Can Mmwave Wireless Technology meet the future capacity crunch

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ICC, June 11th, 2013
Nokia Siemens Networks

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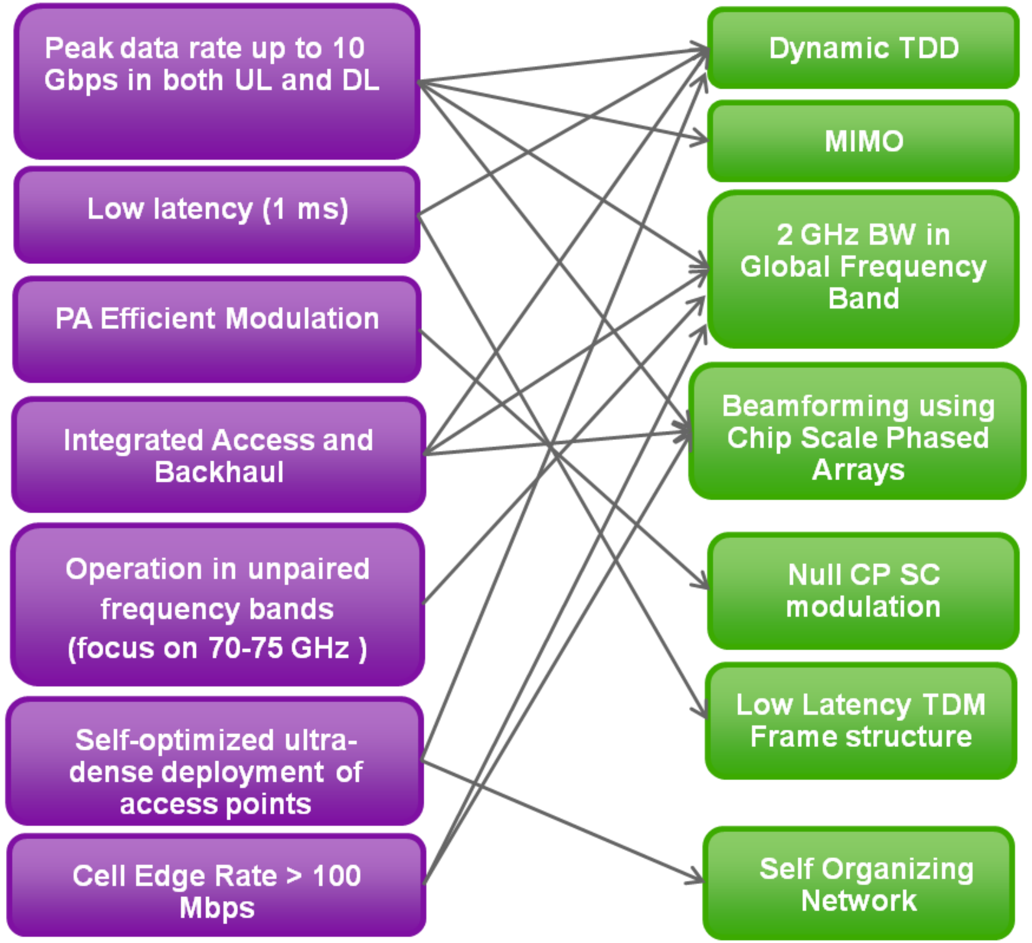
Presentation Outline

- **4G Technology and our view on 5G**
- **Mmwave Spectrum and Propagation**
- **Mmwave Air Interface**
- **Mmwave IC Technology**
- **Integrated Backhaul and Access**
- **Summary**



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4G Technology : LTE-A -> 3GPP Rel-12/13

- **3GPP Rel-12/13 workshop held in June-2012**

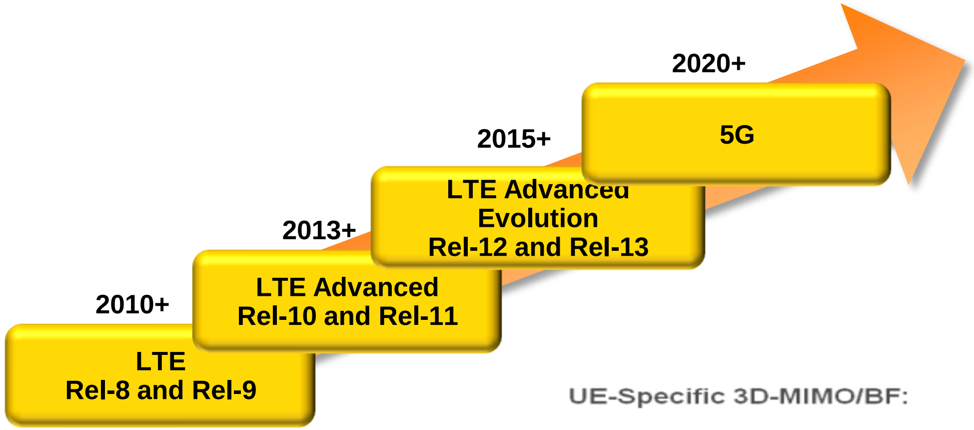
- **Requirements for 3GPP Rel-12/13**
  - Capacity increase to cope with traffic explosion
  - Energy saving and Cost efficiency
  - Support for diverse application and traffic types
  - Higher user experience/data rate
  - Backhaul enhancement

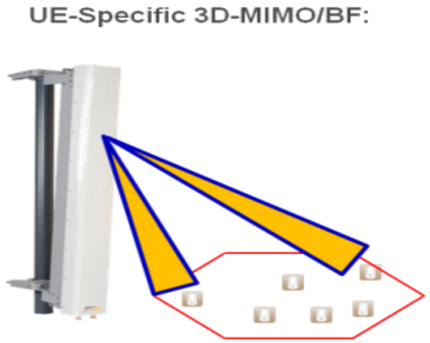
- **Key Study Item**
  - Enhanced Small Cell for LTE

- **Macro Cell Enhancements**
  - LTE Multi-Antenna/site technologies like 3D-beamforming

- Additionally new procedures and functionalities for LTE to support
  - Diverse traffic types
  - Interworking with WiFi, SON, MDT
  - Advanced receivers, MTC, D2D, some HSPA enhancements etc

- 18-24 months of Release 12 timeframe





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Our view on mobile communication evolution beyond 2020

- Several national and regional research project have been launched on B4G/5G and ITU-R 5D has draft documents on “vision for IMT for 2020 and beyond” and ”future technology trends of IMT terrestrial systems” are currently being drafted.

- Motivation for 5G includes: larger traffic volume, higher data rates, lower latency, more connected devices increased reliance on connectivity, new use cases, energy efficiency and lowest TCO.

- Main anticipated technology enables for 5G vision include (see also NSN Insight article)
  - Increasing spectrum availability (both below and above 6GHz)
  - Improve spectral efficiency (by MIMO, advanced transceivers and interference coordination)
  - HetNet (with high focus on small cells)

- NSN has launched internal 5G research projects, is second strongest partner in METIS and has various bilateral discussions with key operators, ecosystem players and academia.

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By 2030 we may need 10000x Capacity

10x Performance

20x Spectrum

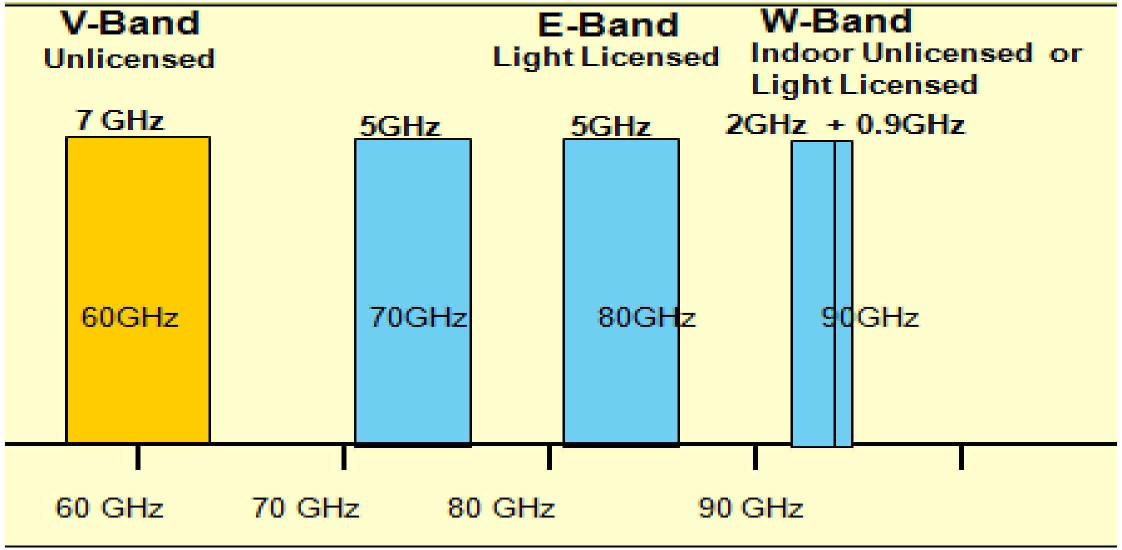
50x Base stations

=

10000x Capacity

Exploit Spectrum > 6 GHz

Pico/Femto Cell Densification



- Focus on 71-76/81-86GHz initially
  - FDD and TDD possible
  - License-light regime in both USA and Europe
  - 90-95GHz is fragmented

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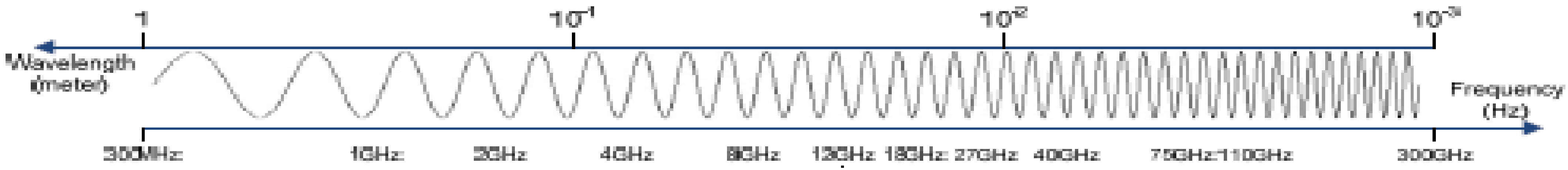
Spectrum, Spectrum and Spectrum



In theory, any spectrum could be freed in the future for 5G above 6GHz

Consider 6-100GHz: 94GHz potentially

If only 1/3 available: 31GHz total

Criteria: consider spectrum which

- already has a Mobile allocation which is harmonized at ITU-R level (economy of scale)
- maximizes amount of spectrum (multiple licensees)
- minimizes changes (least resistance)
- maximizes channel bandwidth (5G requirements)

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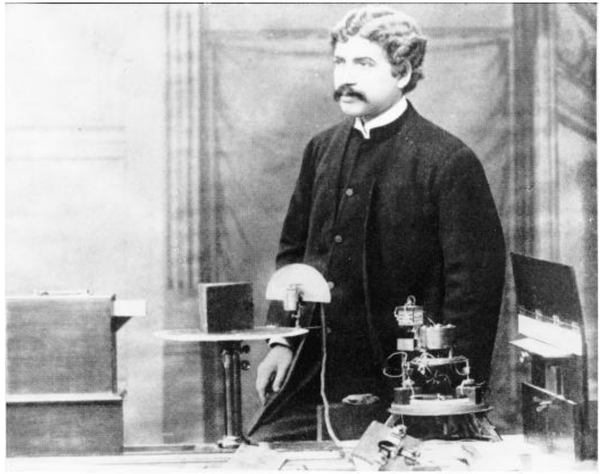
Why Mmwave for 5G Enhanced Local Area Network?

- **Abundance of Spectrum @ 70-90 GHz band**
- **10Gbps of Peak Rate and > 100Mbps Cell Edge Rate**
  - **Utilize 2 GHz BW, Low Latency, Simple Air-Interface**
- **Spectrum well suited for deploying Pico/Femto Cells**
  - **100-150 meters ISD**
  - **Noise limited Scenario**
  - **Dynamic TDD**
- **Massive Antenna Arrays**
  - **Antenna Geometries at Chip Scale**
- **Integrated Access and Backhaul**



Interesting Tid-bits

Sir Jagadish Chandra Bose, in 1895, first demonstrated at Presidency College, Calcutta, India, transmission and reception of electromagnetic waves at 60 GHz, over a distance of 23 meters, through two intervening walls by remotely ringing a bell and detonating gunpowder. For his communication system, Bose developed entire millimeter-wave components such as: a spark transmitter, coherer, dielectric lens, polarizer, horn antenna and cylindrical diffraction grating.

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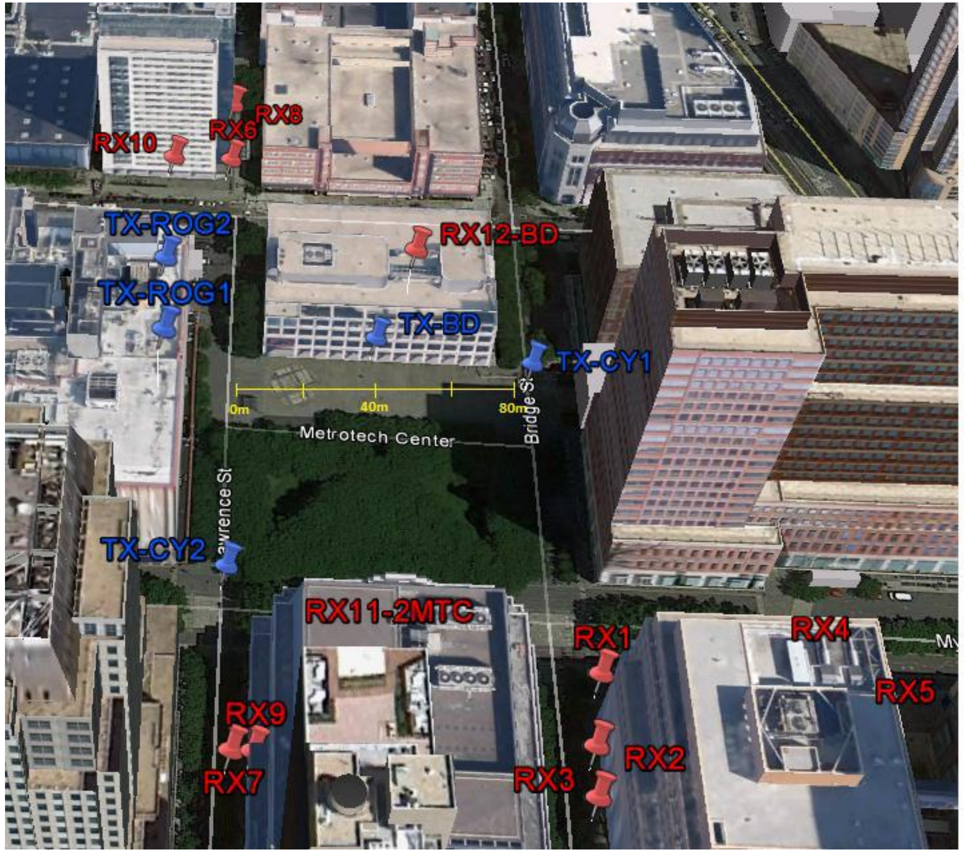
NYU 72 GHz Measurement Campaign in NYC 2013

- Started in March 2013
- Goal: characterize pathloss, polarization, delay spread, signal outage, penetration loss, angle spread at 72 GHz
- **First step:** indoor measurements (4 Tx, 14 Rx locations)
  - Mostly to validate system and test procedures before going outside
  - Also characterize indoor environment at 72 GHz
- **Second step:** outdoor measurement
  - Brooklyn (5 Tx, 12 Rx) and Manhattan (3 Tx, 15 Rx)
  - Backhaul-to-lamppost
  - Lamppost-to-lamppost
  - Lamppost-to-mobile
  - Backhaul-to-backhaul (time permitting)
  - Measurements to be taking with and without foliage, in adverse weather (rain and if permitting snow)

Measurement campaign done with Dr. Ted Rappaport of NYU



Brooklyn Measurement Setup

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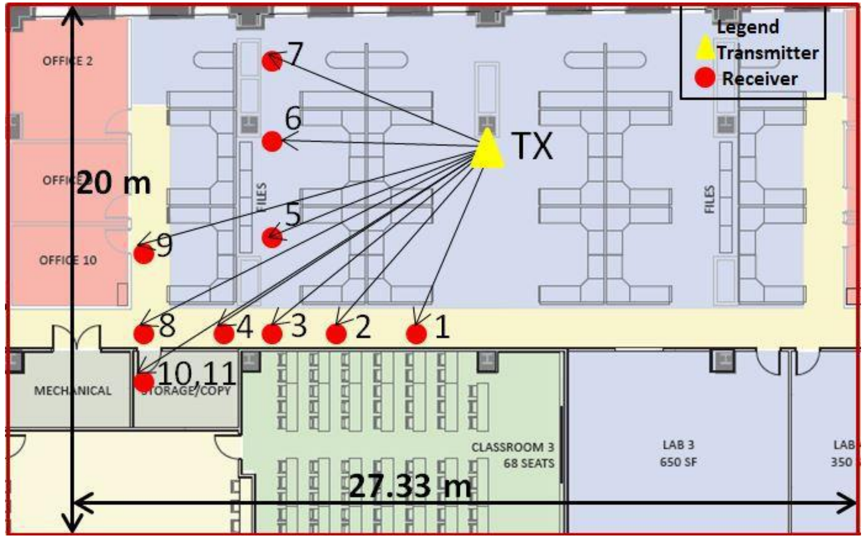
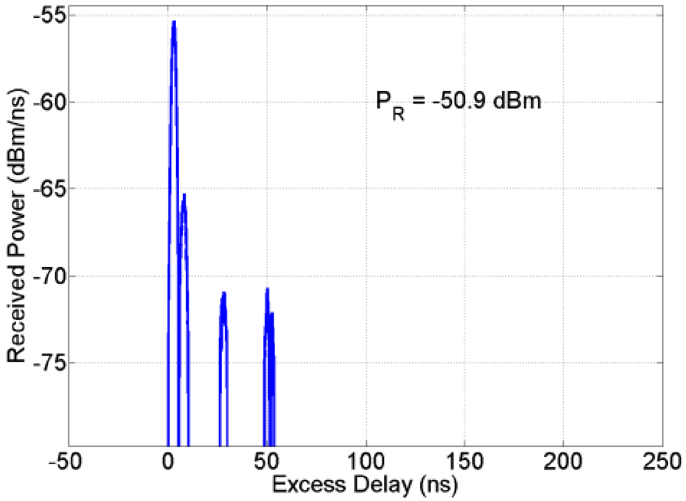
NYU 72 GHz Measurement Campaign in NYC 2013



RX ID	TX-RX Separation (m)	# of Partitions			Transmitted Power (dBm)	Received Power for Free Space (dBm)	Received Power for Test Material (dBm)	Penetration Loss (dB)
		Cubicle Wall	Dry Wall	Wood Door				
1	6.8	1	0	0	12.3	-34.1	-34.9	0.8
2	8.0	2	0	0	12.3	-35.6	-48.2	12.6
3	10.1	3	0	0	12.3	-37.6	-56.7	19.1
4	11.5	2	1	1	12.3	-38.7	-70.6	31.9
5	8.6	2	0	0	12.3	-36.2	-45.7	9.5
6	8.1	1	0	0	12.3	-35.7	-40.9	5.2
7	8.8	2	0	0	12.3	-36.4	-58.2	21.8
8	14.0	3	1	1	12.3	-40.4	-50.9	10.5
9	13.0	2	0	0	12.3	-39.7	-48.5	8.8
10	15.2	2	2	1	12.3	-41.1	-55.7	14.6
11	15.2	2	2	1	12.3	-41.1	-54.4	13.3

Penetration Losses at different Rx Locations @ 73.5 GHz



- Initial Indoor Measurements
  - Multi-path rich indoor environment
  - Viability of indoor communications at E-band

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Mmwave Requirements, Propagation and LB

- **Summary**
  - Higher pathloss compared to <=5 GHz (21 dB worse than 5 GHz, 29 dB worse than 2 GHz)
  - Oxygen/water absorption and rain loss not an issue for radius < 200m and mm-wave frequencies between 70 and 100 GHz
  - Foliage loss is severe
  - Channel variations 30x worse than at 2 GHz
  - Transmission through most objects is reduced at Mmwave but reflection is amplified
  - Delay spread with narrow beam antennas is less than 1 ns in LOS conditions
  - With narrow beam antenna the RMS delay spread in non-LOS conditions has a mean of 7.39 ns and a maximum of 36.6 ns
  - Reflective paths do exist (between 3 and 5 paths) which can be used to establish non-LOS links but with a loss from 15 to 40 dB over LOS

Requirements

B-4G KPI’s	Values	Comment
Peak Data Rate	>10 Gbps	Driven by technology competition
Bandwidth	1-4 GHz	Ample bandwidth available @Mmwave
Minimum data rate	>100 Mbps with 90% probability	Dictates the user experience for B-4G
Duplexing	TDD	Dynamic changes in DL & UL traffic
Latency	< 1msec	True local feel
Inter-site distance	~100m	Indoor and hot spot deployments
Backhaul data rate	>10 Gbps	All-in-one 5GNB

Mmwave System Range

	60 GHz	75 GHz	85 GHz	95 GHz
UL: 10.0 Gbps	6.0 m	4.3 m	5.1 m	4.0 m
UL: 125 Mbps	121 m	113 m	134 m	106 m
DL: 10.0 Gbps	5.3 m	3.8 m	4.5 m	3.6 m
DL: 125 Mbps	111 m	101 m	119 m	95.1 m

Mmwave network must be able to avoid, steer around, or adapt to obstacles

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Addressing the Body Loss Issue

- Body loss at mm-wave bands is quite high, >20dB, due to the high absorption of energy in these bands to water
- In general, mm-wave communication links often require solutions that provide methods to mitigate LOS blockage
- One means to achieve this is to utilize steerable, directional antenna arrays
- These arrays steer the beam in a direction that achieves a link via:
    - Access an alternate base station node this is LOS
    - Access the main, or alternate, base stations with a suitable low loss reflection
- Areas that have been identified for further study to optimize the solution are:
    1. Base station node placement scenarios – where, how many, how far apart
    2. User device antenna scenarios – omni, directional, how many
    3. Detailed channel modeling – Reflection characteristics -> loss & delay profile
    4. Antenna control and MAC algorithms supporting steered beam solutions

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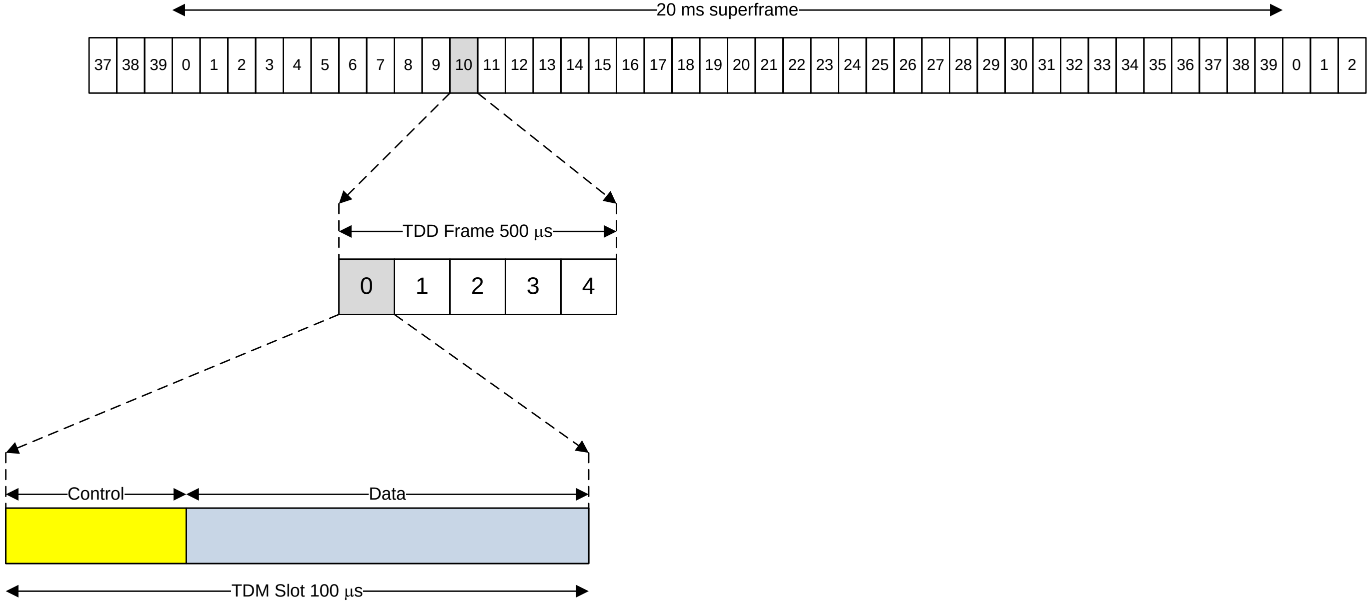
Air-Interface Design: Summary

- **Air-Interface for mmwave**
  - Upbanding LTE to mmwave may not be the right choice
  - TDD (Variable DL/UL traffic, Simpler Transceiver)
    - Frame Size = 500 µs
    - Slot Size = 100 µs
    - Downlink/Uplink Interval : Variable
  - Why not OFDM?
    - Few users per AP, no need for FDM
    - Multiple users have to share the same Tx/Rx beam -> loss of beamforming gain
  - Simple MA technique (Null CP Single Carrier)
    - Null portion enables RF beam switching in the CP without destroying the CP property
    - BW = 2000 MHz
    - Data Block Size = 1024
    - Pilot Block Size = 256

-Modulation

-QPSK, 16 QAM, 64QAM

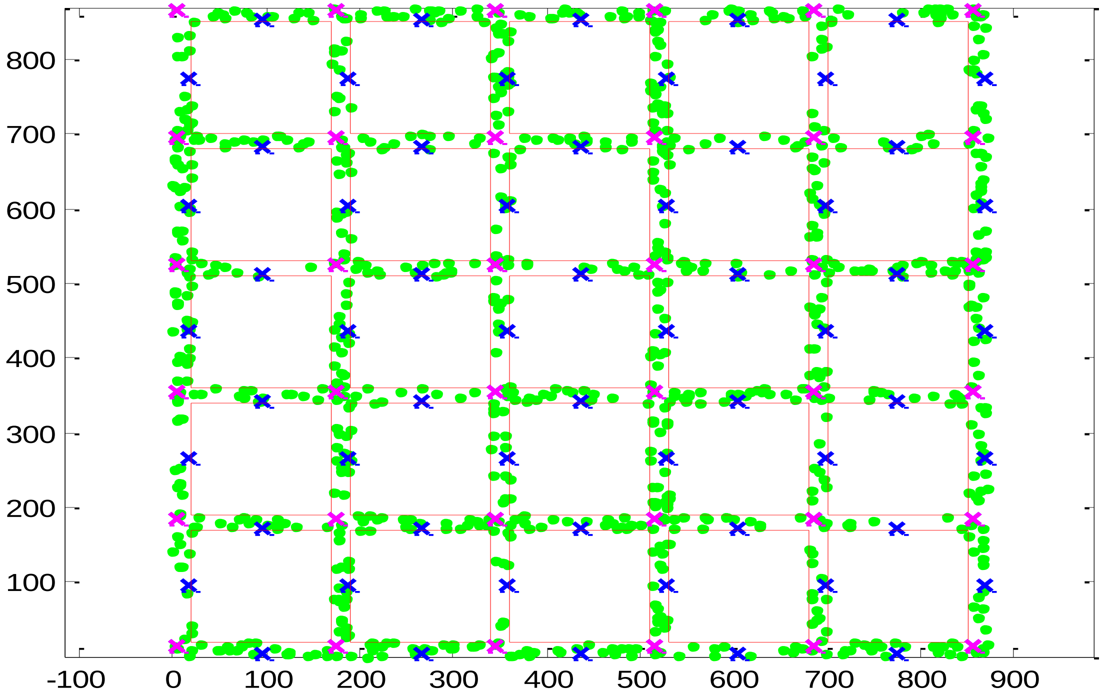
-**Huge Throughput and Cell Edge gains**



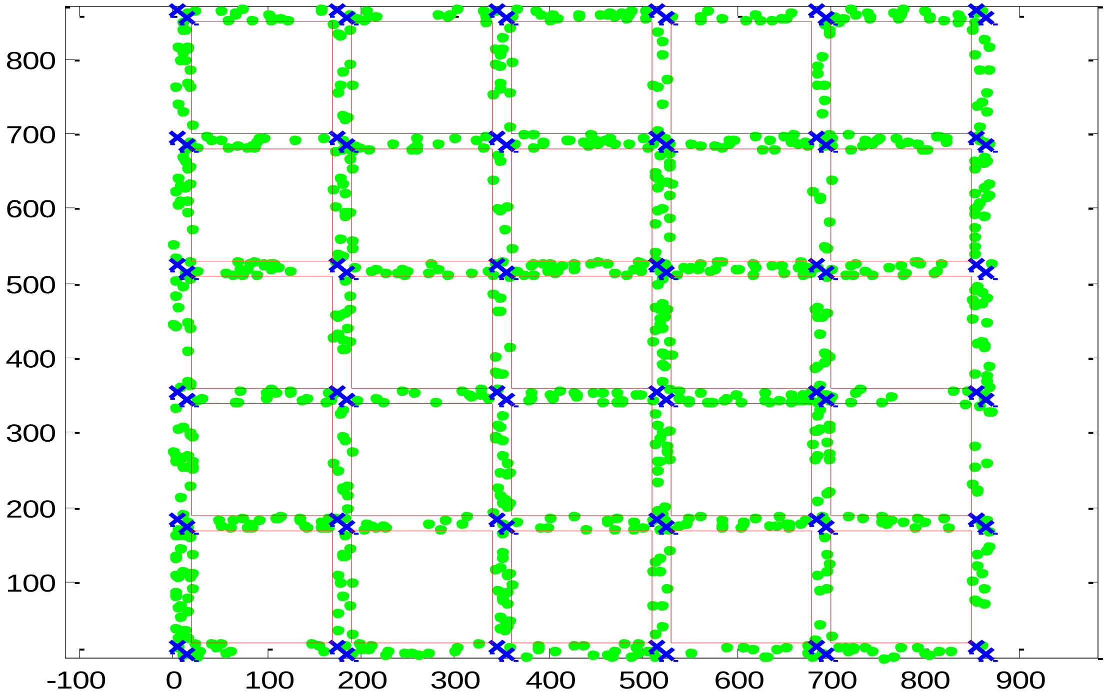
	LTE	802.11ad		B4G-MMW
Frequency Band	< 6 GHz	60 GHz		70 GHz
Supported Bandwidths	TBD	2160 MHz		2000 MHz
Maximum QAM	64	16	64	16
Modulation	OFDM	SC	OFDM	NullCP-SC
Channel Spacing (B)	20 MHz	2.16 GHz	2.16 GHz	2 GHz
FFT Size	2048	512	512	1024
Subcarrier Spacing	15 kHz	*4.2 kHz*	5.1 kHz	*2 MHz*
Sampling Frequency	3.072 MHz	1.76 GHz	2.46 GHz	1.54 GHz
Tsampling	32.6 ns	5.68 ps	406 fs	651 fs
Tsymbol	66.7 µs	245 ns	198 ns	666.7 ns
Tguard	4.7 µs	36.4 ns	52 ns	10.4 ns
T	71.4 µs	291 ns	250 ns	666.7 ns

System Simulation Setup

Setup 1 (36 APs) and Setup 3 (96 Aps)



Setup 2 (72 APs)

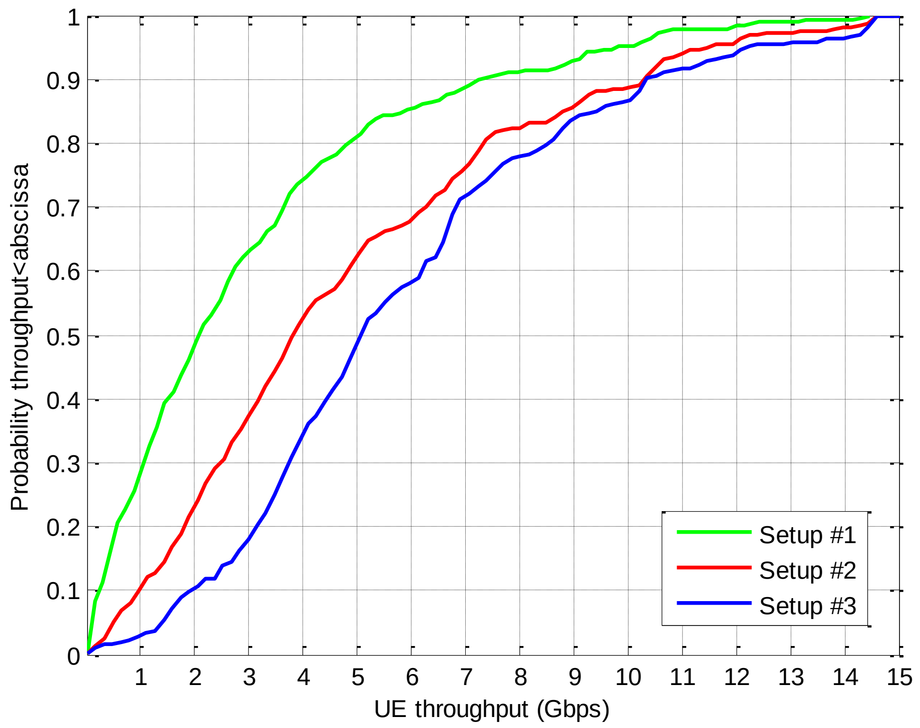


- Green dots are UEs, blue and magenta x's are access points, red square is a city block (made up of multiple buildings)
  - Magenta APs are present both for setup 1 and 3 (setup 1 only has the magenta APs)
- UE assumed 100% blocked if a building is between it and the access point
- UEs attached to outer ring of APs not used when reporting statistics
- Line of sight pathloss used, but channel will add further fading when line of sight is blocked and for reflection losses

System-level results

Setup 1 (36 APs):

Parameters	Values
Average UE throughput	3.01 Gbps
Cell Edge (5%)	24.5 Mbps
Maximum UE throughput	14.5 Gbps
Minimum UE throughput (not in outage)	109 Mbps
Probability of outage (UE TP<100 Mbps)	7.8%



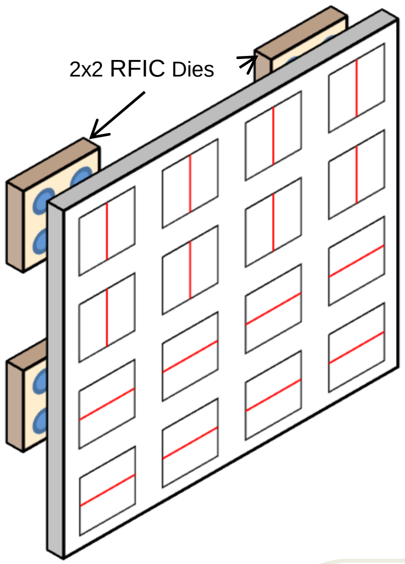
Setup 2 (72 APs):

Parameters	Values
Average UE throughput	4.76 Gbps
Cell Edge (5%)	479 Mbps
Maximum UE throughput	15.7 Gbps
Minimum UE throughput (not in outage)	224 Mbps
Probability of outage (UE TP<100 Mbps)	1.2%

Setup 3 (96 APs):

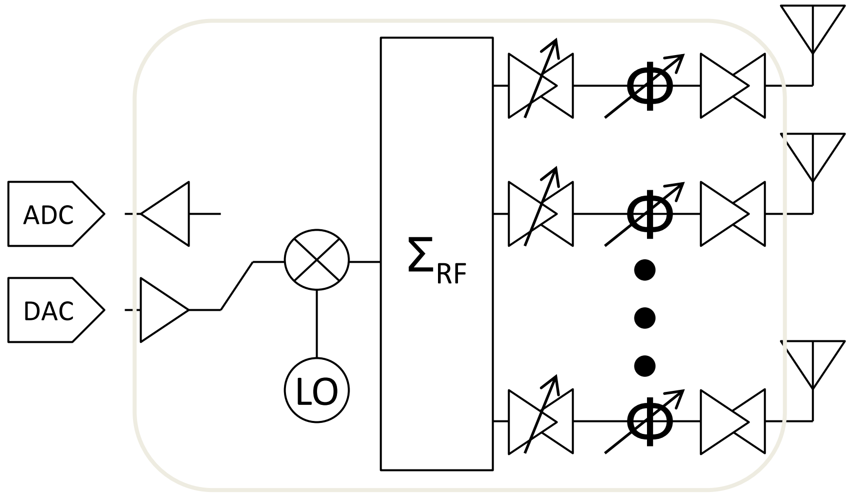
Parameters	Values
Average UE throughput	5.79 Gbps
Cell Edge (5%)	1396 Mbps
Maximum UE throughput	15.7 Gbps
Minimum UE throughput (not in outage)	285 Mbps
Probability of outage (UE TP<100 Mbps)	0.9%

Scalable RFIC Array Topology

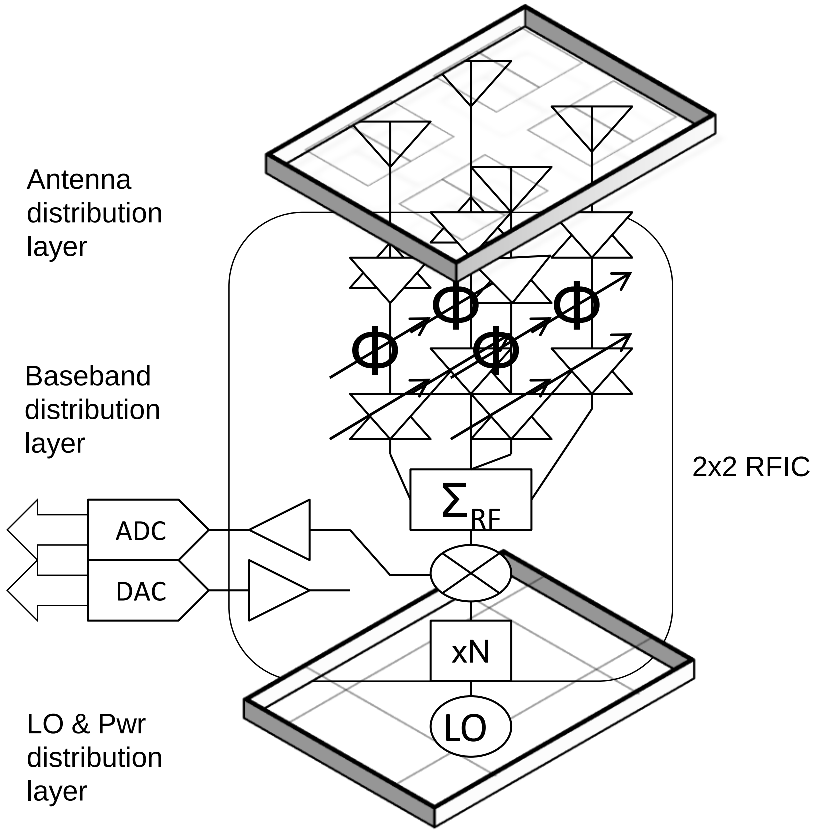


Carrier plate onto which multiple RFIC die are bonded

Multiple layers on carrier plate including:
- Radiating antenna elements
  - (Shown, with dual-polarized elements)
- Antenna feeder/distribution network
- LO distribution network
- Baseband & control network
- Power distribution network

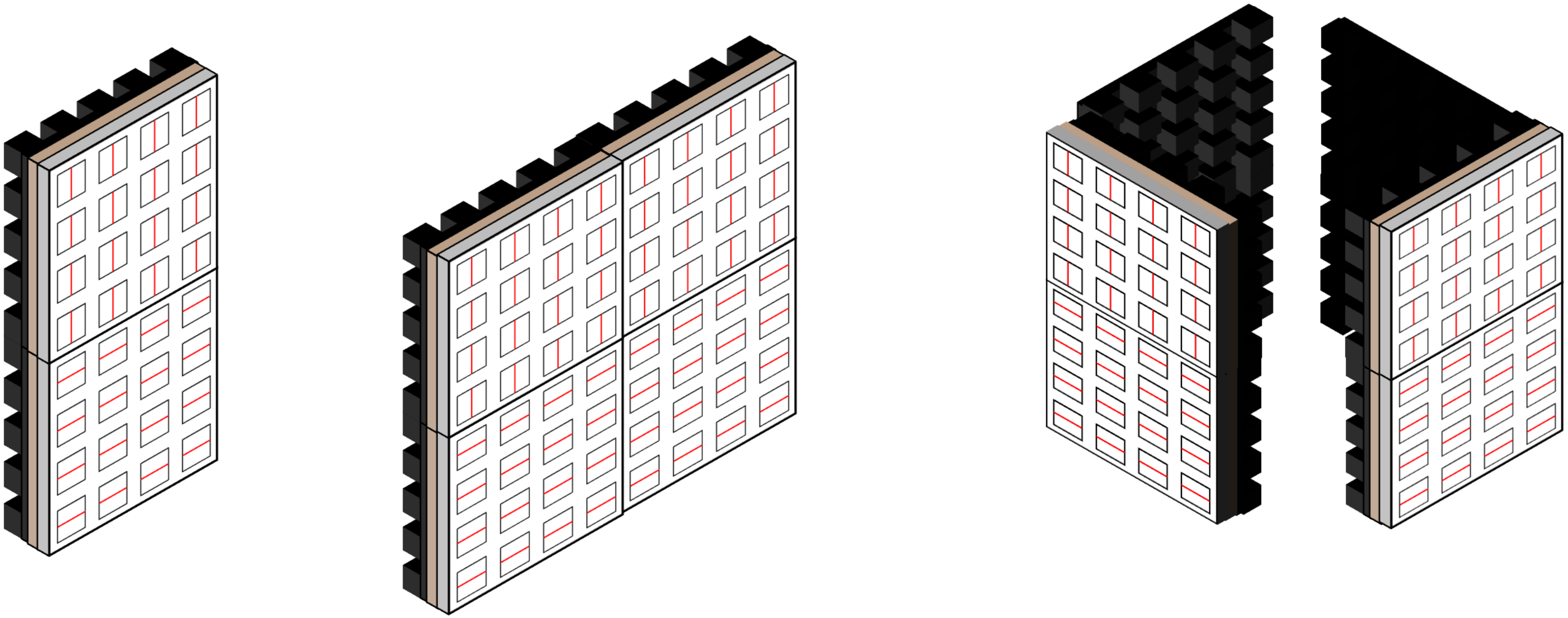


Basic RFIC block diagram with bi-directional elements



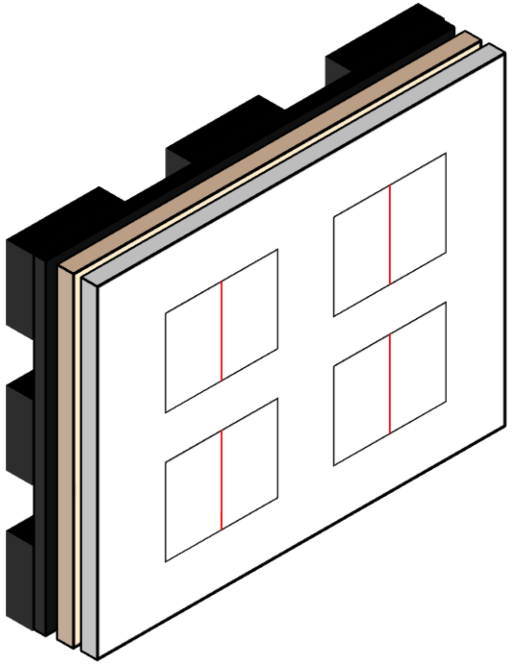
Another view of RFIC with various distribution networks

Base Station Arrays



- Multiple linear arrays are oriented to provide cross-polarization
- To increase system gain multiple arrays of the same polarization are phased together at IF or BB for coherent beamforming
- Multiple sets of arrays used to provide directional / sectorized coverage or can be phased together to provide omni-directional coverage for both access and backhaul layers

User Device Array Example



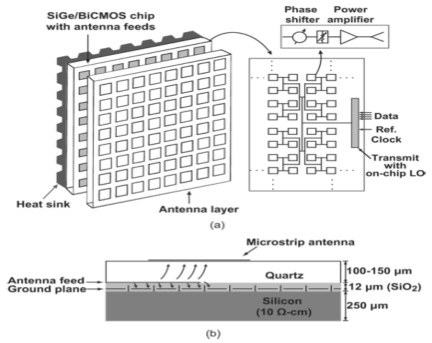
- 2x2 RFIC with linear chip-scale antenna array
  - Chip-scale antenna is metalized quartz layer placed directly onto RFIC die (R1)
  - Small size, low cost, more efficient power coupling
- Dual 2x2 antenna arrays to enable MIMO or diversity performance depending on channel conditions

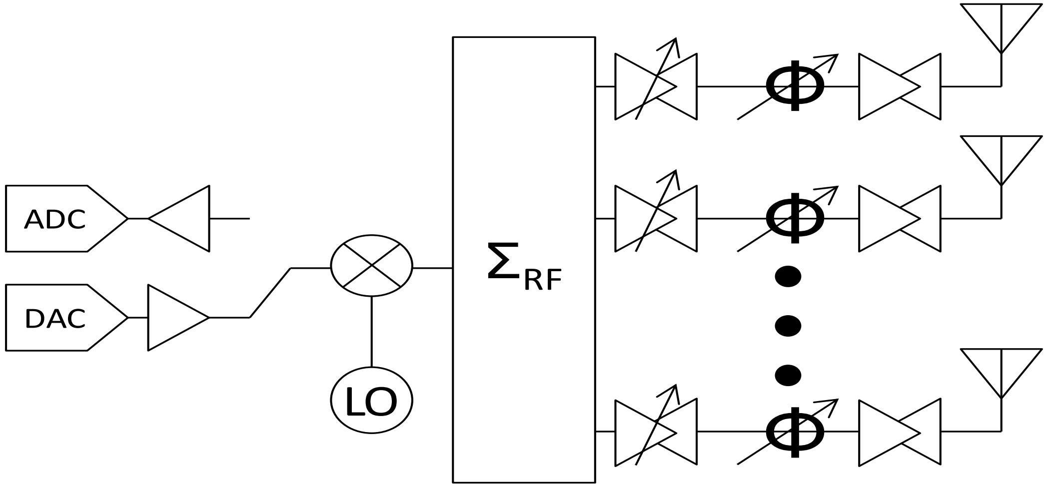
R1: "Millimeter-Wave Wafer-Scale Silicon BiCMOS Power Amplifiers Using Free-Space Power Combining", Rebeiz, et. Al., IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 59, NO. 4, APRIL 2011

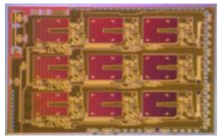
5G – IC Technology for mmWave Communications (1)

Mmwave RFIC design

- **Reduced size, power consumption and cost**
- **Both CMOS and SiGe technology being investigated**
- **Small wavelength -> small effective antenna aperture**
- **Design leading edge high power PA element to prove out link budget**
- **Circuit design of high-efficiency, millimeter-wave Tx & Rx that can be scaled for arrays**
  - **Size of array has significant impact on RFIC power consumption and cost**

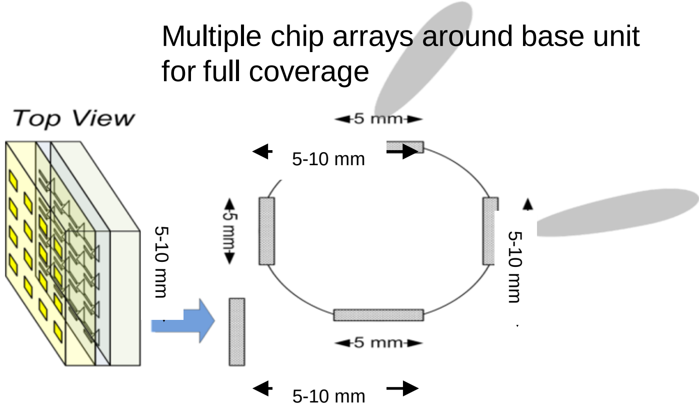






Chip-scale antennas

Multiple chip arrays around base unit for full coverage



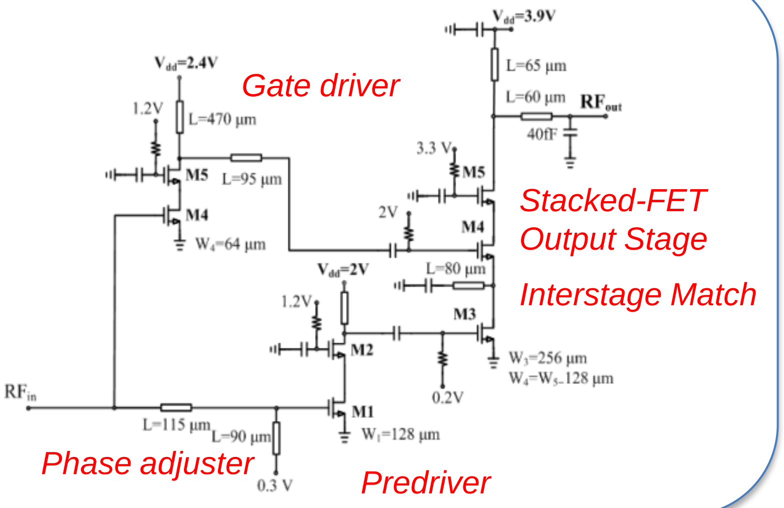
Multiple RFICs combined to form larger arrays at the base station

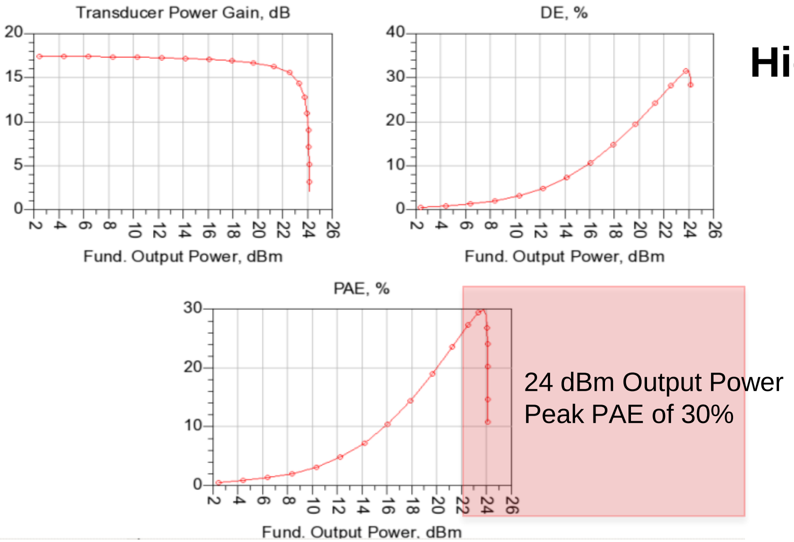
- Bidirectional PA/LNA, mixers on RFICs for compact TDD implementation
- Multiple IF input/output combined on carrier substrate (LTCC, Rodgers, polymer, etc.)
- Single/common high speed ADC & DAC (lowers power consumption)

Atesal, Y.A.; Cetinoneri, B.; Chang, M.; Alhalabi, R.; Rebeiz, G.M.; "Millimeter-Wave Wafer-Scale Silicon BiCMOS Power Amplifiers Using Free-Space Power Combining", *Microwave Theory and Techniques, IEEE Transactions on* , vol.59, no.4, pp.954-965, April 2011

5G – IC Technology for mmWave Communications (2)

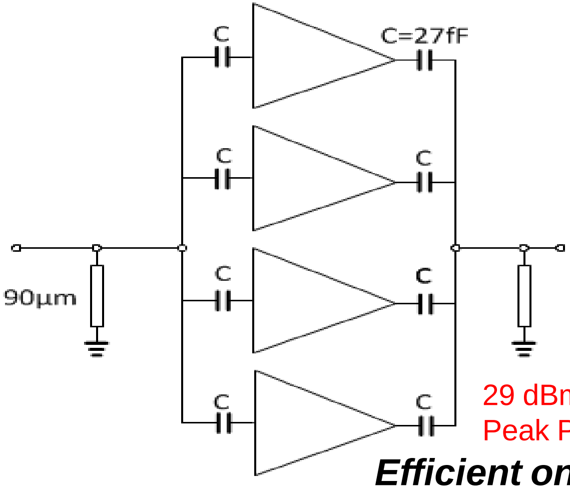
Stacked FET PA

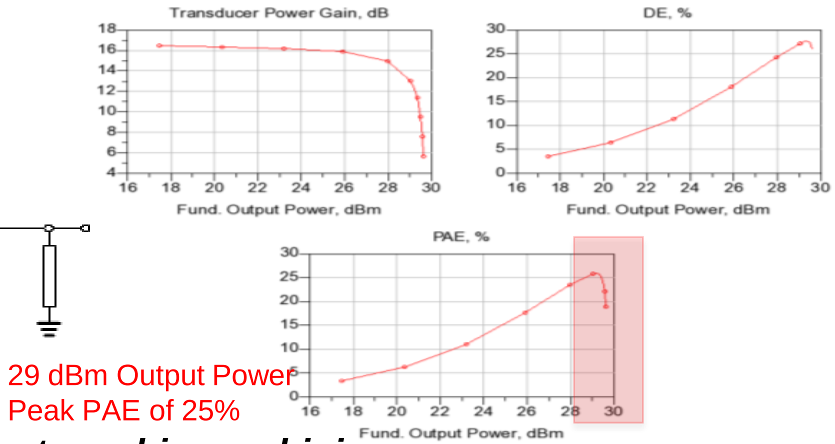




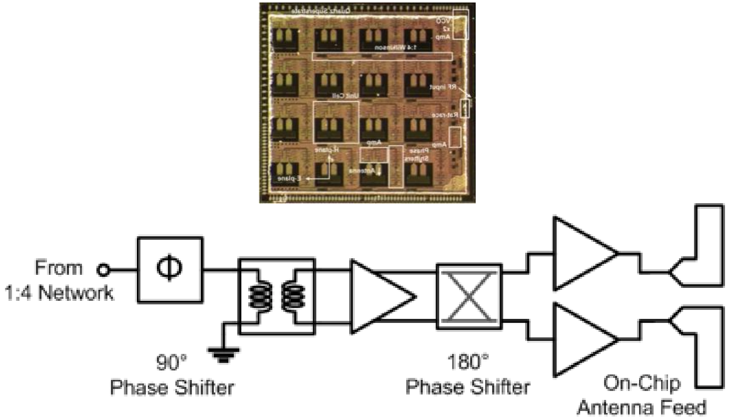
High Transmit Power Achieved Via

- Stacked FET amplifier topology
- Efficient on-chip PA combining
- Free space power combining
  - via phased arrays





Efficient on-chip combining



Free space combining with phased arrays

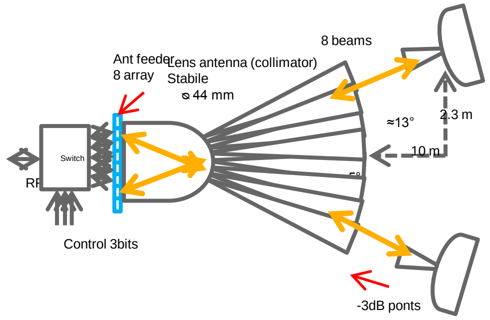
5G Backhaul

NGMN and in general from operators:
Mobile operator builds, owns and manages
the small cells and the small cell last mile backhaul
=> Last hops backhaul is an integral part of small base stations

5G needs Gbits backhaul: only fiber and wireless possible
In most cases fiber is too expensive or not available
Wireless needs mmW band (only band with enough capacity)
LOS is required in mmW band BH (some degree of “nLOS” possible)

Key enablers for mmW BH products are:
- high integration level (to reach low enough capex)
- Electrically steerable antennas
- Directional mesh

} for true SON BH in NLOS environment



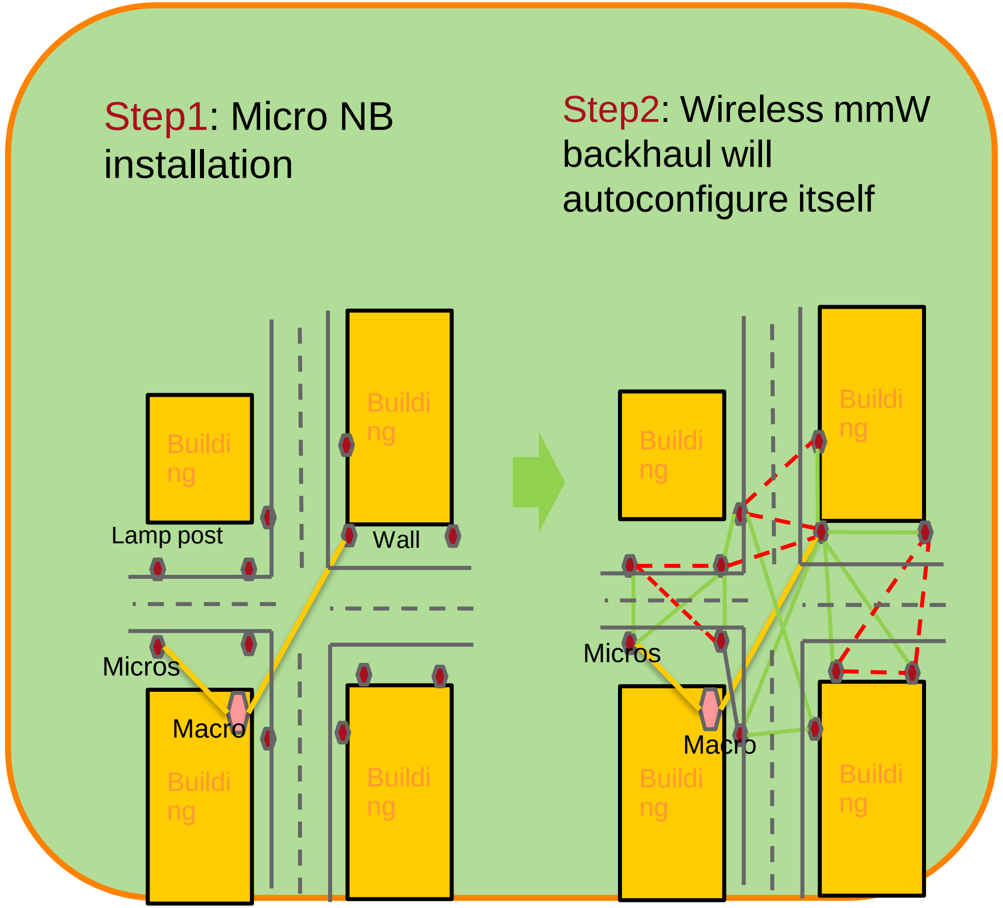
5G mmW Backhaul integrated to mmW Access or separate if <6GHz access

mmW access:

- Access and BH using different array size
  - High end product
- Access and BH with the same platform

⇒ <u>No extra boxes for BH</u>

  - <u>“Just Play” and low end product</u>



<6GHz access:

- mmW BH without mmW access:
  - Same features, true SON
  - Suitable also for LTE
  - Just “Plug and Play”

Time Synchronization
MEF for leased connections

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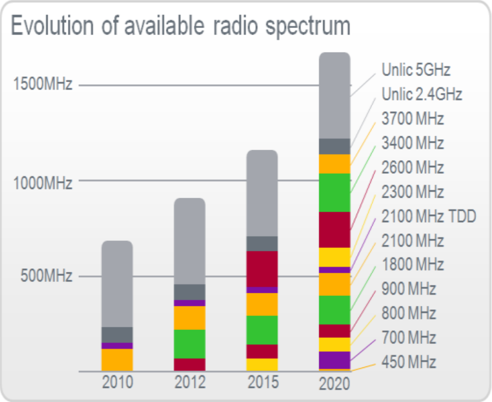
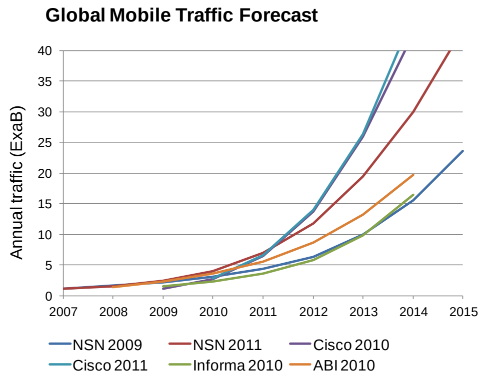
Mmwave -> Final Frontier in Cellular Communications

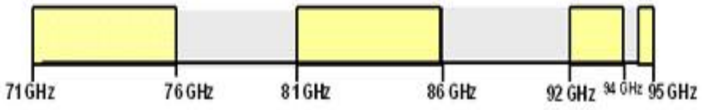
The challenge beyond 2020
- Demand increases exponentially
- Traditional spectrum is finite

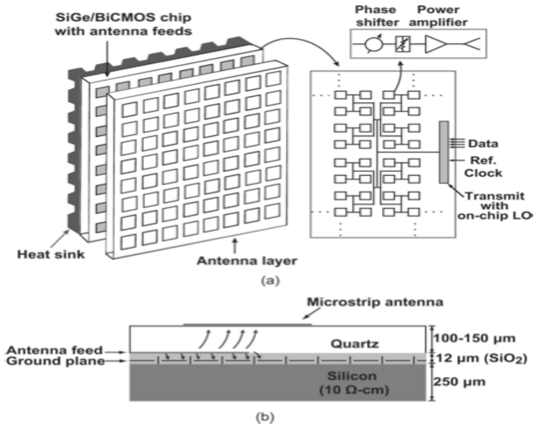
New opportunities @ Mmwave
- Cells are getting smaller
- Large bandwidths are possible
- Noise Limited Scenarios

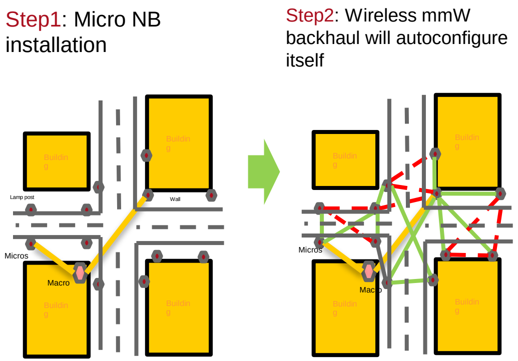
Unique Solutions
- Antenna geometries at chip scale
- Deployment Architecture
    - Address Shadowing and Body Loss
- Dynamic TDD and null CPSC
- Backhaul will be integrated with Access











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