Prototyping Next-Generation Communication Systems with Software-Defined Radio

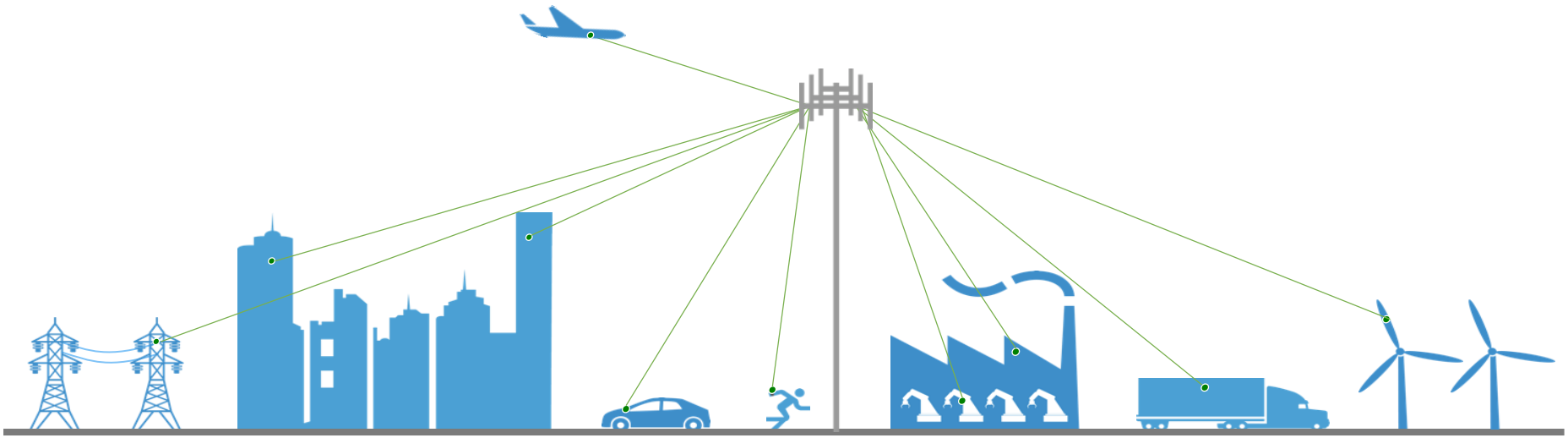
Dr. Brian Wee
RF & Communications Systems Engineer

Agenda

- 5G System Challenges
- Why Do We Need SDR?
- Software Defined Radio Architecture and Platforms
- 5G Vectors of Research
  - PHY Enhancements
  - Massive MIMO
  - mmWave
  - Wireless Networks

Connecting the Hyper Connected Everything

Starts with Prototyping



Data Rate

Capacity

Power Consumption

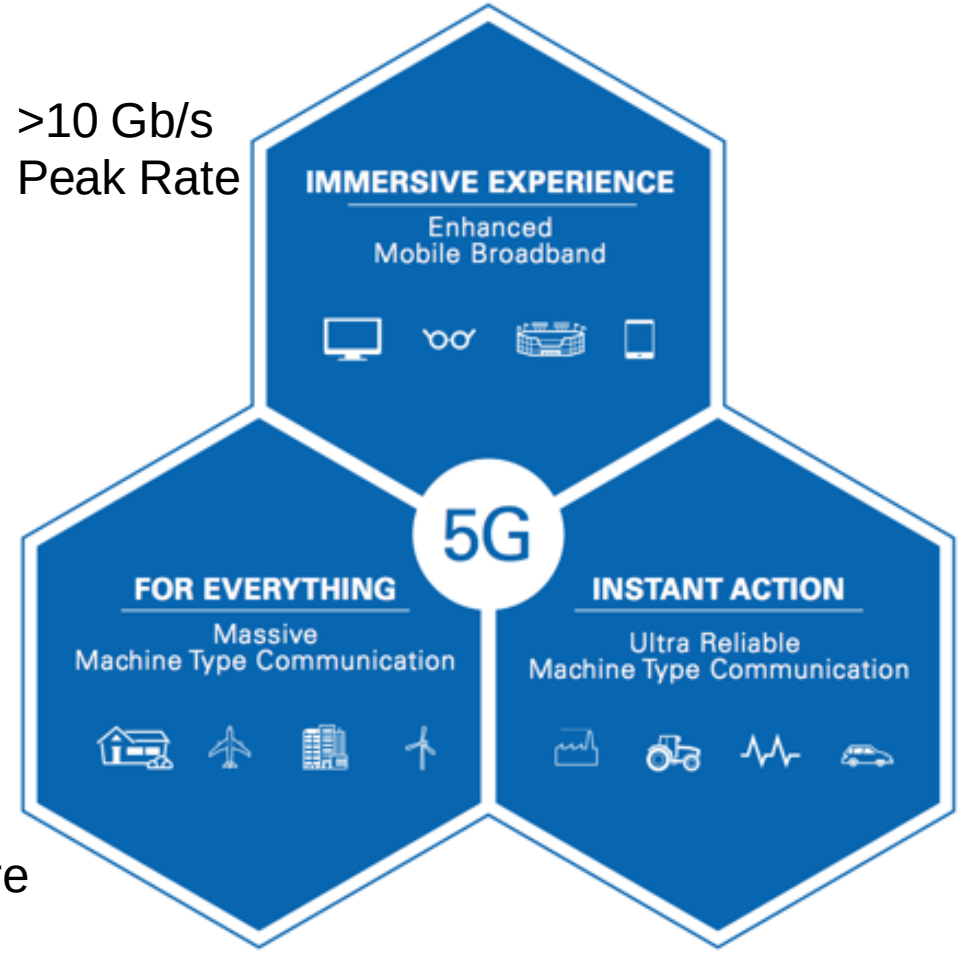
Coexistence

Security

Monitoring

ITU-R Vision for 5G

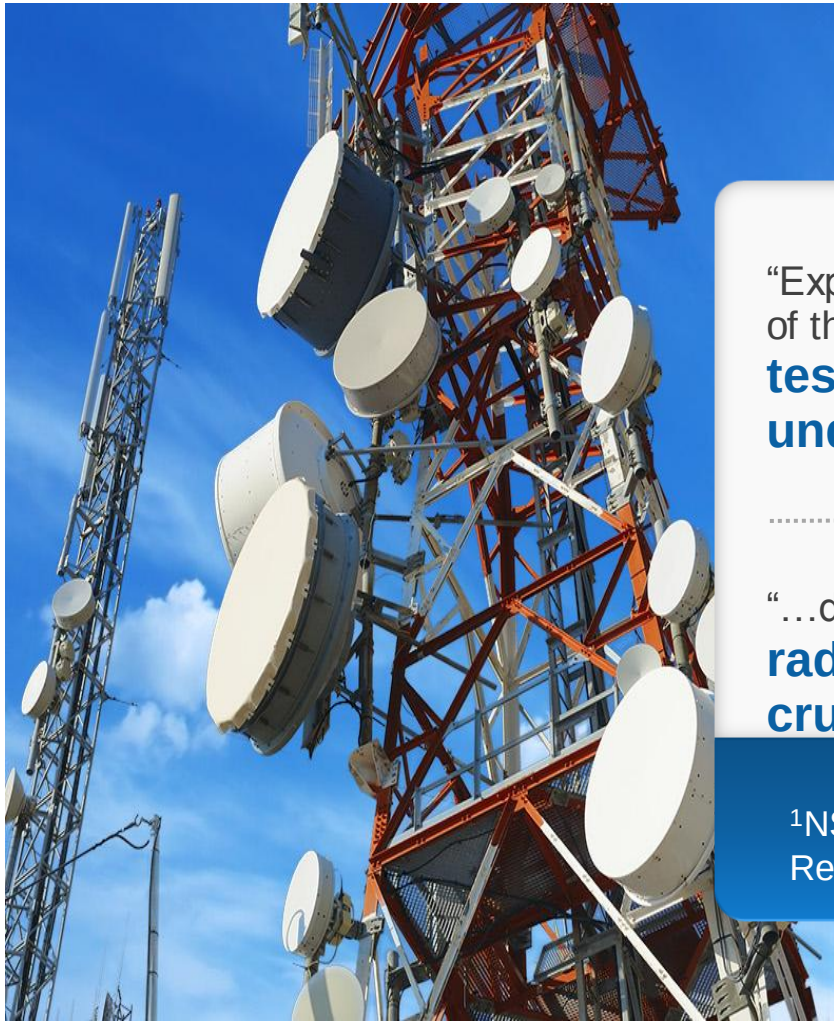
>10 Gb/s
Peak Rate



100 X More
Devices

< 1 mS
Latency

Prototyping Is Critical for Algorithm Research



"Experience shows that the real world often breaks some of the assumptions made in theoretical research, so **testbeds are an important tool for evaluation under very realistic operating conditions**"

"…development of **a testbed** that is able **to test radical ideas** in a complete, working system **is crucial**"

[1]NSF Workshop on Future Wireless Communication Research

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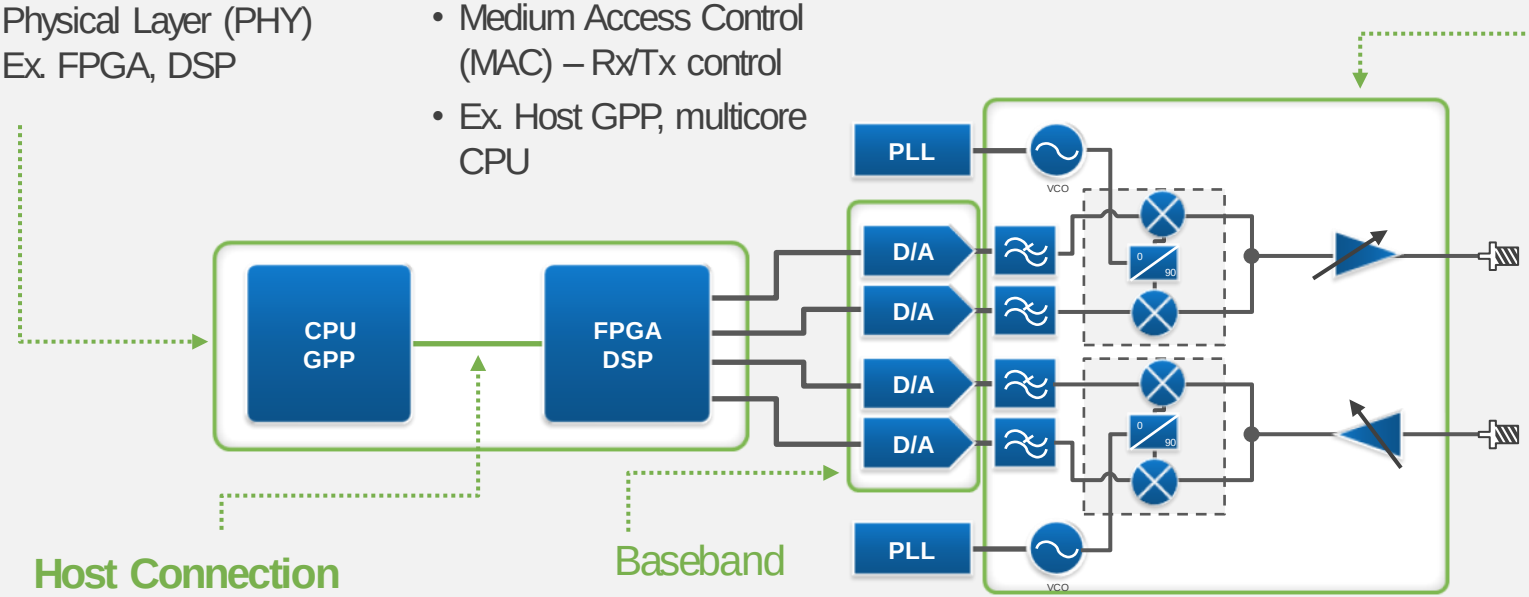
Software Defined Radio Architecture

Multiprocessor Subsystem

Real-time signal processor
- Physical Layer (PHY)
- Ex. FPGA, DSP

Host processor
- Medium Access Control (MAC) – Rx/Tx control
- Ex. Host GPP, multicore CPU



RF Front End
- General Purpose RF
- Dual LOs
- Contiguous Frequency Range

Host Connection

Determines Streaming Bandwidth
Ex. Gigabit Ethernet, PCI Express.

Baseband Converters

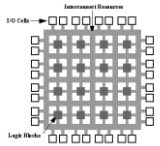
NATIONAL INSTRUMENTS

Today's Development Challenge

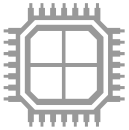
Tools

- Math (.m files)
- Simulation (Hybrid)
- User Interface (HTML)
- FPGA (VHDL, Verilog)
- Host Control (C, C++, .NET)
- DSP (Fixed Point C, Assembly)
- H/W Driver (C, Assembly)
- System Debug

Targets



FPGAs



Multicore Processors

- SDR development requires multiple, disparate software tools
- Software tools don't address system design

- Long Learning Curves
- Limited Reuse
- Need for "Specialists"

- Increased Costs
- Increased Time to Result

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LabVIEW Communications System Design

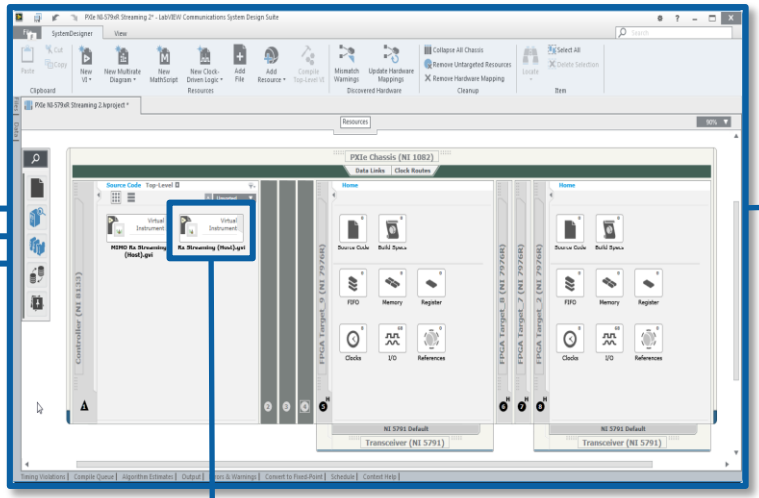
The Next Generation Platform for Software Defined Radio

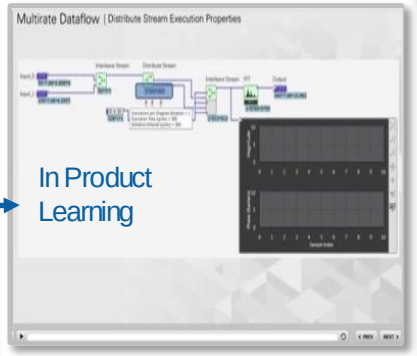
Hardware

Software

Learning

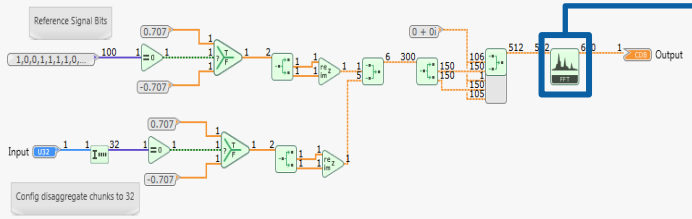
Hardware Aware Design Environment





In Product Learning

Algorithmic Design Languages



Design Exploration

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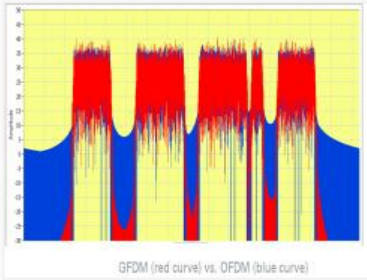
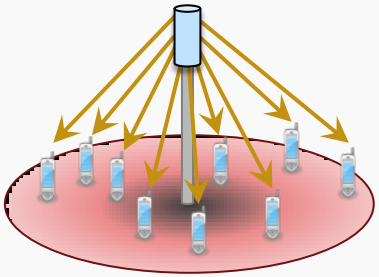
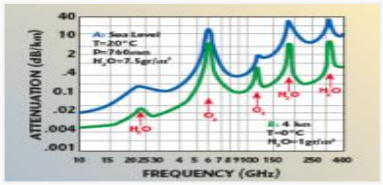
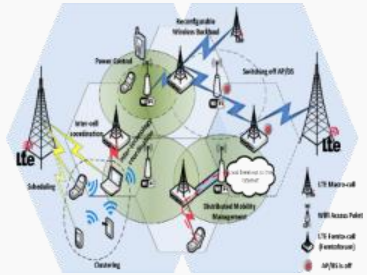
Candidate 5G Technologies In Need of Prototyping

New Modulation	New MIMO Tech	New Spectrum	Higher Density
PHY Waveforms	**Massive MIMO**	**mmWave**	**Densification**
Explore alternatives to OFDM such as GFDM, FBMC, UFMC that can increase PHY flexibility.	Dramatically increase spectral efficiency in existing cell bands by increasing antennas at the basestation by orders of magnitude.	Explore extremely wide bandwidths at higher frequencies once thought impractical for commercial wireless.	Increase access point density across a geography for reduces power, improves spectrum reuse for increased data rates.
 GFDM (red curve) vs. OFDM (blue curve)		 28 GHz, 38 GHz, 60 GHz, and 72 GHz	

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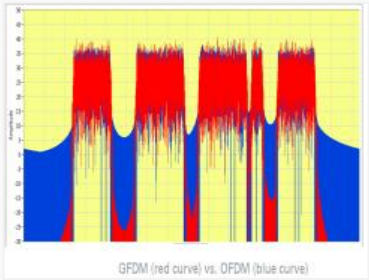
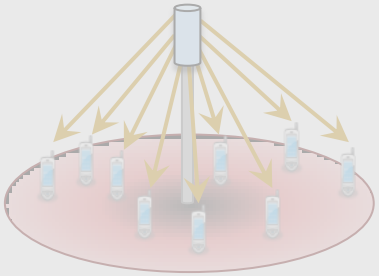
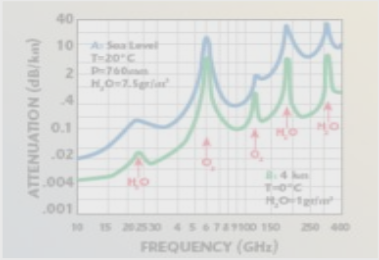
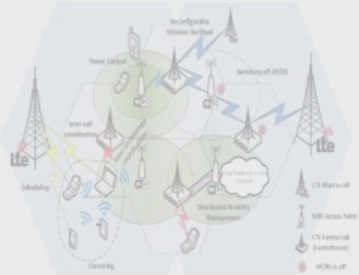
 GFDM (red curve) vs. OFDM (blue curve)		 28 GHz, 38 GHz, 60 GHz, and 72 GHz	

Challenges with existing physical layer implementation

- OFDM is very sensitive against time and frequency asynchronisms
- Interference between: users, carriers, symbols
- Carrier frequency offsets: affect performance in the high SNR regime
- Timing asynchronisms
  - Long cyclic prefix could be used
  - Loss in spectral efficiency → long CP vs ISI/ICI
- Interference "reversal" at receiver, highly complex signal processing

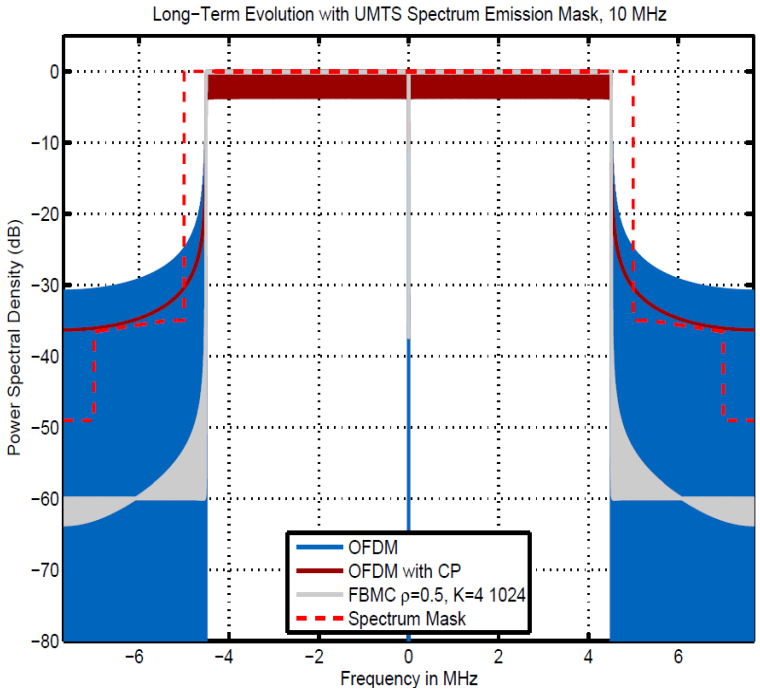
Physical Layer Enhancements

- **FBMC Filter bank multi-carrier** • Polyphase filter banks for pulse shaping in frequency domain • Filtering per sub-carrier • Offset-QAM modulation • No cyclic prefix

- **UFMC Universal Filtered Multi Carrier** • Sub-band filtering (e.g. PRB-wise) • No cyclic prefix , but settling time of filter used as guard period • QAM modulation

- **GFDM Generalised frequency division multiplexing** • Circular pulse shaping • Reduced CP overhead (vs. OFDM) • Spectral shaping • Reduced-complexity equalization

Source: Josef A. Nossek et al:
Filter Bank Based Multicarrier Systems



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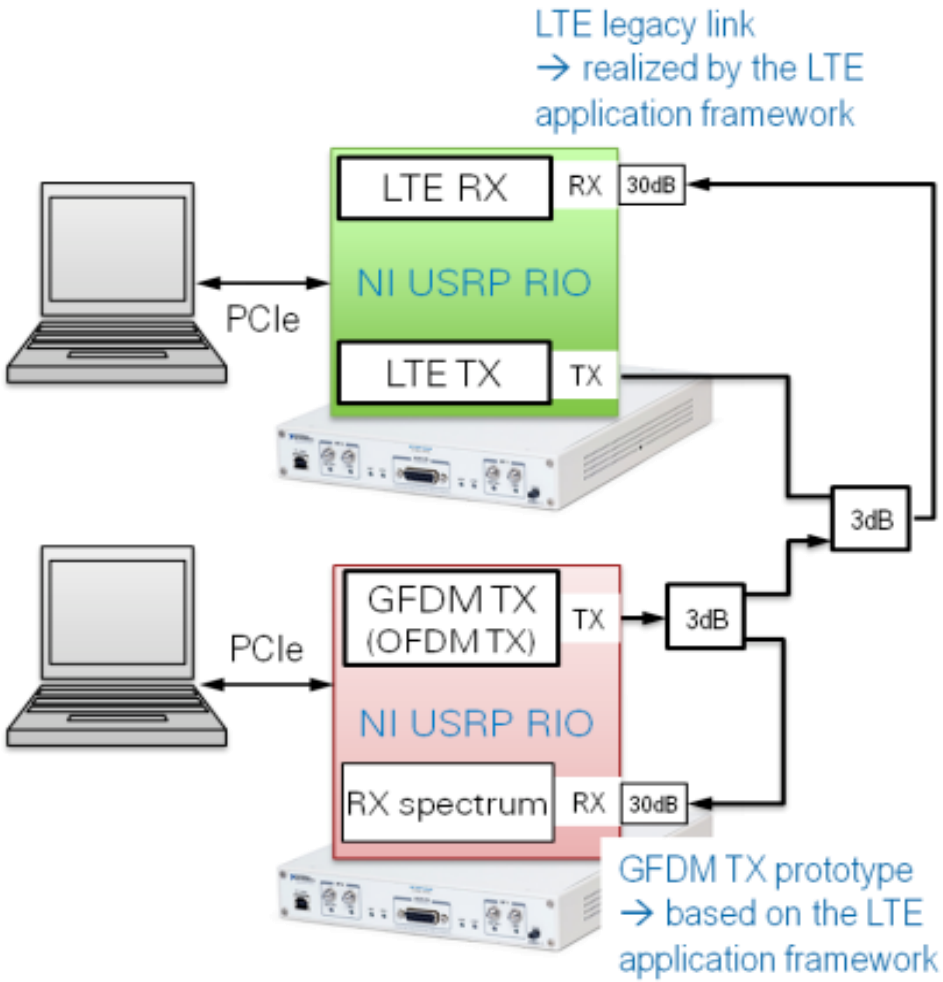
GFDM–LTE Coexistence Prototyping

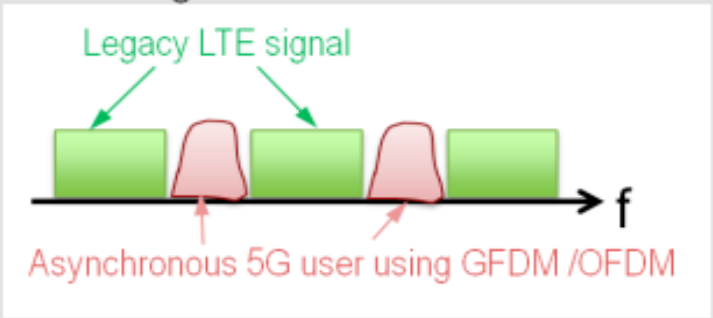


5G demo scenario

5GNOW

Fragmented spectrum use case with

- Synchronous LTE legacy link +
- Asynchronous 5G user using non-orthogonal GFDM waveform



Visualization/KPIs

- BLER of the legacy LTE system
- RX QAM constellations
- TX + RX power spectra

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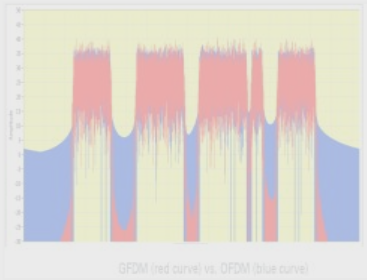
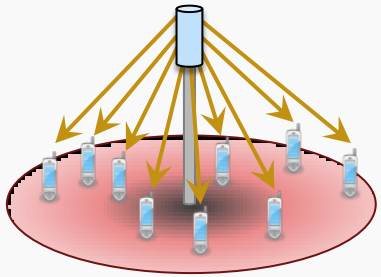
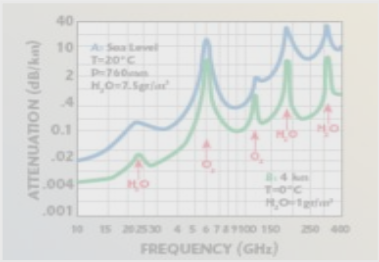
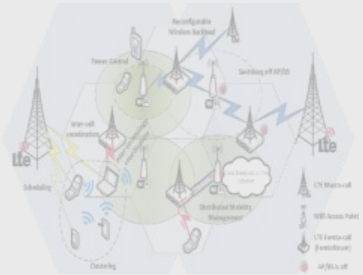
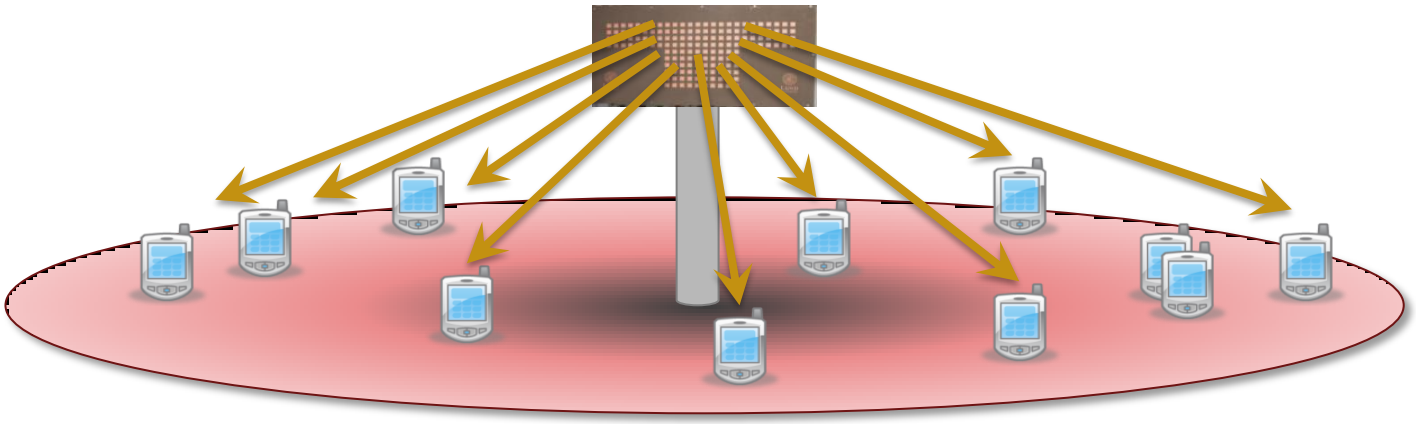
			
		28 GHz, 38 GHz, 60 GHz, and 72 GHz	

Massive MIMO in Cellular Networks



- Give basestation a large array of antennas
  (> 10X higher than current systems)
- Time-division duplexing (TDD)
- Excess antennas guarantee good channel with high probability
- Large number of users can be served simultaneously

T. L. Marzetta, "Noncooperative cellular wireless with unlimited numbers of base station antennas," *IEEE Trans. Wireless Comm.*, vol. 9, no. 11, 2010.

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NI and Massive MIMO

Academic

LUND UNIVERSITY

KU LEUVEN

INDUSTRY

Industry leaders who wish to not be named.

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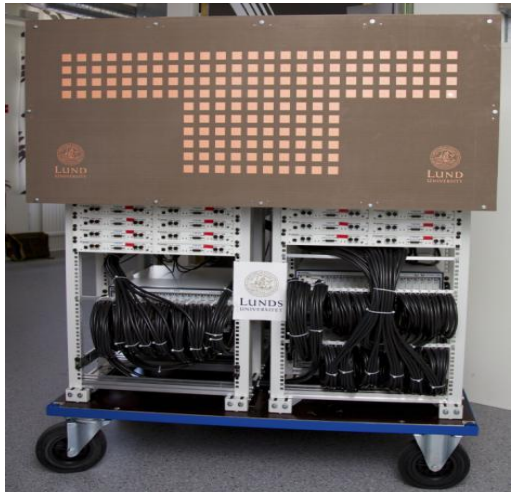
5G Massive MIMO research activities

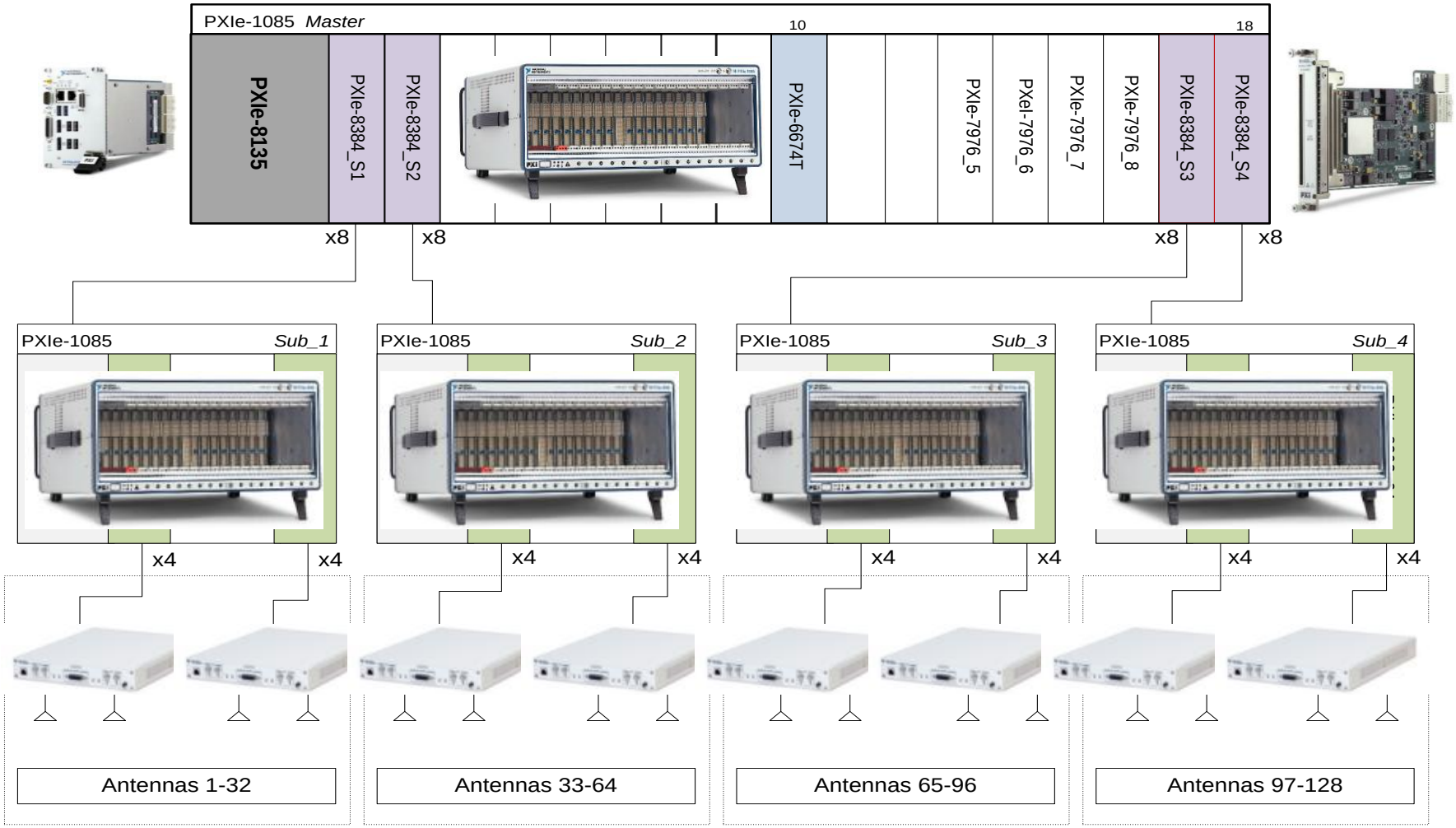
NI and Lund University
Massive MIMO,100x10 antenna system



NI and Bristol University
Massive MIMO, 128x12 antenna system

Bristol and Lund set a new world record in 5G wireless spectrum efficiency an unprecedented bandwidth efficiency of 79.4bit/s/Hz. This equates to a sum rate throughput of 1.59 Gbit/s in a 20 MHz channel

NI Massive MIMO Application Framework

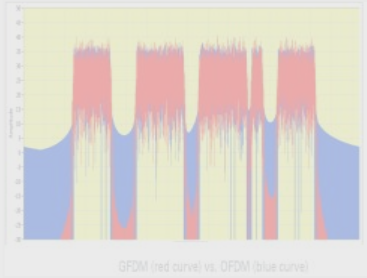


Candidate 5G Technologies In Need of Prototyping

New Modulation

PHY Waveforms

Explore alternatives to OFDM such as NOMA, GFDM, FBMC, UFMC that can increase PHY flexibility.

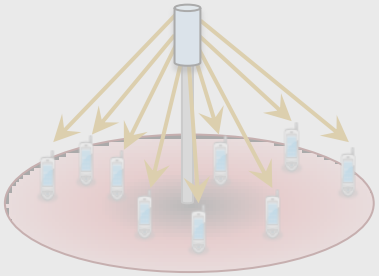


GFDM (red curve) vs. OFDM (blue curve)

New MIMO Tech

Massive MIMO

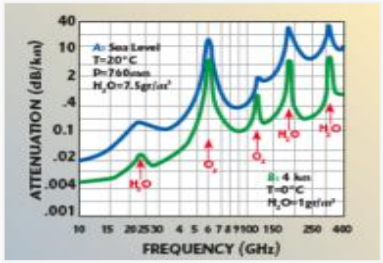
Dramatically increase spectral efficiency in existing cell bands by increasing antennas at the basestation by orders of magnitude.



New Spectrum

mmWave

Explore extremely wide bandwidths at higher frequencies once thought impractical for commercial wireless.

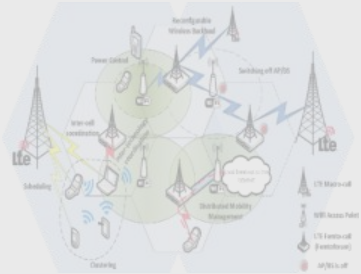


28 GHz, 38 GHz, 60 GHz, and 72 GHz

Higher Density

Densification

Increase access point density across a geography for reduces power, improves spectrum reuse for increased data rates.



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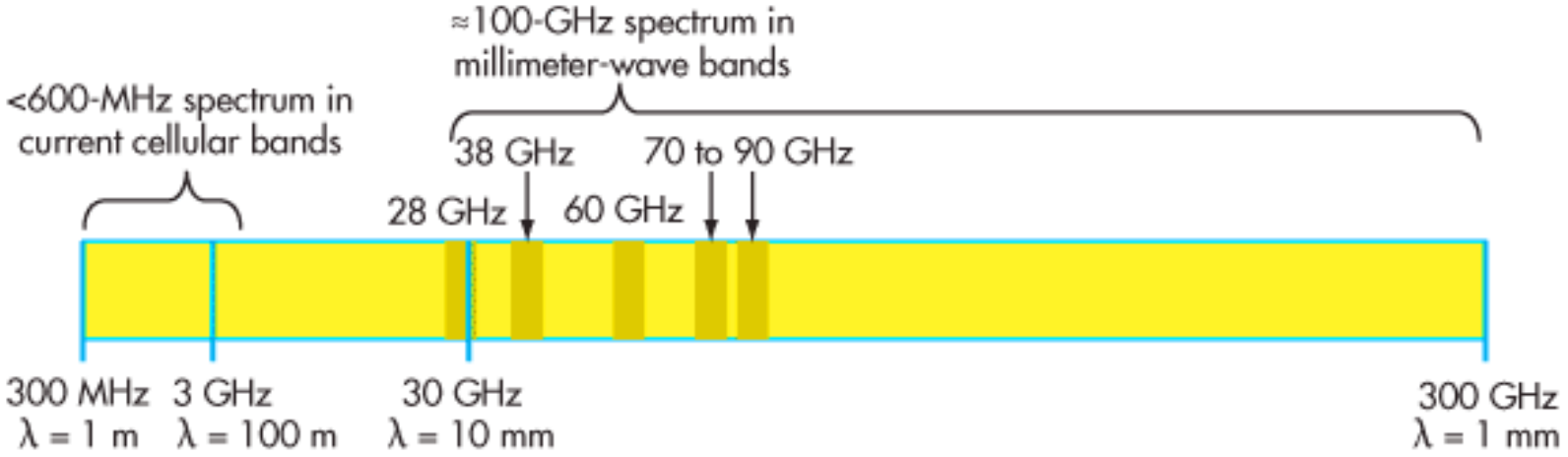
mmWave 5G Technology Vision

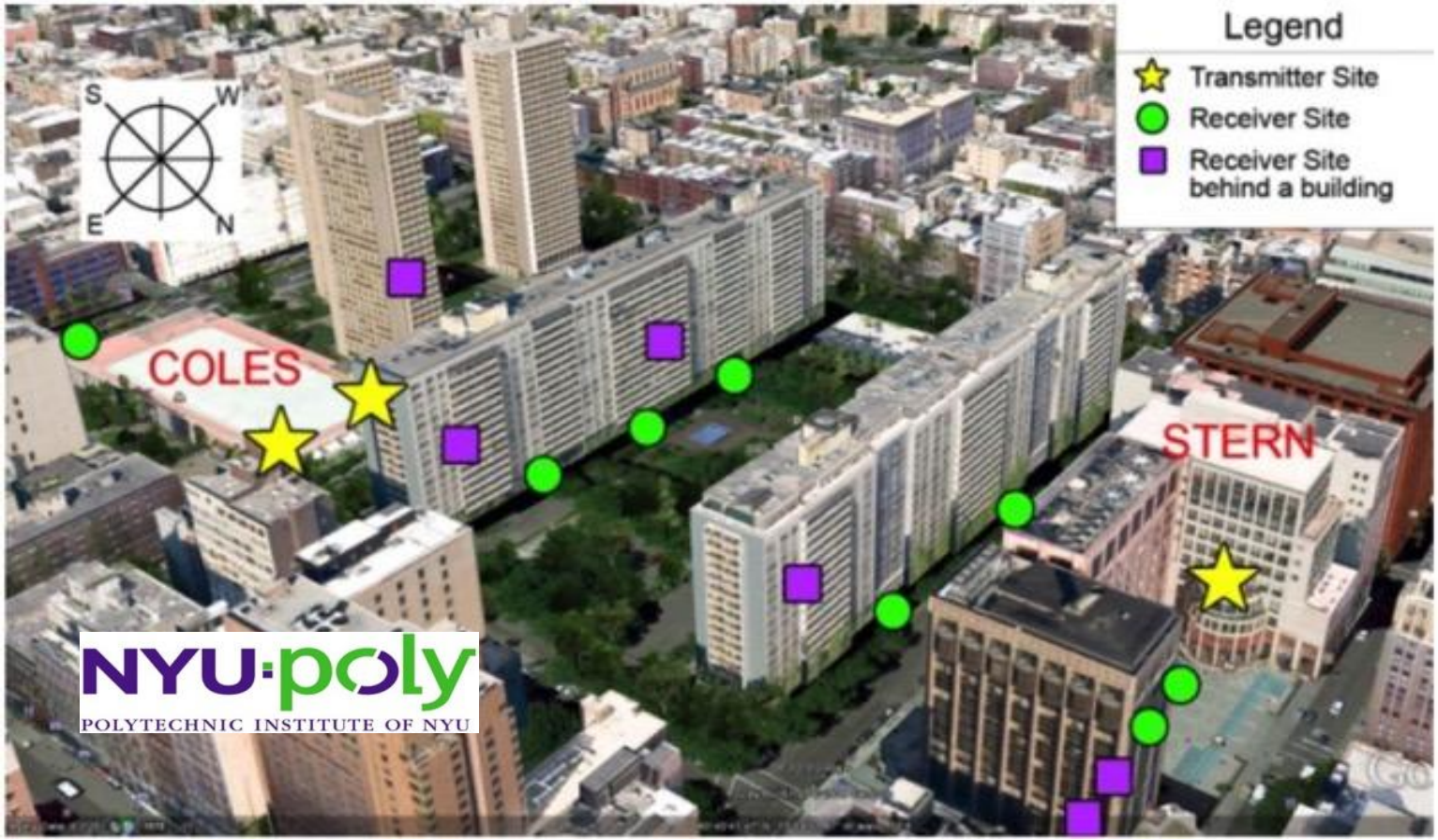


- Existing cellular bands are crowded and expensive
- The next frontier is mmWave frequencies to provide
  - High throughput (**> 10 Gb/s**)
  - Lower latency (**< 1ms**)
- Enables “ultra-definition” media and “tactile” applications

image from electronicdesign.com

mmWave Application Prototypes with SDR

Channel sounding at 28, 38 and 72 GHz



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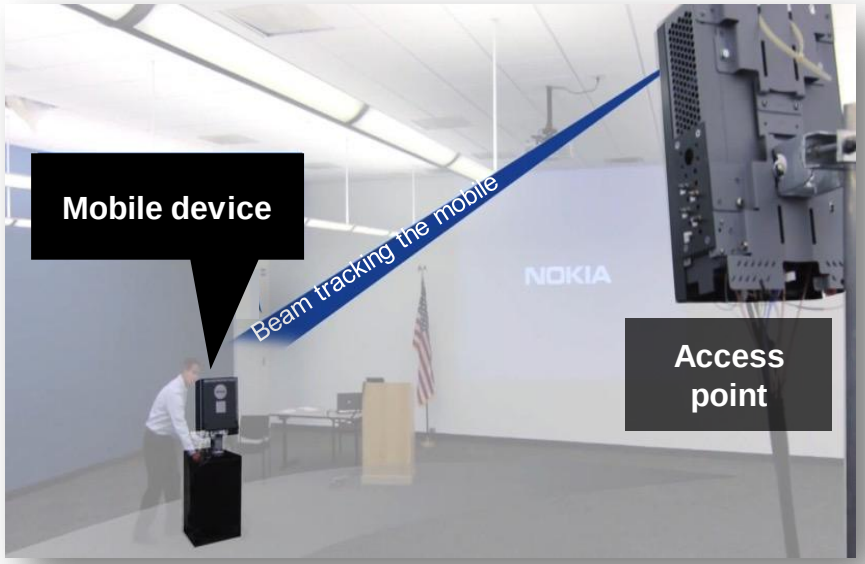
NI and Nokia Demonstrate 10 Gbps Wireless Link

Brooklyn 5G Summit

World's First 10 Gbps mmWave Link - April 2015

Nokia 5G mmWave Beam Tracking Demonstrator (1 GHz BW)



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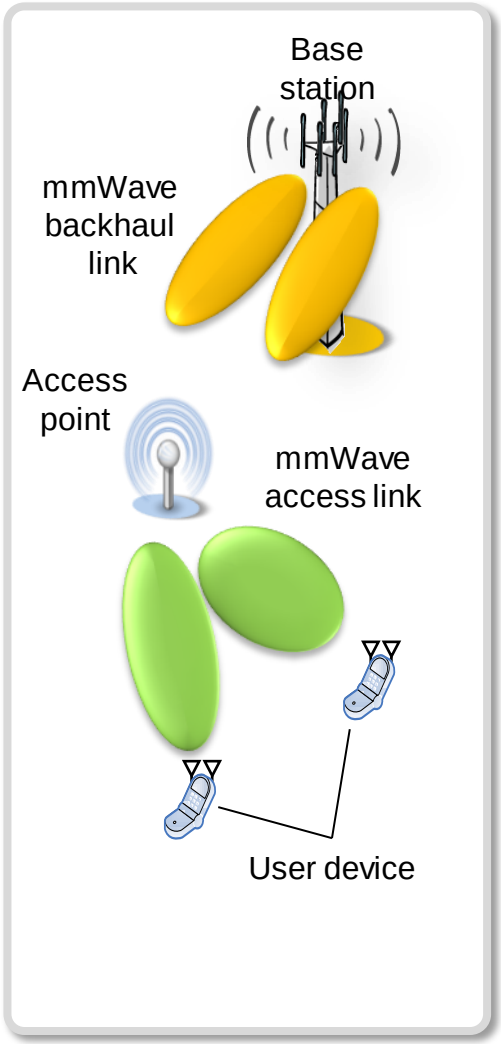
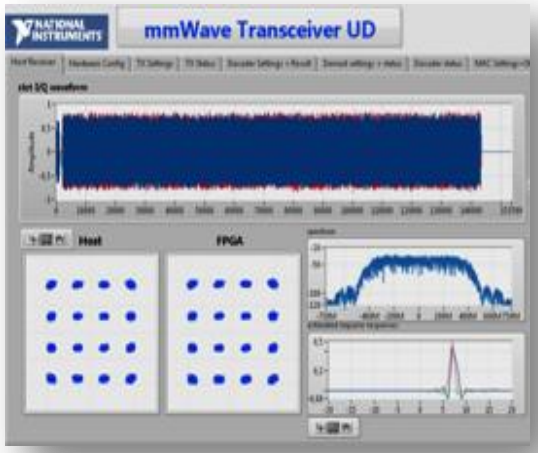
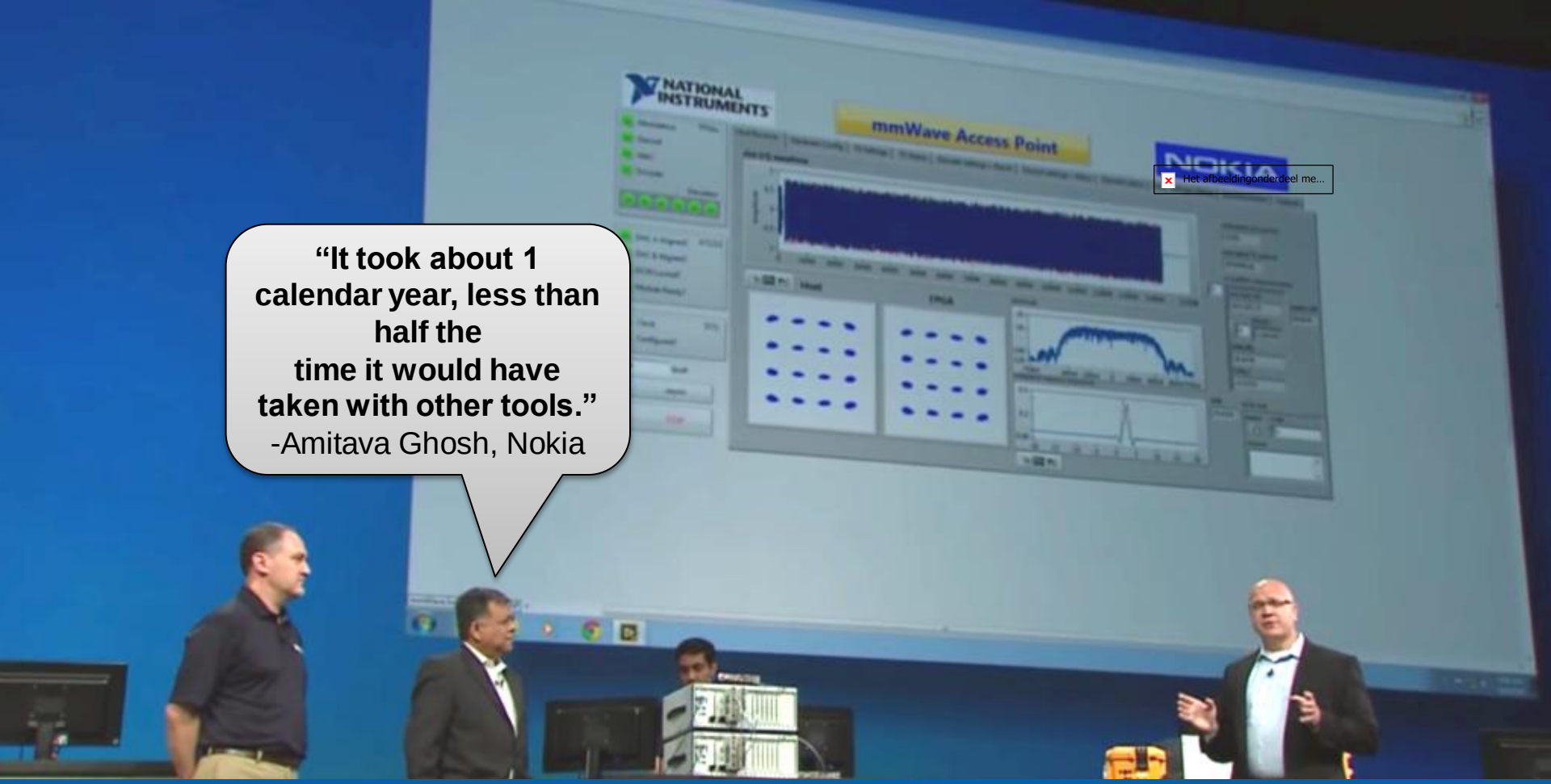
Multi Gbps Cellular Access and Backhaul Prototype



1 GHz BW baseband using COTS product

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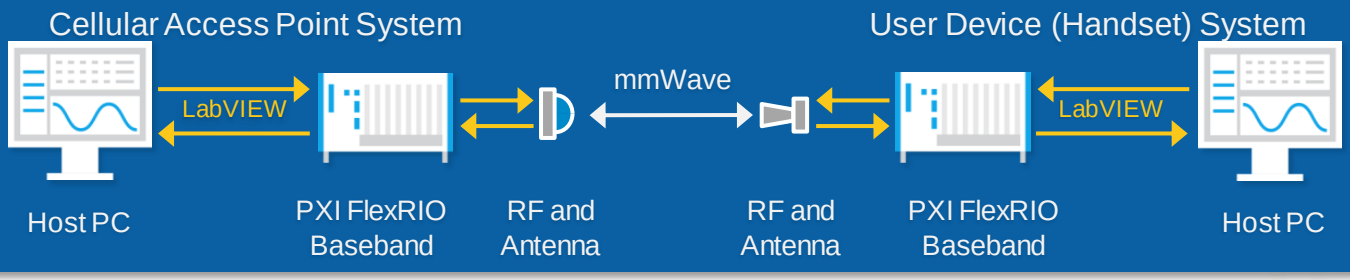
mmWave Access Point
NOKIA
Het afbeeldingonderdeel me...
“It took about 1 calendar year, less than half the time it would have taken with other tools.”
-Amitava Ghosh, Nokia


Cellular Access Point System
User Device (Handset) System
LabVIEW
mmWave
LabVIEW
Host PC
PXI FlexRIO Baseband
RF and Antenna
RF and Antenna
PXI FlexRIO Baseband
Host PC

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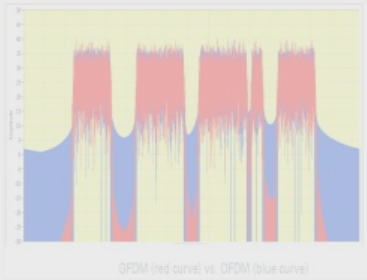	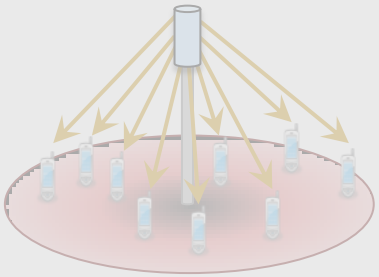	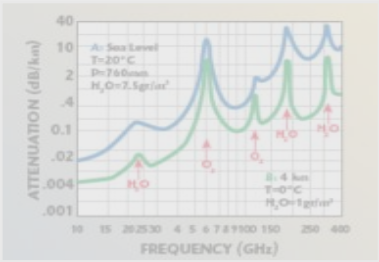	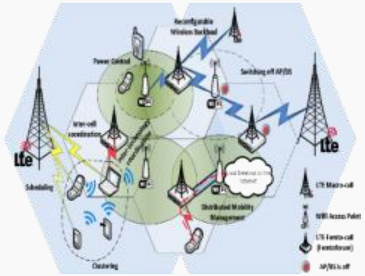
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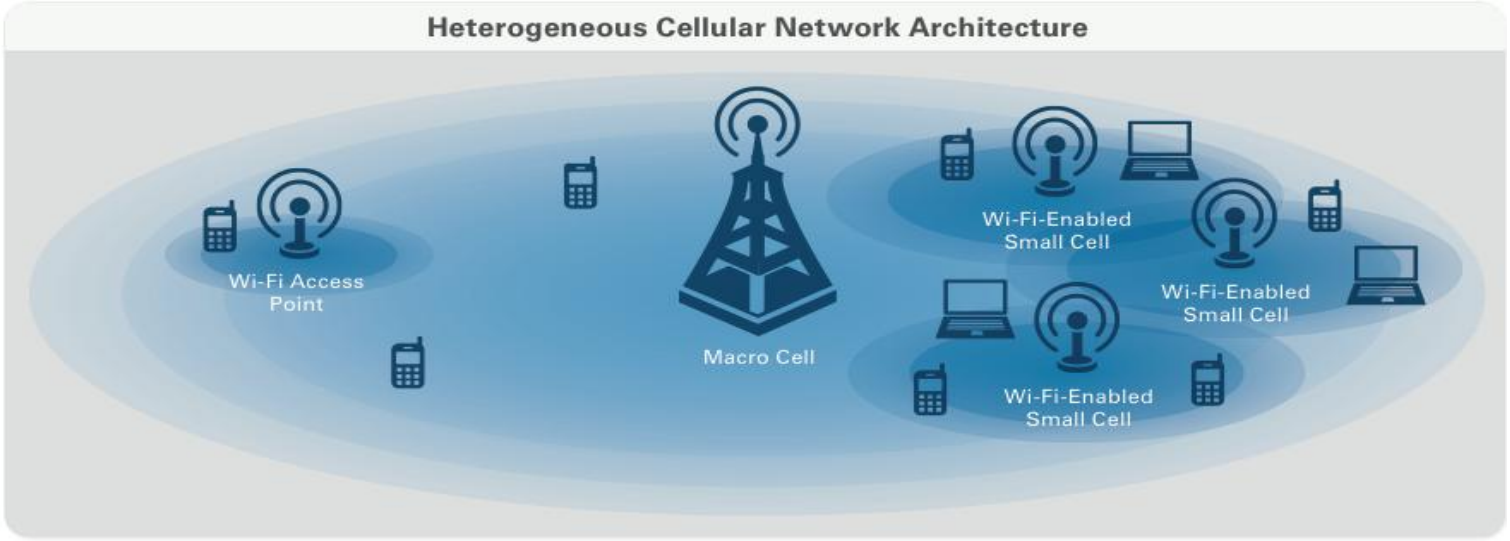
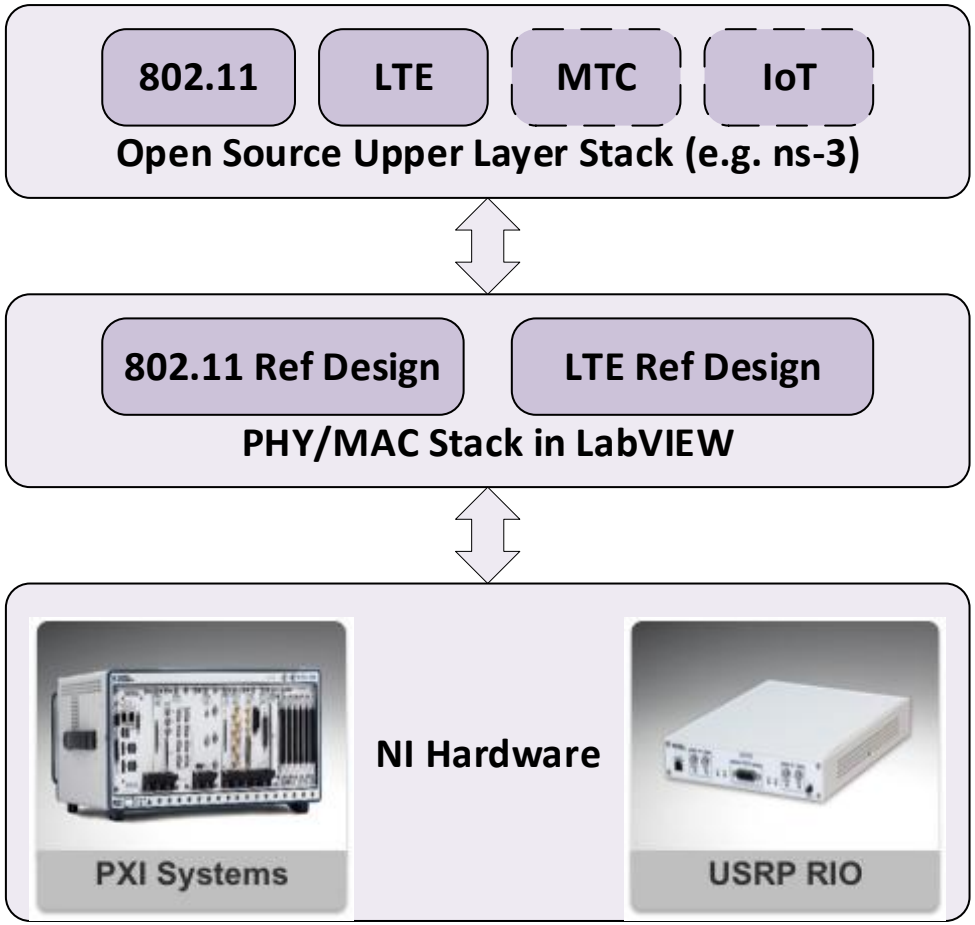
5G Wireless Networks: Design Directions



- Hyperdense networks
- Software defined networking (SDN)
- Cloud radio access network (cRAN)
- Cellular/802.11 coexistence and coordination
- Next-generation 802.11 stack

Architecture for Protocol Stack Explorations



Summary

- Next-generation communication system research and development requires a flexible and easily reconfigurable platform to enable rapid development of algorithms and testbeds

- Software defined radio is providing an ideal platform to rapidly prototype these systems in areas including:
  - Massive MIMO
  - Novel Waveforms
  - mmWave
  - Wireless Testbed/NetworkDevelopment

- **Learn more at: [ni.com/sdr](ni.com/sdr)**

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