HTE RTSZO előadás
Budapest, 2016 november 14

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# 5G Challenge
# From Concept to Reality

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# The Past

→ Pope election 2005 / 8 years ago

Source: http://www.spiegel.de/panorama/papst-momente-bilder-zeigen-vergleich-zwischen-2005-und-2013-a-889031.html

# Today

→ Pope election 2013 / What's the difference?

Source: http://www.spiegel.de/panorama/papst-momente-bilder-zeigen-vergleich-zwischen-2005-und-2013-a-889031.html

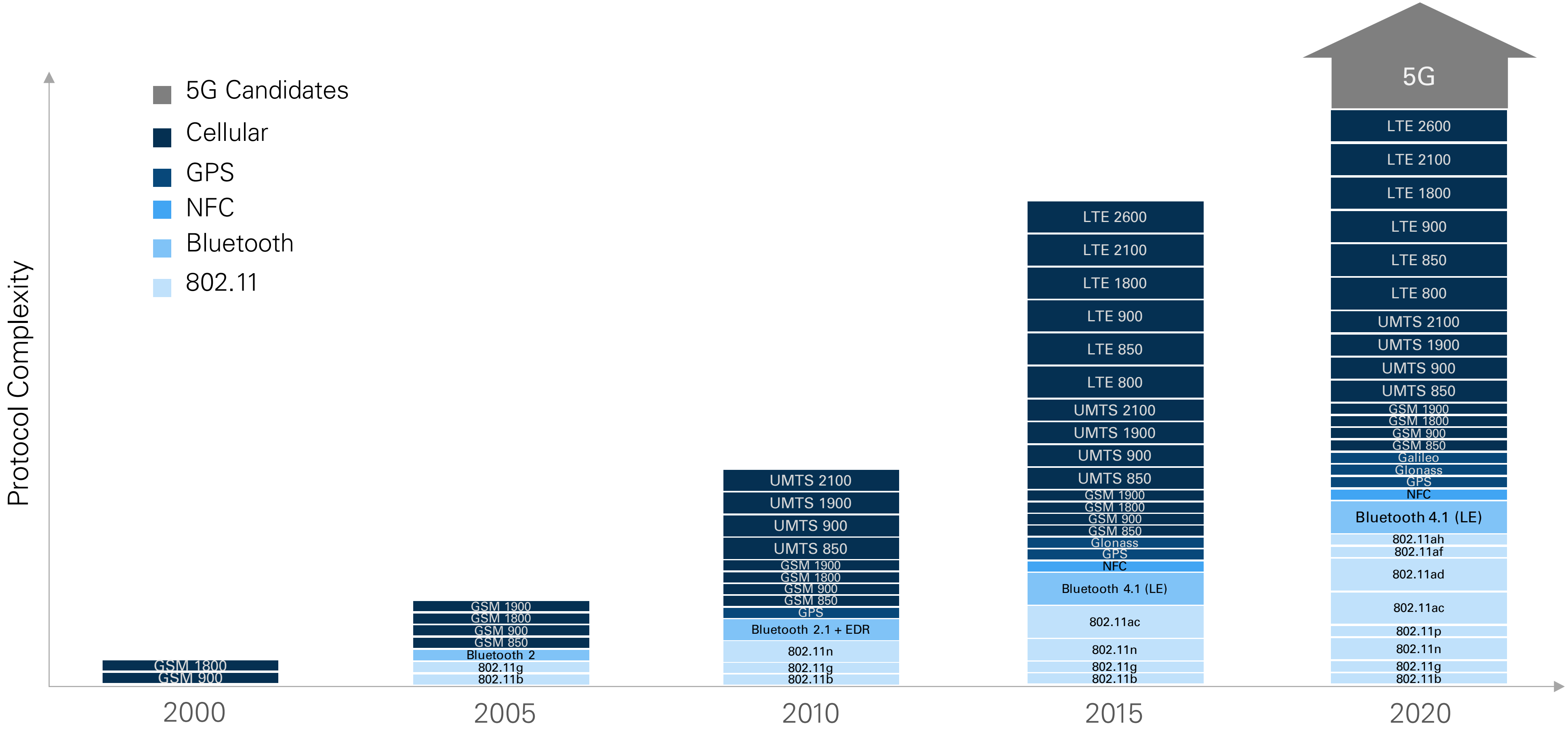
# The Proliferation of Wireless Is Just Beginning

**50 BILLION**
DEVICES CONNECTED BY 2020

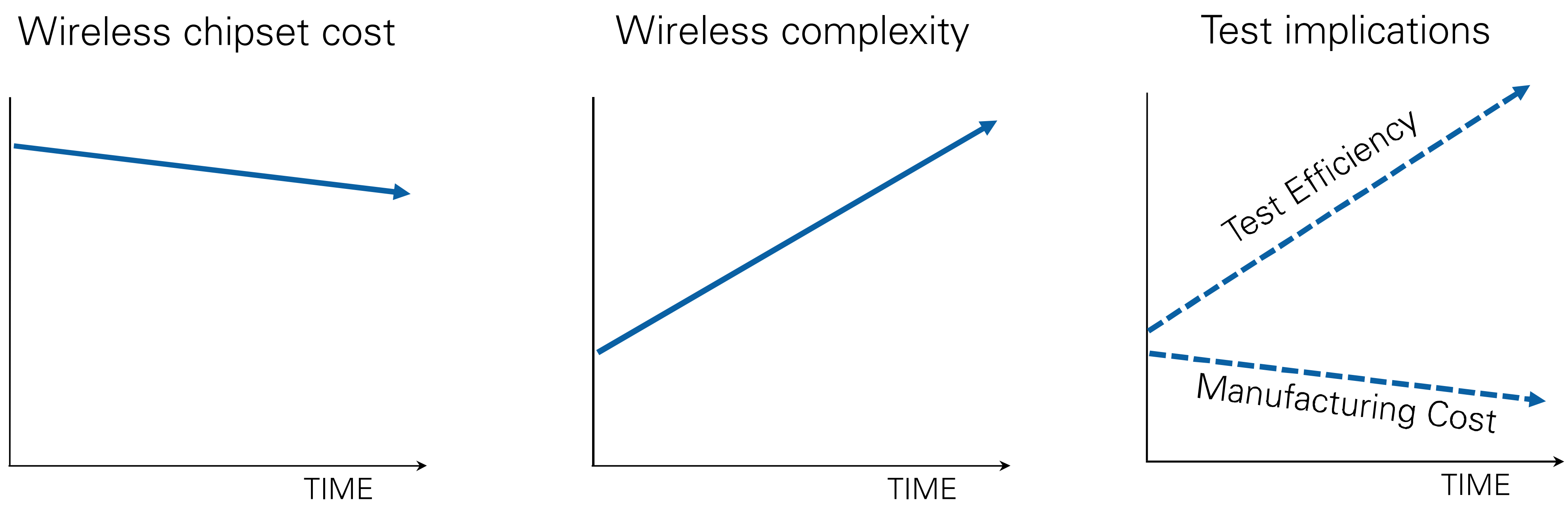
**1.9 BILLION**
SMART PHONES

**85%**
EMBEDDED DEVICES TODAY ARE UNCONNECTED

# Rising Complexity of Wireless Test



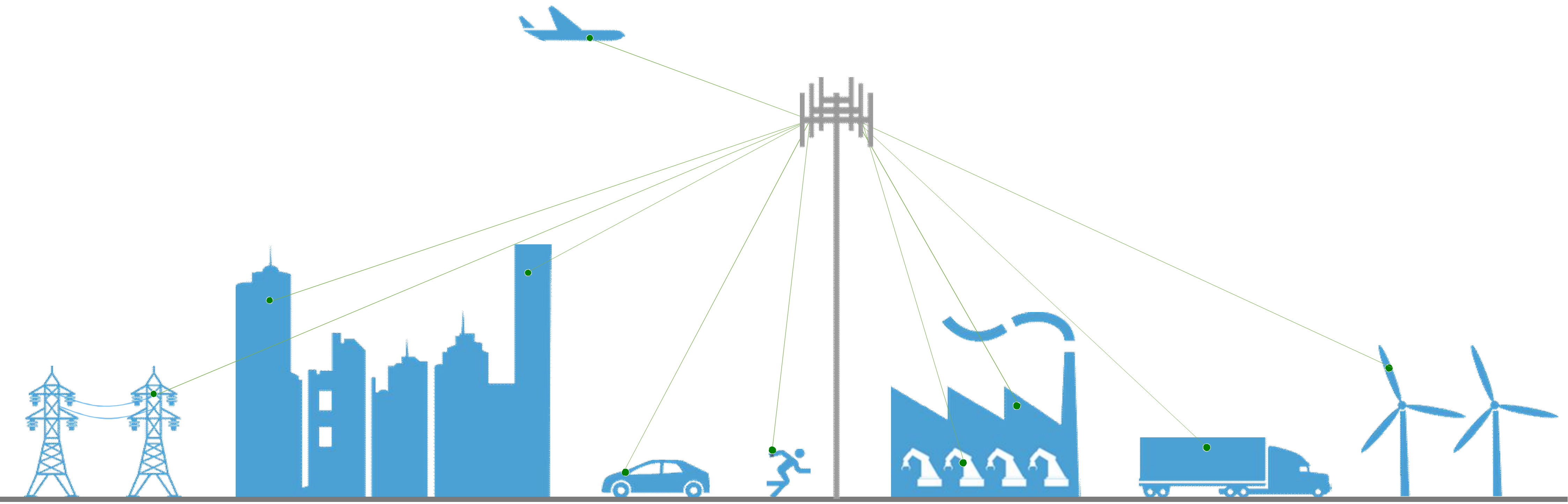
# Test Efficiency Is Key to Staying Profitable




"To remain profitable in the future, companies will need to rethink their approach for wireless test and embrace new paradigms." —Olga Shapiro, Analyst, Frost & Sullivan

# Connecting the Hyper Connected Everything

*Starts with Prototyping*



Data Rate

Capacity

Power Consumption

Coexistence

Security

Monitoring

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# The Future in 2020?

Source: http://gadgets.infoniac.com/apple-black-hope-holographic-device.html


Source: http://news.reviews42.com/google-glass-release-date-price-launch-201/

Source: http://money.cnn.com/gallery/technology/innovation/2013/04/02/tech-broken-promises/index.html


Source: http://www.computerwoche.de/i/detail/artikel/2514162/1/1856734/d2e87-media/

→ Applications call for 5th generation mobile networks

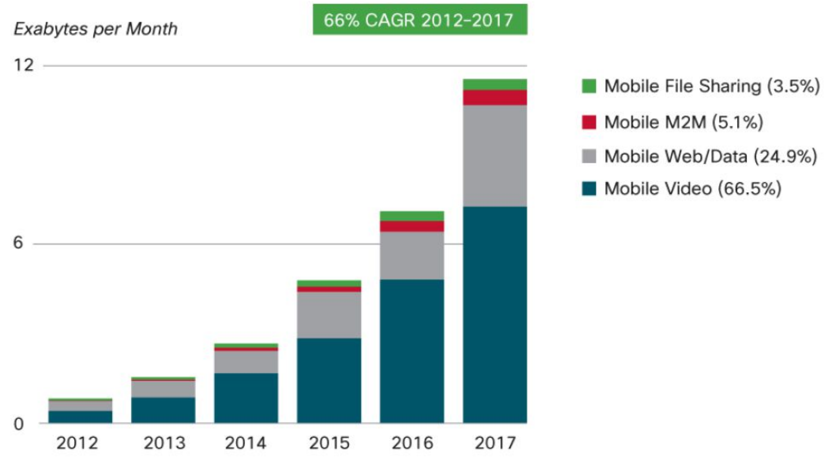
# Introduction to 5G:

# Challenges of Future Mobile Networks

# Applications in 2020

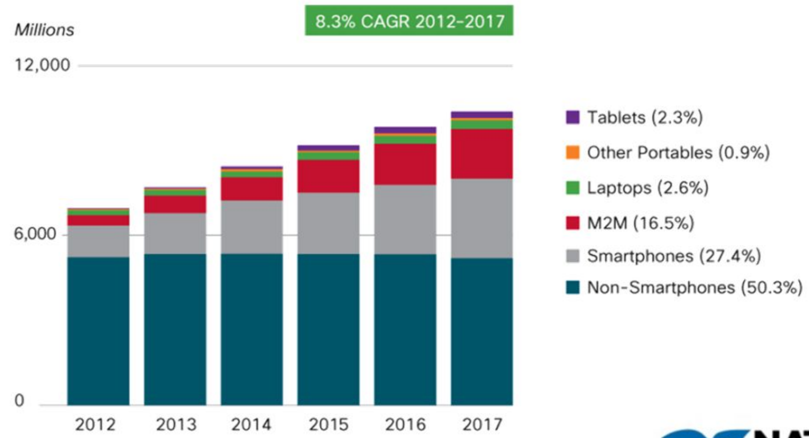
- Cloud data storage
  → ubiquitous access
- Augmented reality, 3D streaming, gaming
  → Real-time communication constraints
  → Low round trip latency of 0.5 - 1ms
  → High data rates
- Data exchange between mobile users, e.g. movies, gaming
  → very high short term data rates
- Monitoring and control applications
  → Huge number
  → Extremely reliable (critical apps like in cars)
  → Low cost, low energy
  → reduced signaling overhead

Traffic by application




Figures in legend refer to traffic share in 2017.
Source: Cisco VNI Mobile Forecast, 2013

Number of connected devices




Figures in legend refer to device/connection share in 2017.
Source: Cisco VNI Mobile Forecast, 2013

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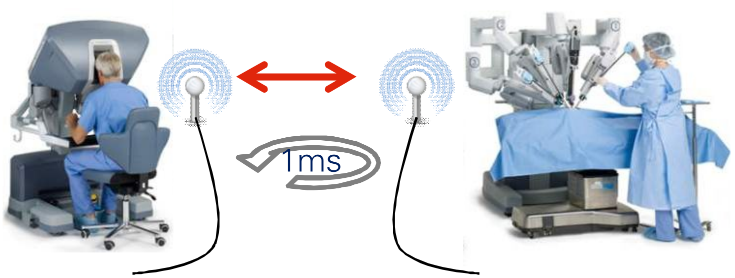
# Control Applications Examples

Source: http://www.sme.org/MEMagazine/Article.aspx?id=67747

- Production / Automation
  (e.g. wireless bus systems)
  - Available: ABB's Wireless-Com
    → 20 ms end-to-end latency
  - Required: response times < 10ms
  - *"Fast drive controls with time constants in the 1 ms range cannot be reliably covered by current wireless technology"*
    (Stefan Svensson of ABB, Challenges of Wireless Communications in Industrial Systems, 2011)

- Tactile / cyber-physical internet
  - E.g. health care – remote surgery
  - Lack of tactile feedback
  - Tactile feedback is latency-critical
  - High reliability required




Source: http://www.medgadget.com/2010/12/robotic_surgery_for_head_and_neck_cancers_shows_promise.html

surgeon Da Vinci surgical robot

→ Investigated in the public-funded German project "FAST" → Signalion participates

# Ways to Tackle the Capacity Challenge

**Larger Spectrum: increase B**

- UWB
- mmWave
- Carrier Aggregation
- Cognitive radio

**Spectrum Efficiency: suppress I / exploit P**

- Multi-user 3D BF / Massive MIMO
- Network MIMO (CoMP)
- Remote radio heads / radio over fiber
- Higher order modulation and network coding
- Robust modulation

$$\frac{C}{\text{bit/s}} = B \log_2 \left\{ 1 + \frac{P}{I + B N_0} \right\}$$

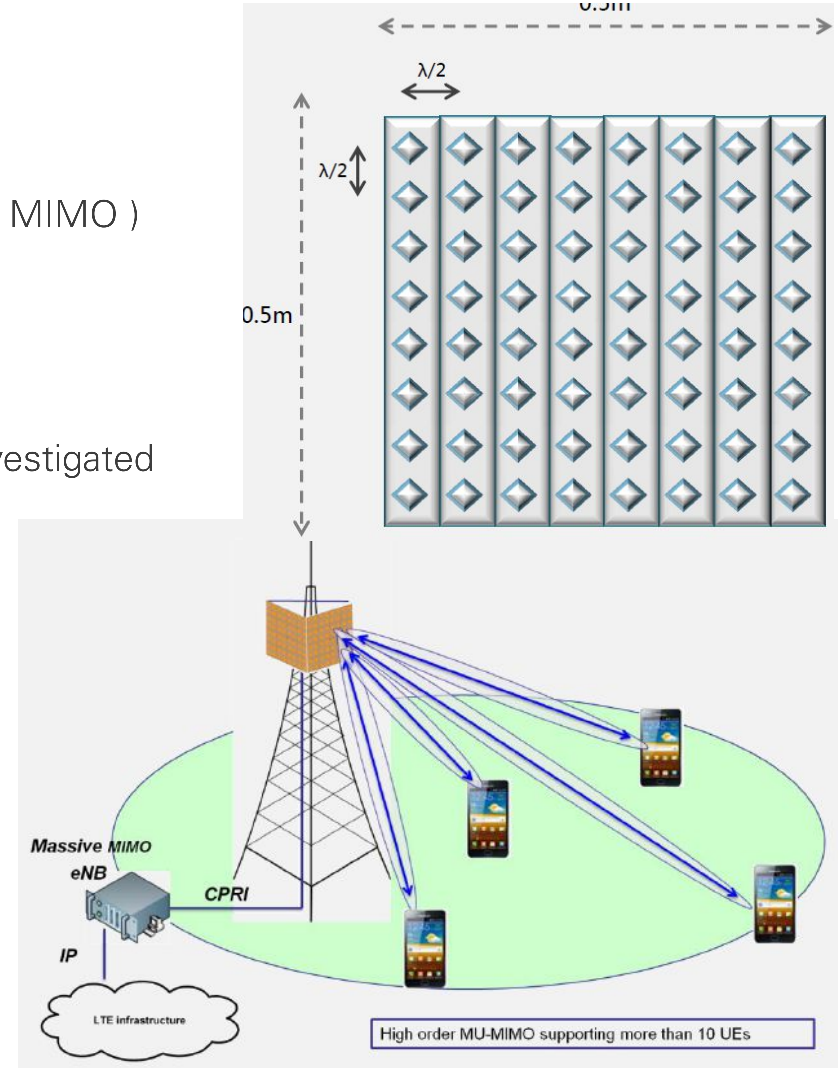
**Network Management: avoid I / exploit B**

- Ultra-dense heterogeneous deployments
- Interference alignment / coordination
- Inter-layer network optimization
- Self-organizing networks
- Multi-RAT (traffic offloading)

# Advanced Multi-Antenna Systems:
# From MIMO to Massive MIMO / BF

# Active Antenna Systems

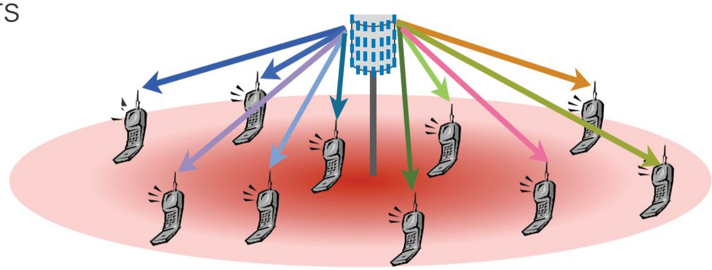
- ALU (lightRadio), Samsung (Full dimensional/FD - MIMO )
- Dynamic adjustment of the radiation pattern
- RF components integrated within array antennas
- Currently systems with up to 64 antennas are investigated
- Challenges:
  - Channel need to be characterized
  - Array calibration, OTA / field tests
  - Freq selective BF (e.g. in elevation)
  - Adaptation to changing channel conditions
    → Accuracy of beam switching /tracking
  - Phase weighting in analog or digital domain



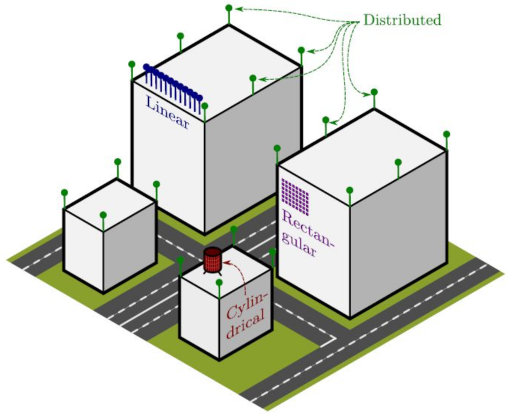

Source: Samsung presentation at Future of 3GPP workshop / RWS-120046

# Massive MIMO

- Hundreds antennas @ base station for serving tens of users
  - Exploit results from random matrix theory
  - Reduced complexity multi user detection
  - Thermal noise and fast fading average out
- Challenges
  - Channel estimation for each path
    → TDD vs FDD (pilot contamination)
  - Synchronization among users / BS antennas
  - Hardware power consumption / Clock distribution
  - Required signal processing power at core unit
    → many parallel decoding chains required
  - Data aggregation at the core unit:
    → 100 x 30.72 MHz x 10 bit quant x 2 IQ = 60 Gbps
- Probably at first only used in UL due to the lack of CSI at BSs
- Requirement: uncorrelated transmission paths → distributed massive MIMO



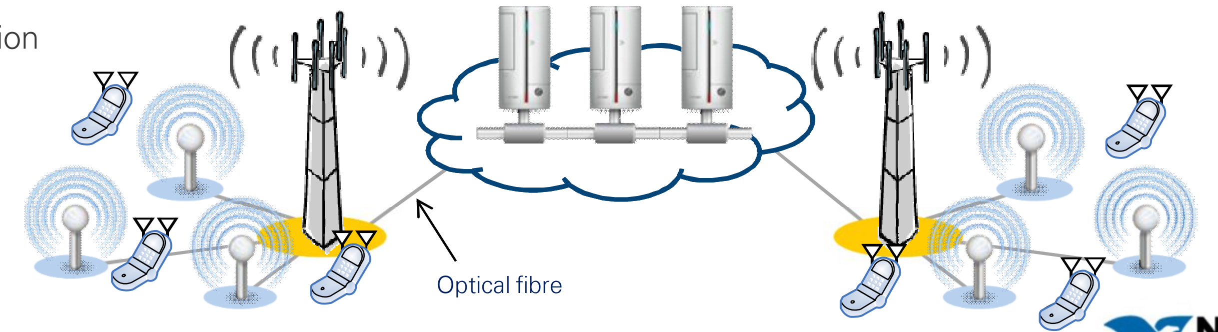
Source: R. Heath: What is the Role of MIMO in Future Cellular Networks




Source: Erik G. Larsson: Massive MIMO: Fundamentals, Opportunities and Challenges

# Network MIMO

- Coordinated multi-point to multi-point transmission (CoMP)
  - Goal: exploit inter-cell interference rather than suppressing it
  - Decentralized signal processing with data exchange among BSs → inter-site CoMP
  - Centralized signal processing → distributed antenna systems or intra-site CoMP
  - Signal processing in cloud → CRAN
- Already introduced in 3GPP/LTE as TM10 → May evolve to massive network MIMO
- Challenges
  - Inevitable path delays and cheap oscillators lead to synchronization problems
  - Backhaul constraints / data streaming from/to core unit → CPRI
  - Control channel and feeback overhead (in DL CoMP)
  - Cluster coordination




See also R. Heath: What is the Role of MIMO in Future Cellular Networks

# Massive MIMO / 3D BF within NI

- **Alcatel Lucent**: 4 antenna BF prototype with phase sync (by Signalion)
- **European MiWaves project**: 3D beamforming for mmWave
- **Massive MIMO lead user opportunities** (ART-W)
  - University of Lund (main driver within research community)
  - University of Surrey (also partner in the MiWaves

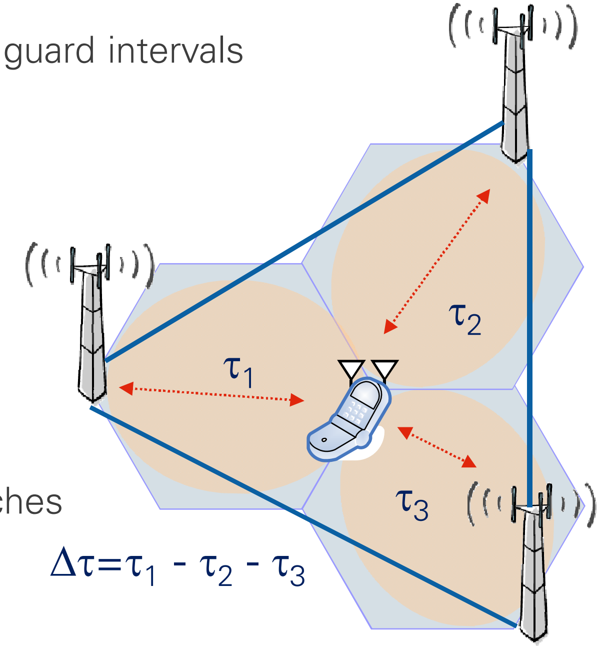
ALU device

Source: Fredrik Tufvesson: Propagation aspects of Massive MIMO Systems

Example of the massive 64 element antenna array of Lund

# Future Heterogenous Networks

- (Asynchronous) distributed cooperative multi-point networks (CoMP, Relays)
  - Inevitable different path delays among users and base stations → speed of light
  - Time synchronization is only possible w.r.t. to one anchor point
  - Problematic for large deployments and short guard intervals
- Low-cost low-energy MTC / M2M
  - no dial-in into network
  - access to network at arbitrary time
- Real-time control
  - Super fast & reliable network access
  - Robustness against synchronization mismatches
- D2D / ad-hoc networks (e.g. disaster relief)
  - No common time reference available



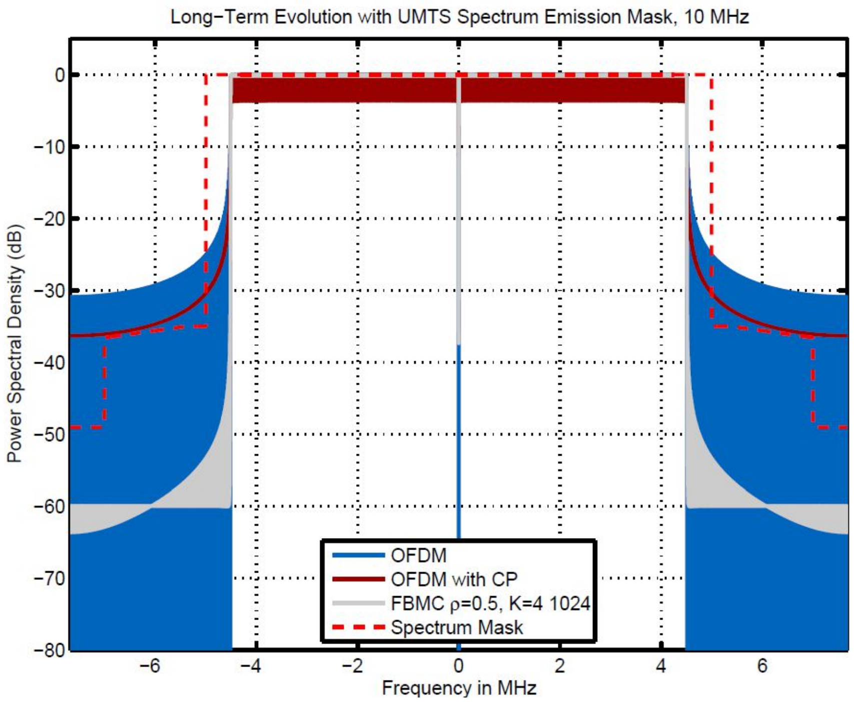
# Asynchronous Multiple Access

- OFDM: Sinc impulses with high side slobes cause strong interference

→ Use other waveforms with higher side lobe suppression

- FBMC
  - Polyphase filterbanks for pulse shaping in frequency domain
  - Offset-QAM modulation
  - No cyclic prefix
- GFDM

  (lead user project with TU Dresden)
  - 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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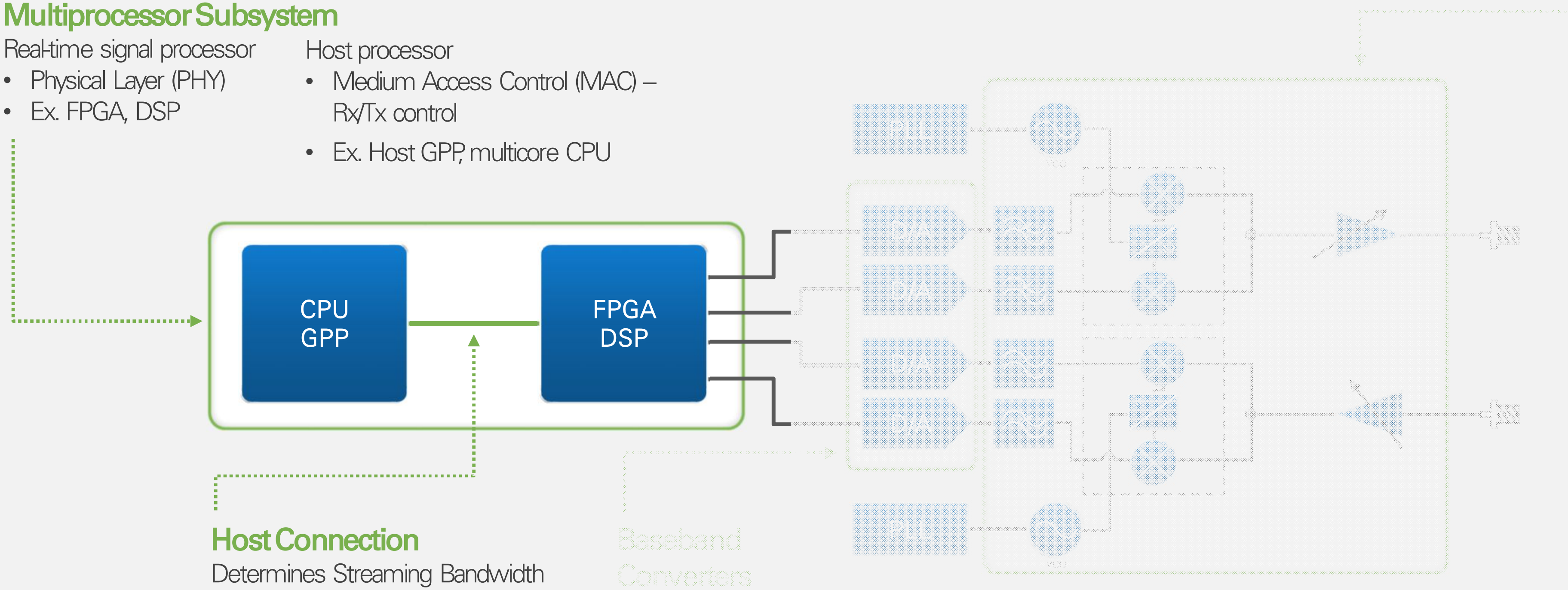
# Software Defined Radio Architecture

**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




**Host Connection**

Determines Streaming Bandwidth
Ex. Gigabit Ethernet, PCI Express.

Baseband Converters

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



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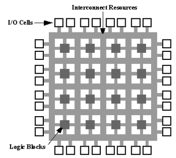
# Today's Development Challenge

## Tools

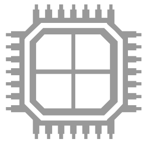
- Math (.m files)
- Simulation (Hybrid)
- User Interface (HTML)
- FPGA (VHDL, Verilog)

- 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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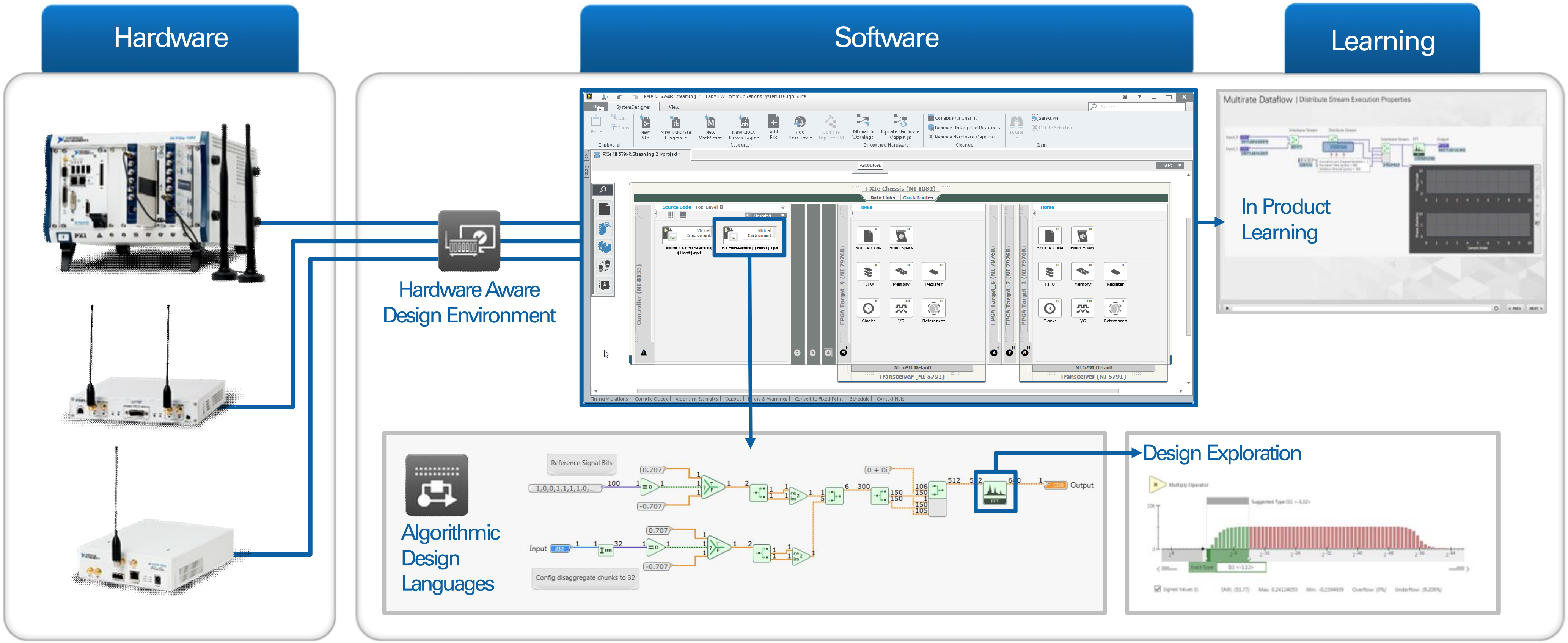
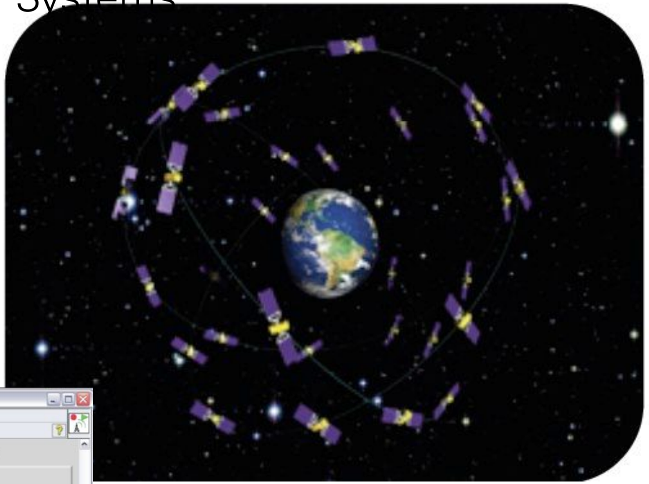
# LabVIEW Communications System Design

*The Next Generation Platform for Software Defined Radio*



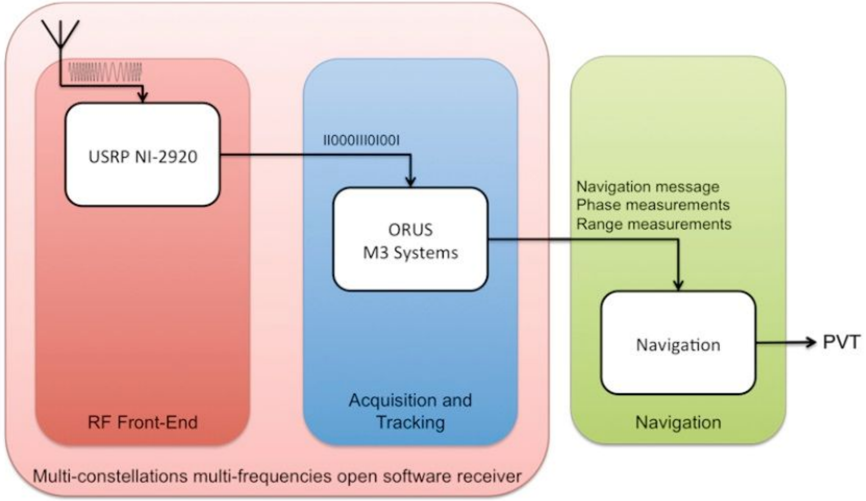
# Developing an Open Multiconstellation GNSS Receiver

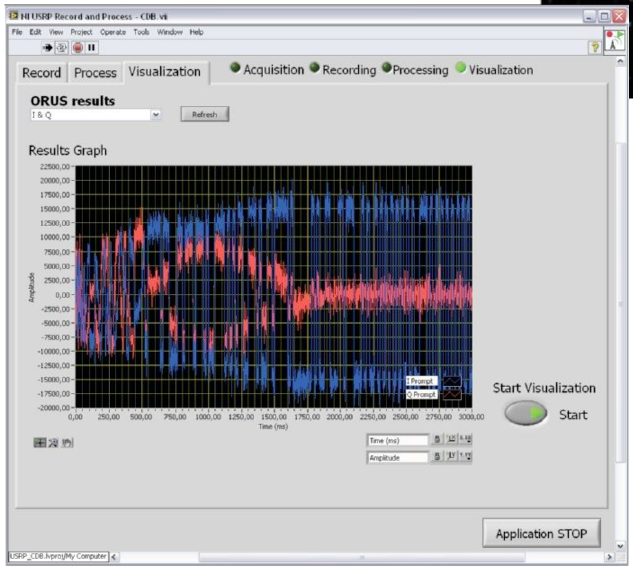
Olivier DESENFANS, M3 Systems



## Multiconstellation Position Tracking

- Track multiple global navigation satellite constellations concurrently, recording, processing, and visualizing the results
- Acquisition performed by ORUS (open software receiver developed by M3)
- Current coverage for both GPS (United States) and Galileo (Europe) constellations





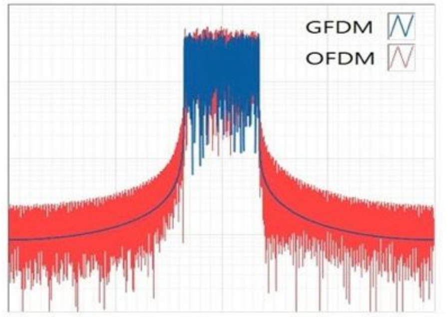

http://sine.ni.com/cs/app/doc/p/id/cs-15407

# 5G Vectors

## PHY Enhancements

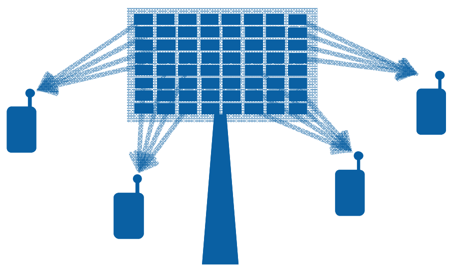
Improve bandwidth utilization through evolving PHY Level

- GFDM
- FBMC
- UFMC
- NOMA
- Full duplex
- LAA



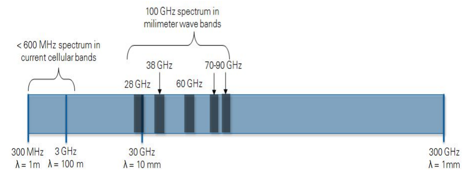

## Massive MIMO

Dramatically increase number of antenna elements on base station



## mmWave

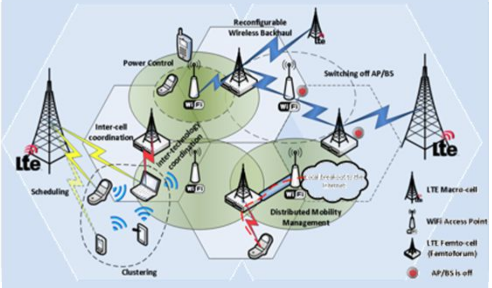
Use potential of extremely wide bandwidths at frequency ranges once thought impractical for commercial wireless.




## Wireless Networks

Consistent connectivity meeting the 1000X traffic demand for 5G

- Densification
- SDN
- CRAN



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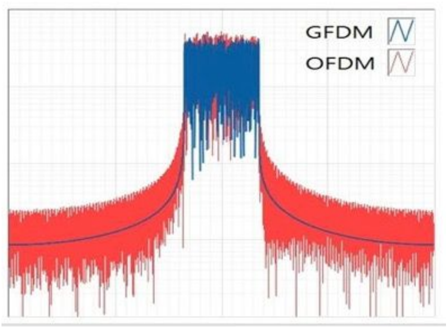


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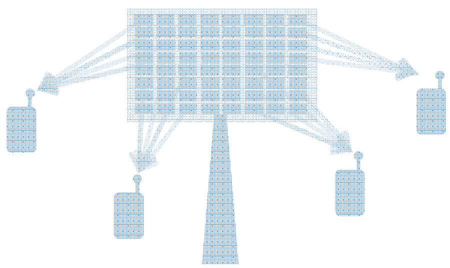

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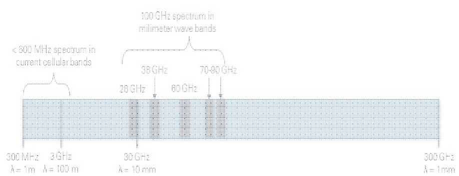

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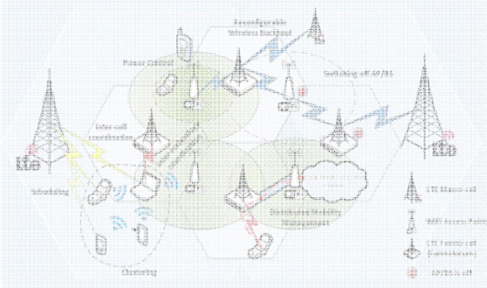
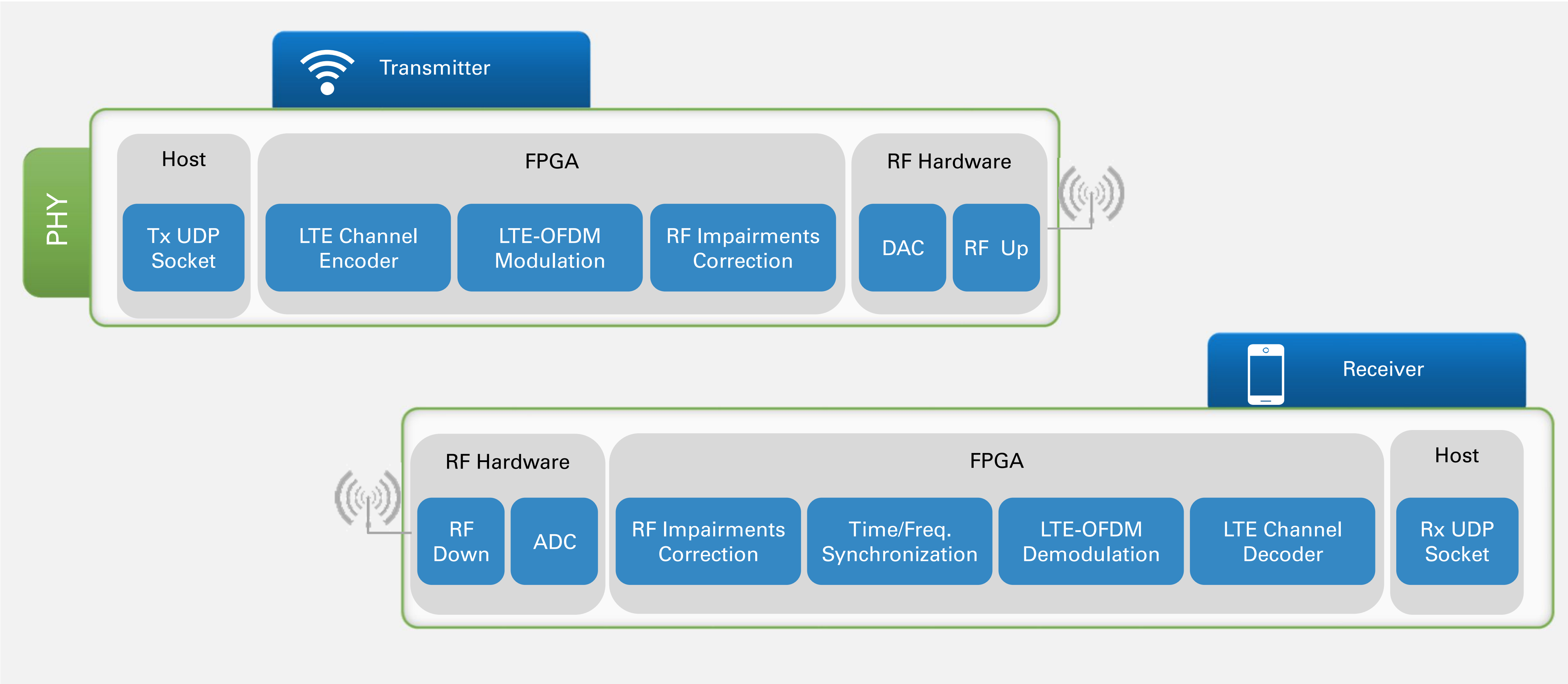
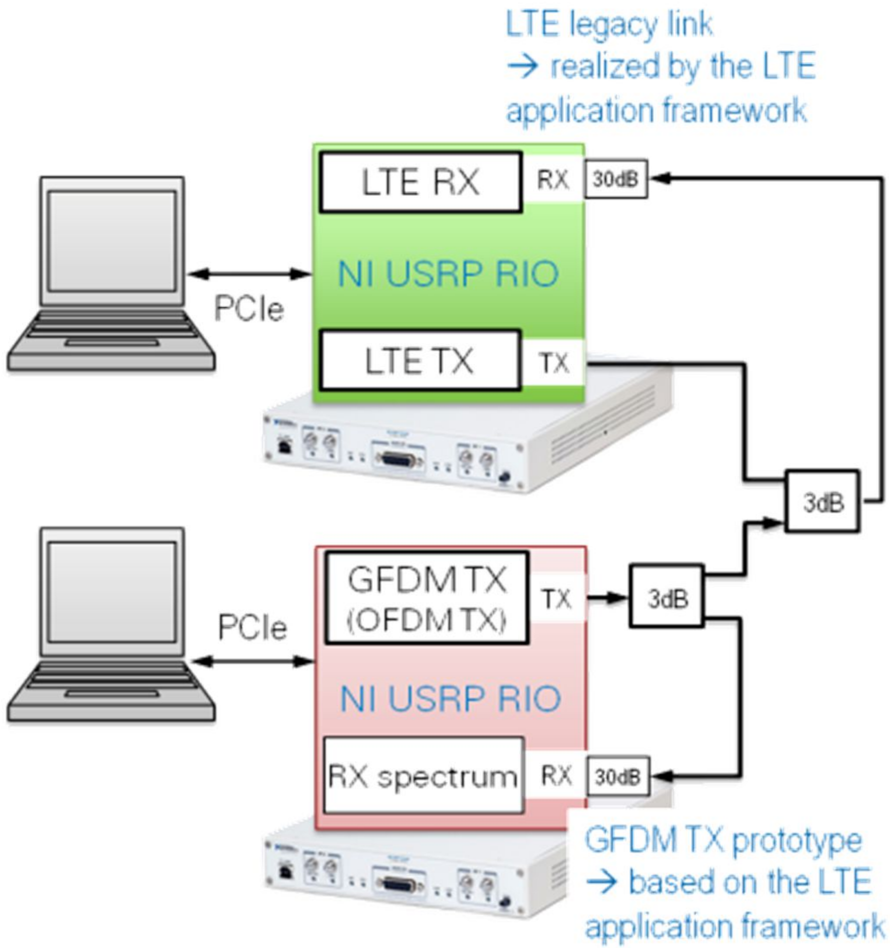


# Open, Modular LTE-OFDM Link

*Using LabVIEW Communications LTE Application Framework*



# GFDM–LTE Coexistence Prototyping

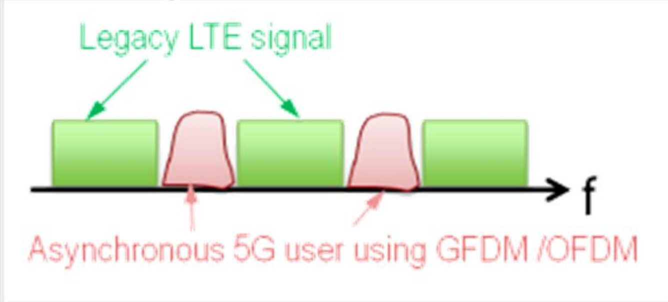



## 5G demo scenario

5GNOW

Fragmented spectrum use case with

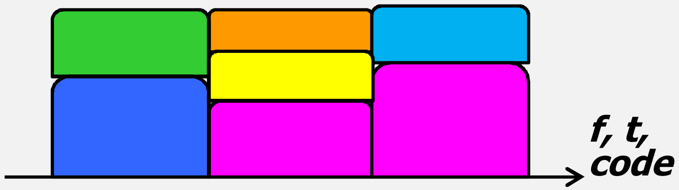
- Synchronous LTE legacy link +
- Asynchronous 5G user using non-orthogonal GFDM waveform




Visualization/KPIs

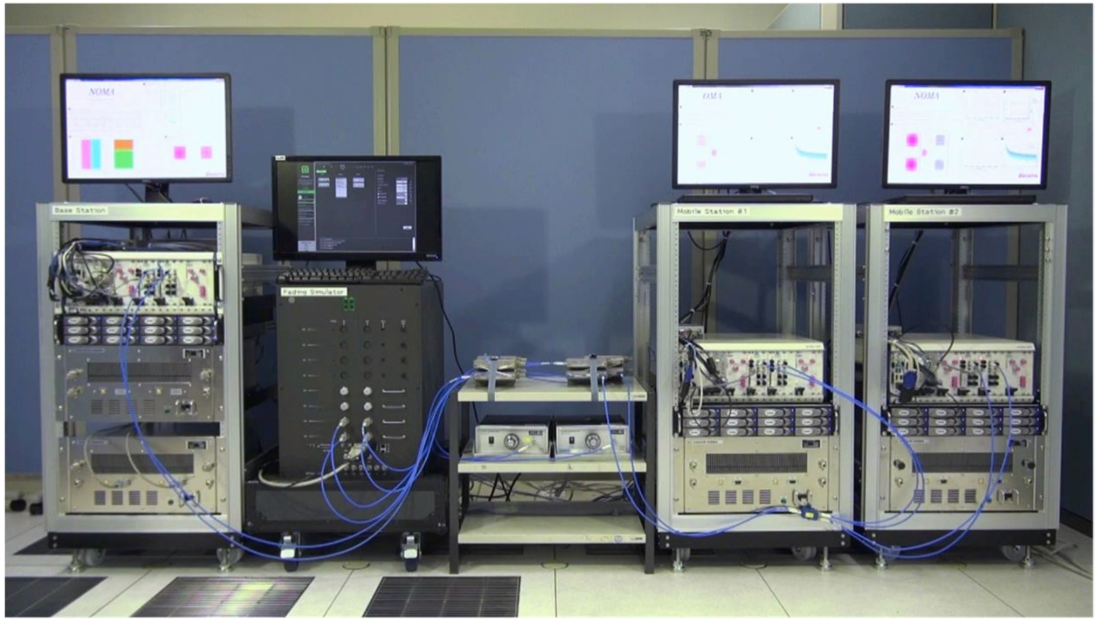
- BLER of the legacy LTE system
- RX QAM constellations
- TX + RX power spectra

# NTT Docomo: NOMA Testbed




**NOMA: Non-Orthogonal Multiple Access**

**Exploitation of power-domain, path loss difference among users, and device processing power**



"By adopting NI's cutting-edge 5G wireless rapid prototyping test system, we expect to see results on performance and capabilities faster on NOMA and higher frequencies."

Takehiro Nakamura, Managing Director of the 5G Laboratory

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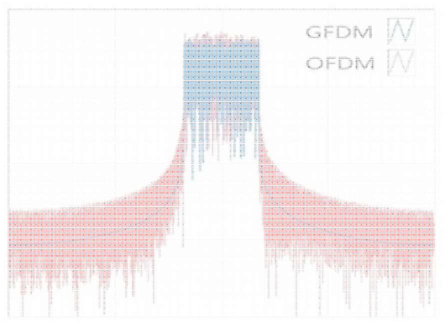


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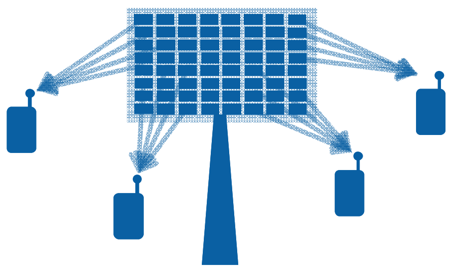

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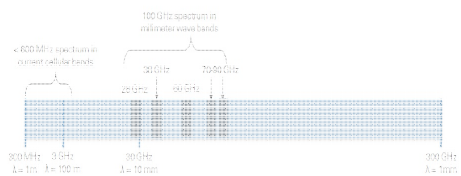

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Consistent connectivity meeting the 1000X traffic demand for 5G

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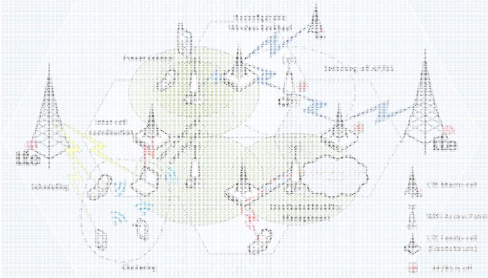
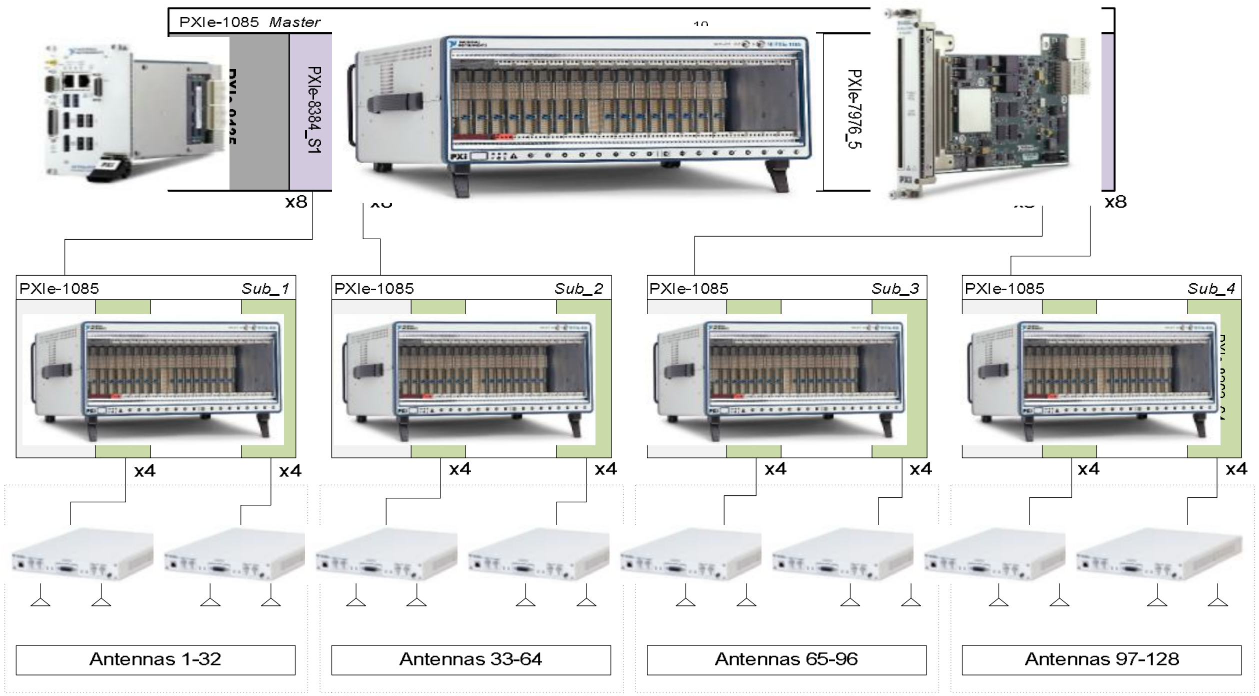


# 5G Massive MIMO Application Framework

Goal: Build a cellular massive MIMO,100x10 antenna system to validate theoretical results with real-time processing




## LTE-like System Parameters

| Parameter | Values |
|---|---|
| No. of base station antennas | 64 - 128 |
| RF Center Frequency | 1.2 GHz – 6 GHz |
| Bandwidth per Channel) | 20 MHz |
| Sampling Rate | 30.72 MS/s |
| FFT Size | 2048 |
| No. of used subcarriers | 1200 |
| Slot time | 0.5 ms |
| Users sharing time/freq slot | 10 |

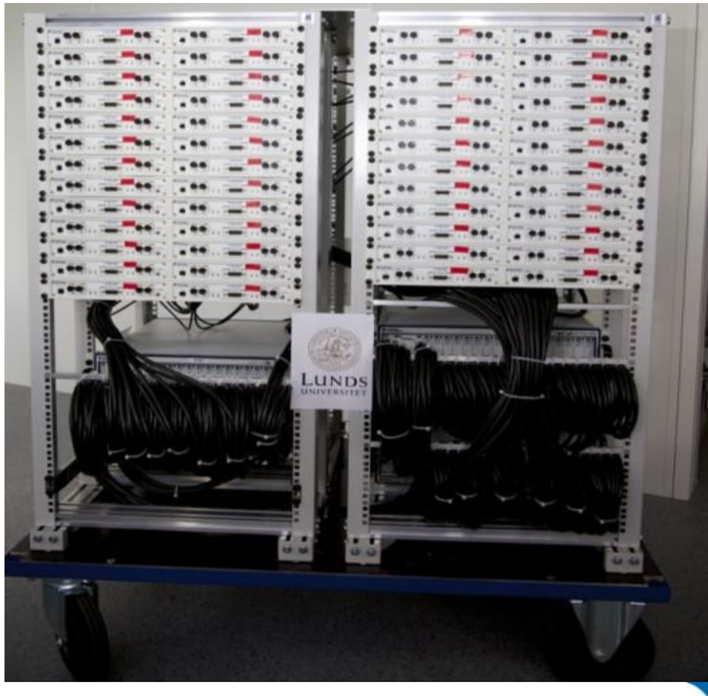
- MIMO base station communicating with a single channel mobile user
- IQ sampling of 15.7GB/s on the uplink and downlink
- TDD operation enabling channel reciprocity

# 5G Massive MIMO at Lund University, Sweden

Goal: Build a cellular massive MIMO,100x10 antenna system to validate theoretical results with real-time processing

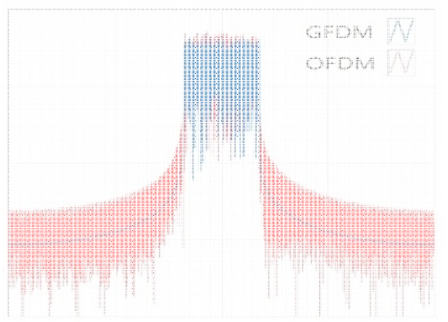
Prof Ove Edfos

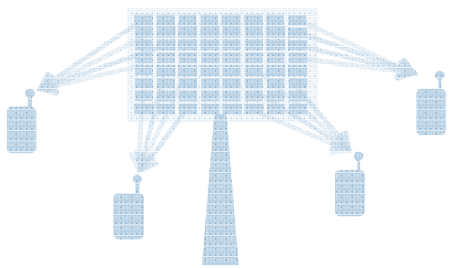
Prof Fredrik Tufvesson

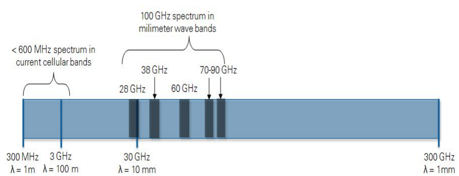



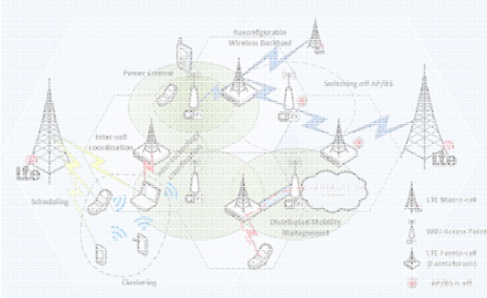
# 5G Vectors

| PHY Enhancements | Massive MIMO | mmWave | Wireless Networks |
|---|---|---|---|
| Improve bandwidth utilization through evolving PHY Level | Dramatically increase number of antenna elements on base station | Use potential of extremely wide bandwidths at frequency ranges once thought impractical for commercial wireless. | Consistent connectivity meeting the 1000X traffic demand for 5G |
| • GFDM<br>• FBMC<br>• UFMC<br>• NOMA<br>• Full duplex<br>• LAA | | | • Densification<br>• SDN<br>• CRAN |



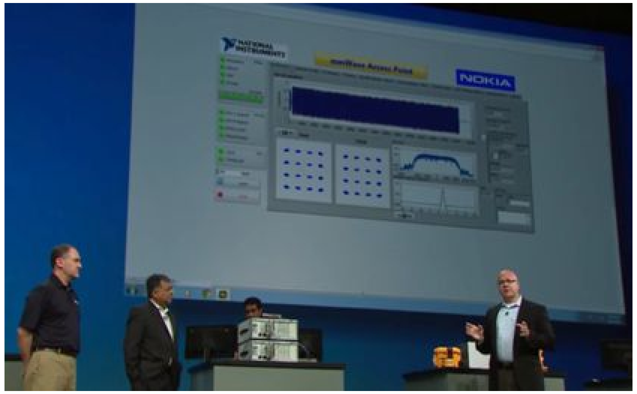



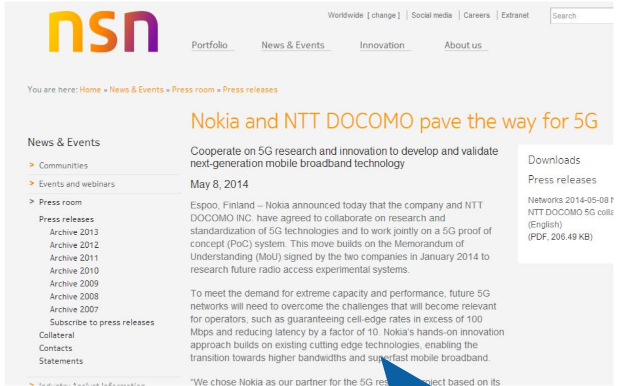


# 2014 Nokia mmWave Prototype

*"The development took the Nokia team one calendar year, half the time of other approaches."*



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## Nokia and NTT DOCOMO pave the way for 5G

Cooperate on 5G research and innovation to develop and validate next-generation mobile broadband technology

May 8, 2014

Espoo, Finland – Nokia announced today that the company and NTT DOCOMO INC. have agreed to collaborate on research and standardization of 5G technologies and to work jointly on a 5G proof of concept (PoC) system. This move builds on the Memorandum of Understanding (MoU) signed by the two companies in January 2014 to research future radio access experimental systems.

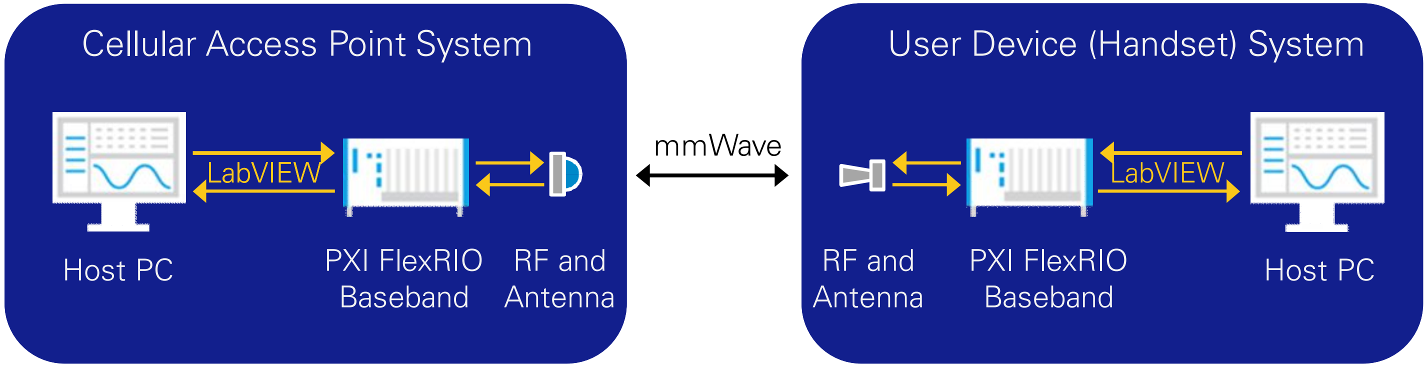
To meet the demand for extreme capacity and performance, future 5G networks will need to overcome the challenges that will become relevant for operators, such as guaranteeing cell-edge rates in excess of 100 Mbps and reducing latency by a factor of 10. Nokia's hands-on innovation approach builds on existing cutting edge technologies, enabling the transition towards higher bandwidths and superfast mobile broadband.

Downloads

Press releases

(English)

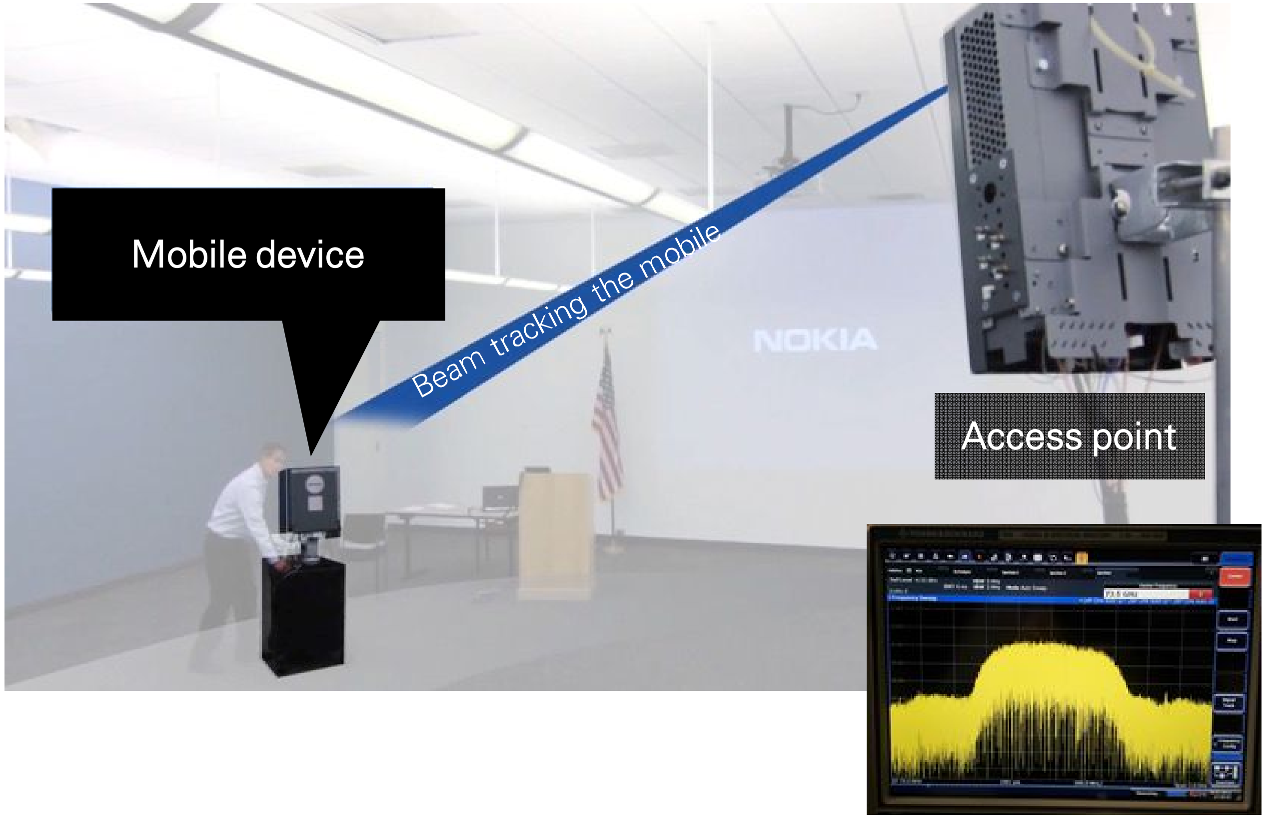
(PDF, 206.49 KB)




The experimental 5G PoC system will be implemented using National Instruments' baseband modules which make up the state-of-the-art system for **rapid prototyping** of 5G air interfaces today.

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



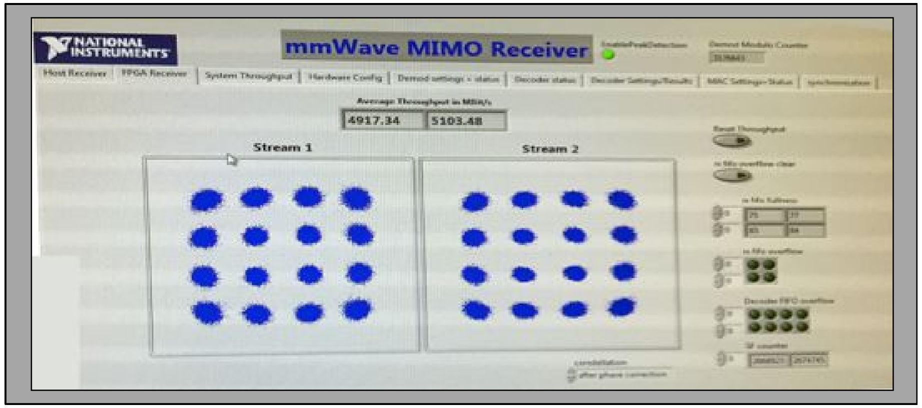


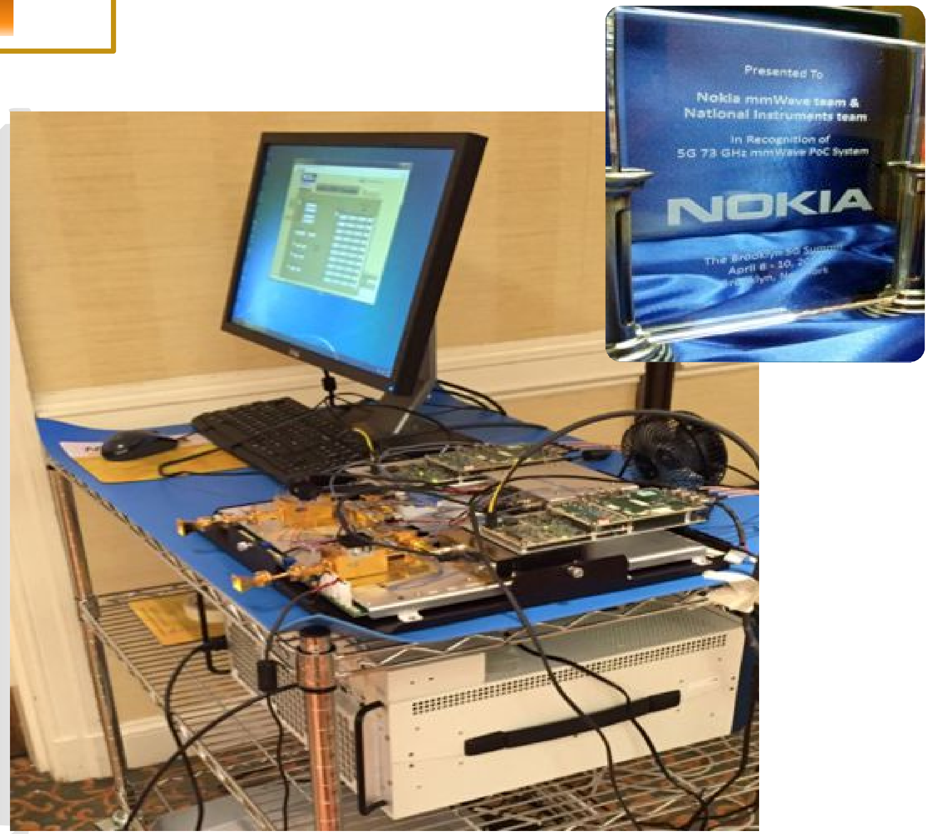



Source: Nokia

# NI and Nokia Demonstrate 10 Gbps Wireless Link

## Brooklyn 5G Summit





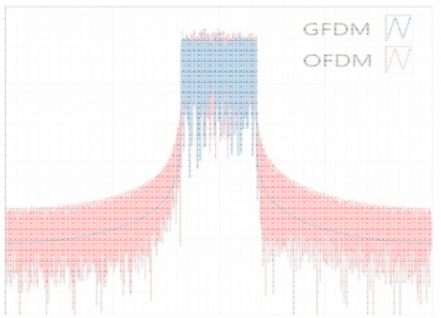

NATIONAL INSTRUMENTS

# 5G Vectors

## PHY Enhancements

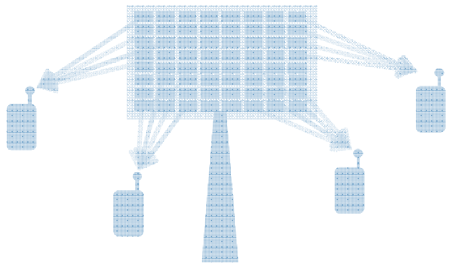
Improve bandwidth utilization through evolving PHY Level

- GFDM
- FBMC
- UFMC
- NOMA
- Full duplex
- LAA



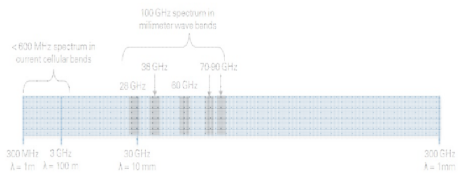

## Massive MIMO

Dramatically increase number of antenna elements on base station



## mmWave

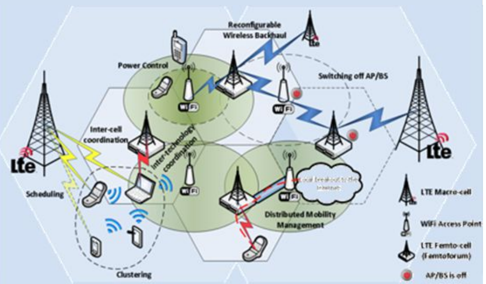
Use potential of extremely wide bandwidths at frequency ranges once thought impractical for commercial wireless.



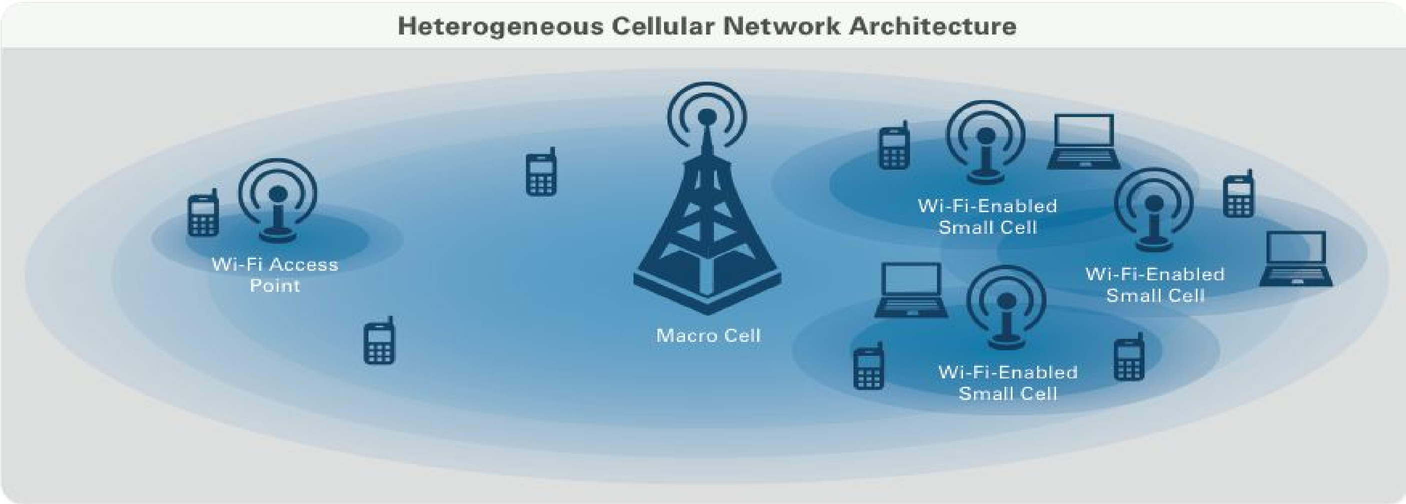
## Wireless Networks

Consistent connectivity meeting the 1000X traffic demand for 5G

- Densification
- SDN
- CRAN

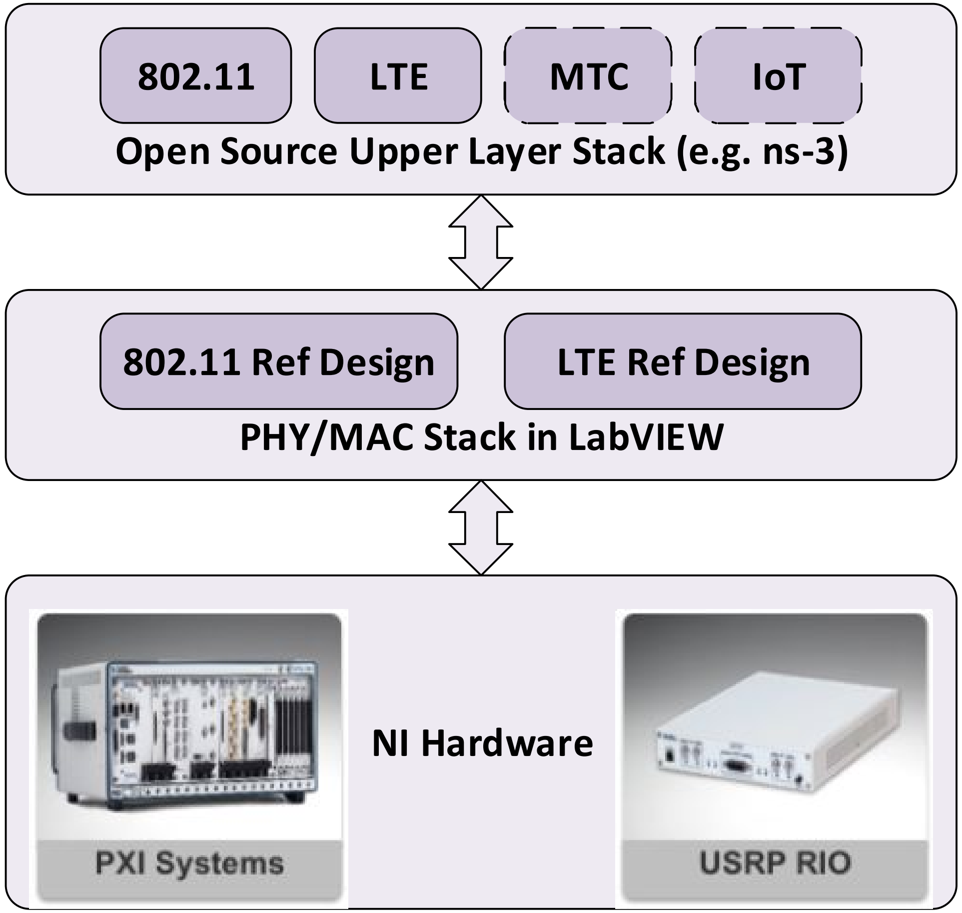


# 5G Wireless Networks: Design Directions




- 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

- SDR is rapidly advancing wireless technologies across industry, academic, and defense applications.

- Platform-based design is accelerating the design flow, significantly improving time to results.

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

# Kérdések és válaszok

- GFDM és FBMC:
  - 5GNOW EU projeckt dokumentumai:, http://www.5gnow.eu
    - Demostrator http://www.5gnow.eu/wp-content/uploads/2015/04/5GNOW_D5.2_final1.pdf
    - Concepts: http://www.5gnow.eu/wp-content/uploads/2015/04/5GNOW_D2.3_final1.pdf