Tomorrow’s Wireless
How 5G is Changing the Future of Wireless

Matthieu RICORD
Product Engineer for Test & RF – National Instruments

ni.com
A Rock Concert When I Was a Teenager
A Rock Concert Today
The Internet of Things Is Now Reality

Based on Moor Insights & Strategy’s report "Segmenting the Internet of Things (IoT)"
The Proliferation of Wireless Is Just Beginning

50 BILLION
DEVICES CONNECTED BY 2020

1.9 BILLION
SMART PHONES

85%
EMBDEDDED DEVICES TODAY ARE UNCONNECTED
The Progression of Wireless

- AMPS
- GSM through EDGE
- UMTS through HSPA+
- LTE
- 5G
- 802.11-1997
  - 802.11a/b
  - 802.11g
  - 802.11n
  - 802.11ac
  - 802.11ad
  - 802.11ax
- Bluetooth
  - Bluetooth Extended Data Rate (EDR)
  - Bluetooth High Speed (HS)
  - Bluetooth Low Energy (LE)

Years:
- 1980
- 1990
- 2000
- 2010
- 2020
ITU-R Vision for IMT-2020 and Beyond

**Enhanced Mobile Broadband (eMBB)**
- Gigabytes In Seconds
- 3D Video, UHD
- Smart Home
- The Cloud

**Massive Machine Type Communication (mMTC)**
- Augmented Reality
- Industry Automation

**Ultra Reliable MTC (uMTC)**
- Mission Critical (ex. Health Care)
- Autonomous Driving
- Smart City

*image source Sarah Yost

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ITU-R Vision for IMT-2020 and Applications

- **Enhanced Mobile Broadband**
  - Streaming 4K Video
  - Augmented Reality
  - 3D Gaming

- **Ultra Reliable, Low Latency Machine Type Communications**
  - Autonomous Driving
  - Mission Critical Applications

- **Massive Machine Type Communications**
  - Smart City
  - Smart Factory

> 10 Gbps peak rates

> 100K connections per cell

< 1 ms latency

Source – Image Courtesy of ITU
Approaching The Pivotal Moment

Multiple Ideas

GSM

Birth of GSM

The Pivotal Year

Broad Based Adoption

1982-85

1987

1988-91

Implementation by a large number of suppliers & operators

Source: www.gsmhistory.com/who_created-gsm
Approaching The Pivotal Moment

Technical ideas from a huge number of sources

5G

Pivotal Moment of Convergence

We are here

Broad Based Adoption

Implementation by a large number of suppliers & operators

Source: www.gsmhistory.com/who_created-gsm

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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**”
Why Prototype?

• To ideate and problem-solve. Build to think.

• To communicate. If a picture is worth a thousand words, a prototype is worth a thousand pictures.

• To start a conversation. To begin answering hardest questions “What is possible?” with defendable answers and move quickly to “Why?”

• To fail quickly and cheaply. Committing as few resources as possible to each idea means less time and money invested up front.

• To test possibilities. Iterating quickly allows you to pursue many different ideas without committing to a direction too early on.

• To manage the solution-building process. Identifying a variable also encourages you to break a large problem down into smaller, testable chunks.

Derived from: An Introduction to Design Thinking, Stanford Design School
Elements of a Wireless System

1 to N Radio Front Ends

Multi-Processor Architecture

Network Infrastructure

RF Hardware

Software IP & Processing

Network & Backhaul

Data Movement & Synchronization
Software Development Challenge

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

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

- Long learning curves
- Limited reuse
- Need for “specialists”

- Increased costs
- Increased time-to-result
Platform-Based Design for Communications Systems

A. Sangiovanni-Vincentelli, UC Berkeley. Defining Platform Based Design. EEDesign, Feb 2002
A Platform Revolutionizes Your Approach to Solutions

- Computers
- Music Player
- Smart Phones
- E-Readers
- Television
- Desktop and Laptops
- iPad
- iPhone
- iPod
- Level
- Wrist Watch

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5G Vectors in Need of Prototyping

**Massive MIMO**
Dramatically increased number of antenna elements on base station.

**Wireless Networks**
Consistent connectivity meeting the 1000x traffic demand for 5G
- Densification
- SDN
- NFV
- CRAN

**PHY Enhancements**
Improve bandwidth utilization through evolving PHY Level and flexible numerology

**mmWave**
Utilize potential of extremely wide bandwidths at frequency ranges once thought impractical for commercial wireless.
Platform-Based Design for 5G

Massive MIMO

Wireless Networks

Multi-RAT

mmWave

Unified Design Software

Hardware Implementations
Platform-Based Design for 5G

- Massive MIMO
- Wireless Networks
- Multi-RAT
- mmWave

LabVIEW™

- Reconfigurable Instruments
- High Performance IO
- USRP RIO SDR
- mmWave Transceiver

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## 5G Vectors in Need of Prototyping

<table>
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- NFV  
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[Diagram of Massive MIMO]  
[Diagram of Wireless Networks]  
[Diagram of PHY Enhancements]  
[Diagram of mmWave]
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Massive MIMO

- Multi-user MIMO with large number of antennas
- Benefits:
  - Beamsteering of downlink signal
  - 10x Capacity
  - 100x Energy Efficiency
  - Lower Latency
  - More Robust to Interference
  - Higher Reliability
NI and Lund University Collaborate on Massive MIMO

World’s first real-time with 100 antennas

Initial results: Received signal constellations – LOS and four users 2 m separation

Vieira, Joao, et al. "A flexible 100-antenna testbed for Massive MIMO."
IEEE Globecom Workshops (GC Workshops), 2014. IEEE, 2014.
NI and Samsung Demonstrate FD-MIMO With LabVIEW Communications and LTE App Framework

Base-station with 32 antenna elements

“Samsung Demonstrates FD-MIMO In Real Time For The First Time In The World…It Accelerates Its Leadership Over Competition For 5G Standard”

english.etnews.com
Massive MIMO

Samsung
Full Duplex MIMO, LTE UE Emulation

Intel
CRAN-Massive MIMO

Southeast University
128-antenna massive MIMO system

Lund University
100-antenna massive MIMO system
Bristol University Achieves 1.5 Gbps in 20 MHz
145 b/S/Hz Spectral Efficiency

- 3.5GHz, 128 antenna system
- 10 UEs
- > 1.5 Gbps in 20 MHz spectrum
- MMSE, precoding in FPGA
- Pilot optimization
- LabVIEW, NI USRP RIOs

Prof Mark Beach
Paul Harris
The Road to Massive MIMO in 5G

Top 10 Open Research Items

- High Mobility Applications
- Distributed Massive MIMO
- Antenna Patterns
- Hybrid Beamforming
- Energy Efficiency
- Improvements in CSI Feedback
- MAC Layer Control
- Network MIMO
- FDD Massive MIMO
- Spectrum Sharing
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100 Year History of mmWave (30 GHz – 300 GHz)

J.C. Bose at the Royal Institution, London, 1897

http://theinstitute.ieee.org/technology-focus/technology-history/first-ieee-milestones-in-india
https://www.cv.nrao.edu/~demerson/bose/bose.html

Modern point-to-point mmWave link
mmWave Technology

- **Automotive Radar**
  - 76-81 GHz

- **IEEE 802.11ad**
  - 55-68 GHz

- **5G Channel Sounding**
  - 28 GHz

- **Flexible Head Design**
  - 154 GHz
mmWave for Mobile Broadband

- mmWave describes signals from 1mm to 10 mm (300 GHz to 30 GHz)
  - Offers extreme bandwidths: up to 100 GHz of spectrum
  - Substantially larger path loss & shorter signal propagation (< 500m)
- Which bands?
  - US, Japan, and Korea are looking at 28 GHz – likely used in 2018 Seoul Olympics
  - Both the ITU and US-FCC has also proposed use of 38 GHz, several carriers doing testing
  - Longer term, much interest remains in 73 GHz due to available spectrum for 2 GHz BW
mmWave Application Areas

Channel Research
- Channel sounding measurements
- Creating channel models
- Validating channel models

Communications Prototyping
- New physical layer/new air interface
- Adapting existing standards from 20 MHz bandwidth to 2 GHz bandwidth
- Over the air testing at new mmWave frequencies
NYU Wireless and NI Collaborate on mmWave Channel Sounding

Research Goal
- Channel sounding at 28, 38, and 72 GHz
- Dense urban environments (New York City)
- Prove viability of mmWave for mobile wireless communications

Advances in mmWave Consideration Results
- NYU published first results in June 2013
- 3GPP calls for further investigation in 2015
- FCC proposes new rules for mmWave in 2015

## Nokia Timeline With NI Platform

<table>
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<tr>
<th>Frequency</th>
<th>Memphis 5G Summit 2014</th>
<th>NIWeek 2015</th>
<th>MWC 2016</th>
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<tbody>
<tr>
<td>73 GHz</td>
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<td></td>
</tr>
<tr>
<td>1 GHz</td>
<td>2 GHz</td>
<td>2 GHz</td>
<td></td>
</tr>
<tr>
<td>1x1</td>
<td>2x2</td>
<td>2x2</td>
<td></td>
</tr>
<tr>
<td>16 QAM</td>
<td>&gt;10 Gbps</td>
<td>&gt;14.5 Gbps</td>
<td></td>
</tr>
<tr>
<td>Peak rate</td>
<td>2.3 Gbps</td>
<td>&gt;10 Gbps</td>
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mmWave Prototypes and Channel Sounding

NYU Wireless
mmWave
Channel Sounding

NTT Docomo
73 GHz
BW = 1 GHz

AT&T
Channel Sounding

Nokia
Multiple
Prototypes

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4.5G: LTE-Advanced Pro

Carrier Aggregation

Full-Dimensional MIMO

License Assisted Access

More Component Carriers
LTE Advanced Pro allows up to 32 component carriers – and allows transmission from multiple eNBs.

More Spatial Streams
LTE Advanced Pro allows up to 16 downlink spatial streams – and eNB’s can beamform in 3D.

New Spectrum
LTE Advanced Pro coordinated with WiFi networks to unlock the 5 GHz spectrum for cellular usage.
3GPP Converging on the 5G New Radio

- 5G New Radio is taking shape in 3GPP
  - OFDM-based Unified Flexible RAT (4 - 40 GHz)
- Verizon 5G mmWave spec released
  - Pre-standard for mmWave in 5G at 28 GHz for Fixed Wireless
Multi-RAT / Enhanced PHY

TU Erlangen
LTE EMBMS

NTT Docomo
NOMA

TU Dresden
GFDM

LG, Yonsei University
Full Duplex Radio
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**Graphs and Diagrams**
- Graph 1: Comparison of different modulation schemes (OFDM vs OQPSK).
- Graph 2: Frequency spectrum analysis showing wide bandwidth utilization.

**Logos**
- National Instruments (ni.com)
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
NI and CROWD Collaborate on Software-Defined Networks (SDN)

Research Goal
- Build testbed for dense LTE/WiFi networks
- Evaluate SDN approaches
- Measure algorithm performance in real network environments

CROWD Testbed Results
- Explored enhanced interference coordination
- Implemented cross-layer PHY/MAC algorithms
- Configured dynamic radio and backhaul
- Managed connectivity

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