5G Experimental System @ High mmWave Band (70 GHz)

Expanding the human possibilities of technology to make our lives better

IEEE 5G and Beyond Testbed Workshop

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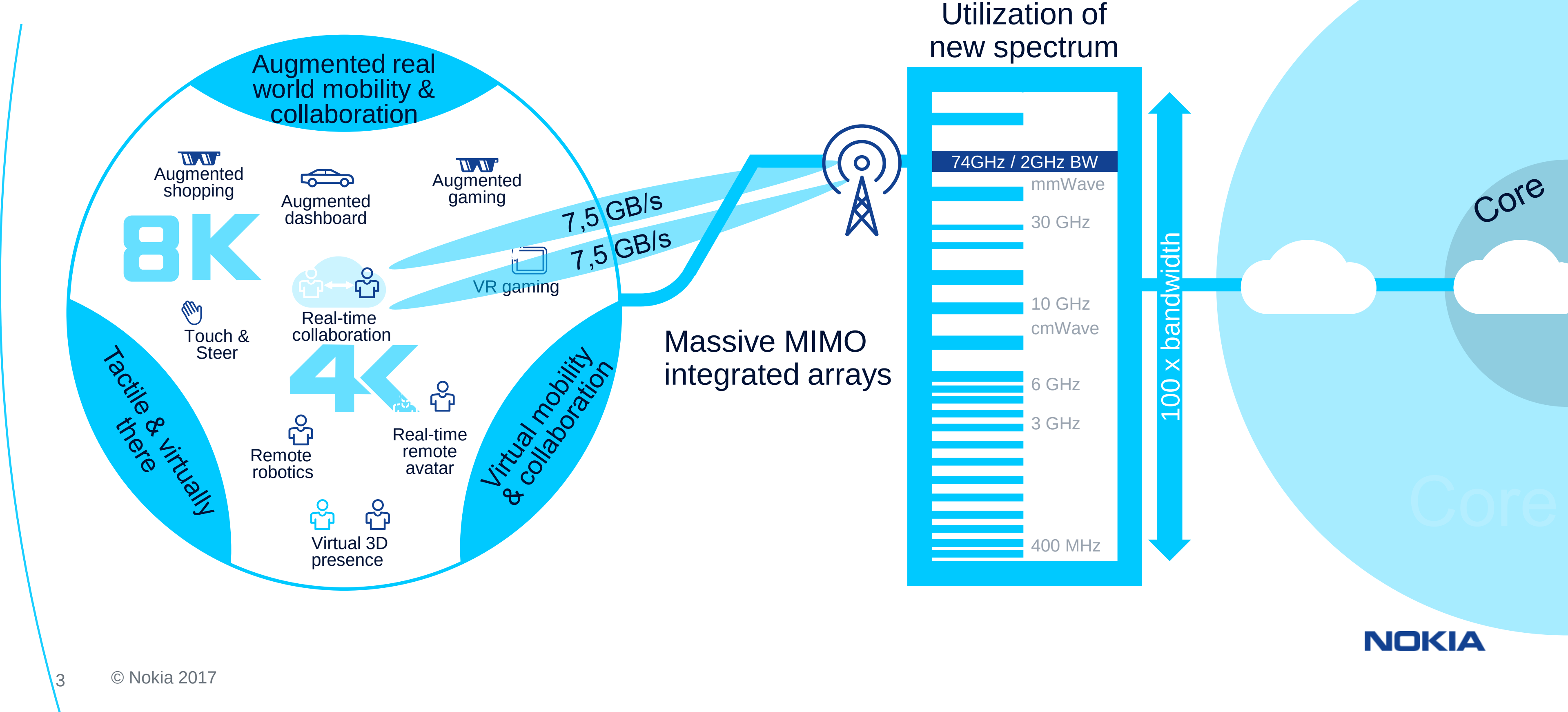
mmWave Use cases, Challenges and Proof Points

Infinite capacity

Utilizing the potentials of mmWave



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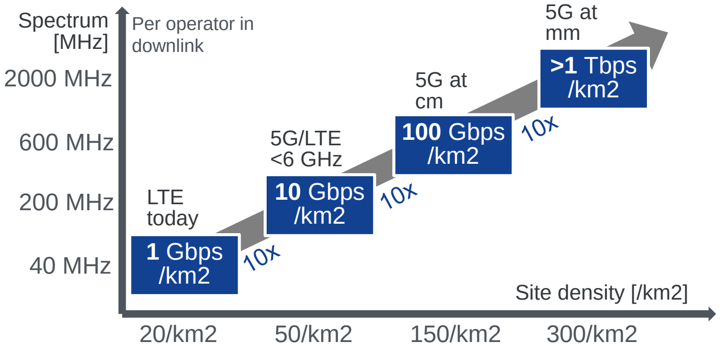
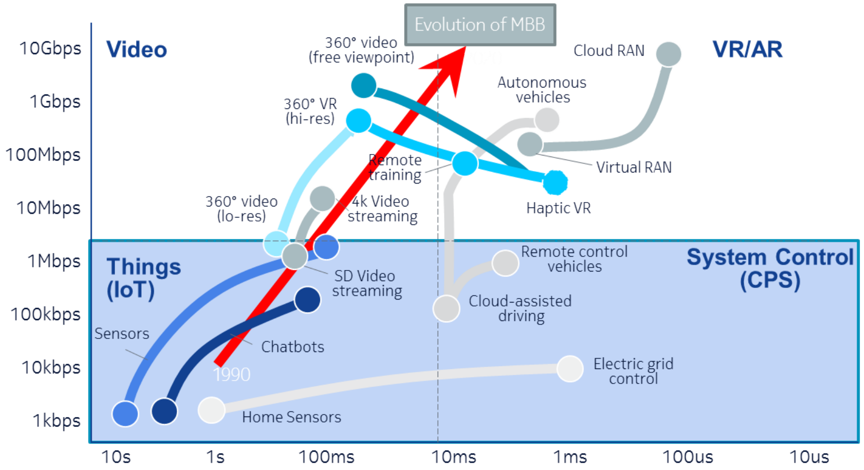
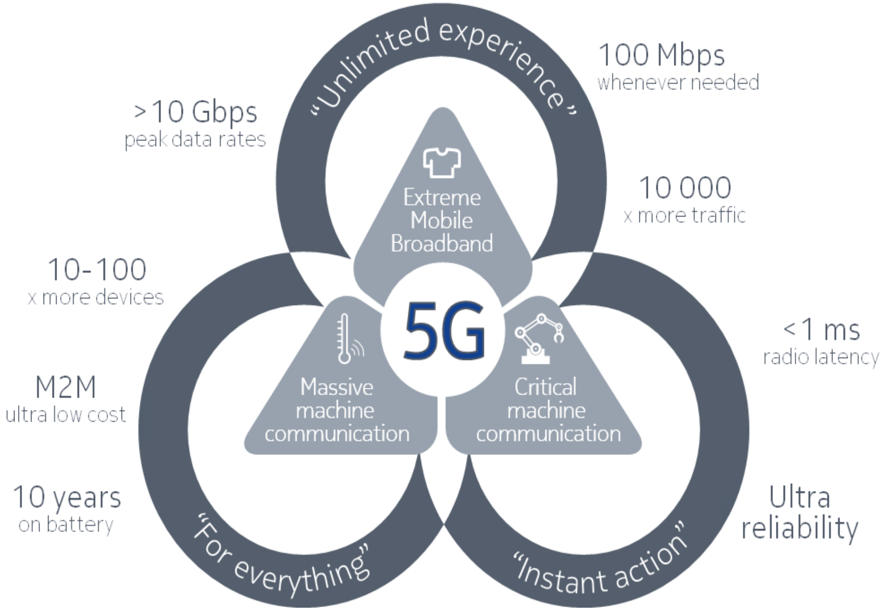
Value capture from 5G Evolution and Revolution towards 1 Tbs/km2 …

Three-pronged requirements for 5G networks







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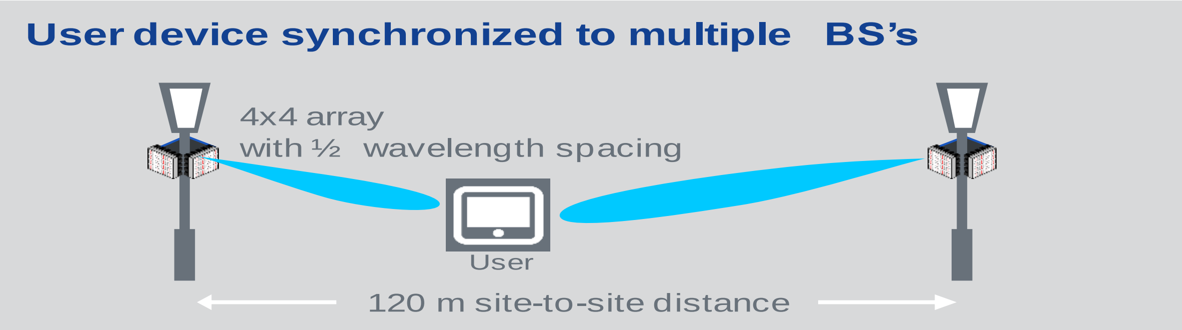
mmWave System Concept

- A much anticipated solution to meet 4G data demand is network densification
  - 4G small cells will be deployed at street-level
  - Micro/pico base stations deployed on lamp posts and sides of buildings.
  - A pico base station will be deployed every city block or roughly 120 meter site-to-site.
- The mmWave system concept is intended to complement this small cell deployment
  - Higher frequency cellular transceivers co-located with the 4G base stations.
  - Simultaneously provide backhaul for 4G and access/backhaul for 5G.



5G mmWave Challenges & Proof Points

- **Unique difficulties that a mmWave system must overcome**
  - Increase path loss which is overcome by large arrays (e.g., 4x4 or 8x8)
  - Narrow beamwidths, provided by these high dimension arrays
  - High penetration loss and diminished diffraction

- **Two of the main difficulties are:**
  - Acquiring and tracking user devices within the coverage area of base station using a narrow beam antenna
  - Mitigating shadowing with base station diversity and rapidly rerouting around obstacles when user device is shadowed by an opaque obstacle in its path

- **Other 5G aspects a mmWave system will need to address**:
  - High peak rates and cell edge rates (>10 Gbps peak, >100 Mbps cell edge)
  - Low-latency (< 1ms)

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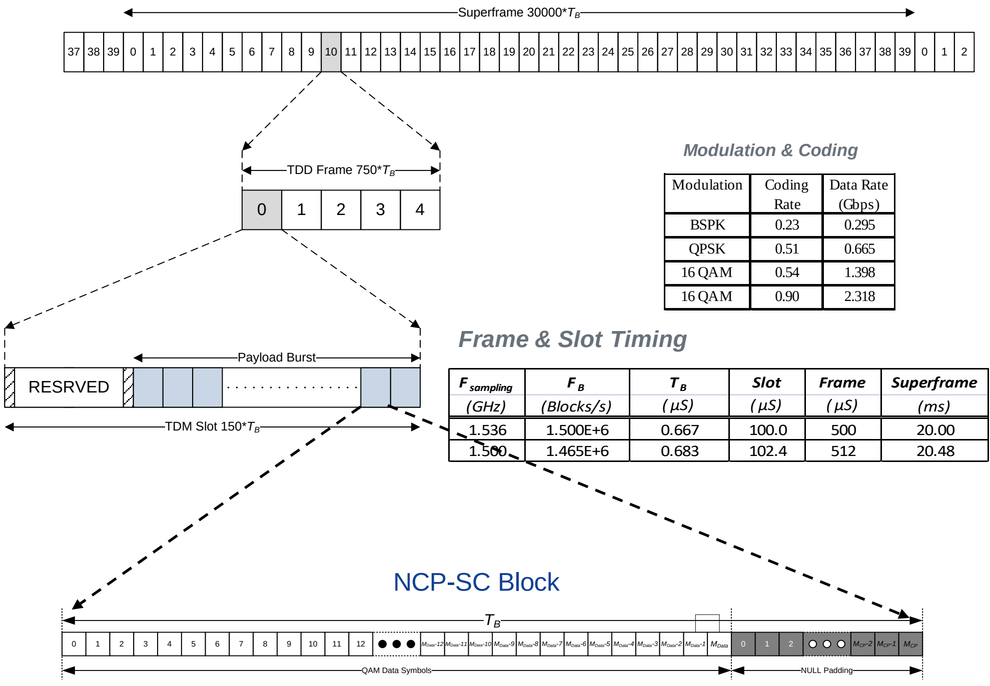
Overview: mmWave Experimental System @ 70 GHz

5G Experimental System Frame Structure

- Analog beamforming has implications for the modulation format used on the mmWave link
  - Beamforming weights are wide-band and, for OFDM, all subcarriers within a TTI must share the same beam
  - Time division multiplexing (TDM) is favored over frequency division multiplexing (FDM)
  - TDM suggests low PAPR modulation techniques can be considered to reduce the PA backoff and maximize the transmission power
- The mmWave link utilizes single carrier modulation to maintain a low. PAPR
  - PAPR is further reduced using $\pi/2$ shifting of BPSK, $\pi/4$ shifting of QPSK
- The QAM symbols are grouped into blocks of 512 symbols
- *The modulation format is called Null Cyclic Prefix Single Carrier (NCP-SC)[8]*
  - M_{data} = 480 and M_{cp} = 32 provides 40 ns RMS delay spread resilience.
  - The null cyclic prefix can be increased or decreased on a per TTI basis without impacting the overall system numerology.
- The experimental system operates with a 1 GHz bandwidth using the 512 symbol NCP-SC block.
- A system with 1024 symbol NCP-SC block to achieve a 2 GHz bandwidth has also been implemented
  - Achieves 15 Gbps peak rate with 2x2 MIMO & 64 QAM



Modulation & Coding

Modulation	Coding Rate	Data Rate (Gbps)
BSPK	0.23	0.295
QPSK	0.51	0.665
16 QAM	0.54	1.398
16 QAM	0.90	2.318

Frame & Slot Timing

$F_{sampling}$ (GHz)	F_B (Blocks/s)	T_B (μS)	Slot (μS)	Frame (μS)	Superframe (ms)
1.536	1.500E+6	0.667	100.0	500	20.00
1.500	1.465E+6	0.683	102.4	512	20.48

NCP-SC Numerology

Block Format	M_{Data}	M_{CP}
A	*480*	*32*
B	*960*	*64*

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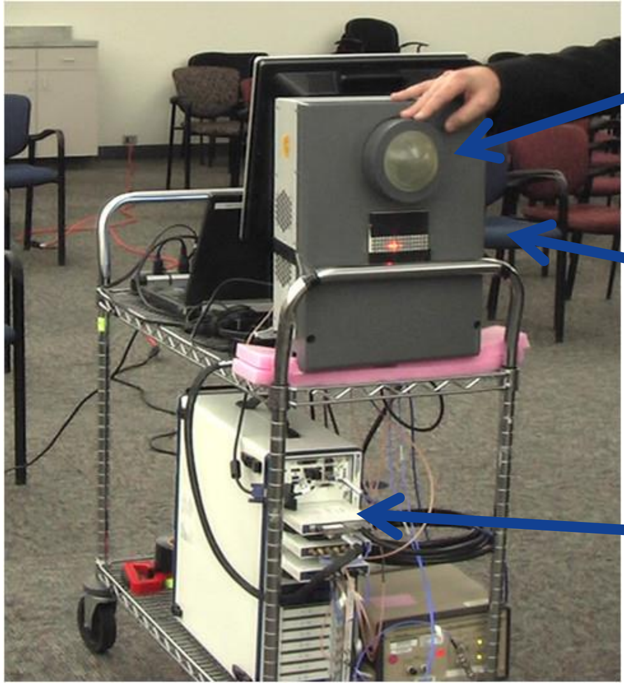
Experimental Units

Base Station



LENs Antenna

RF Unit

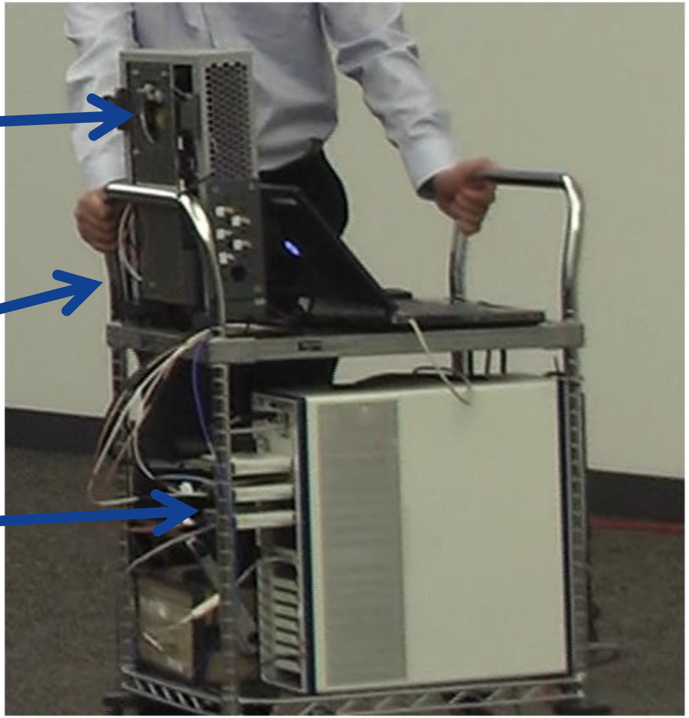
Baseband Unit

Horn Antenna

RF Unit

Baseband Unit

User Device



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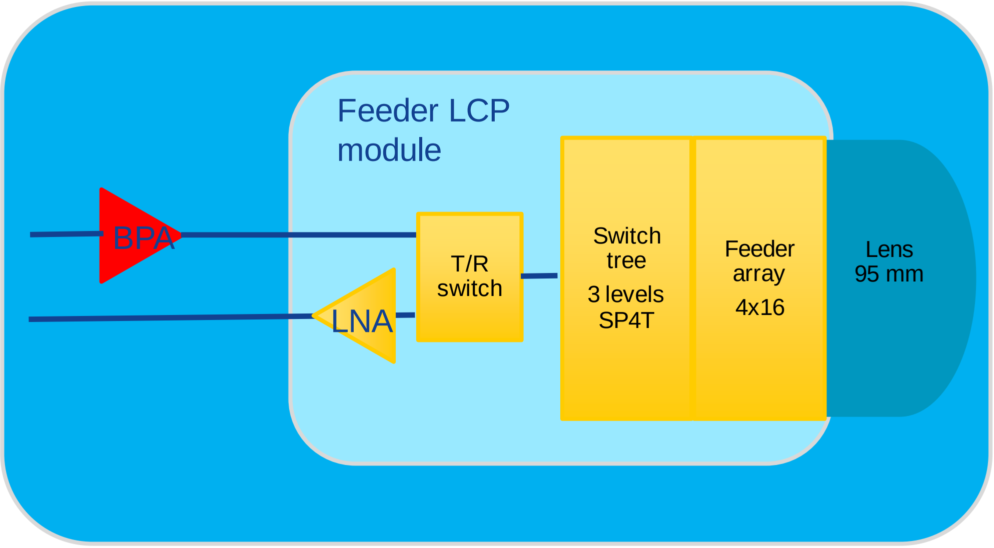
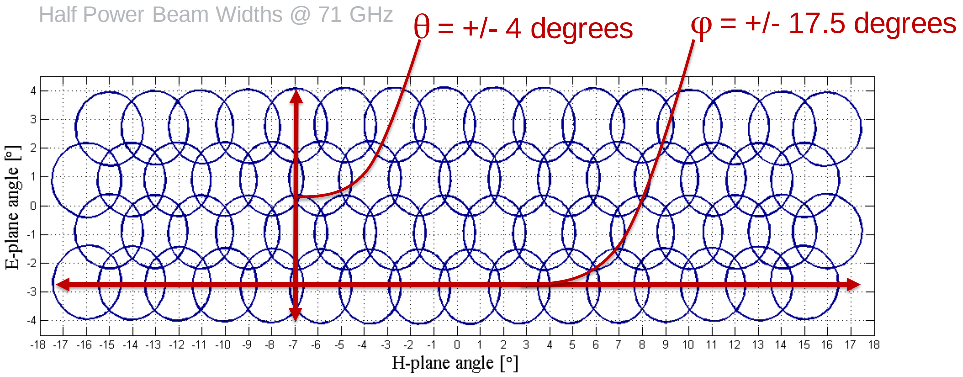
Steerable Lens Antenna

- A dielectric lens focuses the mmWave energy like an optical lens focuses light.
  - Size and curvature of the lens determines the gain and beamwidth of the antenna.
  - Antenna gain 28 dB and the corresponding half-power beamwidth (HPBW) is 3 degrees in both azimuth and elevation.
- Direction of the beam can be selected by moving the position of the focal point at the base of the lenses.
  - 64 patch antennas are switched by 3 levels of SP4T switches that determine which one of the 64 elements is excited for transmission or selected for reception.
  - The HPBWs slightly overlaps that a gain within 3dB can be maintained over the steering range of the lens.
- The combination of the lens and feeder array may be steered +/- 4 degrees in elevation and +/- 17 degrees in azimuth.
- The 3-level switching matrix can be switched with 1 us settling time and driven by the baseband processing unit and switched in synchronization with the TDM slot structure.





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Features: mmWave Experimental System

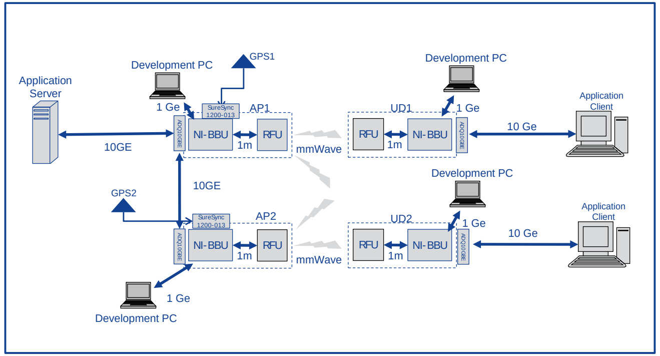
5G mmWave Hardware Demo

Features

1) **Feature 1: 1 GHz BW Single Link @ 70 GHz** √
   - Single-user acquisition and tracking Collaborate on field testing at YRP
   - Mobile World Congress 2015

2) **Feature 2: 1 GHz BW Multi Link @ 70 GHz**
   - Low latency application support < 1 ms √
   - Multi-user acquisition and tracking √
   - Dynamic TDD allocation √
   - Rapid Rerouting – Access Point Diversity

3) **Feature 3: 2 GHz BW Phased Array @ 60 GHz**
   - BBU based on new platform
   - 16 element phased array
   - **2x2 MIMO with 64 QAM modulation**
   - **Peak Rate : 15 Gbps**



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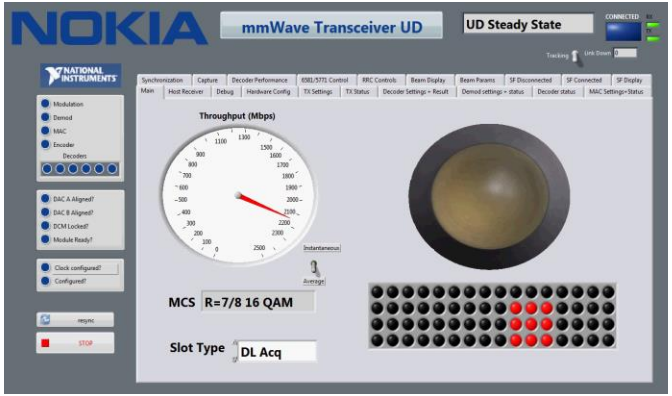
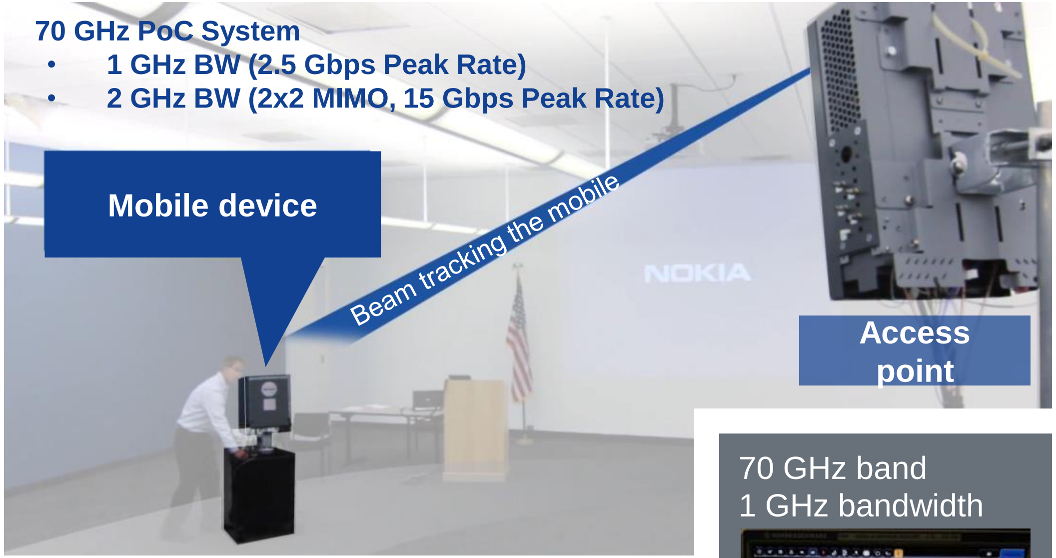
Results: mmWave Experimental System

Nokia 5G mmWave beam tracking demonstrator (70 GHz)

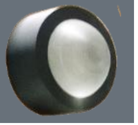
First 5G demos
CEATEC 2014



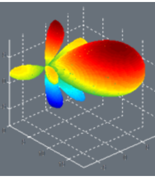
- 70 GHz PoC System
  - 1 GHz BW (2.5 Gbps Peak Rate)
  - 2 GHz BW (2x2 MIMO, 15 Gbps Peak Rate)



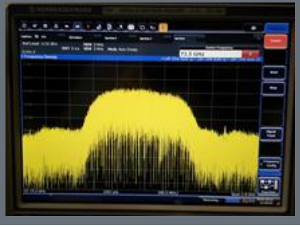
Lens antenna with 64-beam switching



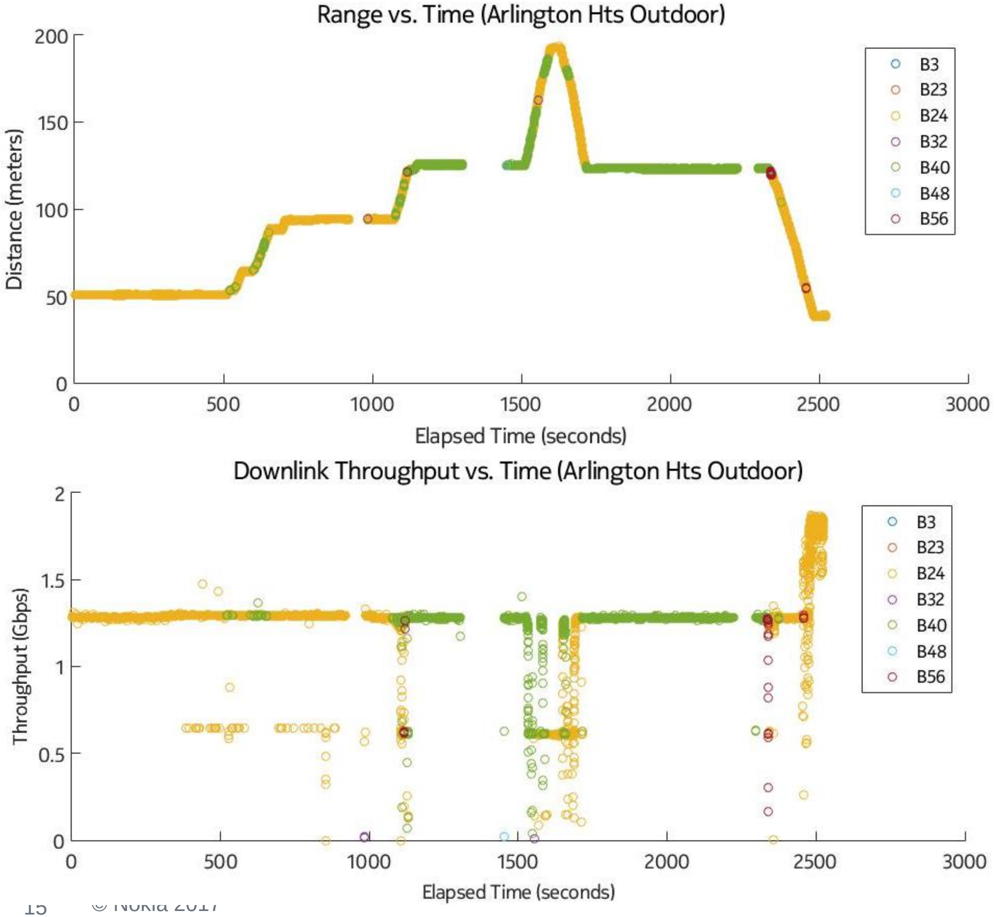
3° beam width



70 GHz band
1 GHz bandwidth



5G mmWave Outdoor results @ AH campus and Tokyo

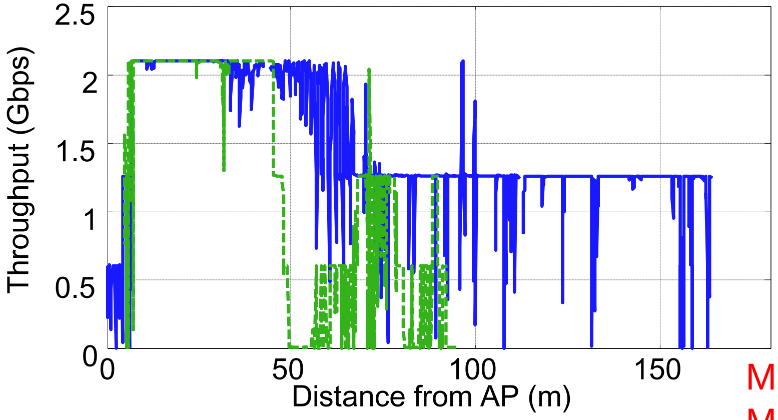


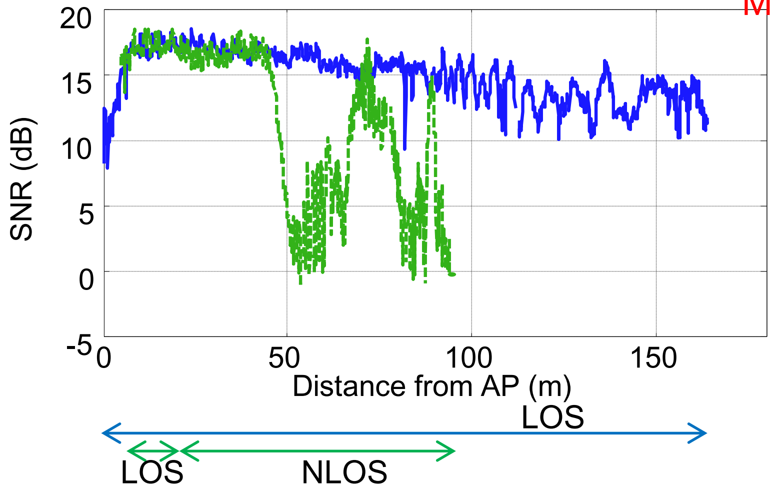
Parameters	Value
Operating Frequency	73 GHz
Bandwidth	1 GHz
Modulation	Null Cyclic-Prefix Single Carrier 16 QAM Single Stream (SISO)
Antenna Beamwidth	3 degrees
Antenna Steering Range	34 degrees Azimuth 8 degrees Elevation

Outdoor Experiments @ 73 GHz very promising

Maximum Range of 200meters

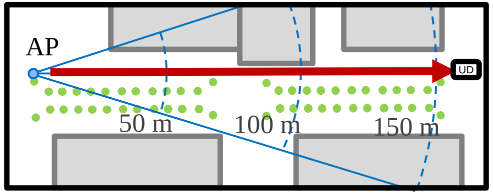
5G mmWave Outdoor results @ AH campus and Tokyo





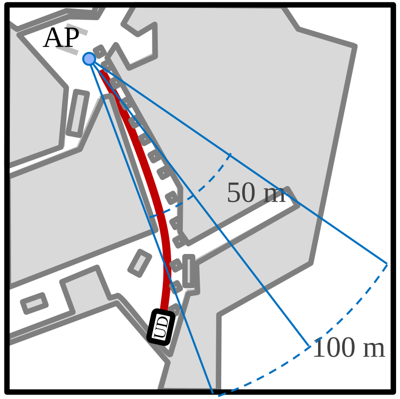
Street canyon

LOS (Minatomirai, Yokohama)



Maxm Range : more than 160 m (LOS)

Maxm Throughput: ~2.1 Gbps



Shopping mall

LOS and NLOS (Roppongi, Tokyo)

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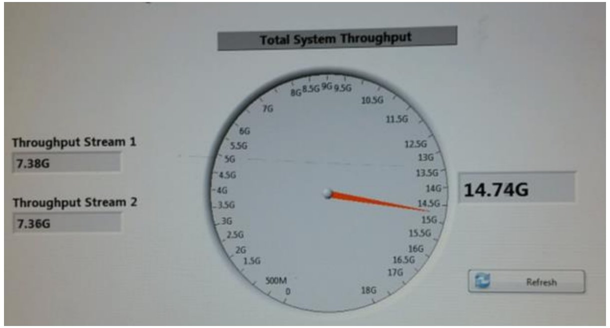
Successfully Conducts 5G Trials @ 73 GHz in Actual-use Environments

MWC -2016 demos at NTT DOCOMO and Nokia Booth

mmWave PoC System @ 74 GHz and 2GHz BW supporting 14.7 Gbps Peak rate

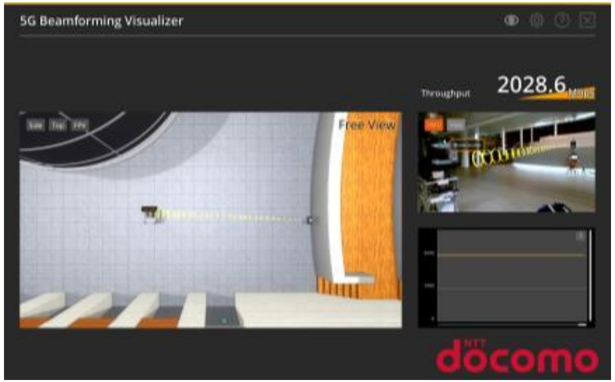
Nokia Booth: High Throughput



Parameters	Value
Operating Frequency	74GHz
Bandwidth	2 GHz
Antenna	Horn Antenna
Throughput	14.7 Gbps

mmWave PoC System @ 73 GHz and 1 GHz BW with Beamsteering and Low Latency

DOCOMO Booth: AR Beam Visualization and Low Application Latency Gigi-bit speeds



Parameters	Value
Operating Frequency	73.5 GHz
Bandwidth	1 GHz
Antenna	Lens w/Beamsteering
One way Latency	<1 msec

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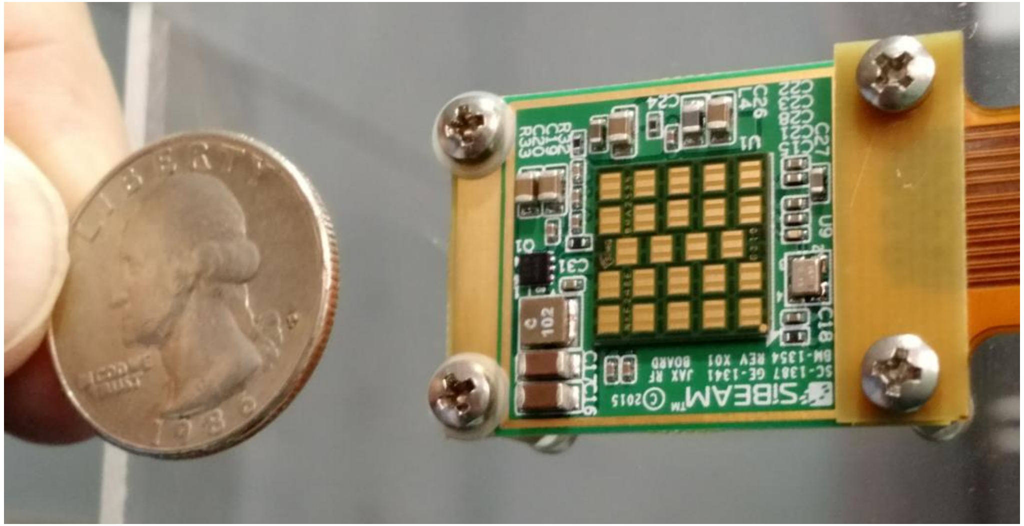
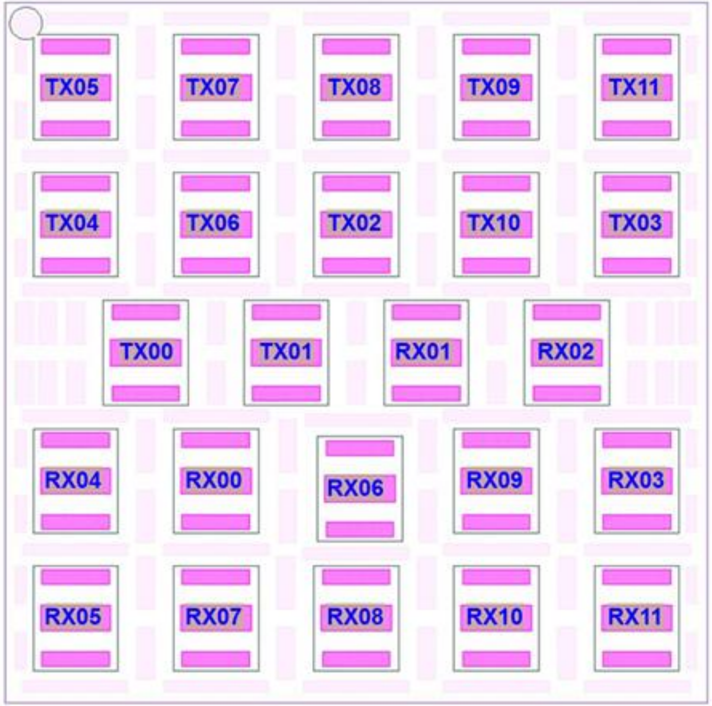
Beamscanning with a Phased Array





Courtesy of SiBEAM, a Lattice Semiconductor company

Milestone 2.2 Demo

Dynamic TDD Coordination and relative performance for different traffic loads

- Goals:
  - Demonstrate that dynamic TDD can perform well for low utilization for geometries
  - Demonstrate that TDD frame coordination is needed between APs when the utilization is high
- New components (Nokia provided):
  - Traffic generator tool based 3GPP TR 36.814 bursty traffic model
  - Demo display application showing dynamic TDD performance

Utilization

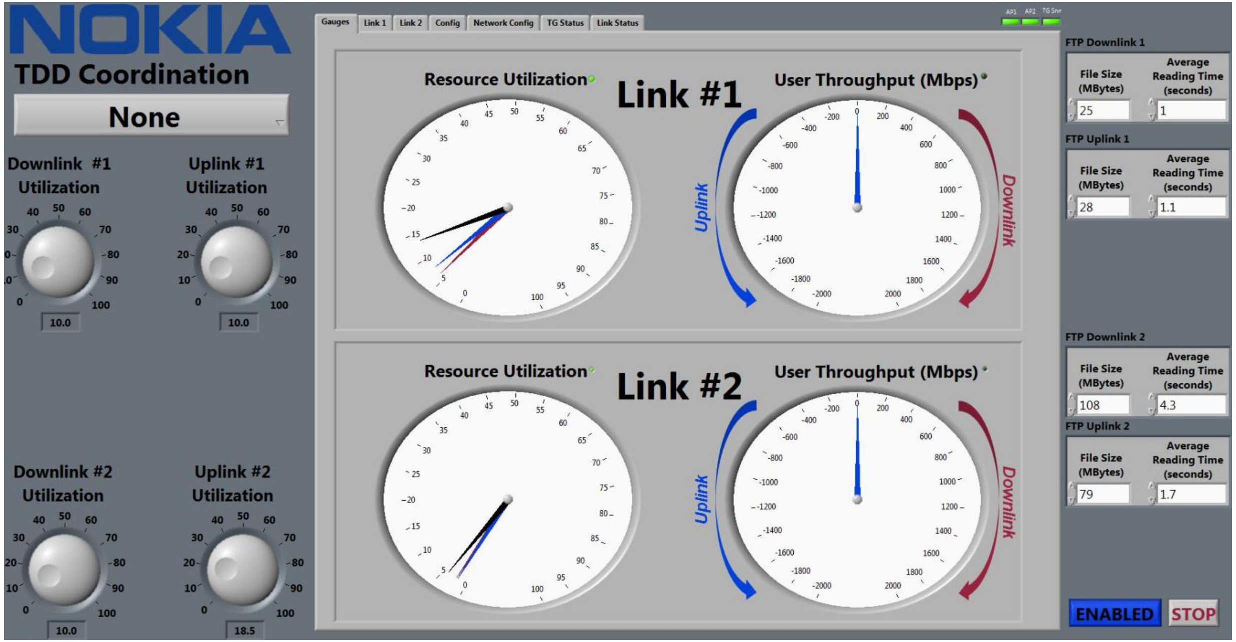
TDD Coordination	Low	Mediu m	High
None	BEST		WORS T
Loose		BEST	
Fixed	WORS T		BEST

First implementation of dynamic TDD @ mmWave!

Milestone 2.2 Demo

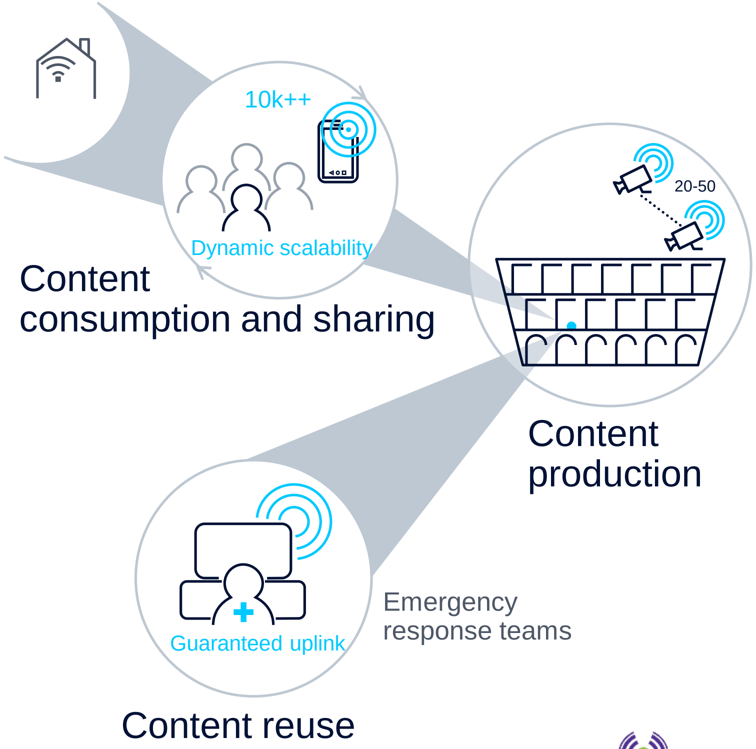
Demo display PC for the dynamic UL/DL split over a mmWave link

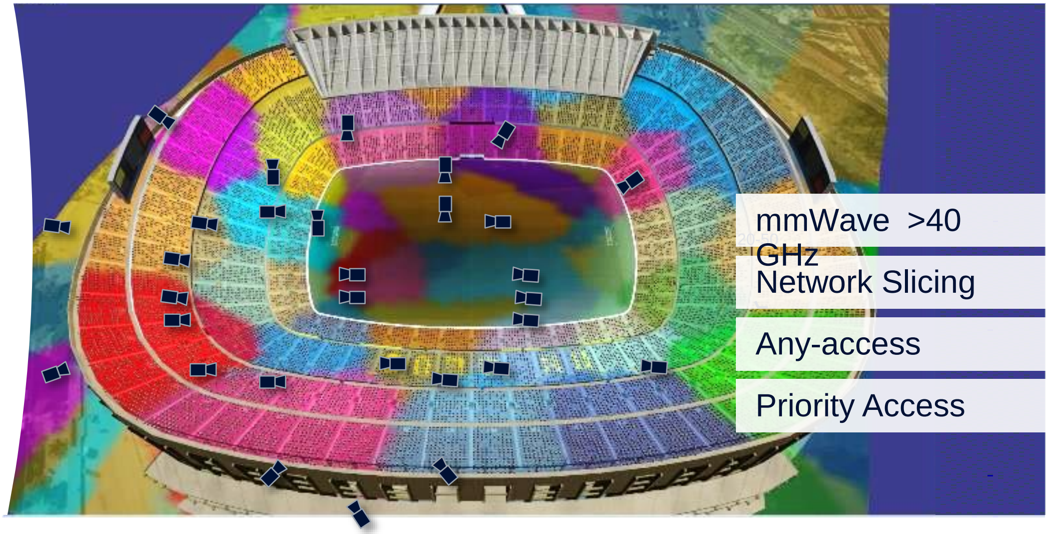
- Demo display application shows key metrics of dynamic TDD operation and interference mitigation
  - Resource Utilization
  - User Throughput
  - FTP model parameters



Dynamic TDD and TDD coordination

For dynamic adaptation to time varying traffic demand





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Nokia 5G mmWave beam tracking demonstrator (70 GHz)

Rapid Rerouting Feature

- **Scenario: 2 APs and 1 UD**
  - APs are configured for overlapping coverage creating a triangle between AP1, AP2 and the UD
  - UD is positioned such that it can detect both APs. UD will display the detected beams from both APs. The UD will maintain connectivity to both the serving and alternate AP.
- **TCP/IP throughput**
  - Iperf application running over the mmWave will be used to demonstrate throughput
  - The throughput will be displayed on the User Device (UD) display showing the raw of PHY throughput of 2 Gbps.
  - Rapid re-routing between APs will show minimal TCP/IP throughput degradation depending on type of re-route.
- **Rapid Rerouting demonstrations:**
  - **Blockage Detection (BD)**: Serving AP is blocked by demonstrator using a mmWave opaque device (many different physical items are suitable).
  - **Make Before Break (MBB)**: UD is rotated slowly to favor the alternate AP initiating a re-route.
  - **Break Before Make (BBM)**: An abrupt change where both APs are blocked and the UD must re-initialize the connection.

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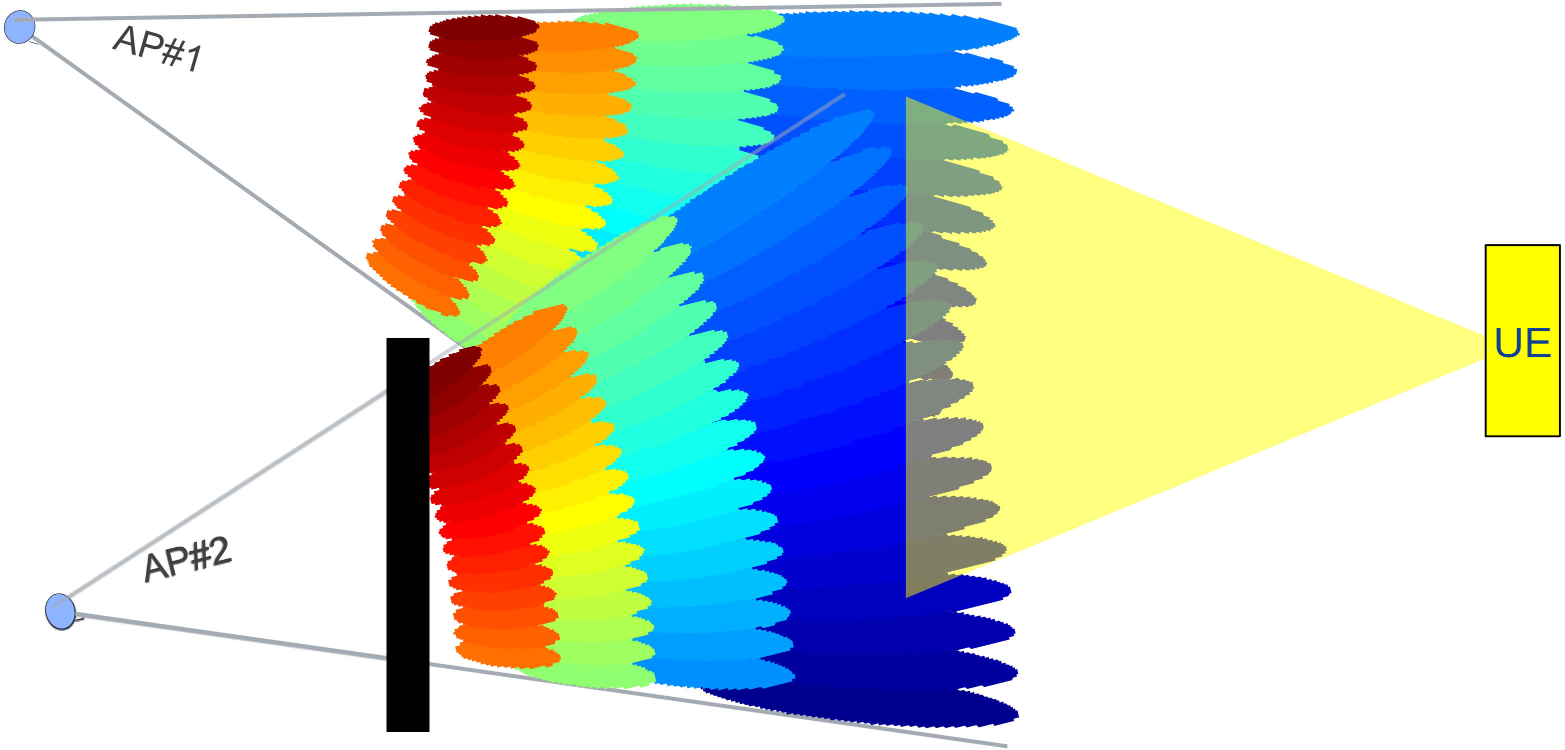
mmWave Rapid Rerouting
Blockage Detection



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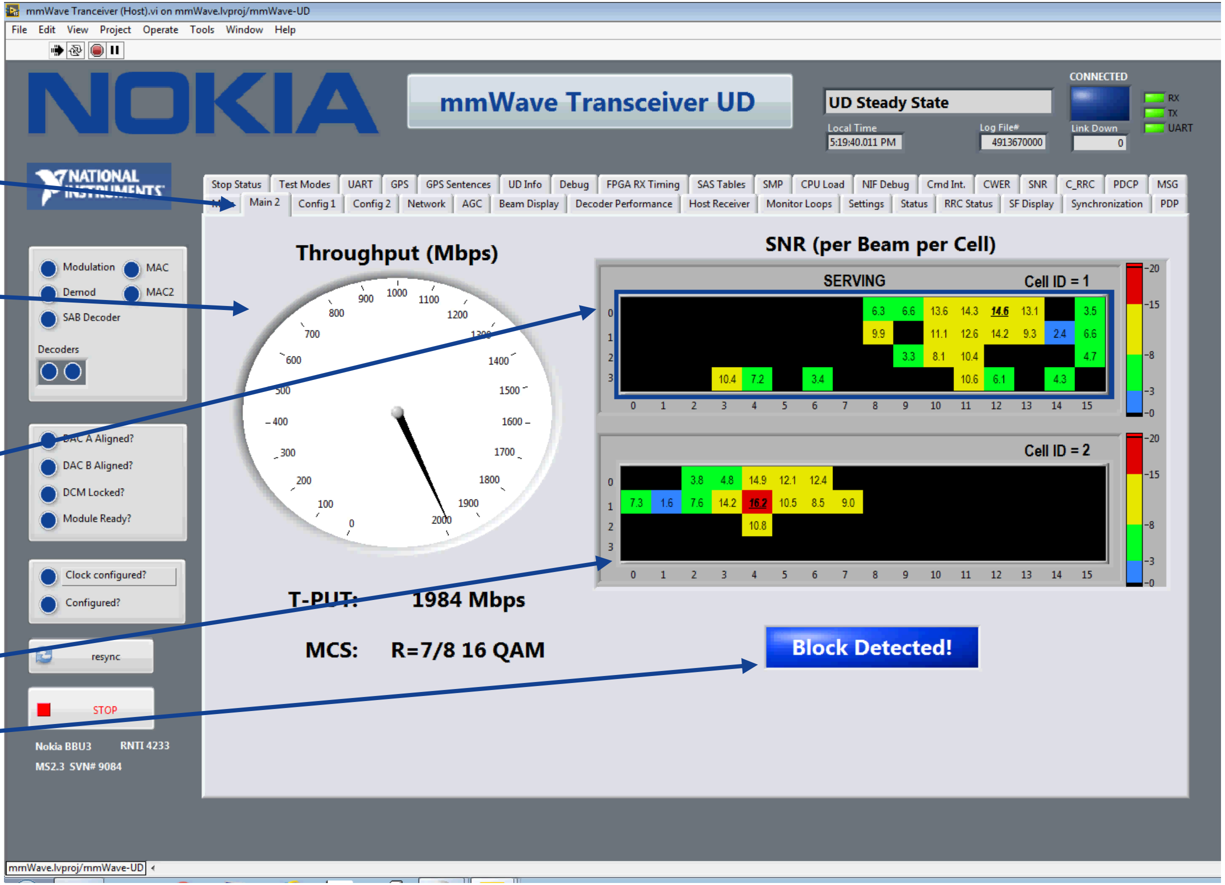
mmWave Rapid Rerouting

Demo Display – “Main 2” tab

- New “Main 2” Tab
  - Main 2 can be used for demonstrations showing physical layer throughput, serving cell and detected beam SNR
- Throughput Gauge
  - Duplicated from the “Main” tab shows the downlink throughput of the UD visible to observers. Throughput and active MCS are visible below in text.
  - Reflects the application throughput running over the link. Recommend Iperf session running over the mmWave link
- SNR (per Beam per Cell)
  - Shows the beam SNR per cell for all 64 beams: 16 QAM 7/8 is in red; 16 QAM ½ is in yellow, QPSK ½ is green and BPSK 1/5 is blue. Undecoded beams are left blank
  - The serving cell is identified by the text “SERVING” and by a blue border
- Blockage Detection
  - When the UD RRC detects an abrupt drop in detected beams, the link will be rerouted and the “Block Detected!” LED will be illuminated for 1 second.



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Summary

Summary

- Experimental systems are critical to proving that higher frequencies can be used to achieve 5G objectives.

- The 73.5 GHz, 1 GHz BW experimental system with a steerable 28 dB gain, 3 degree HPBW antenna helped to prove many of the 5G concepts
  - Feasibility of acquiring and tracking user devices within the coverage area of base station using a narrow beam antenna
  - Achieving Latency of less than 1msec
  - Dynamic TDD using multilink system
  - Rapid Rerouting
    - Multi link system will demonstrate how shadowing can be mitigated with base station diversity and rapidly rerouting around obstacles
- Demonstrated a peak rate of 15 Gbps using 2x2 MIMO and 64 QAM modulation @ MWC-2016

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Contributors

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Q&A

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