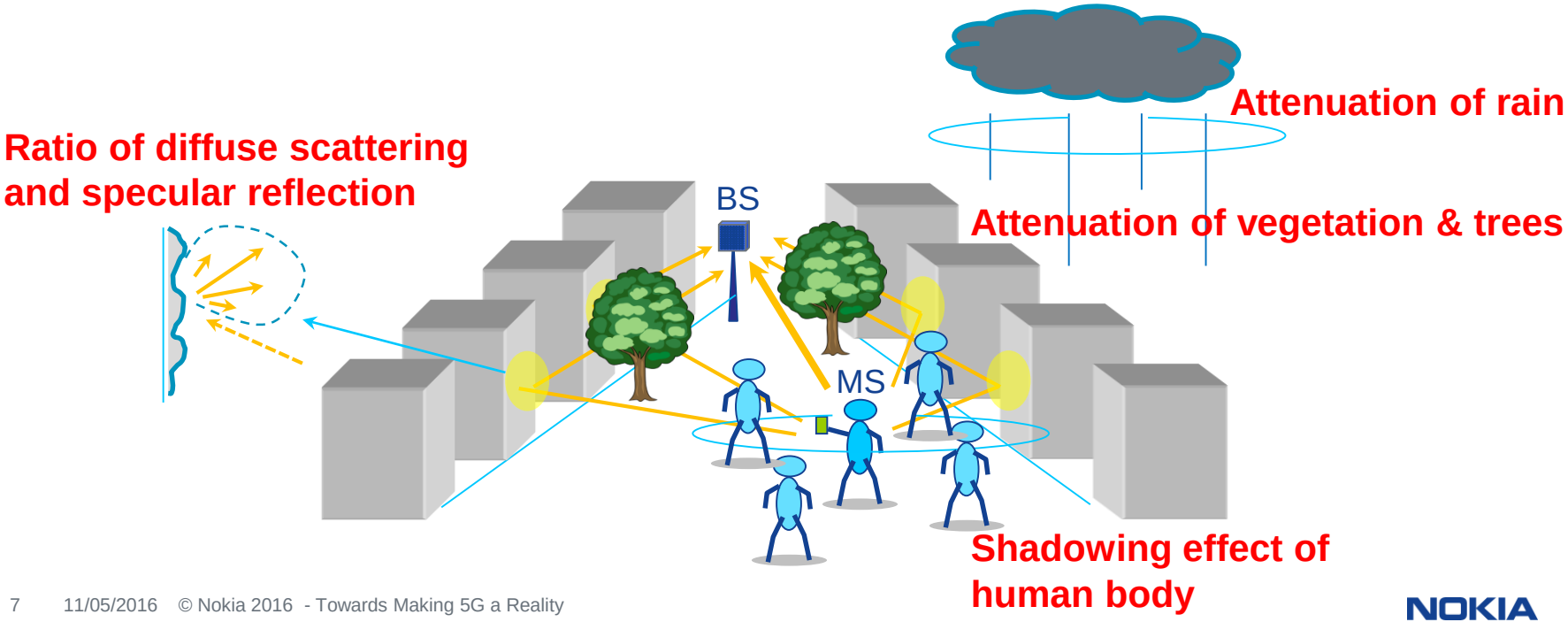
Key Propagation Phenomena at Higher Frequencies

To develop channel model for frequency range above 6 GHz, frequency dependency of path loss and channel properties need to be understood.



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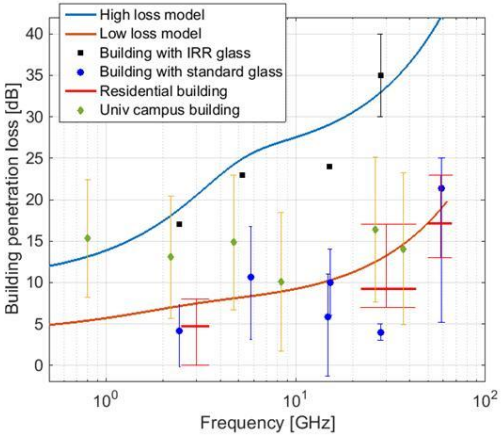
Propagation Challenges for 5G (less than 100 GHz)

FutureWorks

- **Path loss** increases with frequency
  - However, wavelength decreases with frequency
  - Larger number of antennas possible in the same area
  - Leverage large scale arrays to mitigate the larger path loss
- **Diffraction** (e.g., the bending of rays around building corners/roofs) loss increases with frequency
  - No longer a dominant effect after around 10 GHz in outdoor channels
- **Atmospheric/rain losses** are frequency dependent
  - However: small (less than around 2.0 dB for worst-case rain) for cells radii less than 100 m even at 100 GHz
- **Reflections** seem to increase with frequency going from 6 to 100 GHz
  - Smaller objects like lamp posts more reflective as frequencies increase
  - Seems to make up for loss in diffraction in outdoor environments
- **Scattering** increases with frequency,
  - Current measurements are not showing a significant impact below 73 GHz
  - Diffuse scattering more pronounced at higher frequencies
- **Penetration loss** tends to increase with frequency
  - Highly material dependent
  - Certain materials allow even higher frequencies to pass through without much attenuation (e.g., standard glass)

Spatial Consistency:

Penetration Loss:



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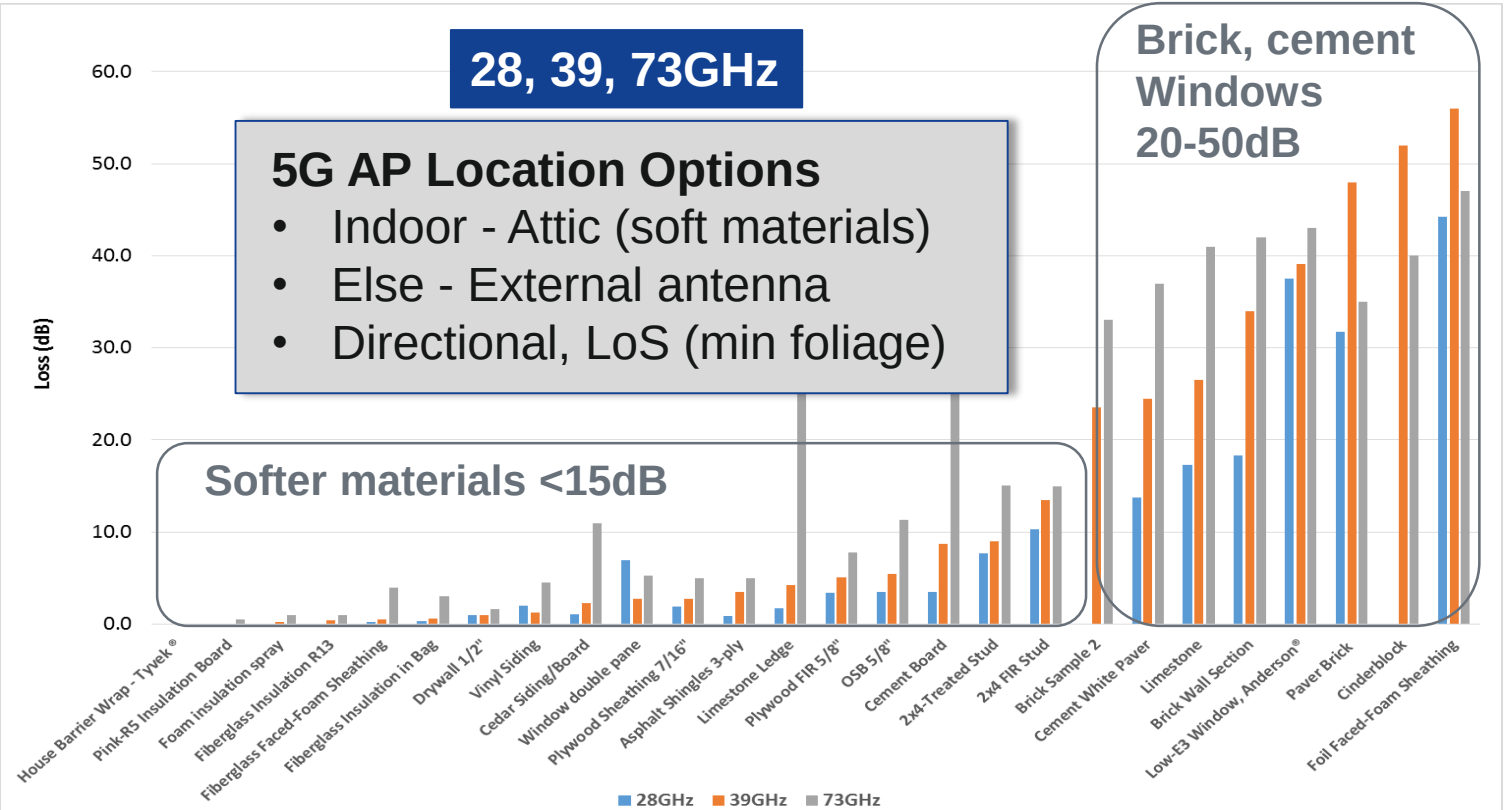
Penetration Loss : cm/mmWave



Note: +5dB if not 90 degrees
Note: 3GPP SIG channel model for 6-100GHz urban done

5G Technical Solutions – Summary of Ten Potential Technologies

Solution	Benefit
Usage of cm and mm waves	10x..100x more capacity
UE agnostic MIMO and beamforming	Network based massive MIMO evolution
Lean carrier design	Low power consumption, less interference
Flexible frame structure	Low latency, high efficiency
Dynamic TDD	Improved performance

Solution	Benefit
Enhanced interference coordination	Higher efficiency
Aggregation of LTE + 5G carriers	Higher data rate with smooth migration
Wireless backhaul with full Duplex	Improved performance
Flexible connectivity, mobility and sessions	Optimized end-to-end for any services
New waveforms	Multiservice flexibility

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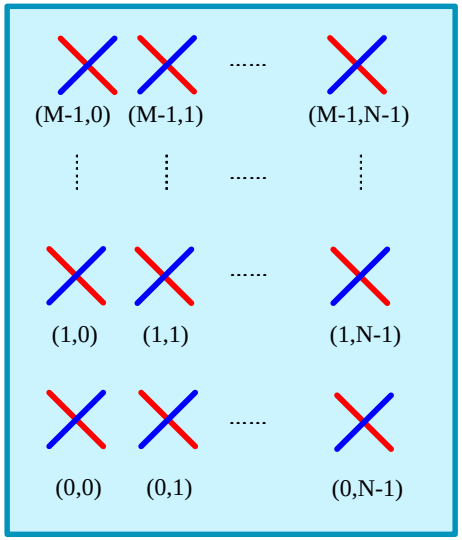
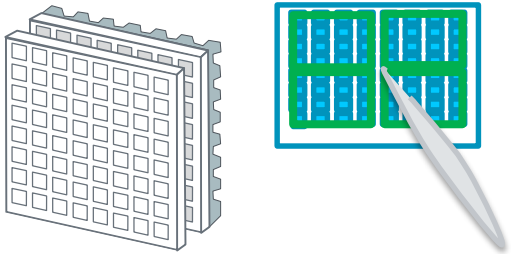
What is “Massive MIMO”?

- **Massive MIMO** is the **extension of traditional MIMO** technology to antenna arrays having a **large number** of **controllable antennas**

- **MIMO** = Multiple Input Multiple Output = **any transmission scheme involving multiple transmit and multiple receive antennas**
  - Encompasses all implementations:
    - e.g.: RF/Baseband/Hybrid
  - Encompasses all TX/RX processing methodologies:
    - e.g., Diversity, Beamforming/precoding, Spatial multiplexing, SU & MU, joint/coordinated transmission/reception, etc.
- **Massive ➔ Large number**: >> 8
- **Controllable antennas**: antennas (whether physical or otherwise) whose signals are adaptable by the PHY layer (e.g., via gain/phase control)





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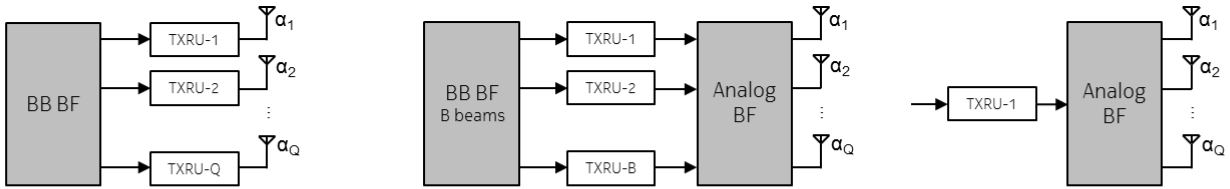
Flexible MIMO and beamforming

- We foresee that fully digital baseband, Hybrid array, Analog/RF array solutions, will be used by different implementations.

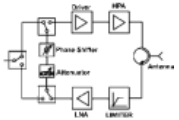


Digital (Baseband) beamforming	Hybrid beamforming	Analog beamforming
Adaptive TX/RX weights at Baseband	Adaptive TX/RX weights at both Analog and Baseband domains	Adaptive TX/RX weights at RF to form a beam
Each antenna element or antenna port has a transceiver unit High number (8->) of transceiver units	Each RF beam has a transceiver unit; Moderate number of transceiver units for capacity (e.g. up to 8)	One transceiver unit and one RF beam with high antenna gain (coverage)
"Frequency-Selective" beamforming	Combination of Analog and Baseband beamforming	"Frequency-Flat" beamforming
Best for capacity and flexibility (subject to high power consumption & cost characteristics when bandwidth increases)	Optimization between both coverage and capacity	Best for coverage (low power consumption & cost characteristics)

Phased Array Technology

Basic technologies vs. band of operation

		3.5 GHz	15 GHz	28 GHz	38 GHz	60 GHz	73 GHz	83 GHz	94 GHz
Wavelength	mm	86	20	11	7.9	5.0	4.1	3.6	3.2
Row/column	#	8	8	8	8	8	8	8	8
Total	#	64	64	64	64	64	64	64	64
Width/Height	mm	342.9	80.0	42.9	31.6	20.0	16.4	14.5	12.8
Technology		T/R Module using Mech array assembly	Monolithic T/R Modules on Interposer	T/R Modules or MMIC on Interposer	T/R Modules or MMIC on Interposer	1 or more MMIC on Interposer board	Multiple MMICs , chip-scale antenna or interposer	Multiple MMICs , chip-scale antenna or interposer	Multiple MMICs using chip scale antenna

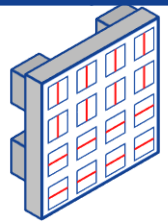


PA, LNA, phase shifter, VGA and T/R diplexing mechanically assemble into phased array. MMIC solutions preferred

Migrate to MMIC as frequency increases to reduce cost and improve manufacture

Transition region where either scalable MMIC or T/R module approach may be viable

Silicon Image 60GHz MMIC on LTCC interposer board with antenna array



Transition region for interposer board vs. chip-scale antennas?

Circuits same size as antenna array.(UCSD 94GHz Chip Scale Ant array)

* MMIC = Monolithic Microwave Integrated Circuit

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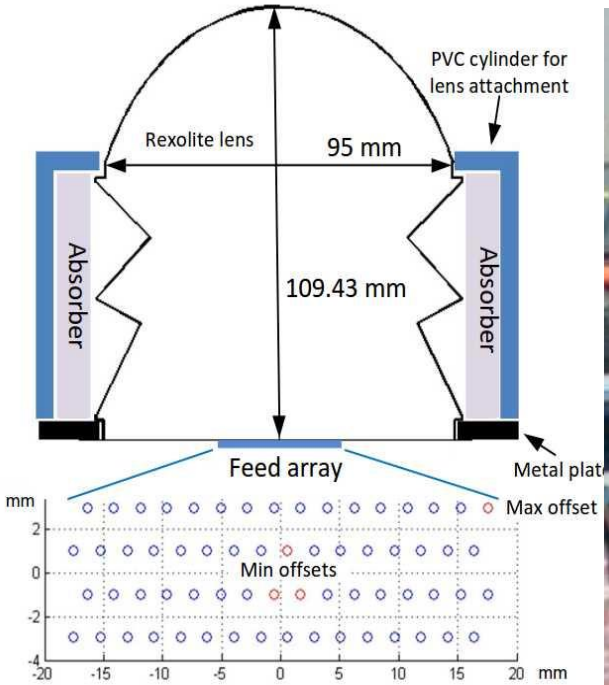
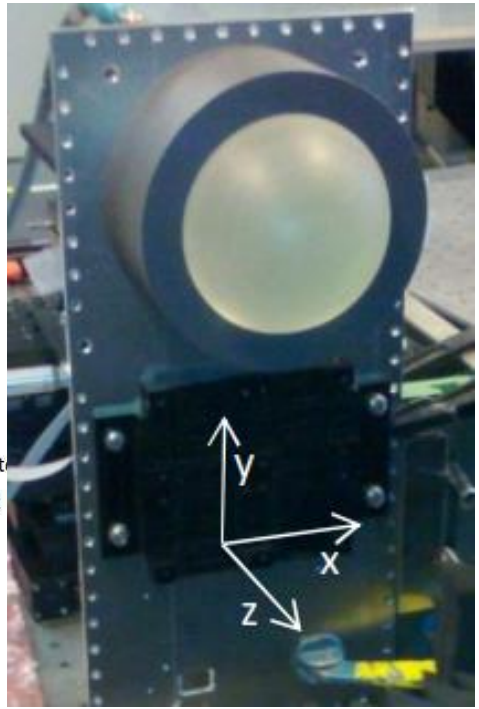
5G mmWave Challenges & Proof Points

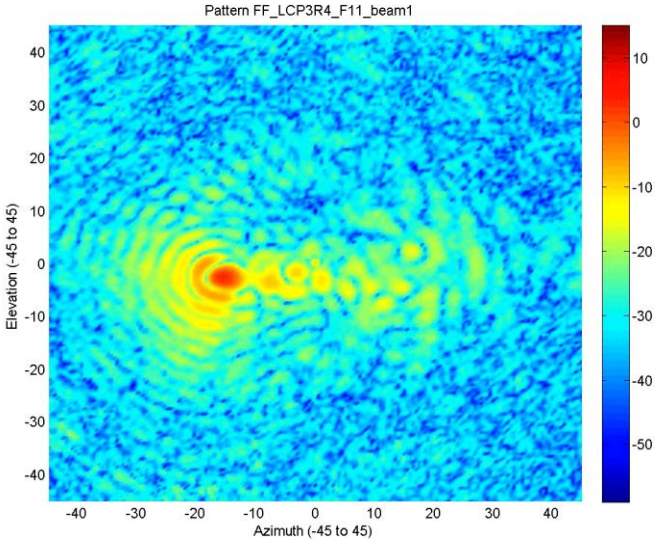
- Unique difficulties that a mmWave system must overcome
  - Increase path loss which is overcome by large arrays (e.g., 4x4 or 8x8)
  - Narrow beamwidths, provided by these high dimension arrays
  - High penetration loss and diminished diffraction
- Two of the main difficulties are:
  - Acquiring and tracking user devices within the coverage area of base station using a narrow beam antenna
  - Mitigating shadowing with base station diversity and rapidly rerouting around obstacles when user device is shadowed by an opaque obstacle in its path
- Other 5G aspects a mmWave system will need to address:
  - High peak rates and cell edge rates (up to 10 Gbps peak, 100 Mbps cell edge)
  - Low-latency (< 1ms)

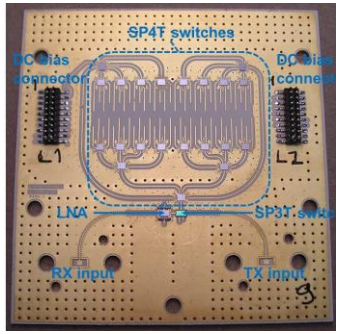
70 GHz Proof of Concept

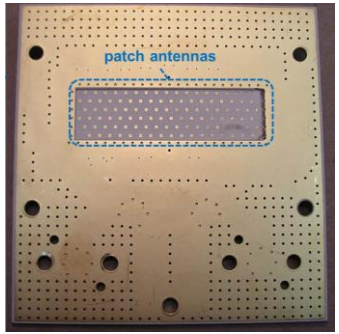
Beam Steering and Acquisition using a LENS antenna







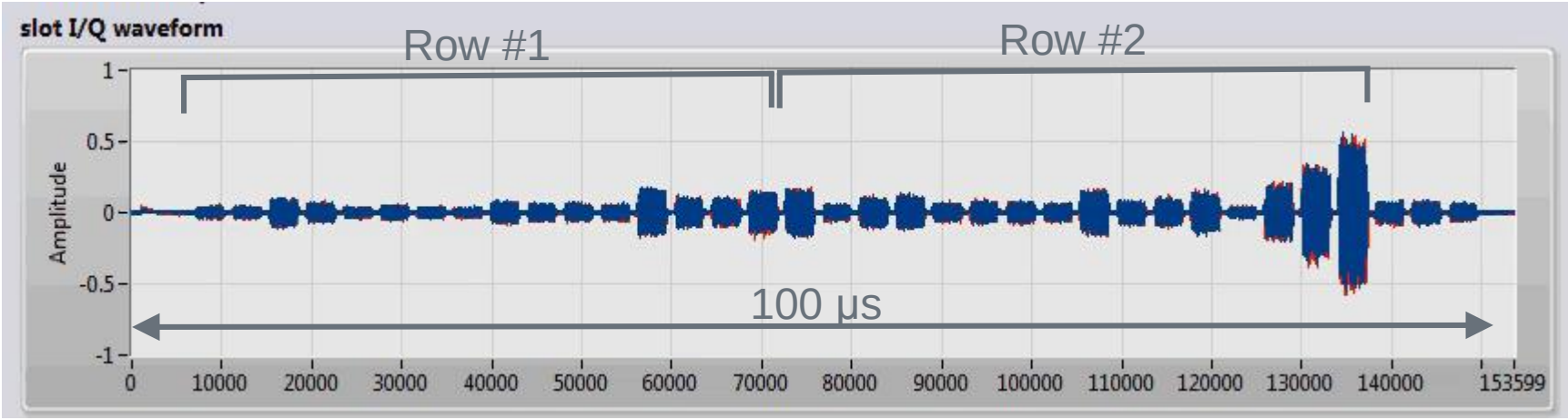




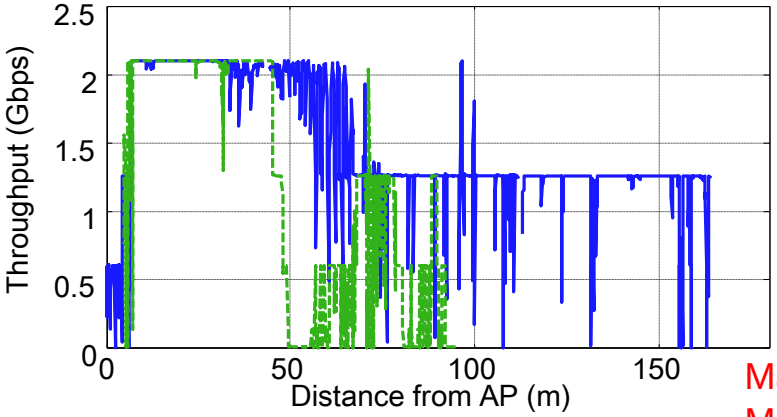
70 GHz Proof of Concept

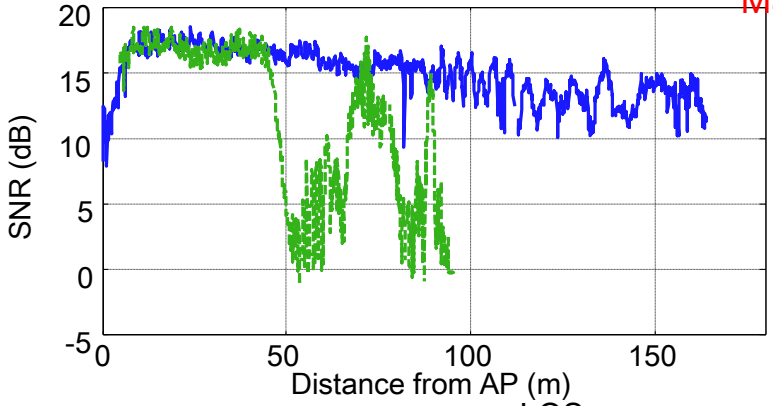
- Rapid beam scanning for tracking and acquisition
- Low-latency implementation operating with a 100 µs TTI
- 2 TTIs employed for beam scanning every 20 ms
- 64 scanned in 200 µs each with a 2 µs dwell time

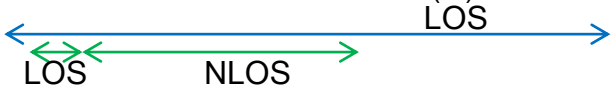
Parameters	Value
Operating Frequency	73 GHz
Bandwidth	1 GHz
Modulation	Null Cyclic-Prefix Single Carrier 16 QAM Single Stream (SISO)
Antenna Beamwidth	3 degrees
Antenna Steering Range	34 degrees Azimuth 8 degrees Elevation



5G mmWave Outdoor results @ Tokyo (SISO 1 GHz BW)





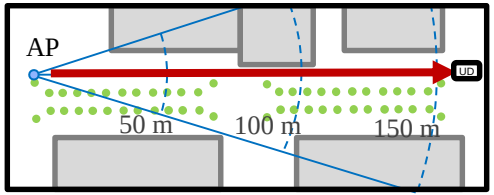


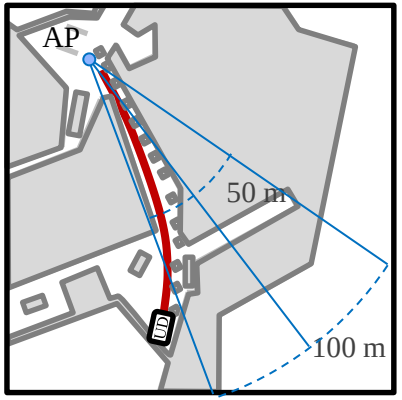
Street canyon

LOS (Minatomirai, Yokohama)

Maxm Range : more than 160 m (LOS)

Maxm Throughput: ~2.1 Gbps





Shopping mall

LOS and NLOS (Roppongi, Tokyo)

Successfully Conducts 5G Trials @ 73 GHz in Actual-use Environments

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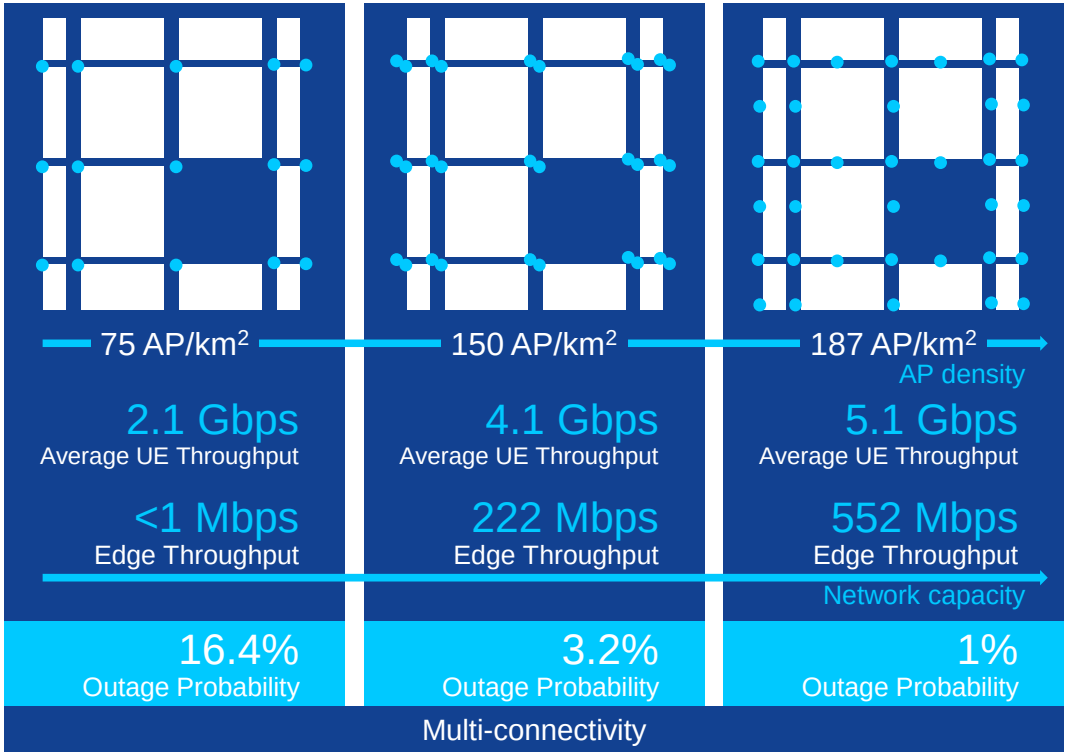
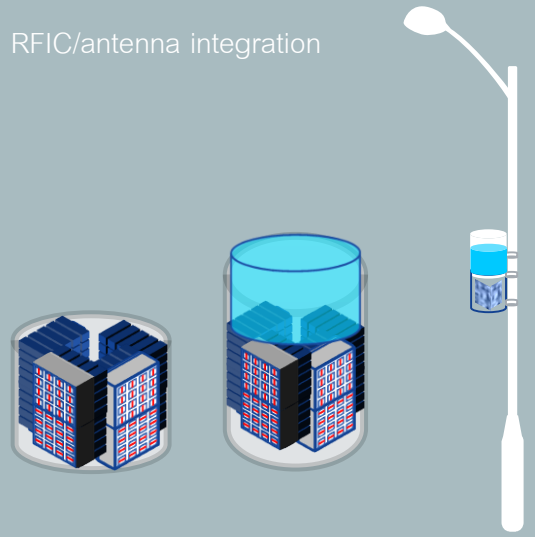
Performance of Massive MIMO @ mmWave
5G requirements can be met even in challenging environments



Performance in outdoor environments

Enabled through

- flexible backhaul
- RFIC/antenna integration



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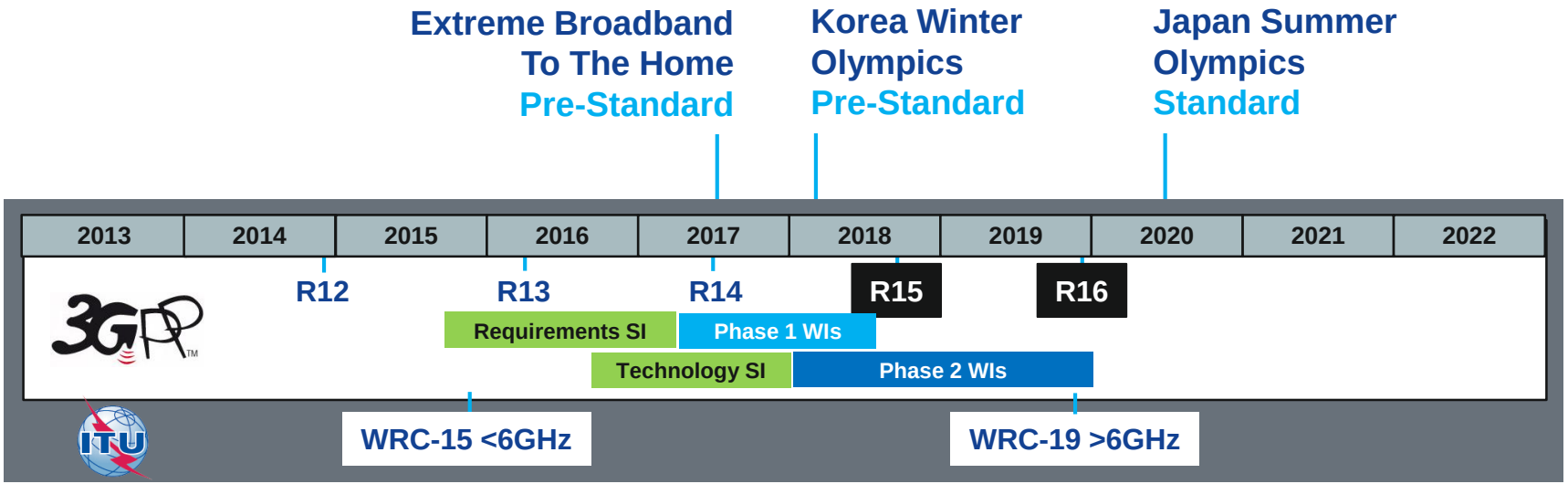
5G Timeline



LTE Extensions

5G Phases

Phase 1 : R15
Phase 2 : R16

Pre-Standard 5G Activities

Q&A

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