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# 5G TESTBED ACTIVITIES - IITH

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# 5G NR BS AND UE DEMONSTRATOR

# 5G NR BS and UE Demonstrator

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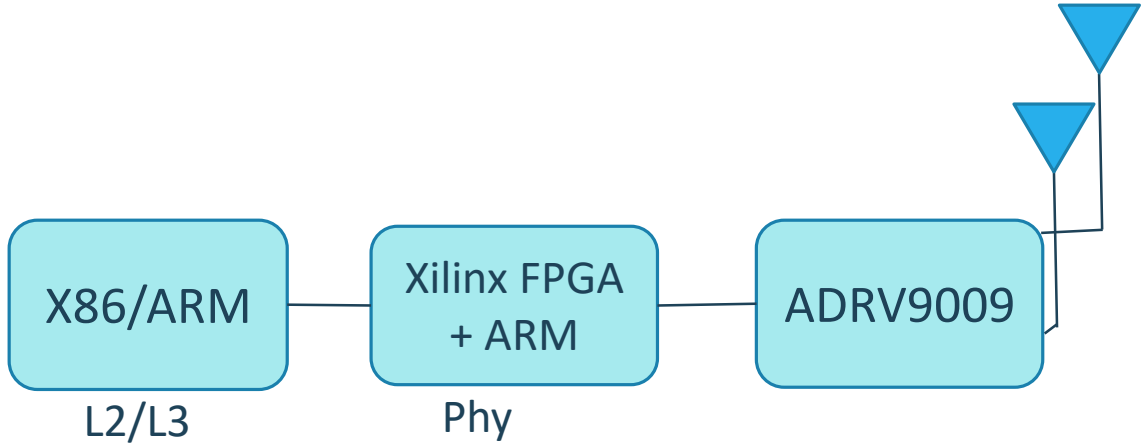
- BS with L1, L2 & L3 compliant with 3GPP Rel-15
- UE with L1, L2 & L3 compliant with 3GPP Rel-15
- Supports FR1 up to 100MHz on Zynq platform
  - ZCU 102 and ZCU 111 boards used
  - ADRV 9009 RF plus external LNA and PA up to 4Rx antenna
  - L1 on FPGA and ARM, L2/3 on ARM/x86
  - FFT, LDPC and Polar in hardware
- PHY tested with SystemVue, Mathworks and R&S



# 5G NR BS: Features

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| Channel/Signals | | Features |
|---|---|---|
| Downlink Transmitter | SS Burst | PSS/ SSS/ PBCH/ Polar |
| | PDSCH | All DMRS configuration/ PTRS |
| | | 8 DL Layers/ 256 QAM/ HARQ/ LDPC |
| | PDCCH | All Search-space set/ Polar |
| | CSIRS | 32 ports/ All configurations |
| Uplink Receiver | PUSCH | All DMRS configuration/ PTRS |
| | | 4 UL Layers/ HARQ/ LDPC |
| | | Phase Estimator/ Channel Estimator/ MMSE Equalizer |
| | PRACH | All formats/ Sub-6 and mmWave |
| | PUCCH | All formats/ Polar/ RM |
| | SRS | Full Band SRS, SRS hopping, time-domain and frequency domain estimations |

# 5G NR UE: Features

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| Channel/Signals | | Features |
|---|---|---|
| Downlink Receiver | SS Burst | PSS/ SSS/ PBCH/ Polar Decoder |
| | PDSCH | All DMRS configuration/ All PTRS configurations |
| | | 8 Layers/ 256 QAM/ HARQ/ LDPC |
| | | Phase Noise Estimator/ Channel Estimator/ Equalizer |
| | PDCCH | All Search-space set/ Coreset/ Polar |
| | CSI-RS | 32 Tx ports/ All configurations |
| Uplink Transmitter | PUSCH | All DMRS configuration/ PTRS |
| | | 4 UL Layers/ All Redundancy versions/ LDPC |
| | PRACH | All formats/ Sub-6 and mmWave |
| | PUCCH | All formats/ Polar/ RM |
| | SRS | 1 Tx transmission |

# 5G NR L2/L3 Features

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| | Features | Status |
|---|---|---|
| RRC, NAS | Support for idle, inactive & connected states. NAS Support | Supported |
| SDAP | Reflective QoS, QFID & DRB mapping [Dl & UL] | Supported |
| PDCP | RoHC, Integrity Protection, Ciphering, Deciphering, PDCP Duplication | Supported |
| Measurement Reporting & RLM | RLM based on CSI-RS, SI-RSRP, CSI-RSRQ, CSI-SINR, SS-SINR measurements | Supported |
| Handover | Inter-gNB Handover, Intra-RAN Handover, Inter-Freq Handover, TDD-FDD Handover, | 50% of features supported |
| RLC & MAC | Segmentation, Reassembly, Re-segmentation, HARQ, Mux, Demux, Logical Channels, Transport Channels support | Supported |
| Slicing & Beam Failure | Slicing Support, Beam Failure Detection & Recovery | To be supported |

# 5G NR: Code Validation with Matlab

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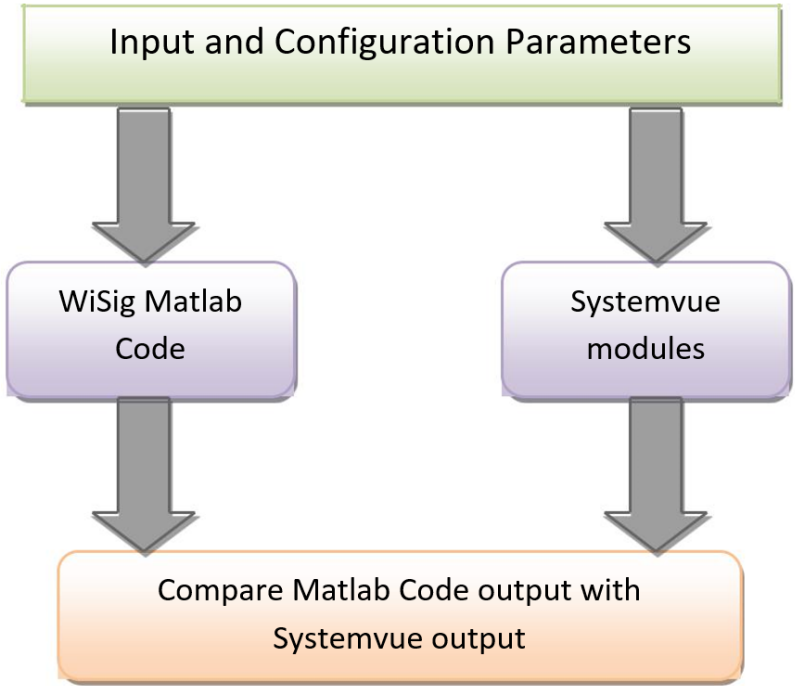
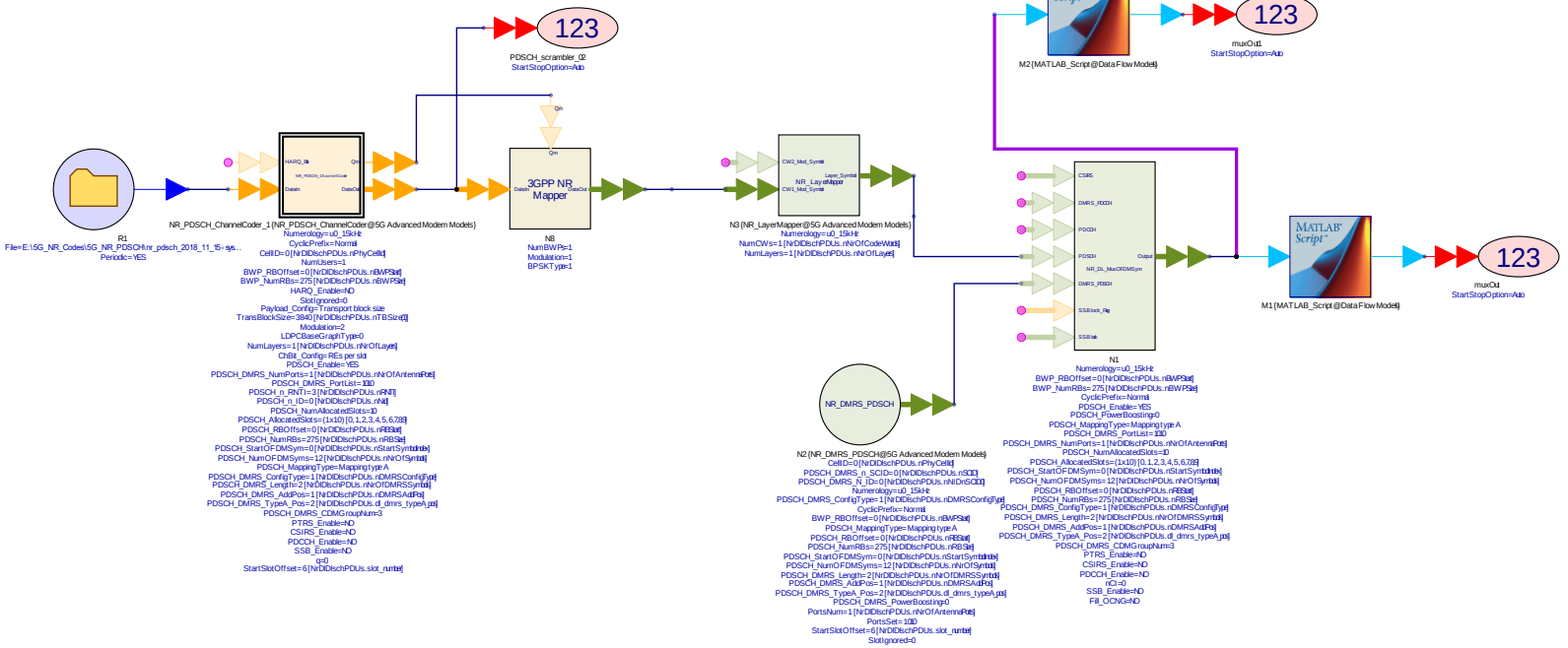
- Matlab has some modules available in their 5G library
  - For a given configuration, we generate outputs from our code and Matlab code and match them

- Our BS Matlab code gives inputs to the UE Matlab code and we ensure code compatibility for some modules

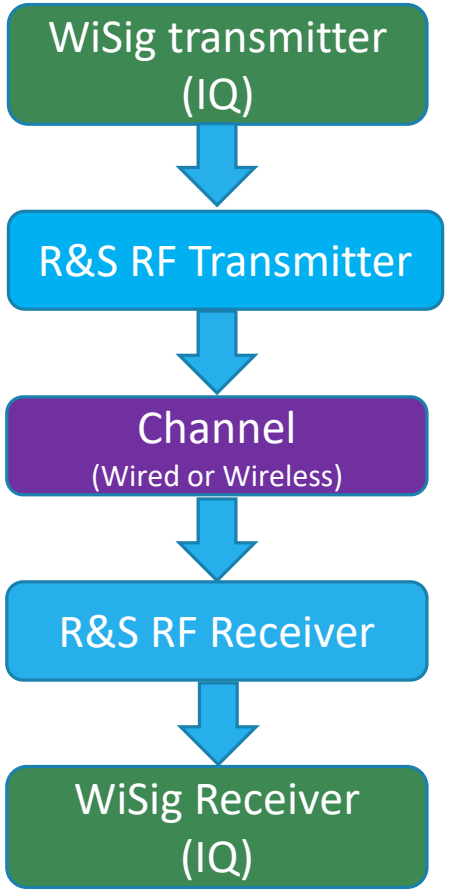
- Each channel results are also compared with LTE performance using similar configurations and we ensure same performance as in LTE

# 5G NR: Code Validation with Keysight SystemVue

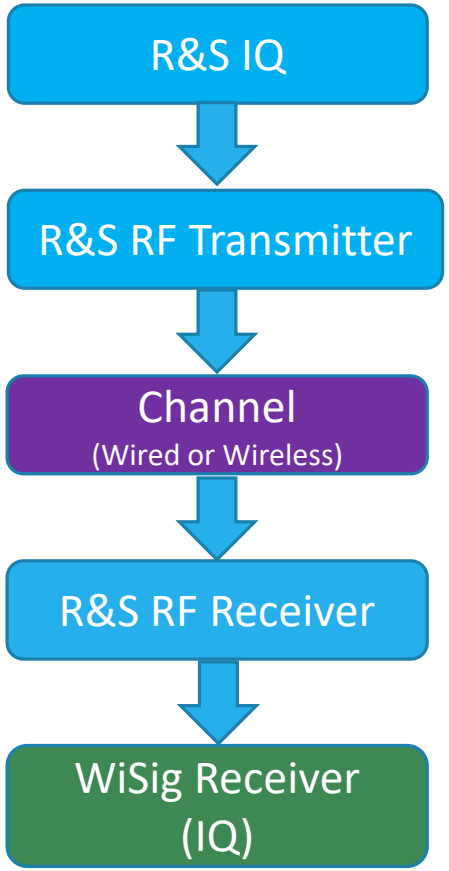


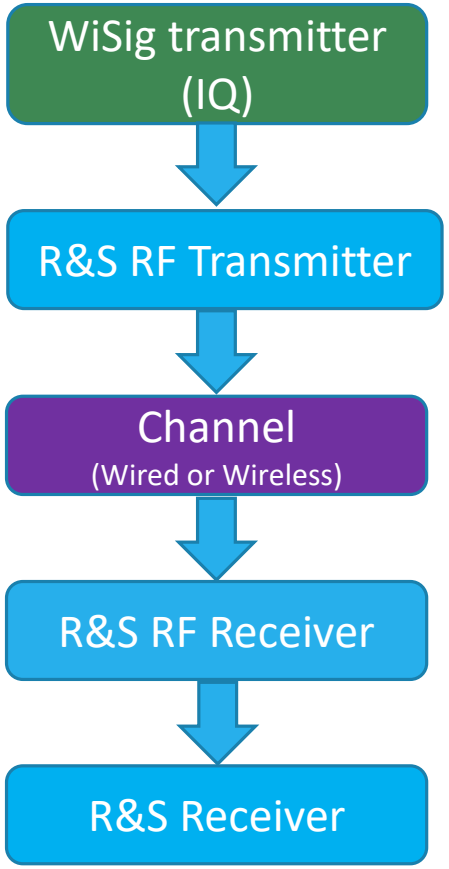
# 5G NR: Code Validation with R&S




WiSig Transmitter with WiSig Receiver




R&S Transmitter with WiSig Receiver




WiSig Transmitter with R&S Receiver

# 5G NR: Code Validation with R&S

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Setup:


SSBurst (WiSig Tx):

- 15kHz SCS
- 10MHz Bandwidth
- 15.36Msamples/sec
- SSB periodicity - 5ms

2.4 GHz Omni-directional antennas

# NR BS PHY Raspberry Pi-USRP Implementation

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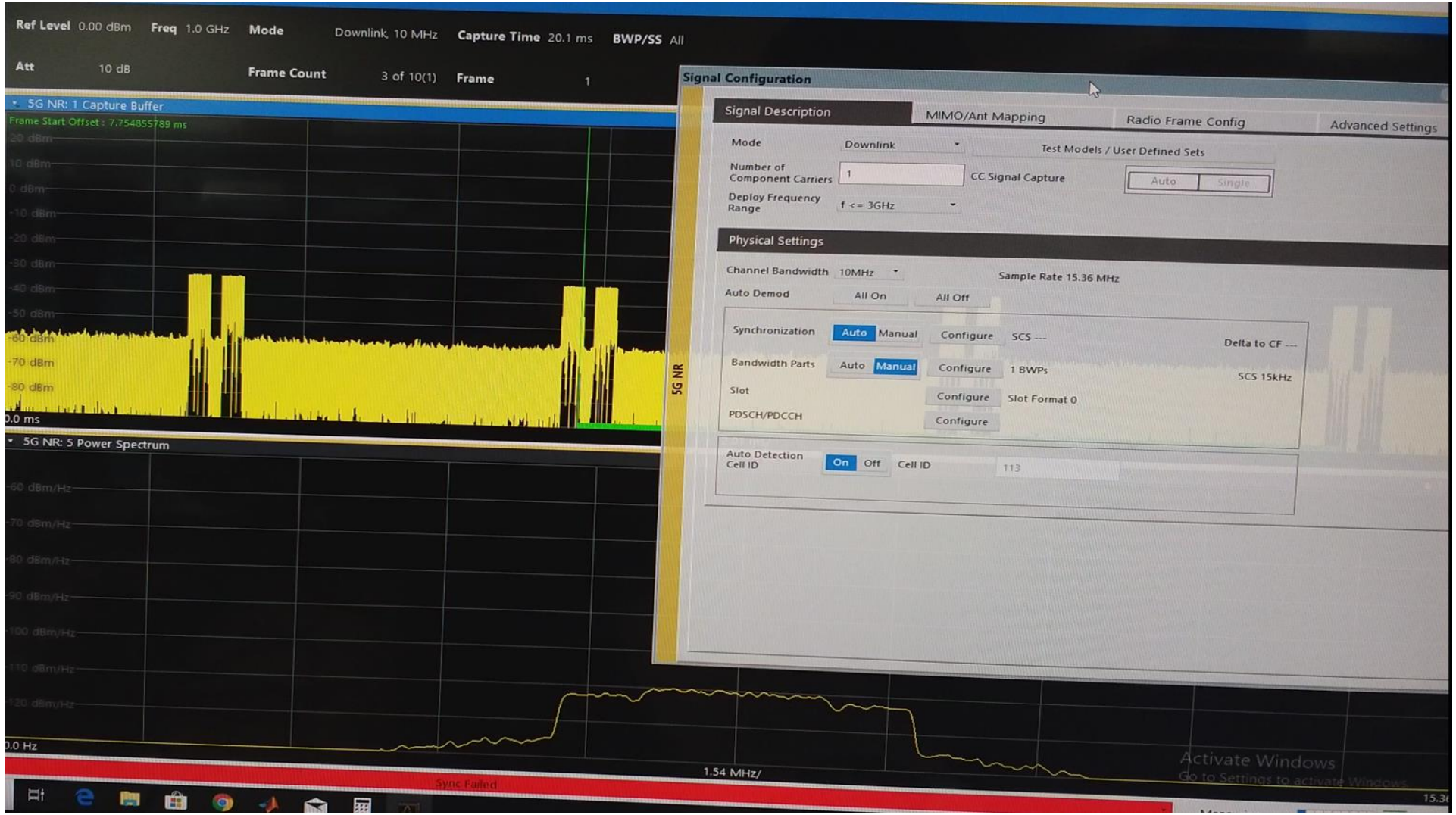
Results 01:

- Frame synchronized
- Cell Id detected by R&S



# NR BS PHY Raspberry Pi-USRP Implementation

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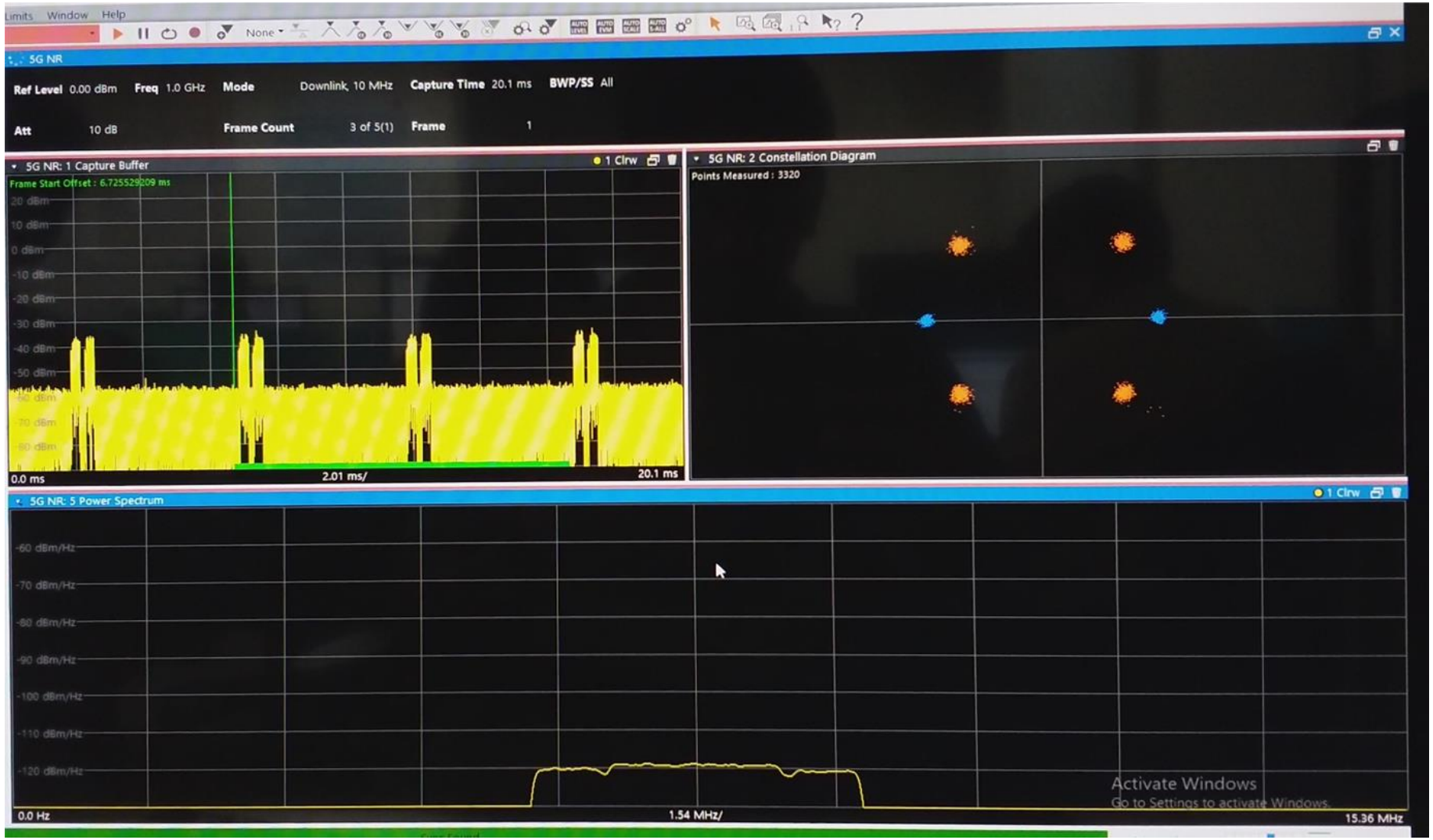
Results 02:

- Frame synchronized
- Cell Id detected by R&S
- Clear Constellation



# BS L1-L2 Integration (Ongoing)

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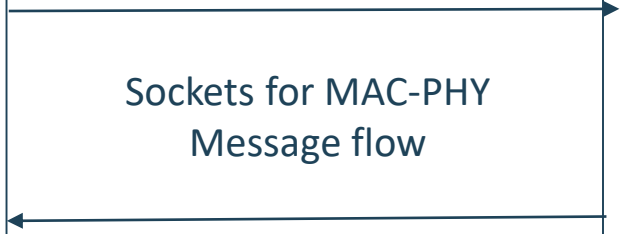
| MAC | PHY |
| --- | --- |
| -NR FAPI from Small Cell Forum integrated<br>-FAPI P5 and P7 messages handlers integrated<br><br>-Next Step:<br>- Integration of RRC Messages with FAPI | -NR FAPI from Small Cell Forum integrated<br>-FAPI P5 and P7 messages handler integrated<br><br>-In Progress:<br>-Integration of L1 controller with FAPI |



# Massive MIMO

# Non-linear Precoding based Massive MIMO

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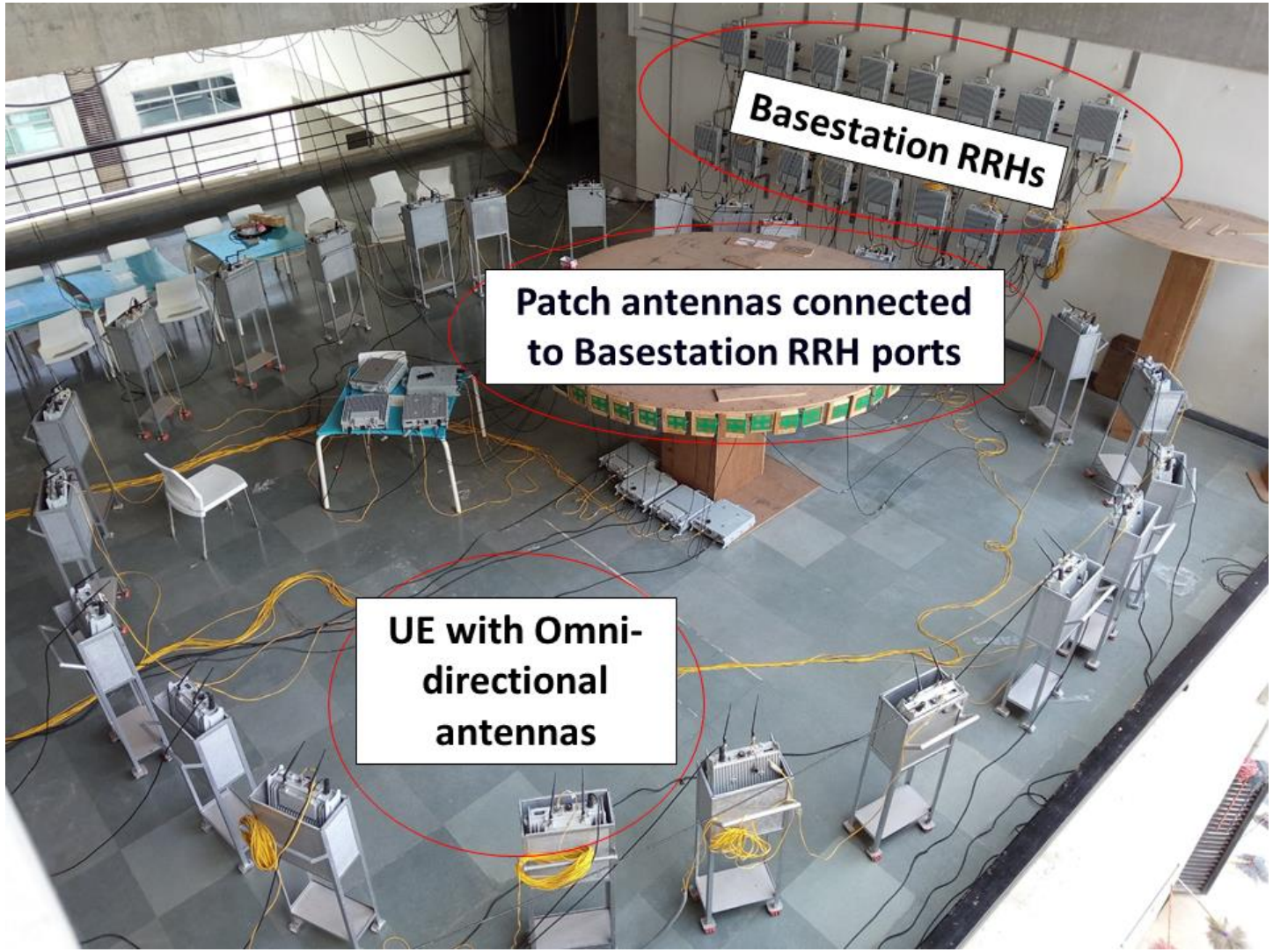
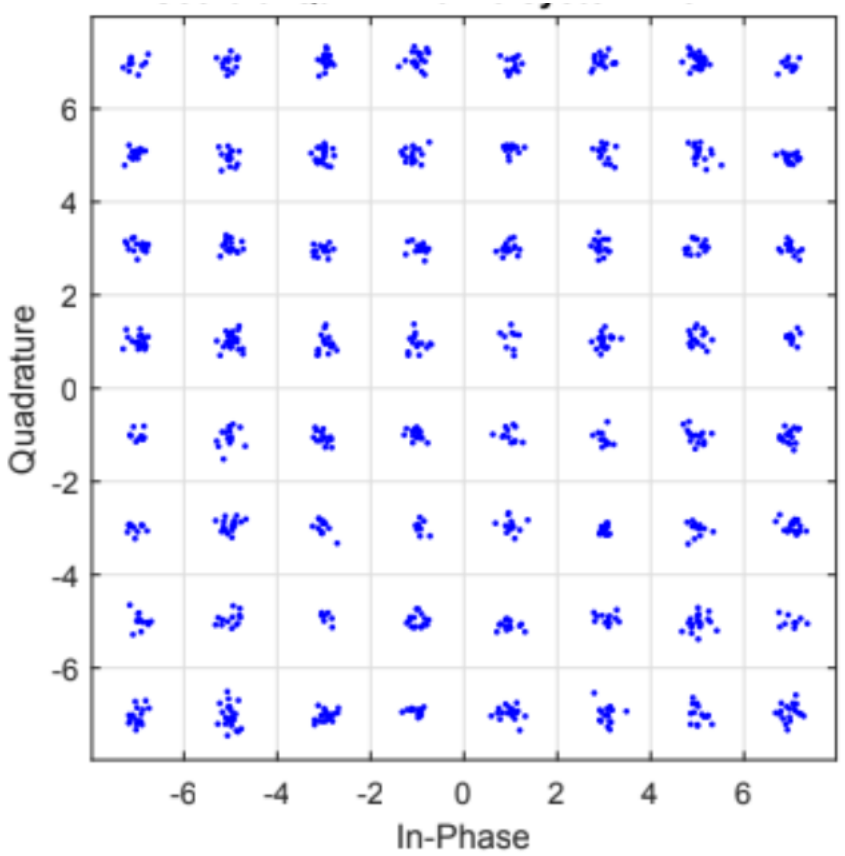
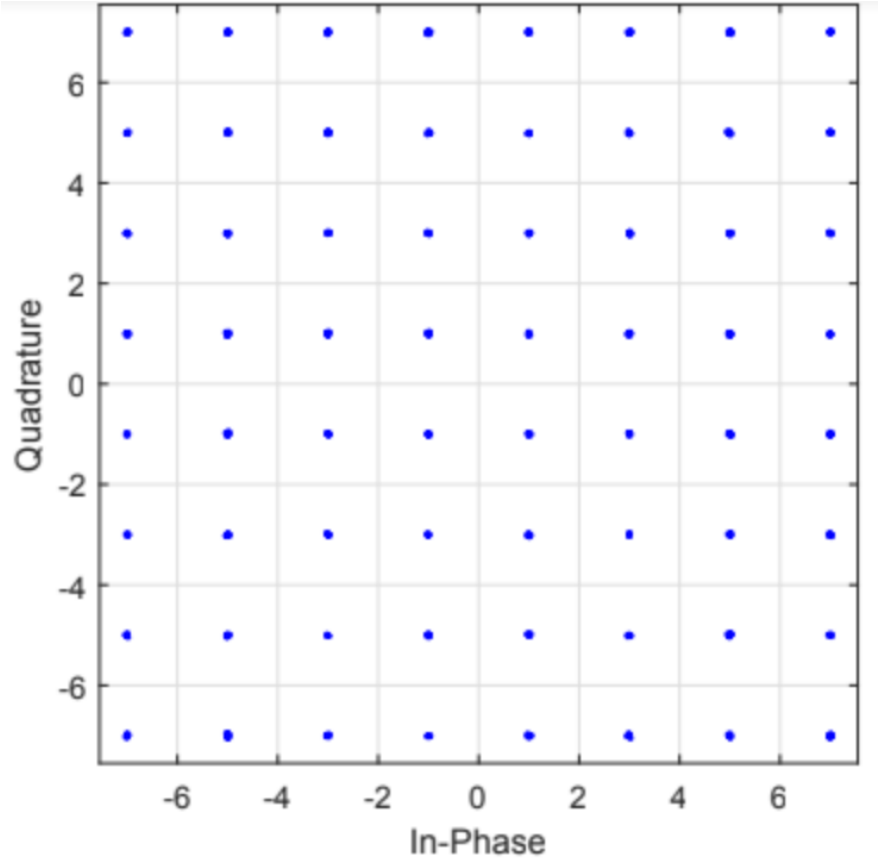
- 48 layers in a $360^0$ cell
- Only 48 RF chains are used for 48 layers
- Modulations used are QPSK, 16-QAM, 64-QAM
- Modulation is decided based on channel conditions
- Non-linear precoder with advanced base-band algorithms used to cancel the inter layer interference



# Retrieved constellations in a simulation environment




**Linear Precoder**




**Non-linear Precoder**

# Retrieved constellations in a real-time DEMO

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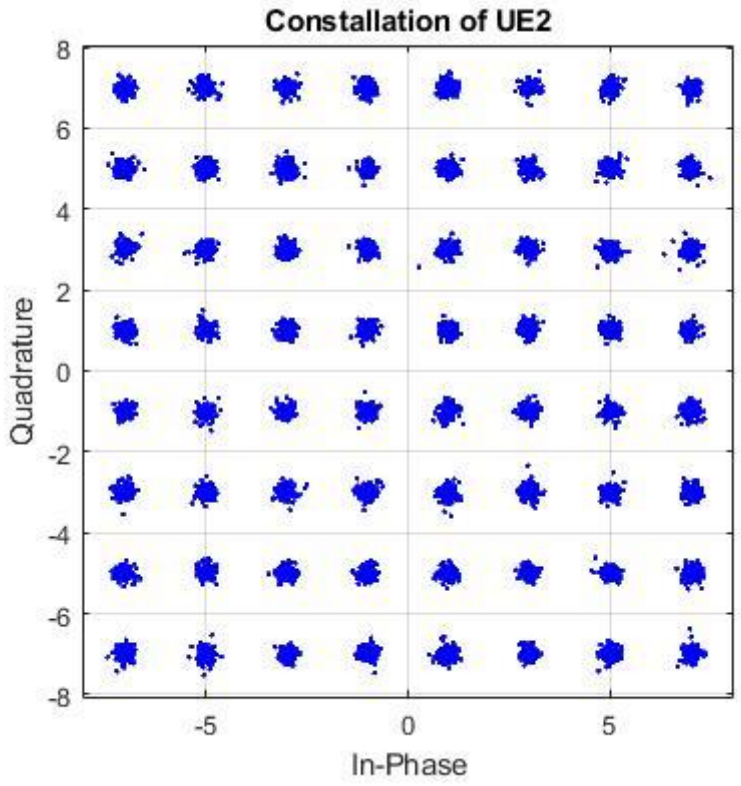
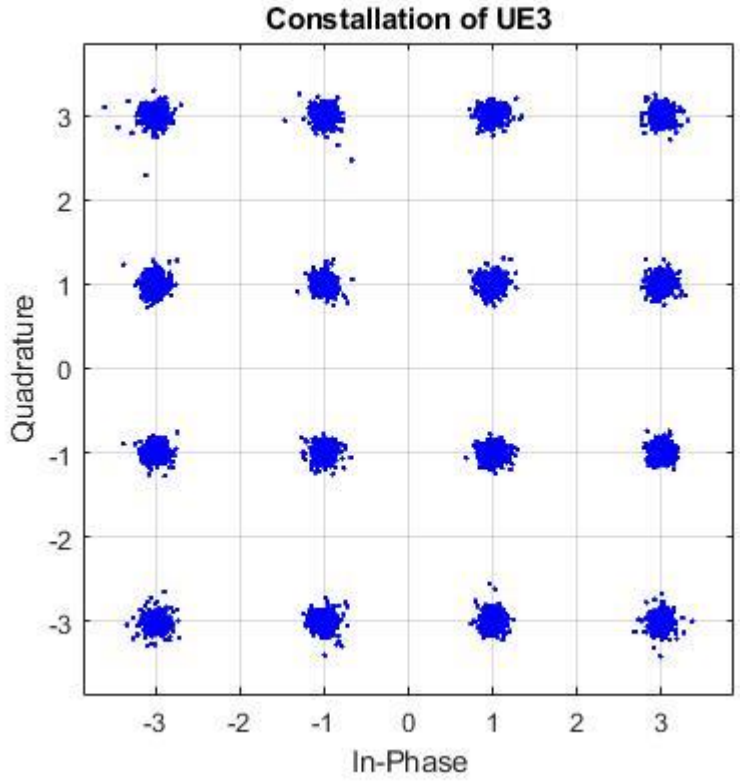
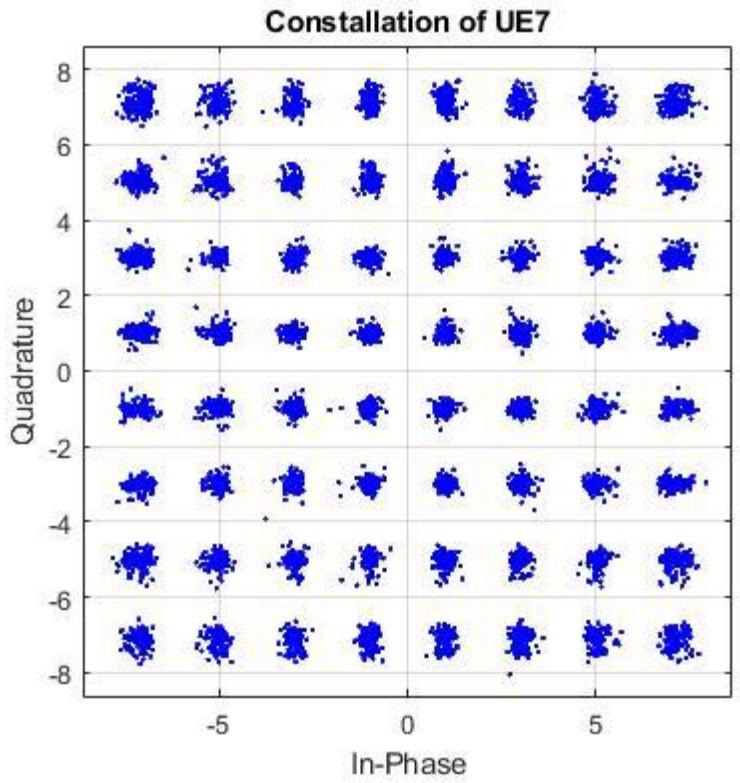
**64QAM**




**16QAM**




**64QAM**



# Massive MIMO with Non-linear Precoder results

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| Parameters | Value |
|---|---|
| MIMO Size | 48Tx 48Rx<br>(12 Tx 12 Rx - 90°sector) |
| Number of data streams | 48 |
| Number of RF chains | 48 |
| Bandwidth | 20 MHz |
| Center Frequency | 2.3 GHz (Band 40) |

Spectrum Efficiency:

10-60 bits/sec/Hz per sector

**(Mean: 40 bits/sec/Hz/sector)**

Throughput on 20 MHz:

800 Mbps per 90°sector

**Cell Throughput is 3.2 Gbps**

**48 RF chains at 100% energy efficiency**

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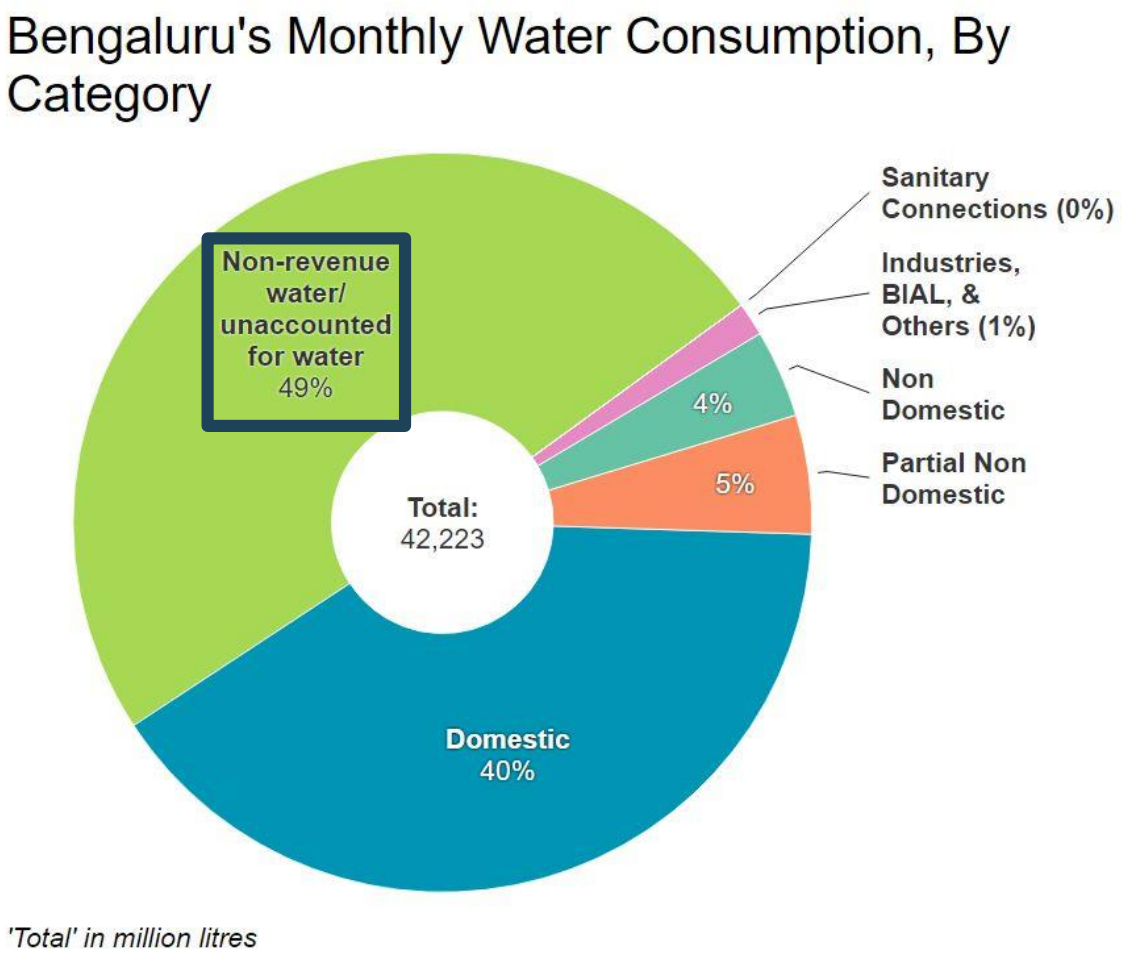
# NB-IoT

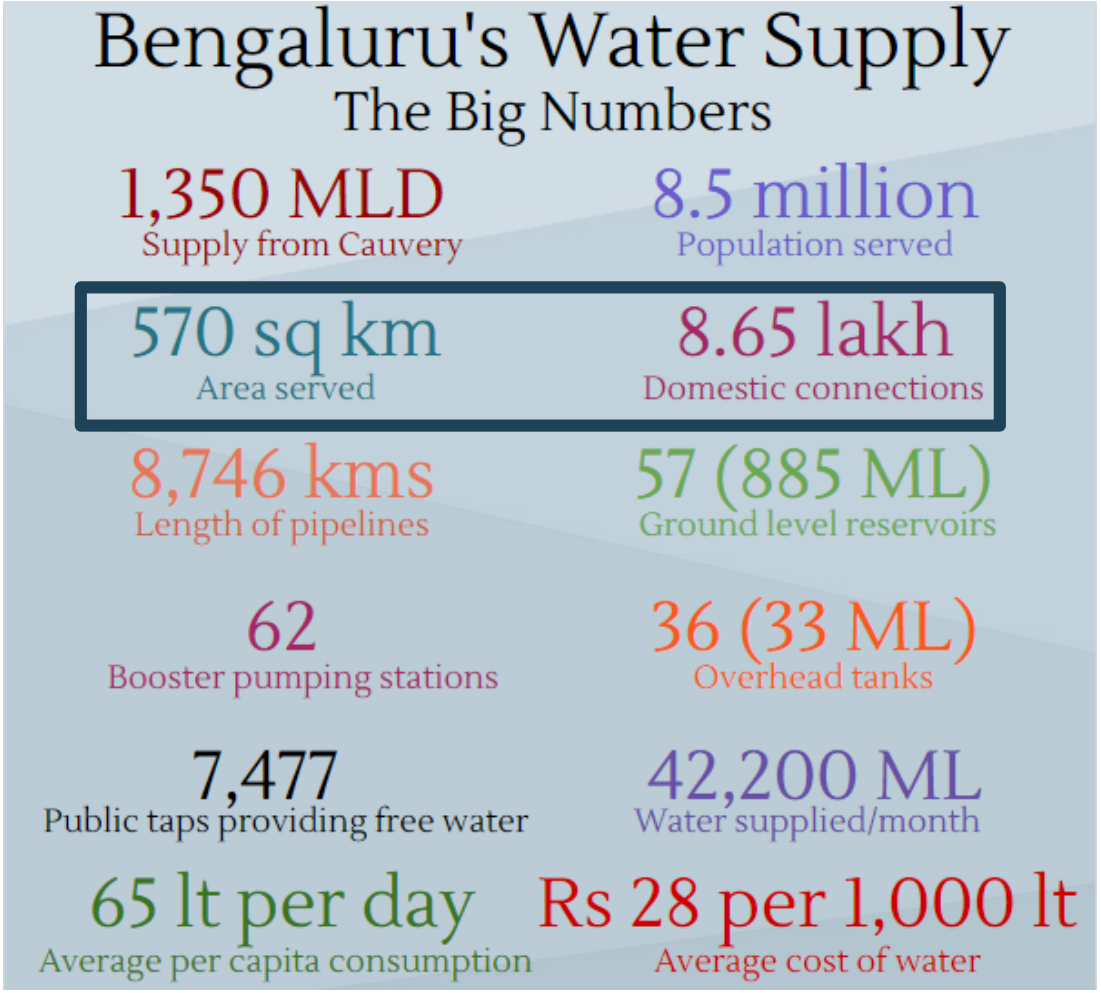
# IoT

- Not new but markets are here now!
- Existed earlier in industrial automation, vending machines, tracking, etc.
- Recently markets started increasing drastically
- New applications + lower device costs


Image Source: Ericsson.

# Water Supply Management Case Study




Source: http://www.indiaspend.com/cover-story/bengaluru-wastes-nearly-50-water-supply-from-cauvery-53879

# Electricity Metering Case Study

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- City wide deployment of NB-IoT Network (2.4 million meters for houses)
- Electricity Meter + IoT Comm Module required
- ~10% added cost ($1 Comm Module)

**Table 7.5: Electricity access to households across Bengaluru Urban district**

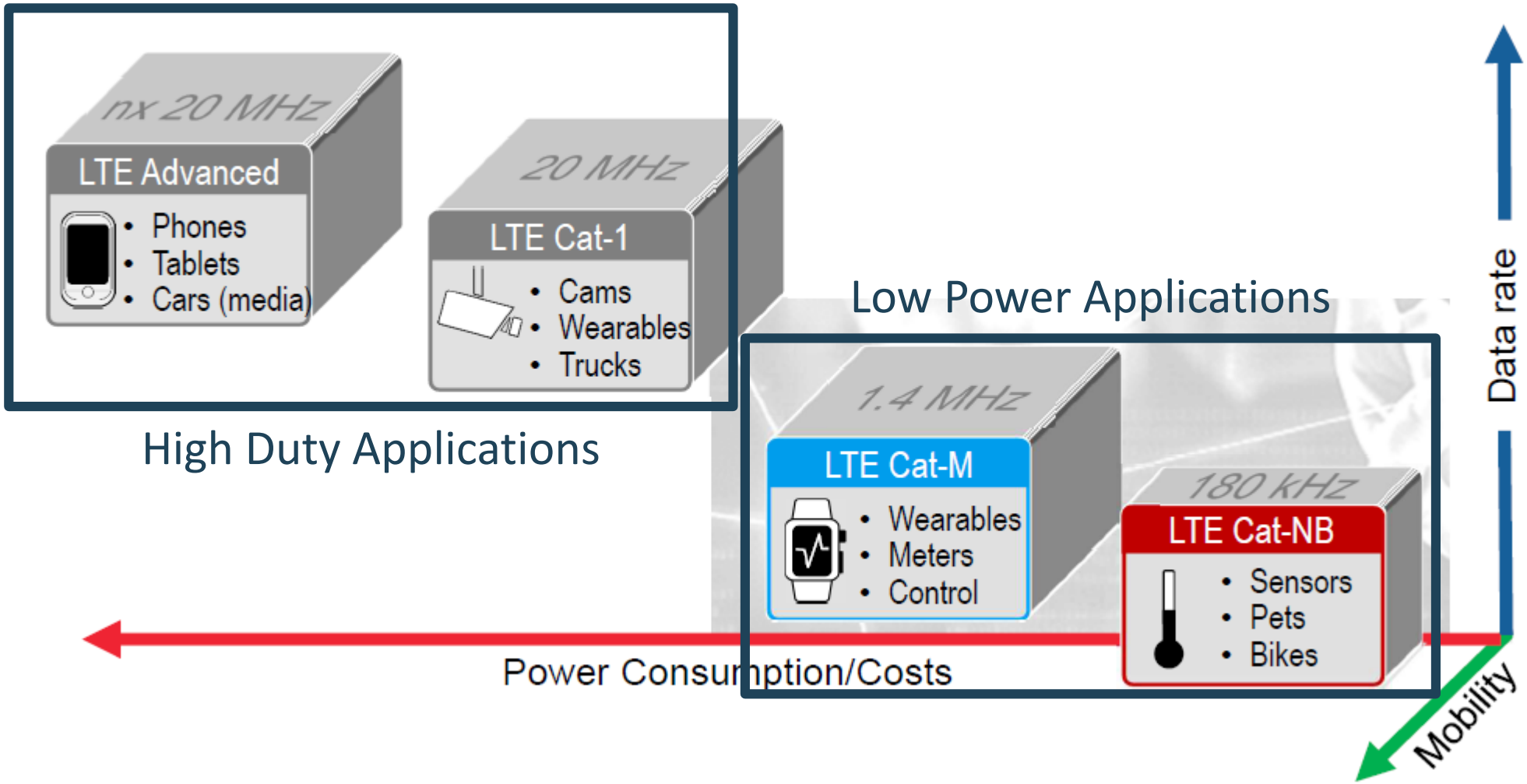
| | Total | Households with access to electricity | Per cent |
|---|---|---|---|
| **Anekal** | 128132 | 123905 | 96.7 |
| **BBMP** | 2105894 | 2069750 | 98.3 |
| **Bengaluru East** | 22317 | 21526 | 96.5 |
| **Bengaluru North** | 75881 | 73189 | 96.5 |
| **Bengaluru South** | 44832 | 42261 | 94.3 |
| **District** | 2377056 | 2330631 | 98.0 |

Source: Census 2011, Department of Census, Government of India.



Image Source: http://www.gsma.com/iot/narrow-band-internet-of-things-nb-iot/

# 3GPP Cellular IoT




Source: Rohde and Schwartz, “Emerging Communication Technologies Enabling the Internet of Things”, White Paper, Nov. 2016.

# NB-IoT (Cellular LPWAN)

- Software upgrade to existing cellular base stations (already reach every corner of city)
- Licensed Spectrum deployment (guaranteed QoS)
- Low bit rate (~100s of Kbps)
- Device battery life 10-15 years
- Massive number of connected devices


Image Source: Ericsson Mobility Report, Nov. 2016.

# NB-IoT + GNSS SoC

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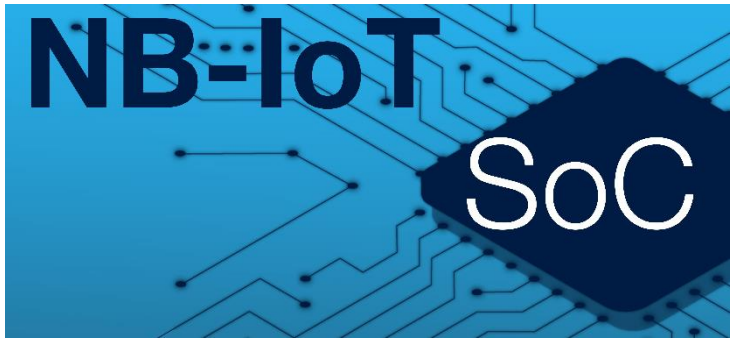


- Cellular modem connects to LTE or 5G BS
  - GNSS for location
  - Phy plus stack in software
  - Deep coverage – underground meters or sensors can connect
- Production ready SoC in Q2 2020
- Operator testing Q2 2020

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# THANK YOU