Keysight Measurement Forum 2016

You, Gwang-Yeol

Understanding 5G Candidate Technologies and R&D Solutions

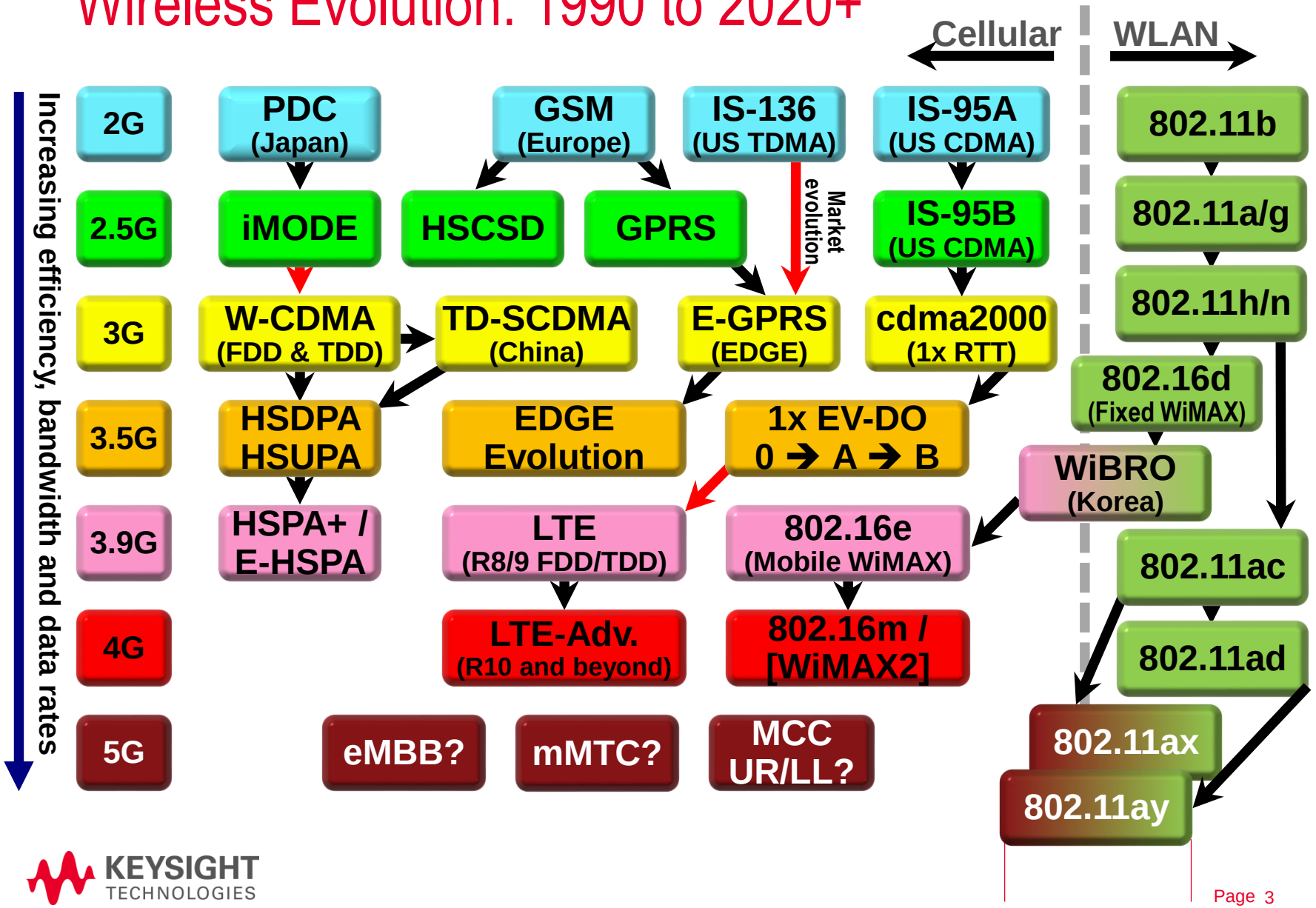
KEYSIGHT TECHNOLOGIES

HARDWARE+SOFTWARE+PEOPLE=INSIGHTS

Agenda

- ✓ 5G Vision & Requirements
- ✓ 5G Enabling technologies
  - Evolution of current cellular technology
  - Revolution of new radio access technology
- ✓ mmWave design challenges
- ✓ Keysight in 5G & Case study

Wireless Evolution: 1990 to 2020+



KEYSIGHT TECHNOLOGIES

5G Drivers and Vision

Massive Growth in Mobile Data Demand

Massive Growth in No. of Connected Devices

Exploding Diversity of Wireless Applications

Dramatic Change in User Expectations of Network

For the User*

Amazingly fast

Great service in a crowd

Best experience follows you

Super real-time and reliable communications

Ubiquitous things communicating

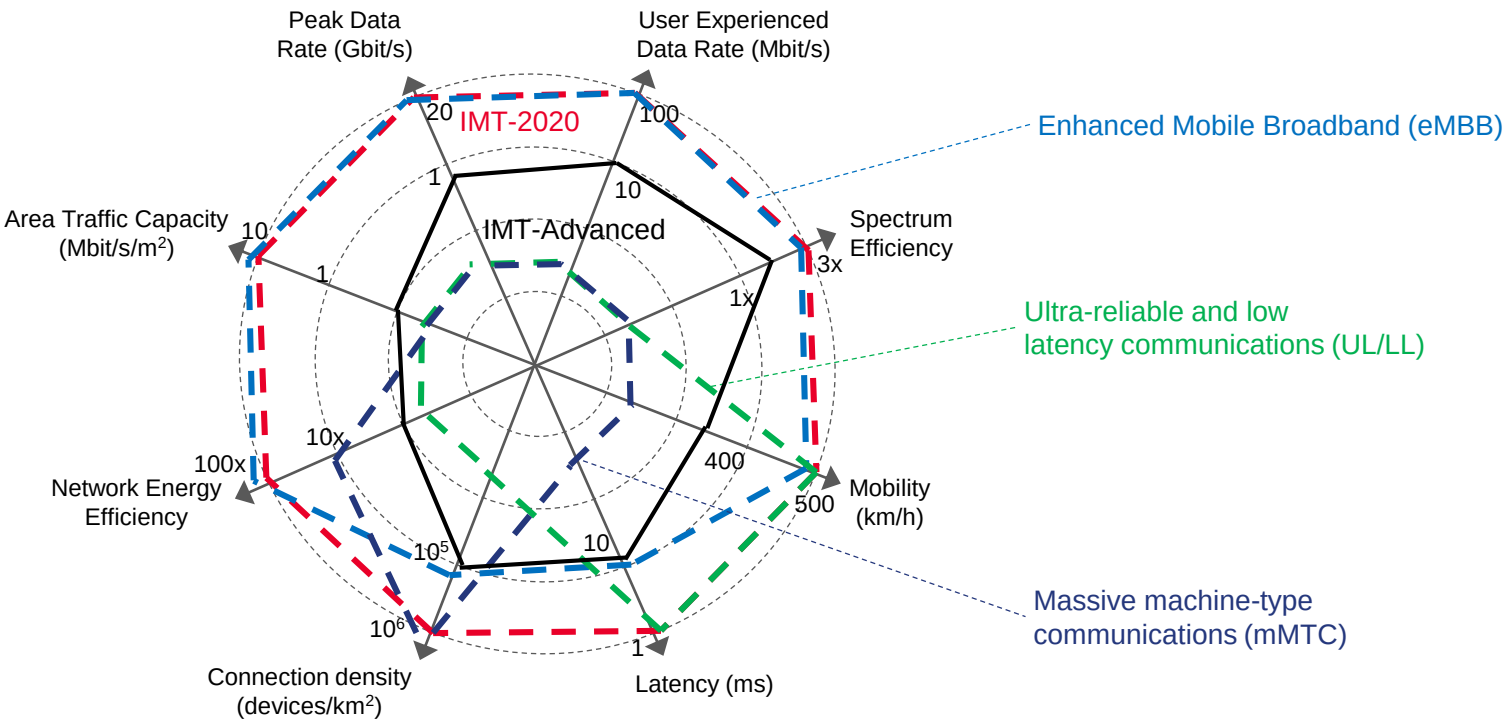
*Courtesy of METIS

- 100x Data Rates
- 1000x Capacity
- 100x Densification
- 1ms Latency
- Reliability 99.999%
- 100x Energy Efficiency

All founded on a solid business model

5G Key Performance Indicator from ITU-R IMT-2020 vision

Spider diagram for 8 KPIs and Proposed 5G use cases



Proposed 5G Use Cases

eMBB

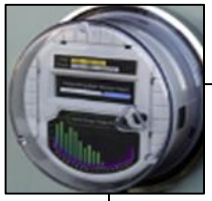
Enhanced Mobile Broadband (eMBB)

- 10-20 Gbps peak
- 100 Mbps whenever needed
- 10000x more traffic
- Support for high mobility (500 km/h)
- Network energy saving by 100 times

Virtual Reality

Augmented reality

mMTC



Massive Machine Communication (mMTC)

- High density of devices (2x10^5 - 10^6/km^2)
- Long range
- Low data rate (1 - 100 kbps)
- M2M ultra low cost
- 10 years battery
- Asynchronous access

UR/LL

Ultra reliability and low latency (UR/LL)

- Ultra responsive
  - <1 ms air interface latency
  - 5 ms E2E latency
- Ultra reliable and available (99.9999%)
- Low to medium data rates (50 kbps - 10 Mbps)
- High speed mobility

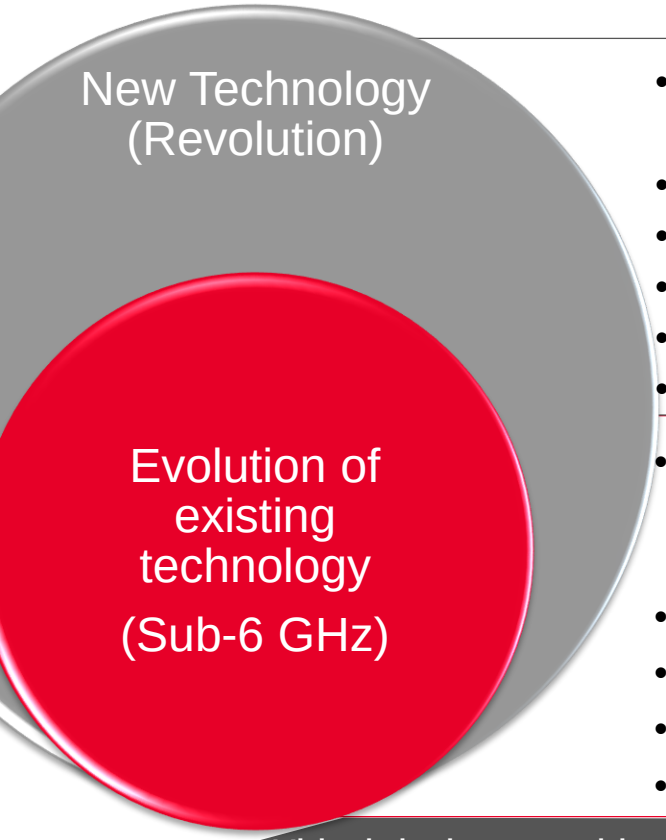
Driverless car

Remote surgery

KEYSIGHT TECHNOLOGIES

5G Enabling Technologies

Evolution of existing technology + Revolution of new technology

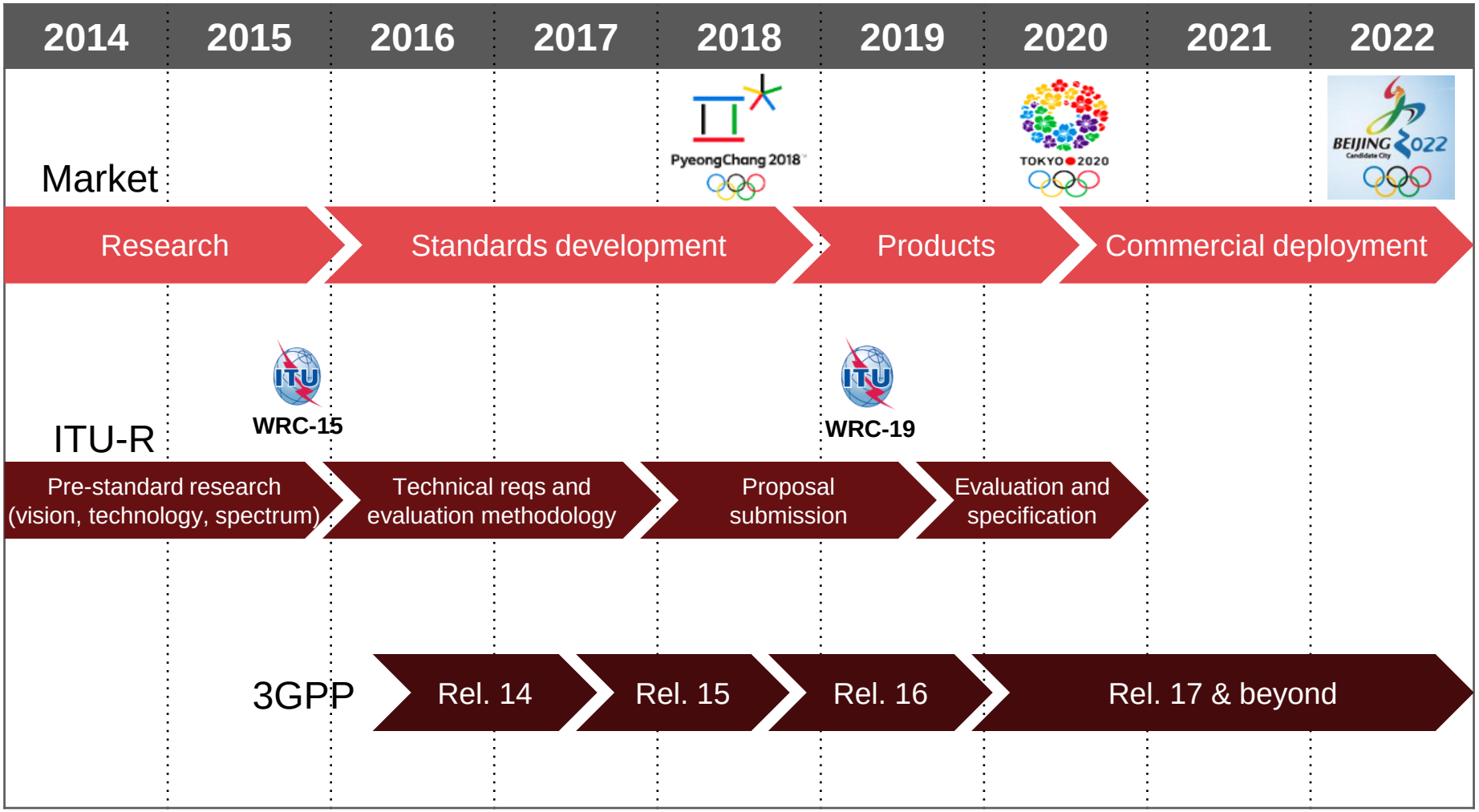


- Microwave and mmWave frequency bands (licensed and unlicensed)
- Wide bandwidth – up to 2 GHz or wider
- Massive MIMO - Number of BS antennas >> Number of UE's
- New waveforms and new radio access technology (RAT)
- In-band full duplex
- Software based network architecture: SDN and NFV

- Evolution of current cellular technologies – LTE-A/LTE-A Pro
  - Example: license assisted access (LAA); enhancement to machine type communication (MTC) or NB-IoT
- New waveforms and new radio access technology (RAT)
- New frequency bands below 6 GHz
- Ultra-dense networks – small cells and WLAN access points
- Evolution of RAN architecture (Advanced C-RAN)

With tight interworking between exiting technologies and the new technologies

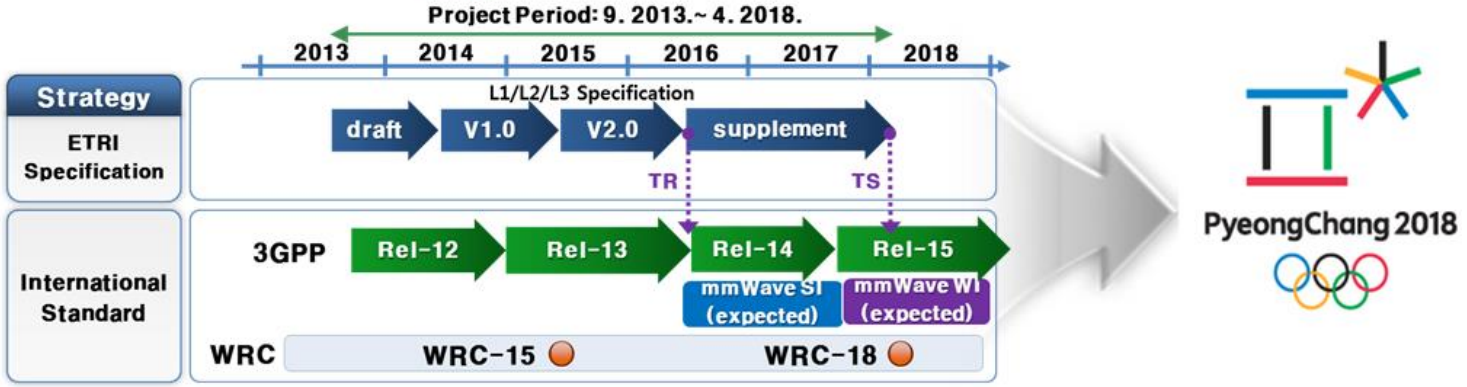
5G Overall Timeline



기가코리아 5G 프로젝트

기가코리아 5G 프로젝트

- 배경
  - 새로운 무선 기기와 서비스의 등장
  - 무선 트래픽의 폭발적인 증가 (10년 내 1000배 이상)
  - 셀룰러 이동 통신을 위한 미사용 밀리미터파 대역의 개척
- 개요
  - 기가코리아 5G 프로젝트는 2013년 9월에 Kick-Off
  - 2018년 평창 동계올림픽에서 5G 시범 서비스 예정
- 목표
  - 기가 비트 이동 서비스를 위한 밀리미터파 (10 ~ 40 GHz) 기반 광대역 시스템
  - 평균 데이터 전송률: 사용자 단말 당 1 Gbps
  - 셀 용량: 셀 당 100 Gbps



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Spectrum in Sub-6 GHz

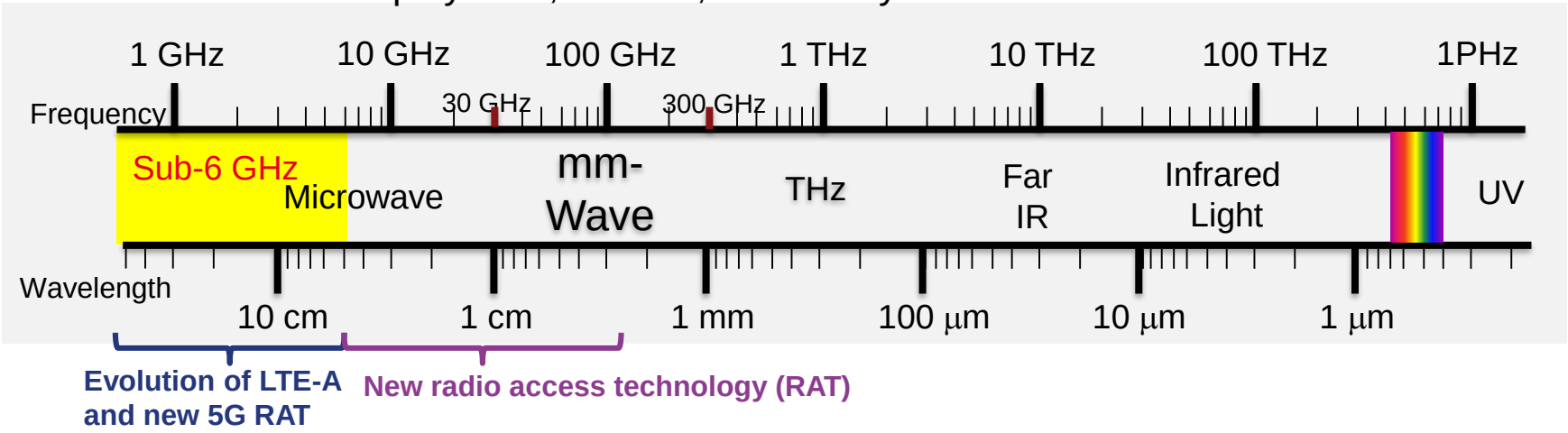
New and flexible spectrum usage

– Sub-6 GHz will use existing licensed and unlicensed spectrum

– New global sub-6 GHz bands for mobile broadband identified at WRC-15*
http://www.itu.int/pub/R-ACT-WRC.11-2015/en

- WRC-15 initiated studies on frequency bands for advanced 5G technologies in multiple bands between 24-86 GHz and will report back to WRC-19 (nothing is guaranteed for WRC-19 for IMT-2020)

– Phase 1 of 5G deployment, in 2020, most likely be in sub-6 GHz



*World Radiocommunication Conference 2015 (2-27 November 2015, Geneva)

Evolution of Existing Technology

LTE-Advanced/LTE-Advanced Pro

LTE-U / LTE-LAA	• 5 GHz ISM Band

Data + Control
Licensed Anchor

Data only
Unlicensed (5 GHz)

Carrier Aggregation

LTE-Unlicensed (LTE-U): based on 3GPP Rel 10-12 and LTE-U Forum spec
LTE-License Assisted Access (LAA) part of 3GPP Rel-13

- Licensed spectrum remains top priority for operators
- LTE over unlicensed gives operators another option to offload traffic to unlicensed spectrum using LTE-U/LTE-LAA

Carrier Aggregation	• Up to 32 CCs including LAA operation • TDD-FDD joint operation
Dual Connectivity	• Simultaneous connection to macro & small cell
Full-Dimension MIMO (FD-MIMO)	• Simultaneously supports elevation and azimuth BF • High order MIMO with up to 64 antenna ports at eNB
Narrow Band IoT (NB-IoT)	• New narrowband radio technology to address the requirements of the Internet of Things (IoT) (Rel. 13)
Vehicle to Vehicle (V2V) communication	• Support for V2V services based on LTE sidelink (Rel. 14)

Increasing Frequencies: Challenge and Opportunity

Free-space Path Loss

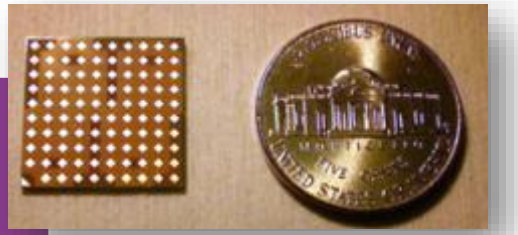
$$Power_{RX} = Power_{TX} + AntGain_{RX} + AntGain_{TX} - 20log_{10}(4\pi R) - 20log_{10}\left(\frac{f}{c}\right)$$

Distance Frequency

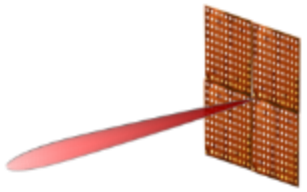
- In words. For a given distance, as the frequency increases, the received power will drop unless offset by an increase in some combination of transmit power, transmit antenna gain, and receive antenna gain.
- The decrease in power as a function of frequency is caused by the decrease in the antenna aperture.

The Good News:
- Higher frequency antennas elements are smaller
- Easier to assemble into electronically steered arrays
- Reduced interference. Energy goes where it's needed
- Improve performance in dense crowds (5G goal)
- Higher frequencies→wider bandwidths: faster (5G goal)

Challenges:
- Increased complexity with more elements
- Multiple antenna arrays required for spherical coverage
- Discovery and Tracking (mobile devices)

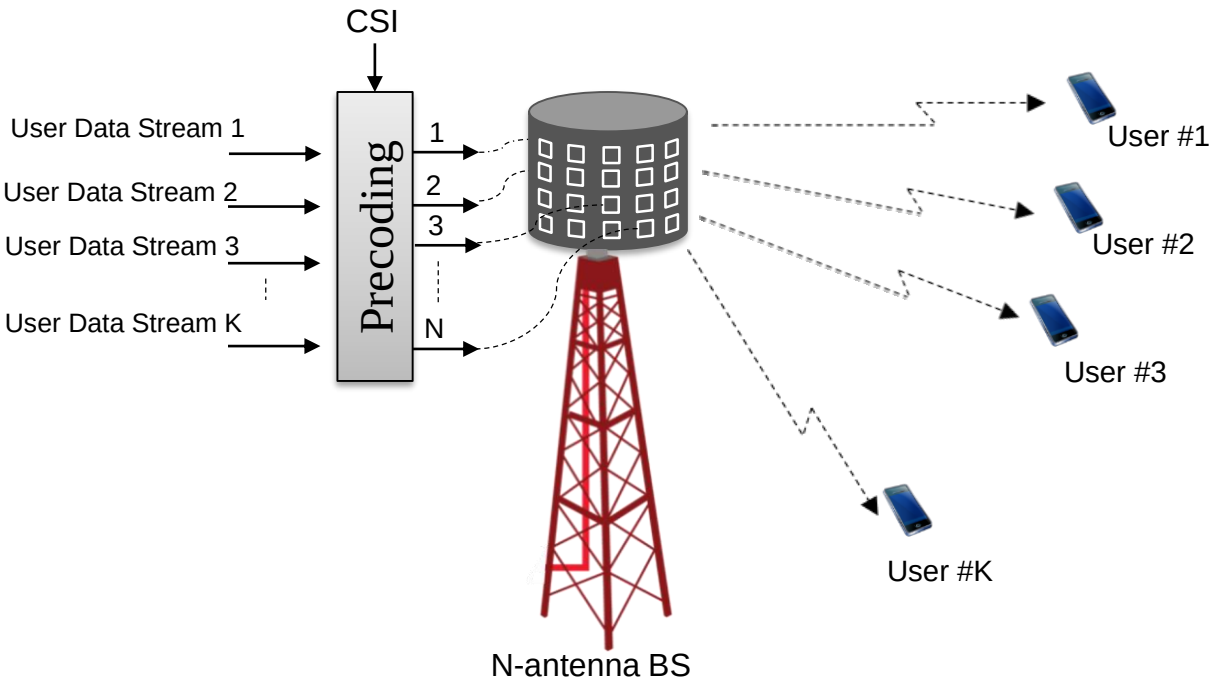


IBM 94 GHz Array
Can Tile for Larger Arrays
IBM Press Release, June 2013



Massive MIMO

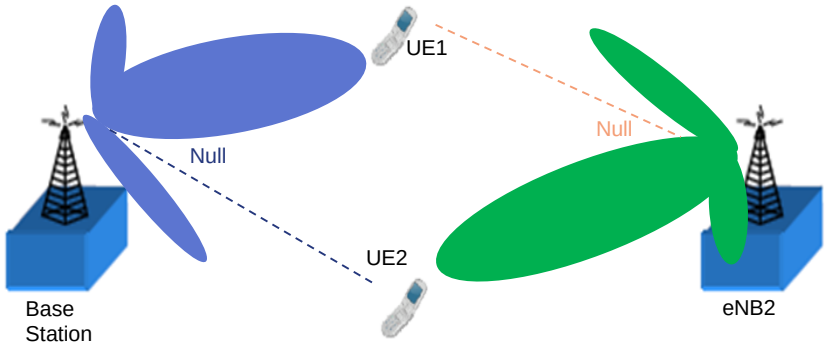
- **Description:** *Massive MIMO is Multiuser MIMO (MU-MIMO) where the number of base station antennas is >> the number of users to improve the SINR*
- **Motivation:** *Higher Reliability, Higher Throughput, Lower TX Power*

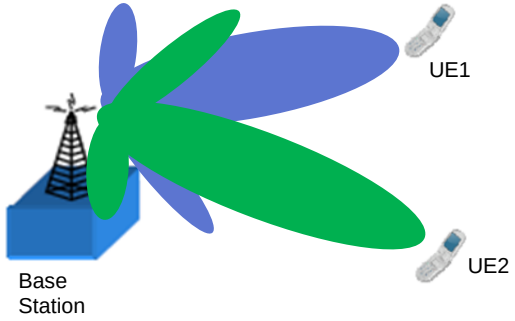


Beamforming

- Beamforming Gain (dB) improvement compared to omnidirectional or broadcast transmission/reception.
  - Increase cell-edge throughputs
  - Increase cell coverage

- Spatial Selectivity improvement
  - Mitigate inter-cell interferences
  - Mitigate inter-user interferences
  - Improve spectrum efficiency (SDMA, Space Division Multiple Access)



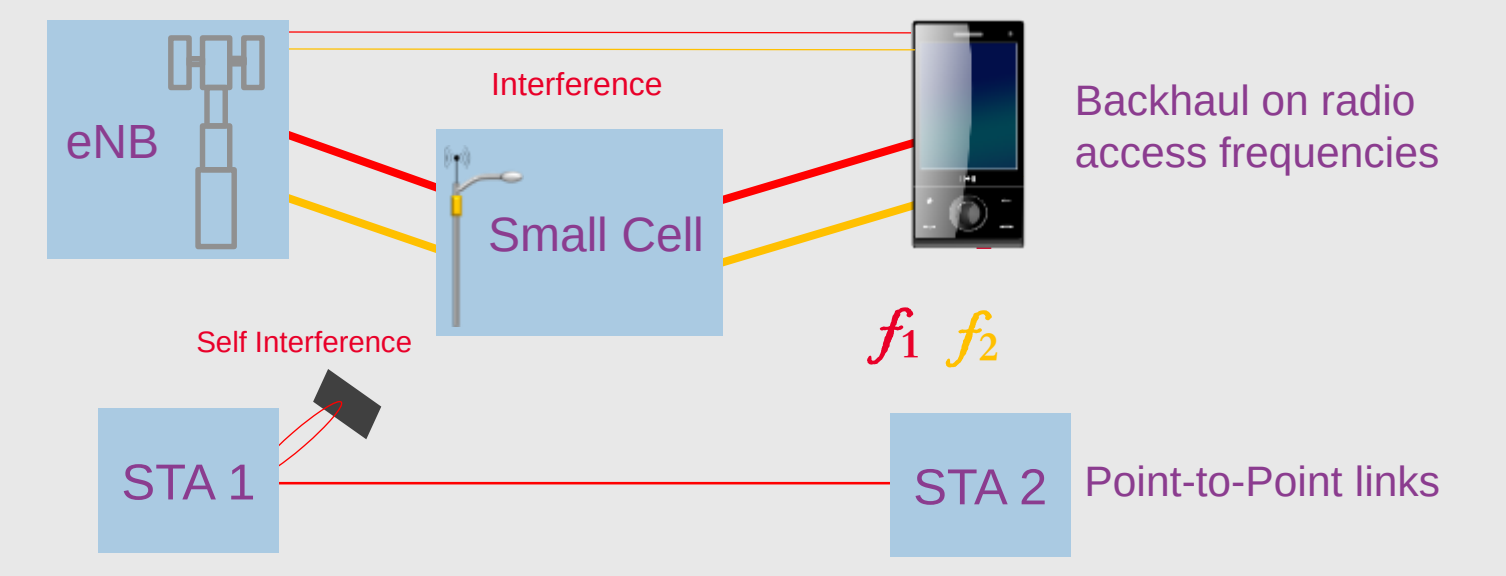


In-Band Full Duplex (IBFD)

What is it?

– Today, FDD and TDD radios are half duplex – can not transmit and receive on same channel at the same time
  - Why? self-interference is much larger than received signal

– In-band full duplex (IBFD) allows simultaneous transmission and reception on a same channel – theoretically up to 2x spectral efficiency
  - This would require self-interference cancellation



New Air Interface for 5G

– New air interface for sub-6 GHz and > 6 GHz are being researched for the various 5G use cases

– New waveforms, modulation formats and multiple access schemes are being researched for both < 6 GHz and > 6 GHz

Duplex	Multiple Access Scheme	Waveform Type	Modulation Format

• FDD
• TDD
• Flexible Duplex
• Full Duplex
	• OFDMA
	• SCMA
	• NOMA
	• MUSA
	• plus more…
		• Single-carrier
		• Multi-carrier:
		  • CP-OFDM
		  • FBMC
		  • UFMC/UF-OFDM
		  • GFDM
		  • plus more
			• OQPSK
			• QAM
			• New constellation mapping
			• plus more…

Note:
- For < 6 GHz, it is most likely both FDD and TDD will be deployed vs. TDD only in mmWave
- For < 30 GHz, it is most likely multi-carrier waveforms such as OFDM, FBMC, UFMC will be deployed vs. single carrier waveform in mmWave bands

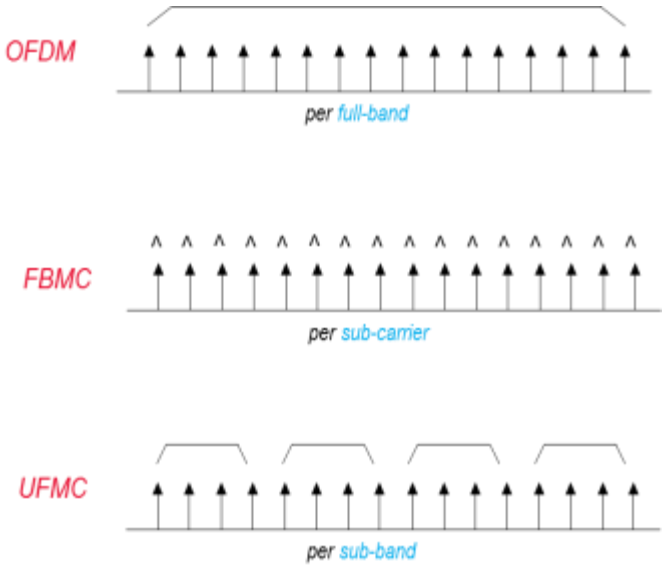
- Orthogonal Frequency Division Multiplexing(OFDM)
- Filter Bank Multicarrier(FBMC)
- Universal Filtered Multicarrier(UFMC)
- Universal filtered OFDM (UF-OFDM)
- General Frequency Division Multiplexing (GFDM)
- Orthogonal Frequency Division Multiple Access (OFDMA)
- Non-orthogonal Multiple Access (NOMA)
- Sparse Code Multiple Access (SCMA)
- Multi-User Shared Access (MUSA)

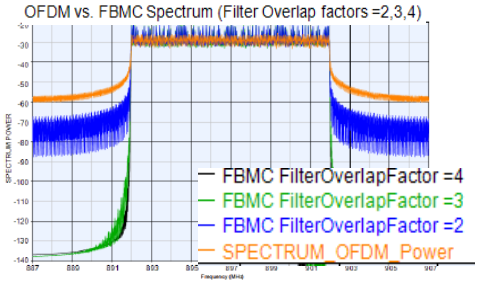
Candidate Waveforms

Multicarrier waveforms and filter operation

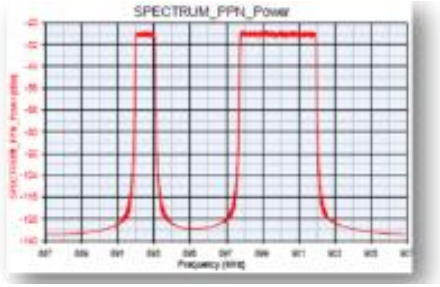
Some contenders:

- **Cyclic Prefix based OFDM (CP-OFDM)** – used in LTE
  - Filter per full-band, uses cyclic prefix to separate symbols
  - Not efficient for small packets
- **Filter Bank Multicarrier (FBMC)**
  - Filter per subcarrier, reduced side lobes, no cyclic prefix
  - Offset-QAM (OQAM) used to achieve orthogonality
- **Universal Filtered Multicarrier (UFMC)**
  - Also known as universal filtered OFDM (UF-OFDM)
  - Filter per sub-band, reduced side lobes, no cyclic prefix
  - Claim to be efficient for both large and small packets
  - QAM may be used for modulation

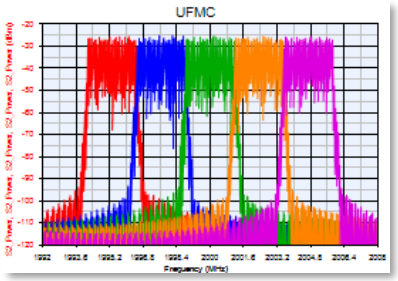




OFDM vs. FBMC using different filter overlap factor



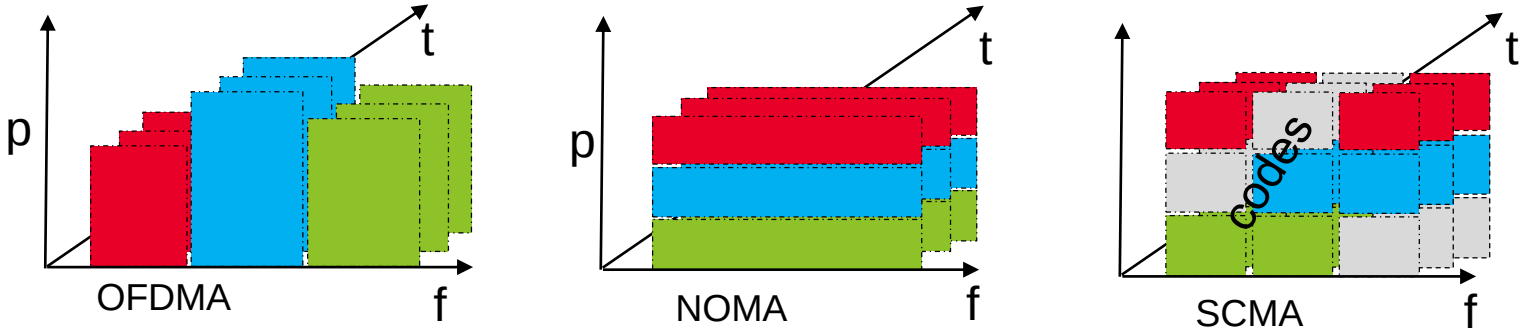
FBMC fragmented spectrum



UFMC multiplex of sub-bands

Multiple-Access Techniques

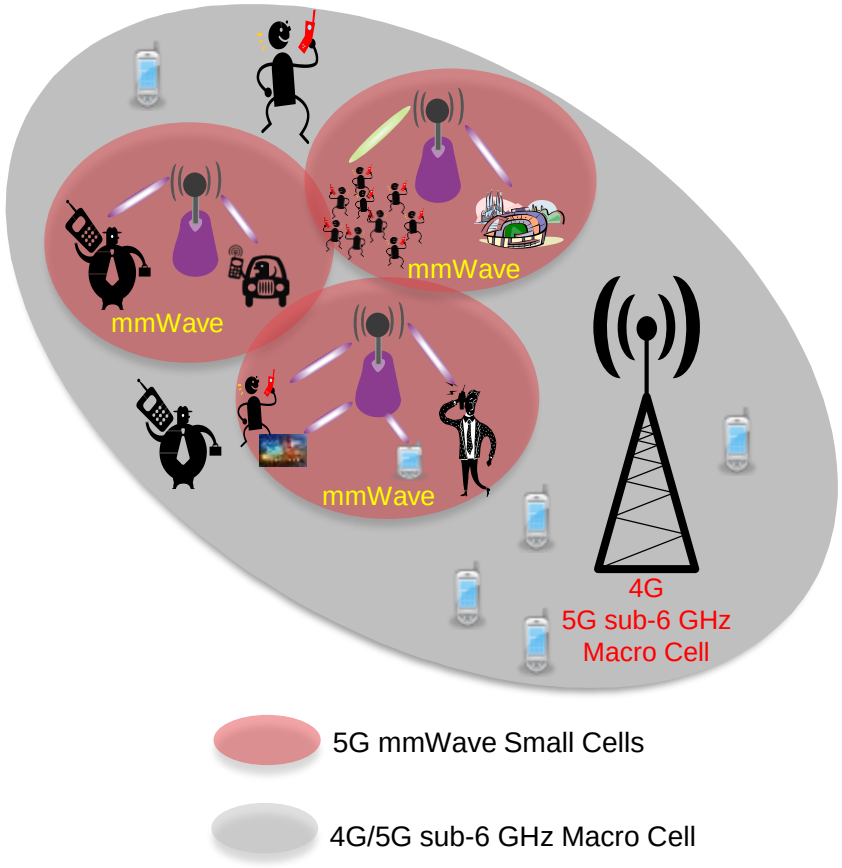
- Orthogonal Frequency Division Multiple Access (OFDMA)
  - Resource-Block (Sub-Carrier/Time) domain orthogonal technique
- Non-orthogonal Multiple Access (NOMA)
  - Power-domain quasi-orthogonal technique
- Sparse Code Multiple Access (SCMA) and Multi-User Shared Access (MUSA)
  - Code-domain, quasi-orthogonal techniques



5G Applications at mmWave

Small cells access and backhaul

- Signals in mmWave attenuates quickly. This means smaller cell size i.e. Small cells
- Abundant mmWave contiguous spectrum = very high overall system capacity
- “Great Service In a Crowd” is one of the visions of 5G.
  - mmWave small cells will enable ultra-dense deployment in large cities and very crowded locations, ex. stadiums, with high guaranteed throughput
- mmWave enables very efficient frequency reuse, allowing small cells to be placed close enough to enable high capacity
- mmWave is also used for small cell backhaul, line-of-sight (LOS)



Note: 5G will also be used for Macro Cells using sub-6 GHz frequency.

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mmWave Design Challenges

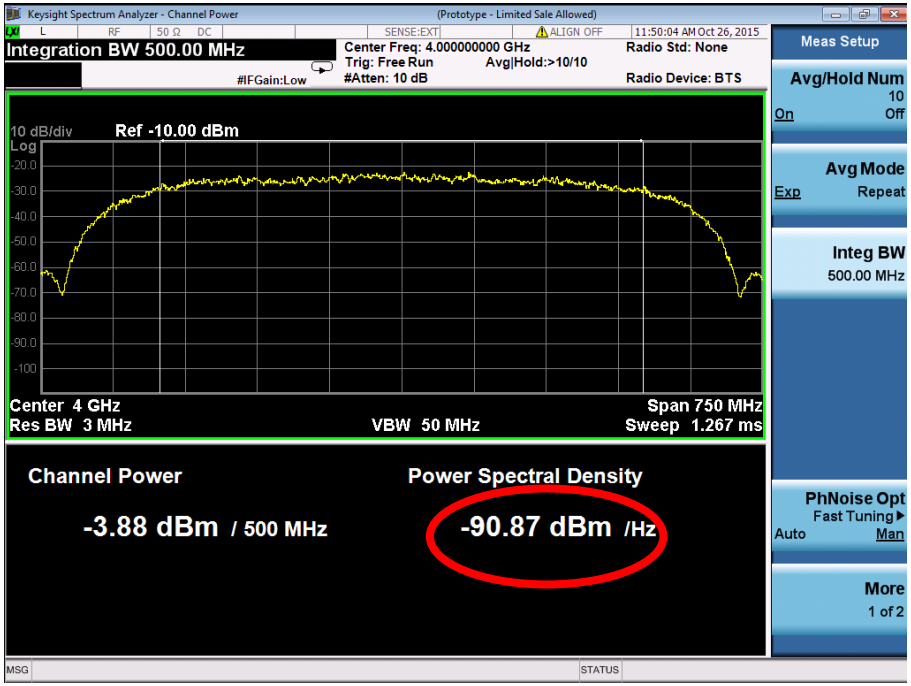
High Frequency	High Bandwidth	High Path Loss	High Data Rate
Phase Stability	High IF Converters (use 2nd Nyquist)	Directional Antennas Usually Required	Power consumption
Amplifier Efficiency	I and Q channel match over frequency	Large codebook space for Beam Steering	Algorithm Complexity
Output Power	Integrated Noise Power	Beam forming complexity	Prototyping (FPGA's usually not fast enough)
Antenna Complexity	IF/RF Flatness	Robust Modulation and Coding (MCS)	IO (memory, interfaces to CPU's etc)
Quadrature Errors (Homodyne)	A/D and D/A Converters (power consumption)	Discovery and Tracking affect MAC and MCS	High sample-rate data to/from converters

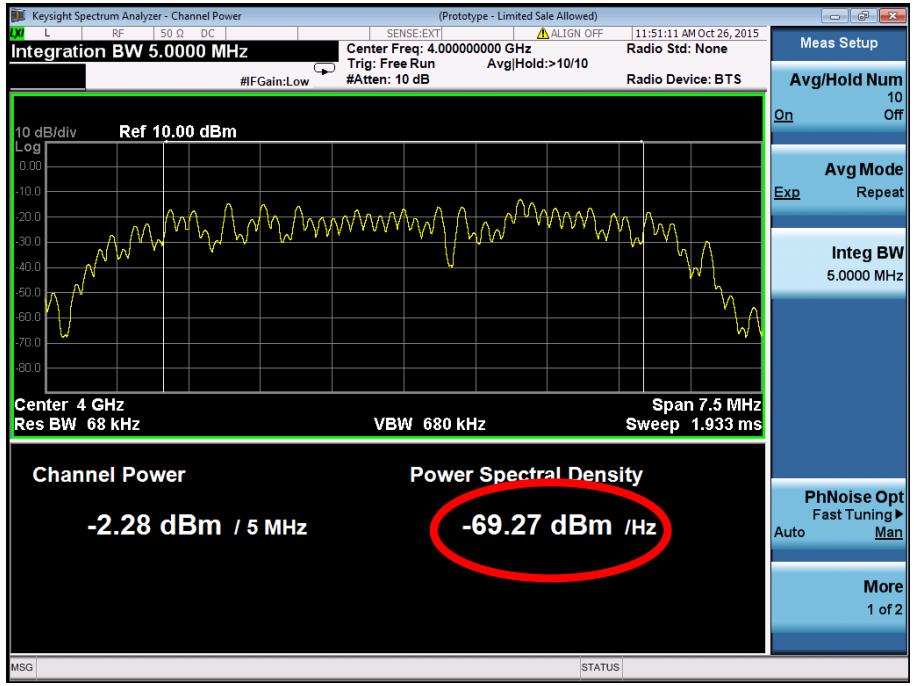
mmWave Design Challenges

High Bandwidth

Integrated Noise Power

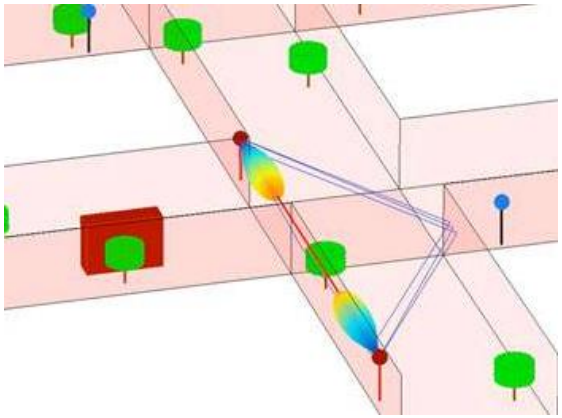
- Larger signal bandwidths means… greater amounts of noise power
- Drives requirements for antenna gain, and receiver noise figure
- Receiver sensitivity can be problematic

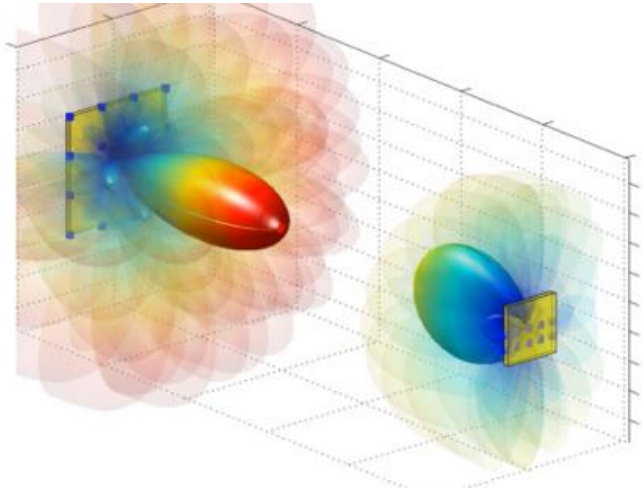




mmWave Design Challenges

High Path Loss
Directional Antennas Usually Required
Large codebook space for Beam Steering
Beam forming complexity
Robust Modulation and Coding (MCS)
Discovery and Tracking affect MAC and MCS





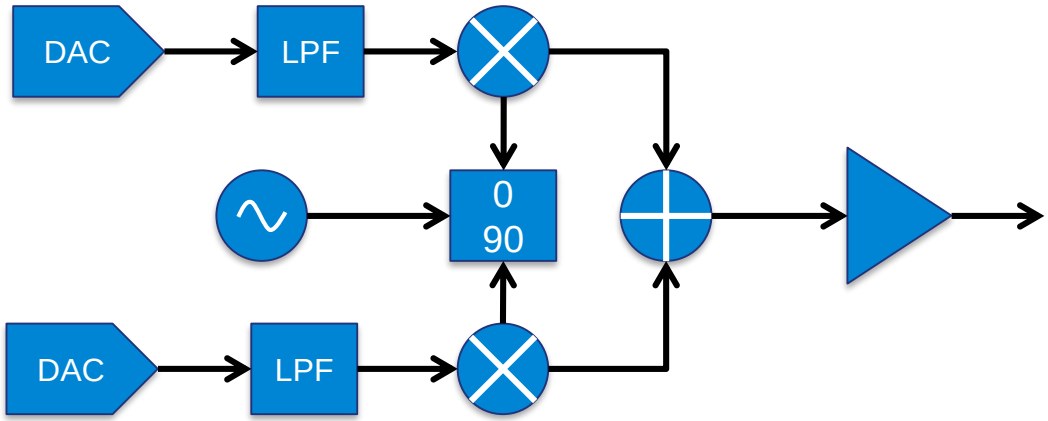
University of BRISTOL

- Station discovery requires search protocols
- Need to establish correct aim of highly directional antennas, or use wide beam (low gain) for discovery
- MAC/PHY must support wide range of device capabilities

mmWave Design Challenges

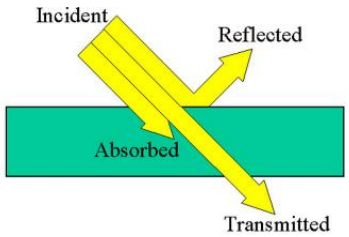
High Frequency/BW
Phase Stability
I and Q channel match over frequency
Quadrature Errors (Hom odyne)

- Phase stability / frequency accuracy
- Quadrature errors
- DC/LO feedthrough
- Frequency Dependent I / Q Mismatch



Issues Facing Cellular mmWave Connectivity

1. Holding it the wrong way
2. Body shadowing
3. Moving vehicles



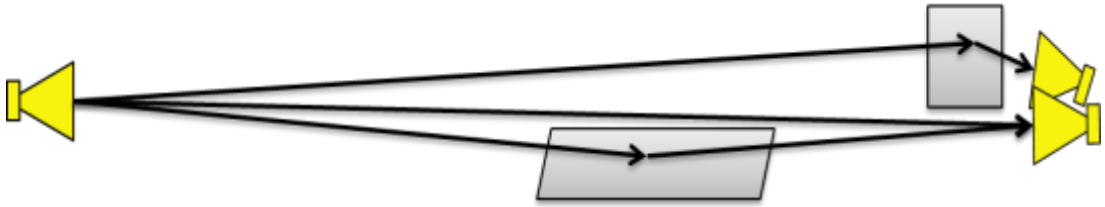
4. Outdoor to indoor coverage
5. Can we afford to build a high enough density mmWave network with the ability to maintain multiple links per user?

Channel Models are Critical for 5G

Very little experience with radio-access technologies in the mmWave bands.

- Directional antennas required. New concept for mobile devices
- Propagation through materials. Signals will pass through walls, even at 60 GHz.
- Channel dynamics affects signal design and beam forming (algorithms and MAC design)
- Interference (sidelobe performance requirements, null steering)

Need 3D models

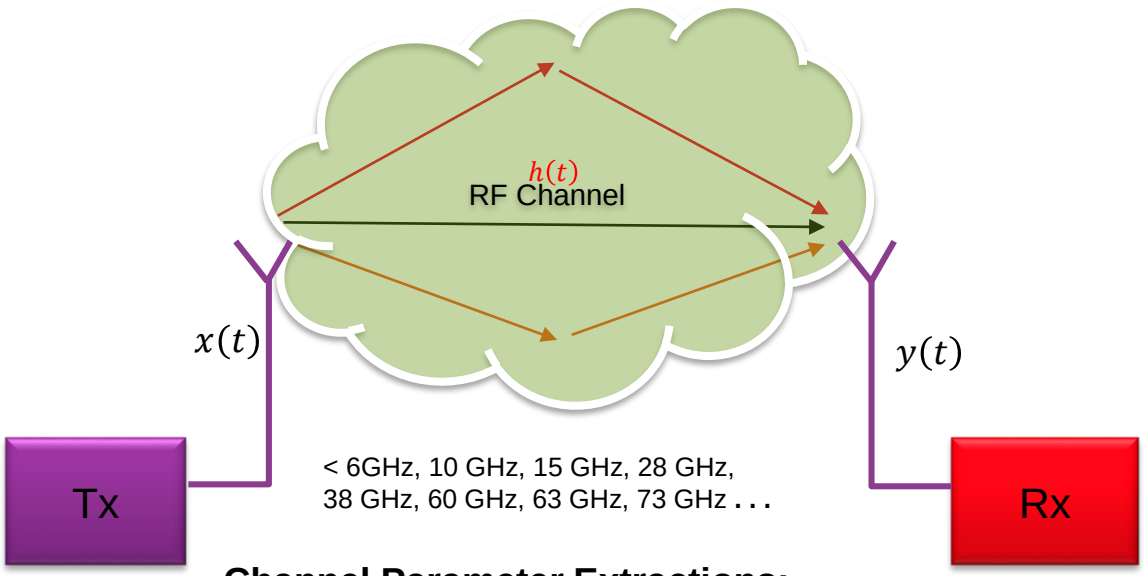


For Massive MIMO the channel model affects:

- Choice of frequencies for the technology. 3, 6, 15, 28, 39, 60, 70GHz?
- Antenna design, number of antennas required
- Amplifier design (dynamic range, power, ACPR and other nonlinear behaviors such as AM/PM)
- Signal design (coherence time)
- Reciprocity calibration accuracy
- Total power requirements (especially for the BS)

5G Channel Sounding

Understand characteristics of mmWave channels



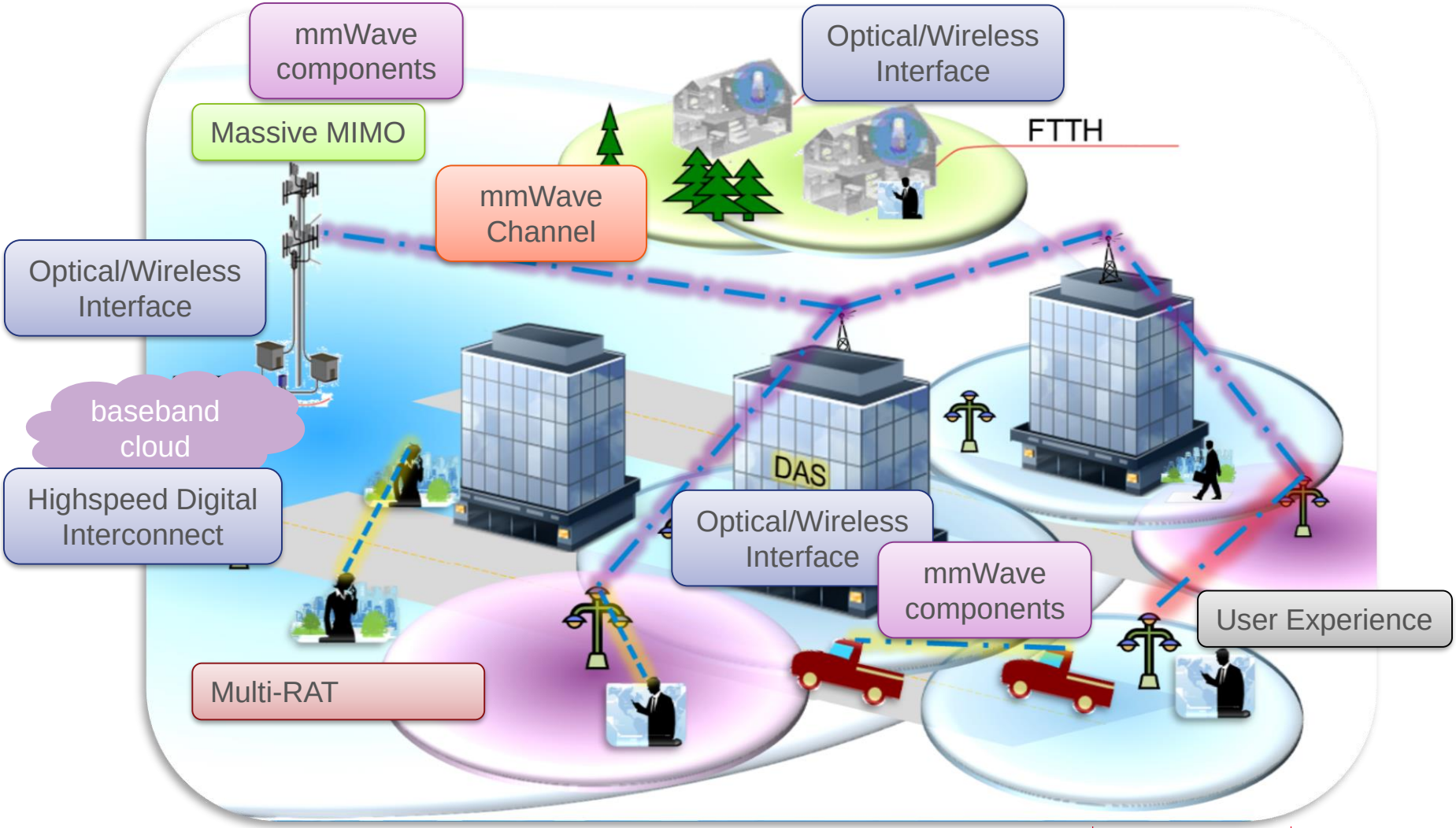
Channel Parameter Extractions:

- Path loss, absolute path delay, power delay profile (PDP)
- AoA / AoD
- Doppler Shift

Technical Challenges

- Signal generation and capture
  - mmWave frequency band
  - Ultra-broad bandwidth
  - Multi-channel
- Data streaming & storage
- Channel parameter estimation processing
- Calibration and synchronization

5G Measurement Opportunities



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5G Early Research

New Technologies -> New Challenges -> New Measurements

- **100x Data Rates**
- **1000x Capacity**
- **100x Densification**
- **1ms Latency**
- **Reliability 99.999%**
- **100x Energy Efficiency**

Requires Enabling Technologies

– Some research topics are:

- RF & µW (< 6GHz):
  - New PHY/MAC; up to 200 MH z BW
- uW & mmWave (> 6 GHz):
  - New PHY/MAC
  - 500 MHz to 2 GHz BW (depending on frequency)
- Channel models at mmWave:
  - Very little experience with radio -access technologies in the mmWave bands
- New waveform types and radio access technologies
- Multi-antenna technologies such as Massive MIMO

Drives Measurement Demands

1. Quantify new modulation & multiple-access schemes
2. Measure wide bandwidths, high frequencies, fast bit rates
3. Measurement & calibration of smart antennas
4. Modeling & validation of new networks

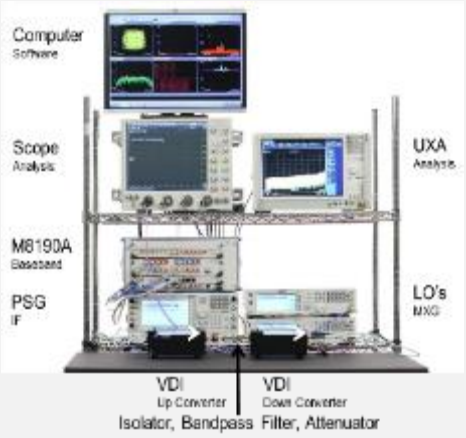
KEYSIGHT TECHNOLOGIES

Keysight Test Solutions for 5G Research

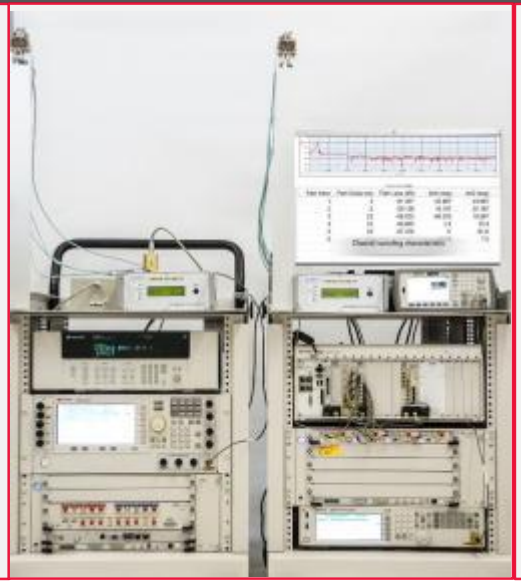
Benchtop and modular signal generation and analysis

Wideband RF/µW/mmWave Reference Solution

Signal Generation & Analysis

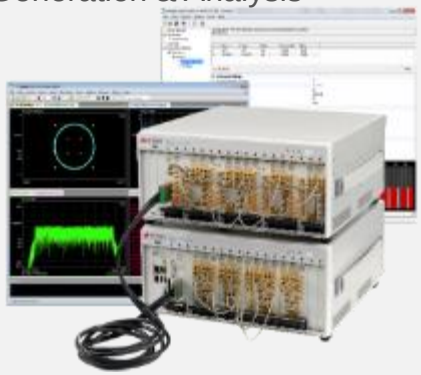


Channel Sounding Reference Solution



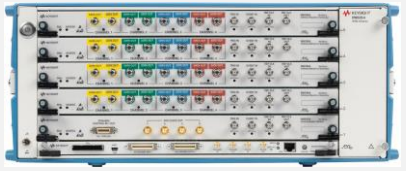
Sub-6 GHz MIMO

Phase Coherent Signal Generation & Analysis



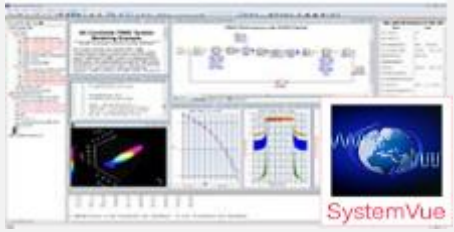
Massive MIMO Transmitter & Receiver

M8195A 65 GSa/s Arbitrary Waveform Generator with M8197 Synchronization module

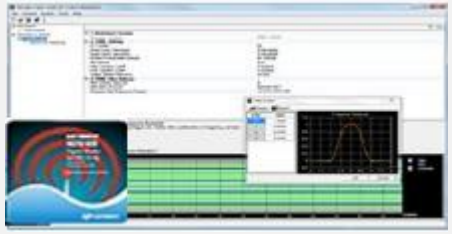


M9703A AXIe 12-bit High-Speed Digitizer/Wideband Digital Receiver

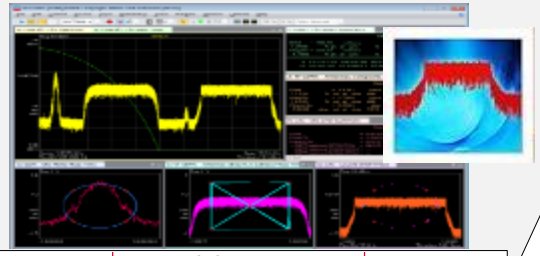
SystemVue Simulation Software with 5G Library



Signal Studio Software with Custom 5G



89600 VSA Software with Custom OFDM/Demod



Keysight Research Partnership & Collaboration

Recent Collaboration Announcements in Media

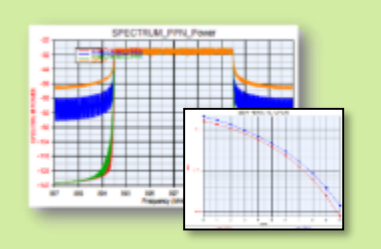
- Keysight Technologies Collaborates with University of Bristol on 5G Wireless Technology Research http://about.keysight.com/en/newsroom/pr/2015/08sep-em15125.shtml
- Keysight Technologies Collaborates with NTT DOCOMO on 5G Wireless Communication Systems: http://about.keysight.com/en/newsroom/pr/2015/22jul-em15104.shtml
- Keysight Technologies, KT Corporation Sign Memorandum of Understanding to Collaborate on 5G Technology Development http://about.keysight.com/en/newsroom/pr/2015/24jun-em15094.shtml
- Keysight Technologies Participates in Joint Demonstration on Next-Generation 5G Wireless Communication Systems with China Mobile at Mobile World Congress, Feb 27, 2015 http://about.keysight.com/en/newsroom/pr/2015/27feb-em15047.shtml
- Keysight Technologies Joins NYU WIRELESS to Advance 5G Mobile Technology, Dec 8, 2014 http://about.keysight.com/en/newsroom/pr/2014/08dec-em14178.shtml
- Keysight Technologies and Kwangwoon University Radio Research Center Co-host 5G and mmWave Workshop, Dec 4, 2014 http://about.keysight.com/en/newsroom/pr/2014/04dec-em14174.shtml
- Keysight Technologies Supports B4G/5G Technology Development at National Taiwan University's High-Speed Radio Frequency and mmWave Center, Oct 21, 2014 http://about.keysight.com/en/newsroom/pr/2014/24oct-em14155.shtml
- Keysight Technologies Joins 5G Forum in South Korea, Aug 11, 2014 http://about.keysight.com/en/newsroom/pr/2014/11aug-em14115.shtml

SystemVue 5G Baseband Exploration Library

Industry's first 5G baseband exploration library

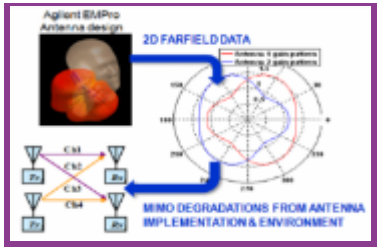
W1906BEL 5G baseband exploration library - A flexible platform for innovation

- Physical layer modeling of 5G PHY candidate and MIMO
- C++ source code enables early research, with a versatile simulation platform
- Keysight is committed to evolve toward the world's first 5G standard compliant library



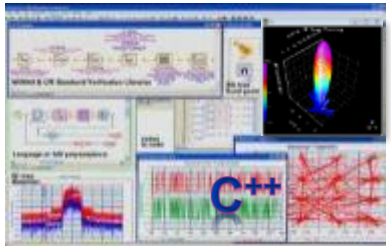
Modeling New Physical Layer

- Provides 5G candidate TX/RX waveforms
  - Multi-carrier modem Tx/Rx processing chain
  - FBMC,OFDM, etc…
- Usable with 4G standard library



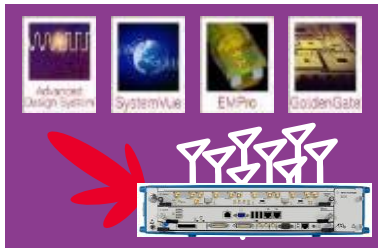
Multi-Antenna Techniques

- Advanced / adaptive signal processing
  - MIMO
  - Digital beamforming
- Combined 2D/3D MIMO channel simulation(W1715)



Platform Enables "V" Lifecycle

- Realistic RF environments
- Polymorphic Baseband modeling
  - Custom C++ model builder
  - MATLAB®
  - HW implementation



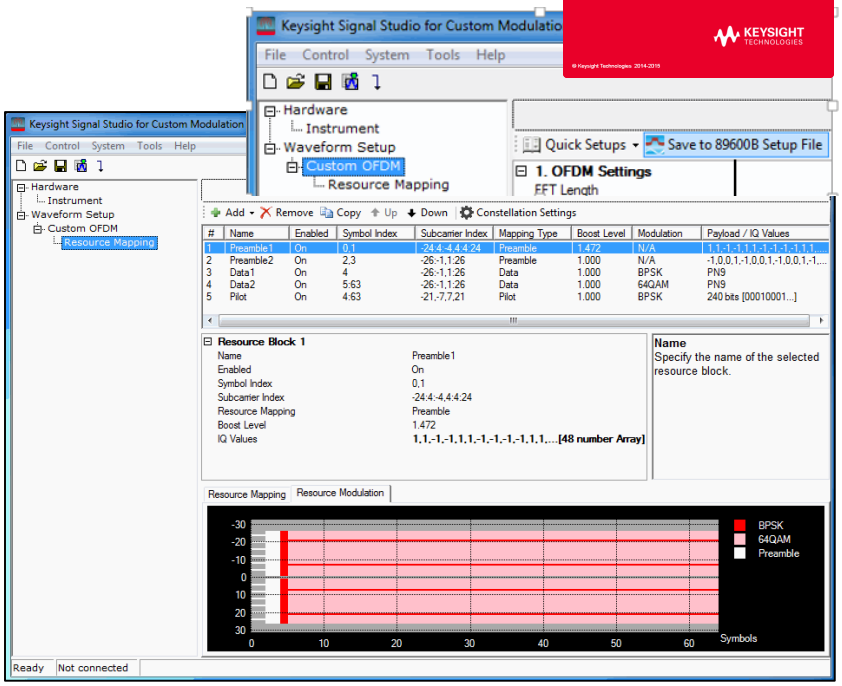
Tackling Multi-Domain Issues

- Integrates with additional technology domains
  - SystemVue
  - ADS/EMPro
  - Keysight Instruments

N7608B Signal Studio for Custom Modulation

- Flexible suite of tools that simplifies creation and modification of custom waveforms:
  - 5G waveforms: FBMC,GFDM,UFDM and F-OFDM
  - Custom OFDM waveforms
  - Custom IQ waveforms

- Signal creation companion to the 89600 VSA software (options BHK & BHF) modulation analysis



N7614B Signal Studio for Power Amp Test

Crest Factor Reduction	
1. Basic	
CFR Algorithm	Peak Windowing
Target PAPR	8.00 dB
Max Iteration	10
Max WindowLength	10
Beta	12

Before CFR		After CFR	
10%	3.65 dB	10%	3.65 dB
1%	6.55 dB	1%	6.50 dB
0.1%	8.50 dB	0.1%	7.90 dB
0.01%	10.65 dB	0.01%	7.95 dB
0.001%	11.65 dB	0.001%	7.95 dB
0.0001%	11.65 dB	0.0001%	7.95 dB
Peak	11.65 dB	Peak	8.00 dB
ΔEVM	--- %	ΔEVM	2.20 %

KEYSIGHT TECHNOLOGIES

Keysight Arbitrary Waveform Generators

Choose the performance you need

- High Resolution
- Wide Bandwidth

M8190A

M8195A

M8196A

M8190A

14 bit 8 GSa/s /
12 bit 12 Gsa/s

5 GHz analog bandwidth

Best signal quality and longest playtime

2 channel on 1 module

SFDR: up to -90 dBc .

M8195A

8 bit 65 GSa/s

25 GHz analog bandwidth

Highest speed, bandwidth and port density in a 1-slot AXIe module

Up to 4 channel on 1 module
Jitter 5 ps pp @ 32 Gb/s
SFDR: up to -80 dBc
Integrated 16-tap FIR filter

M8195A

8 bit 96 GSa/s

32 GHz analog bandwidth

Highest speed, bandwidth and port density in a 1-slot AXIe module

Up to 4 channel on 1 module
Jitter 5 ps pp @ 32 Gb/s
SFDR: up to -73 dBc

Keysight mmWave Signal Generators

Performance

Price

The agile UXG Analog
N5193A, Up to 40GHz

The High Performance PSG,
E8267D, Vector, 31.8, 44GHz

The High Performance Analog PSG
E8257D, 31.8, 40, 50, 67GHz

E8257D/67D + mmW Source Module, up to 500GHz

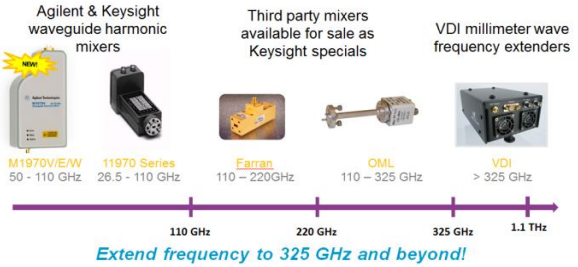
The Pure and Precise MXG
N5183B, Analog, up to 40GHz

The Cost-Effective EXG
N5173B, Analog, up to 40Ghz

E8257D/67D + VDI mmW Source Module, up to 1.1THz

X-Series Benchtop Signal Analyzers

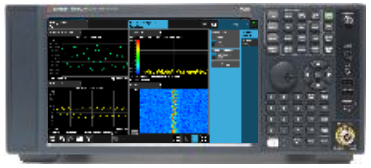
The Benchmark for Accessible Performance



CXA

Leading low-cost tool

- 9 kHz to 26.5 GHz, 25 MHz BW
- **Enhanced phase noise**
- Cost-effective testing in general-purpose and educational applications



EXA

Maximum value up to millimeter-wave

- 10 Hz to 44 GHz, 40 MHz BW
- **Enhanced phase noise**
- Find answers faster with tighter margins and shorter test times

MXA

Optimum choice for wireless

- 10 Hz to 26.5 GHz, 160 MHz BW
- Real-time spectrum analysis
- Flexibility to quickly adapt to evolving test requirements today and tomorrow

PXA

Benchmark for demanding applications

- 3 Hz to 50 GHz, **510 MHz BW**
- **DDS LO**
- Real-time spectrum analysis
- Measurement options that range from excellent to exceptional

UXA

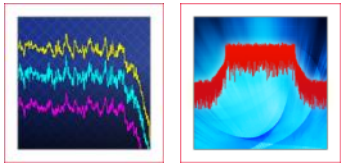
Wide-open performance

- 3 Hz to **50 GHz**, **1 GHz BW**
- Real-time spectrum analysis
- Deeper views of elusive and wideband signals
- See more and take your design farther

X-Series applications

Ready-to-use measurements

- Phase noise, noise figure, analog demod
- **Pulse, LTE/LTE-Advanced, W-CDMA**



89600 VSA software

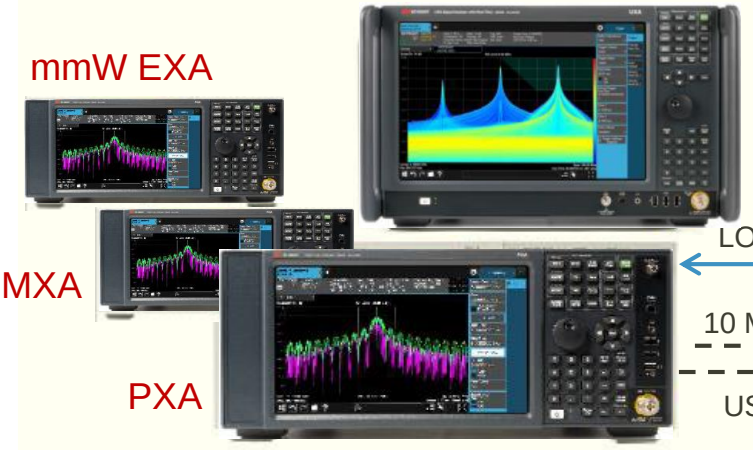
Comprehensive demodulation & vector signal analysis

KEYSIGHT TECHNOLOGIES

Z9071B mmWave Wideband SA solution

X-Series SA + M1971E + Scope + 89600 VSA
2GHz analysis BW for 55-90 GHz carriers

Keysight UXA/PXA/MXA/EXA



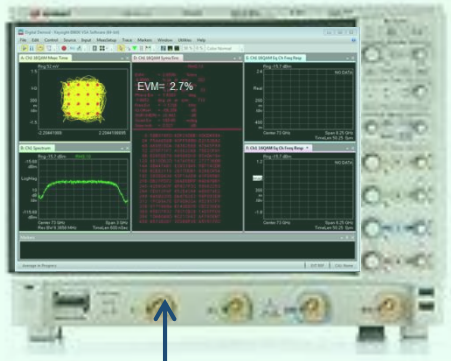
LO/IF

10 MHz REF out

USB

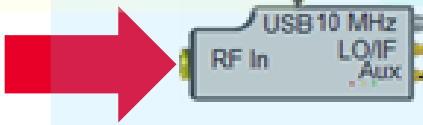
X-Series SA provides mixer control, carrier characterization, and WB spectrum analysis

DSOS804A S-series Scope w/ 89600 VSA



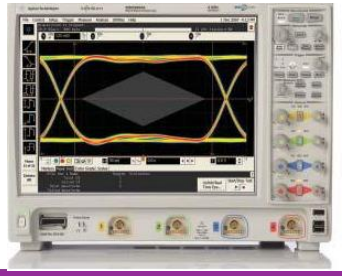
Scope and VSA provide digital demodulation for WB signal over 2 GHz

mmW WB signal input
Waveguide WR-12



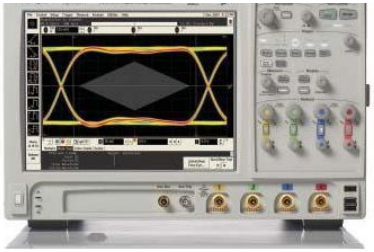
M1971E WB smart mixer
(Opt 001: 60-90 GHz
Opt 003: 55-90 GHz)

Keysight mmWave Infiniium Series Oscilloscopes



S-Series
250 MHz – 8 GHz

- World's fastest 10-bit ADC scope
- Mixed signal oscilloscope models available
- 20 GSa/s on 2 ch, 10 GSa/s on 4 ch
- 15.4" display

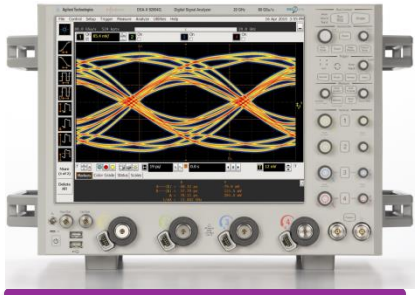


90000A Series
2.5 GHz – 13 GHz

- Low noise/jitter
- 40 GSa/s on 4 ch
- 1 Gpts max memory depth per channel
- 12.1" display

V-Series
8 GHz – 33 GHz

- 2 ch up to 33 GHz
  4 ch up to 16 GHz
- 80 GSa/s on 2 ch
  40 GSa/s on 4 ch
- ***World's fastest MSO***
- Industry's lowest noise
- 12.1" capacitive touch



Z-Series
20 GHz – 63 GHz

- 2 ch up to 63 GHz
  4 ch up to 33 GHz
- 160 GSa/s on 2 ch
  80 GSa/s on 4 ch
- Industry's lowest noise
- 15.4" display
- 2 Gpts max memory

Using the 89600B VSA software, these oscilloscopes can be useful demodulators, especially for very wide bandwidth and high frequency signals

KEYSIGHT TECHNOLOGIES

Keysight mmWave Vector Network Analyzer

Performance

mmWave/THz VNA System
PNA/PNA-X+(mmW Controller+mmW Test Head
Up to 2THz

PNA-X(N524XA), NVNA
Industry-leading performance
10 M to 8.5/13.5/26.5/43.5/50/67 GHz

2-port PNA with U3022A E10 test set

PNA multi-port VNA System
50GHz, up to 24 ports
70GHz, up to 16 ports

PNA(N522XA) Performance VNA
10 M to 8.5,13.5/26.5/43.5/50/ 67GHz

PNA-L(N523XA) World's most capable value VNA
300 kHz to 8.5, 13.5, 20 GHz, 10 MHz to 43.5, 50 GHz

Keysight mmWave Power Measurement

Peak Power Analyzer
- **Peak, Average, CCDF (<30MHz VBW)**
- **Pulse Measurement**

Performance

9KHz-110GHz Power Meter & Sensor Selection

P-Series
- Peak, Average, CCDF (<30MHz VBW)
- Wireless Networking (WLAN, WiMAX, MIMO)

P-Series LXI
- Peak, Average, CCDF (<30MHz VBW)
- Compact, modular, faceless

EPM-P
- Peak & Average (<5MHz VBW)
- Wireless Com (GSM, EDGE, WCDMA, Bluetooth, etc)
- Radar Pulse Tr > 200ns

EPM
- Average Power
- R&D & Mfg (Std Rack Size)
- Military & ATE Systems

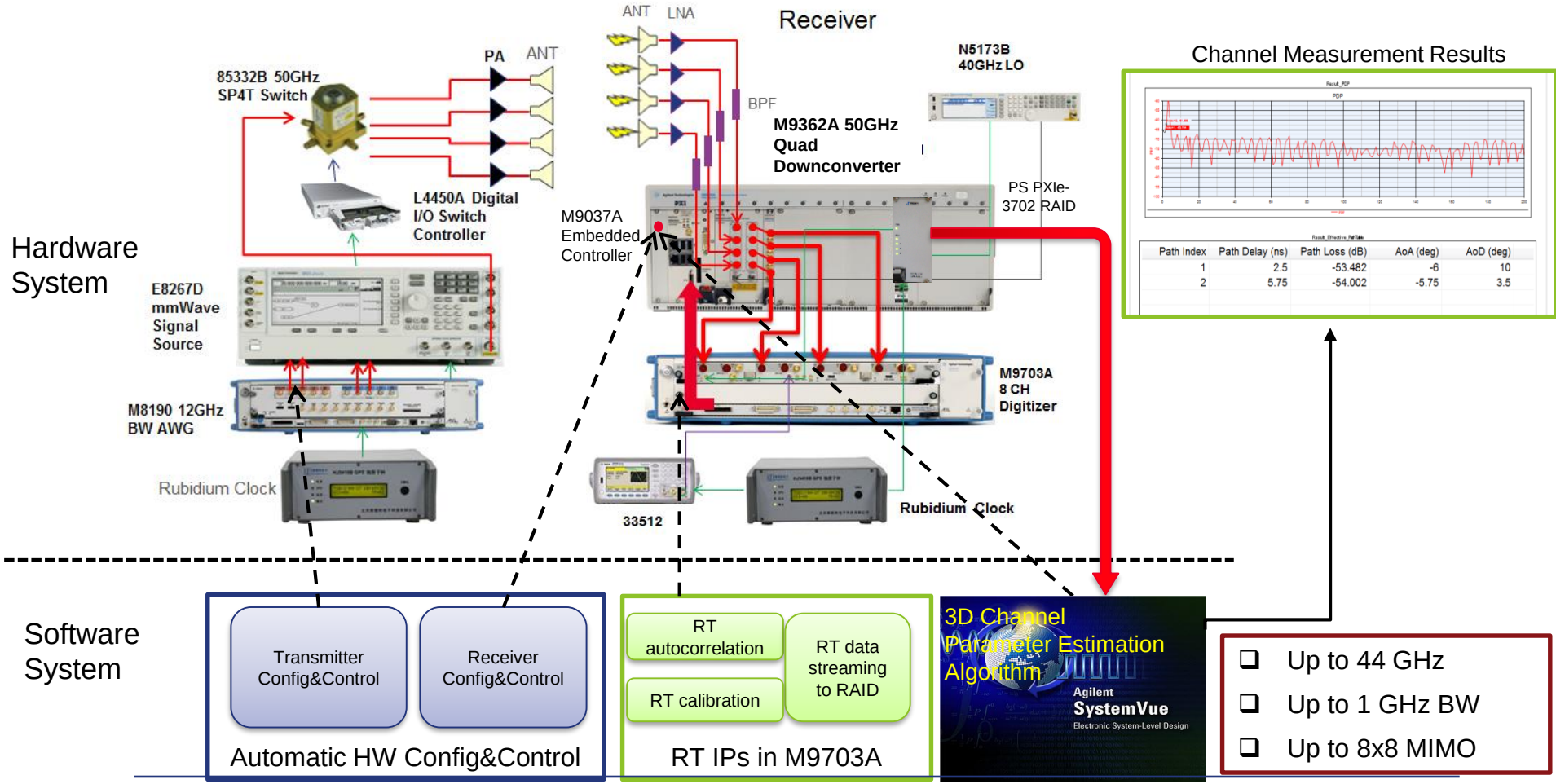
N1914A EPM Power meter
- **V/W8486A waveguide sensor (Average Power)**
  - 50-75GHz, 75-110GHz -30 to +20 dBm
- **N8488A 67GHz Thermocouple Power Sensor**
  - 10MHz – 67GHz, -35 to +20dBm
  - Connector type: 1.85mm (male)

Handheld Power Meter
- Average Power
- Handheld solutions

USB Sensors
- Average Power
- Low Cost Solution
- SIM market, R&D & Mfg

Price

5G MIMO Channel Sounding Reference Solution



5G Channel Sounding Reference Solution

www.keysight.com/find/solution-5GSounding

BENEFITS:

- Accurate broadband, multi-channel channel sounding measurements with system-wide calibrations, precise timing and synchronization
- Fastest, real-time data capture and processing of multi-channel CIR data
- Scalable to more channels and future 5G development

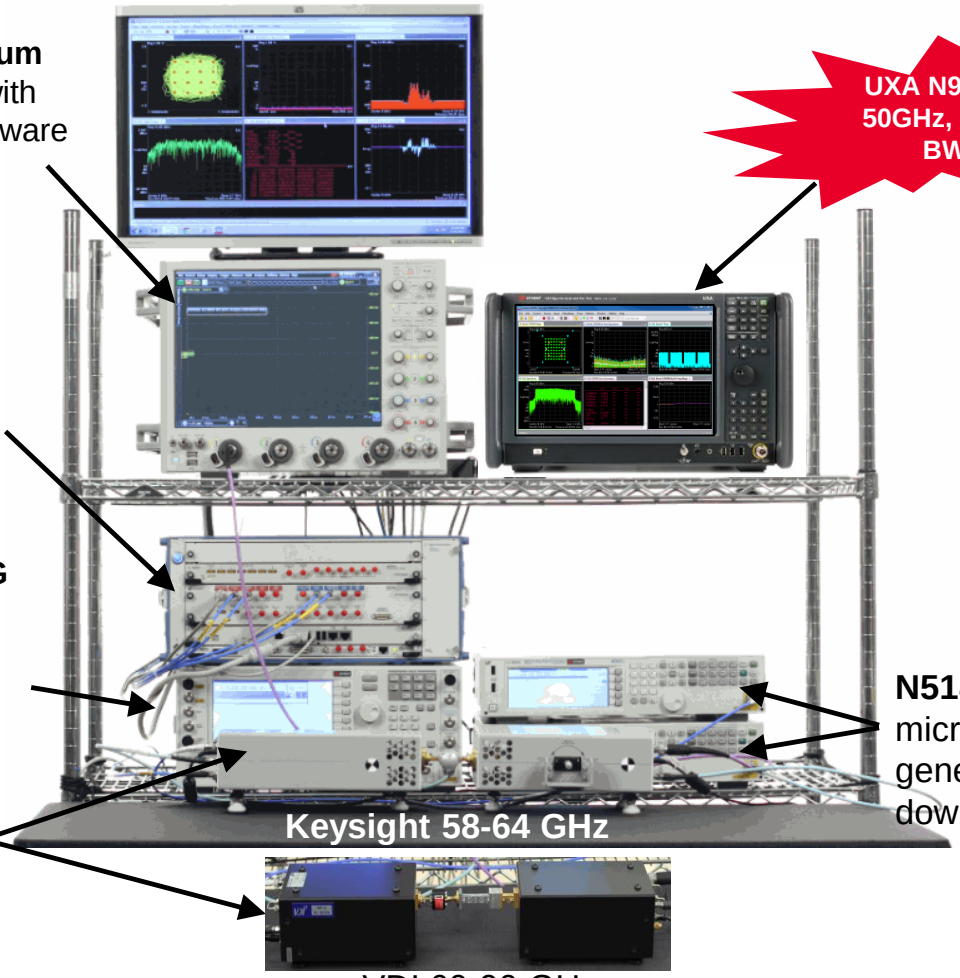
Flexible Testbed for 5G Waveform Generation & Analysis

63 GHz Infiniium oscilloscope with **89600 VSA** software

M8190A AWG with **SystemVue W1906 5G Baseband Exploration Library** and **N7608B Signal Studio for Custom Modulation** software installed on embedded controller

44 GHz **E8267D PSG** vector signal generator with wideband IQ inputs

Millimeter-wave upconverters / downconverters



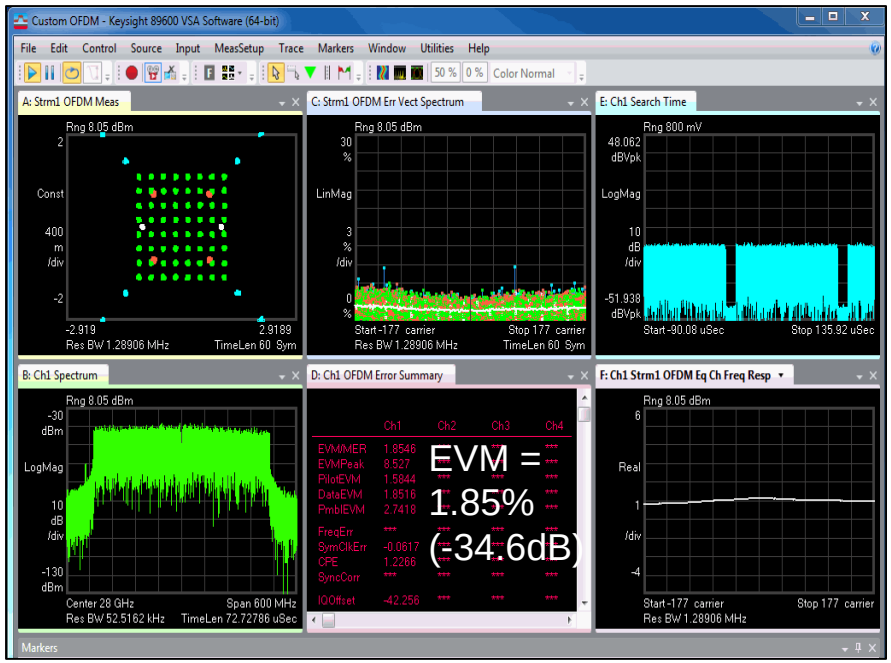
N5183B MXG microwave analog signal generators for upconverter/ downconverter LO's

VDI 60-90 GHz

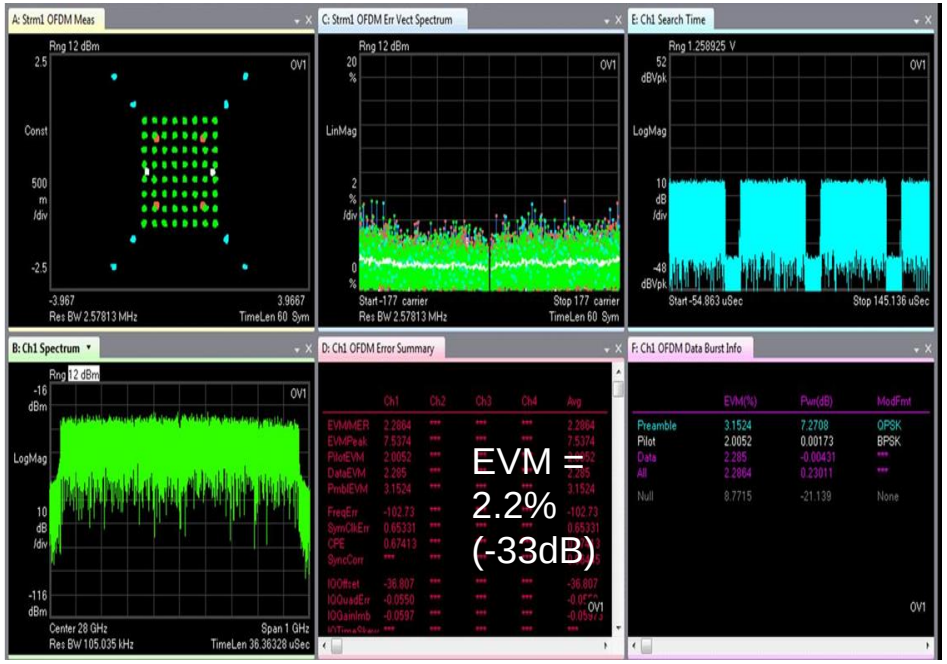
*Note: Different test equipment configurations may be used dependent on frequencies and bandwidths

Case Study - Wideband OFDM 64QAM at 28 GHz

500 MHz BW Modulation with Channel Equalization Enabled

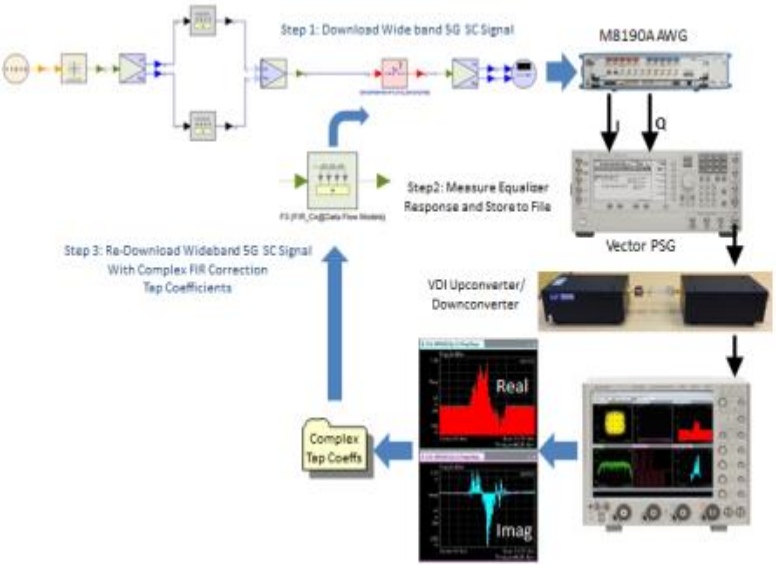


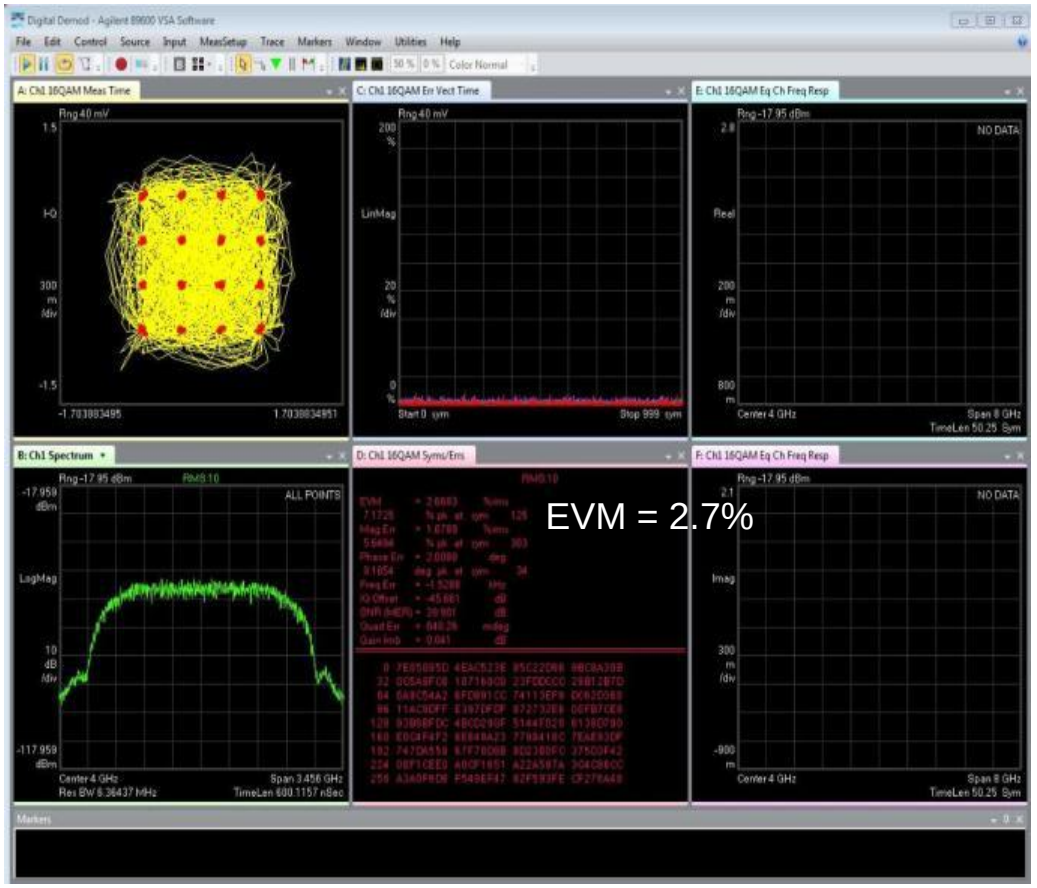
1 GHz BW Modulation with Channel Equalization Enabled



Case Study - Wideband Single Carrier 72 GHz

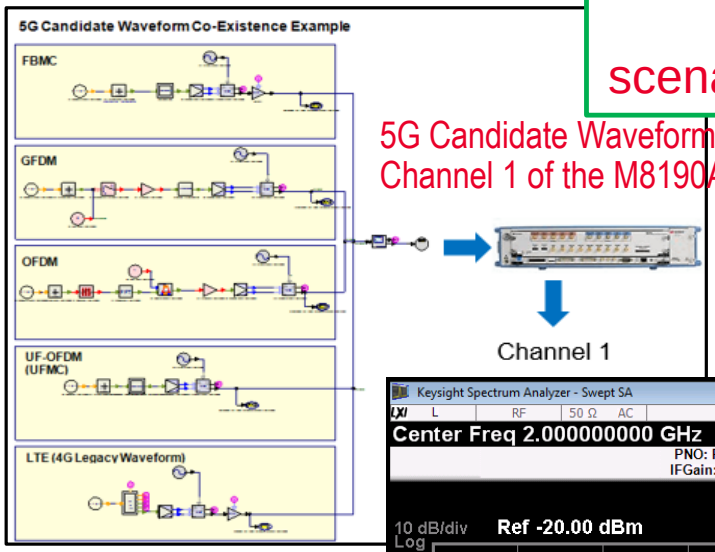
2 GHz Wideband Single Carrier Modulation 4 GHz Downconverter Output
*After Corrections **without*** Adaptive Eq. (7 GHz IF → 72 GHz → 4 GHz IF)





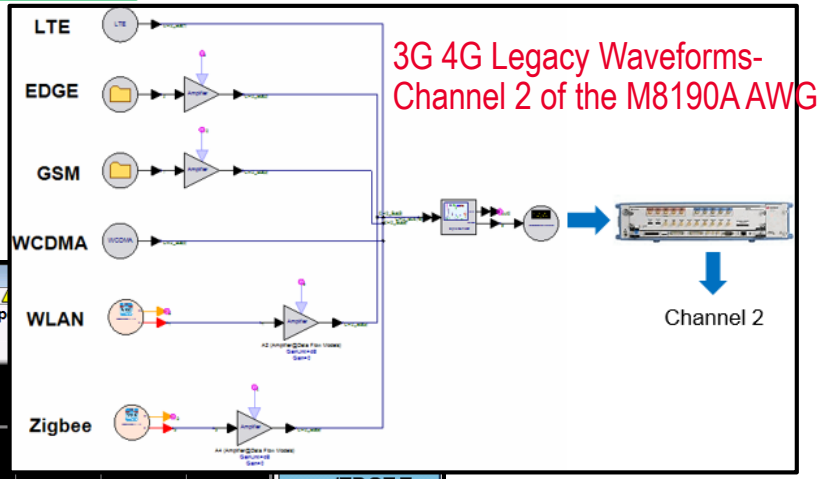
Combined 3G, 4G, 5G Waveforms- Channels 1 and 2 of the M8190A AWG

Coexistence
scenario and evaluation



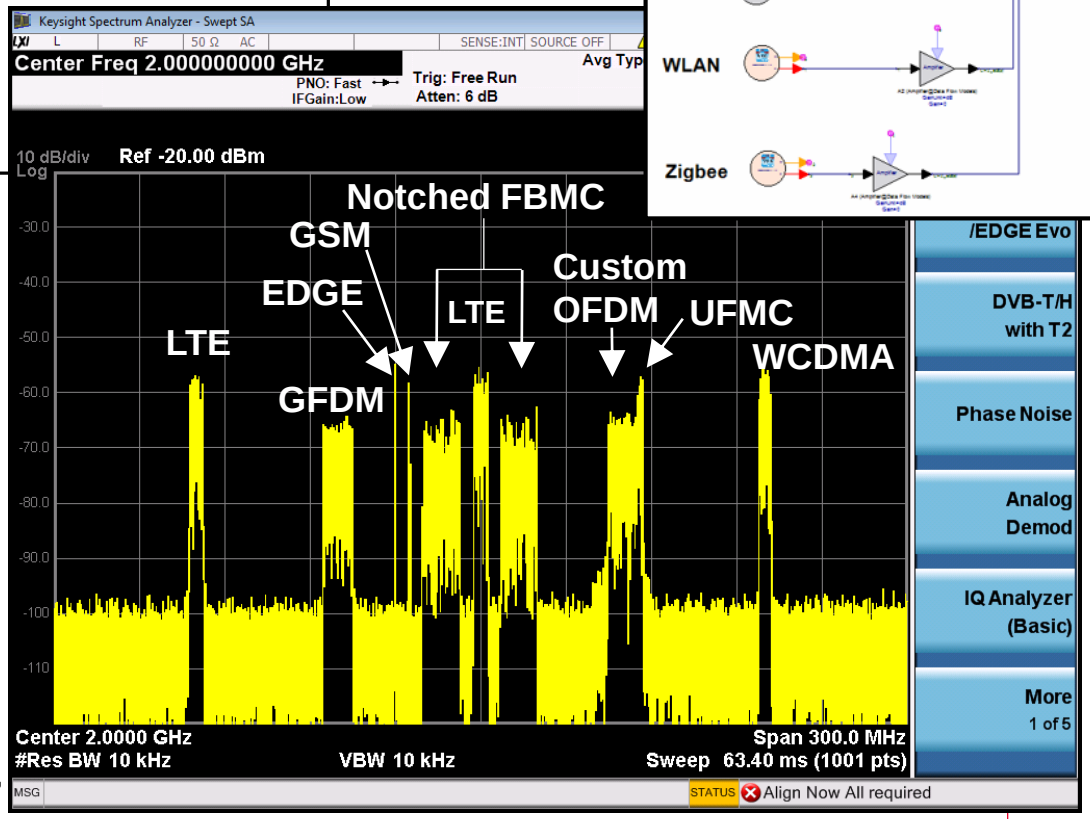
5G Candidate Waveforms-
Channel 1 of the M8190A AWG

Channel 1

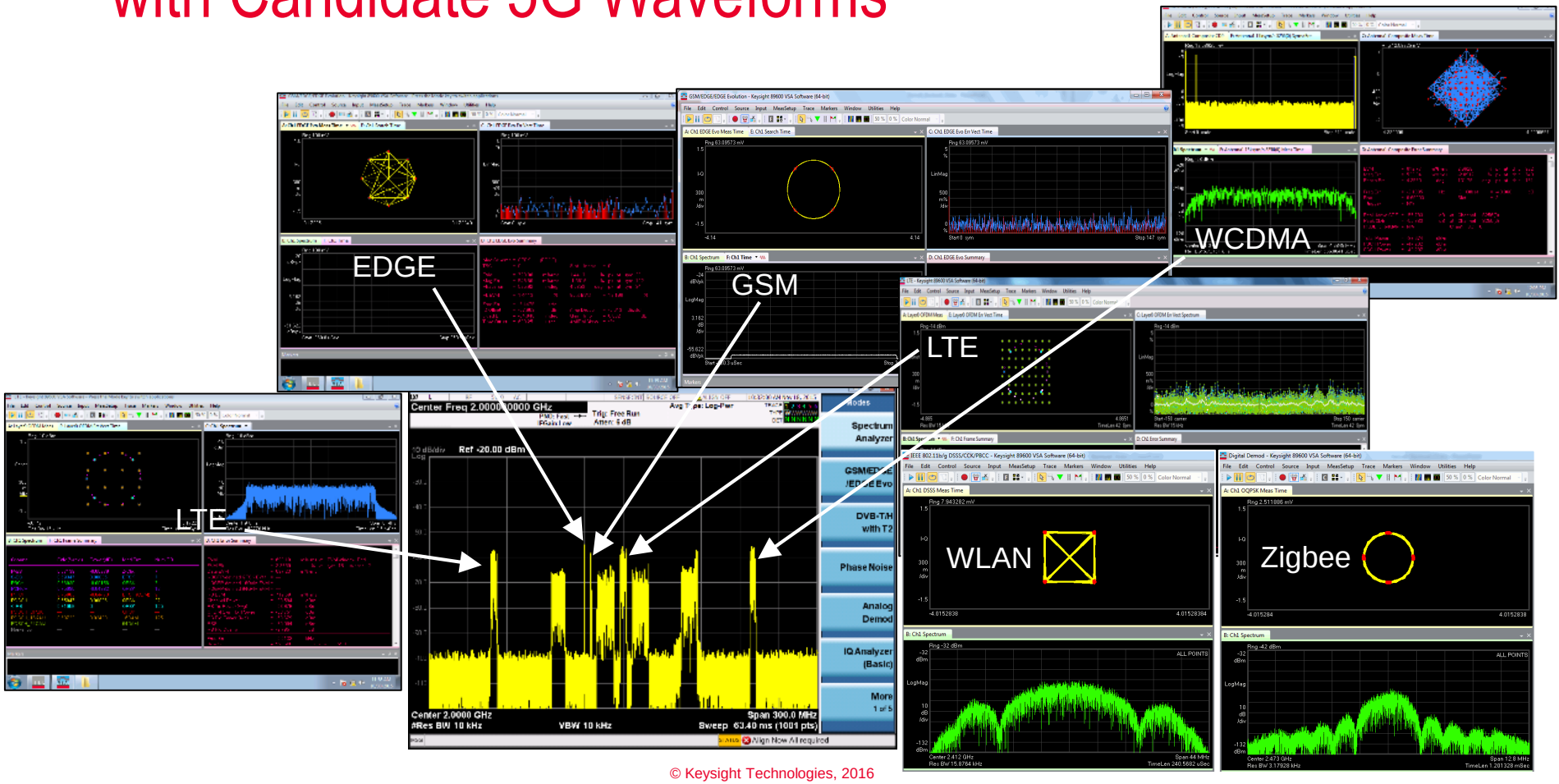


3G 4G Legacy Waveforms-
Channel 2 of the M8190A AWG

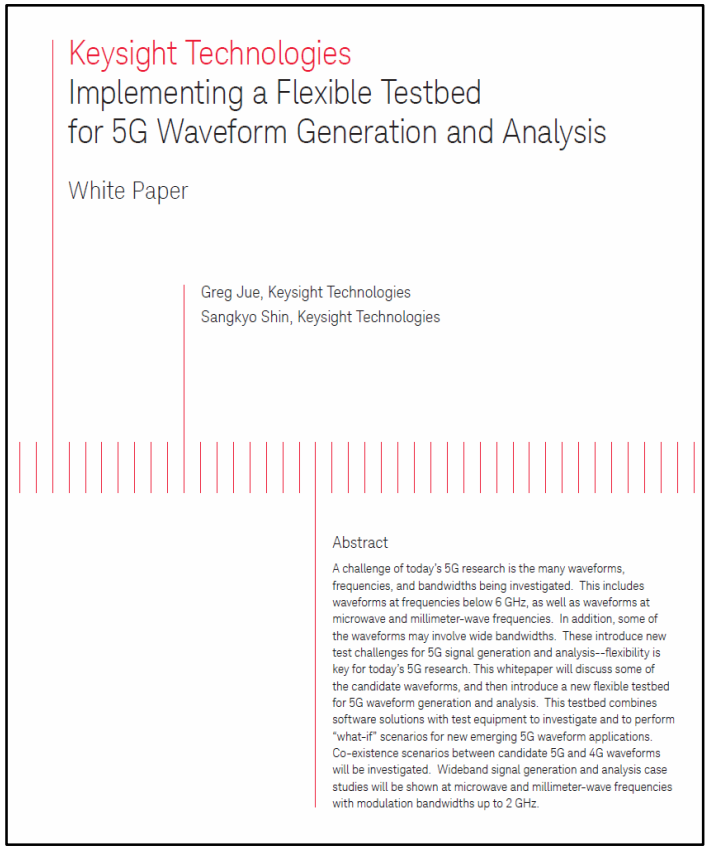
Channel 2



Coexistence of 3G, 4G Waveforms with Candidate 5G Waveforms



New Whitepaper- Download it from: **www.keysight.com/find/5G-insight**



Keysight Technologies

Implementing a Flexible Testbed for 5G Waveform Generation and Analysis

White Paper

Greg Jue, Keysight Technologies
Sangkyo Shin, Keysight Technologies

Abstract

A challenge of today's 5G research is the many waveforms, frequencies, and bandwidths being investigated. This includes waveforms at frequencies below 6 GHz, as well as waveforms at microwave and millimeter-wave frequencies. In addition, some of the waveforms may involve wide bandwidths. These introduce new test challenges for 5G signal generation and analysis--flexibility is key for today's 5G research. This whitepaper will discuss some of the candidate waveforms, and then introduce a new flexible testbed for 5G waveform generation and analysis. This testbed combines software solutions with test equipment to investigate and to perform "what-if" scenarios for new emerging 5G waveform applications. Co-existence scenarios between candidate 5G and 4G waveforms will be investigated. Wideband signal generation and analysis case studies will be shown at microwave and millimeter-wave frequencies with modulation bandwidths up to 2 GHz.

Thank You !