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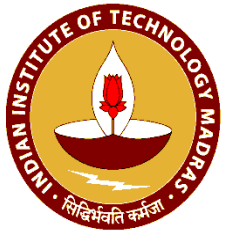

Perspective on LTE-A HetNets

K. Giridhar, IIT Madras

EE5141 Course, October 25, 2014

Wireless Access Standards

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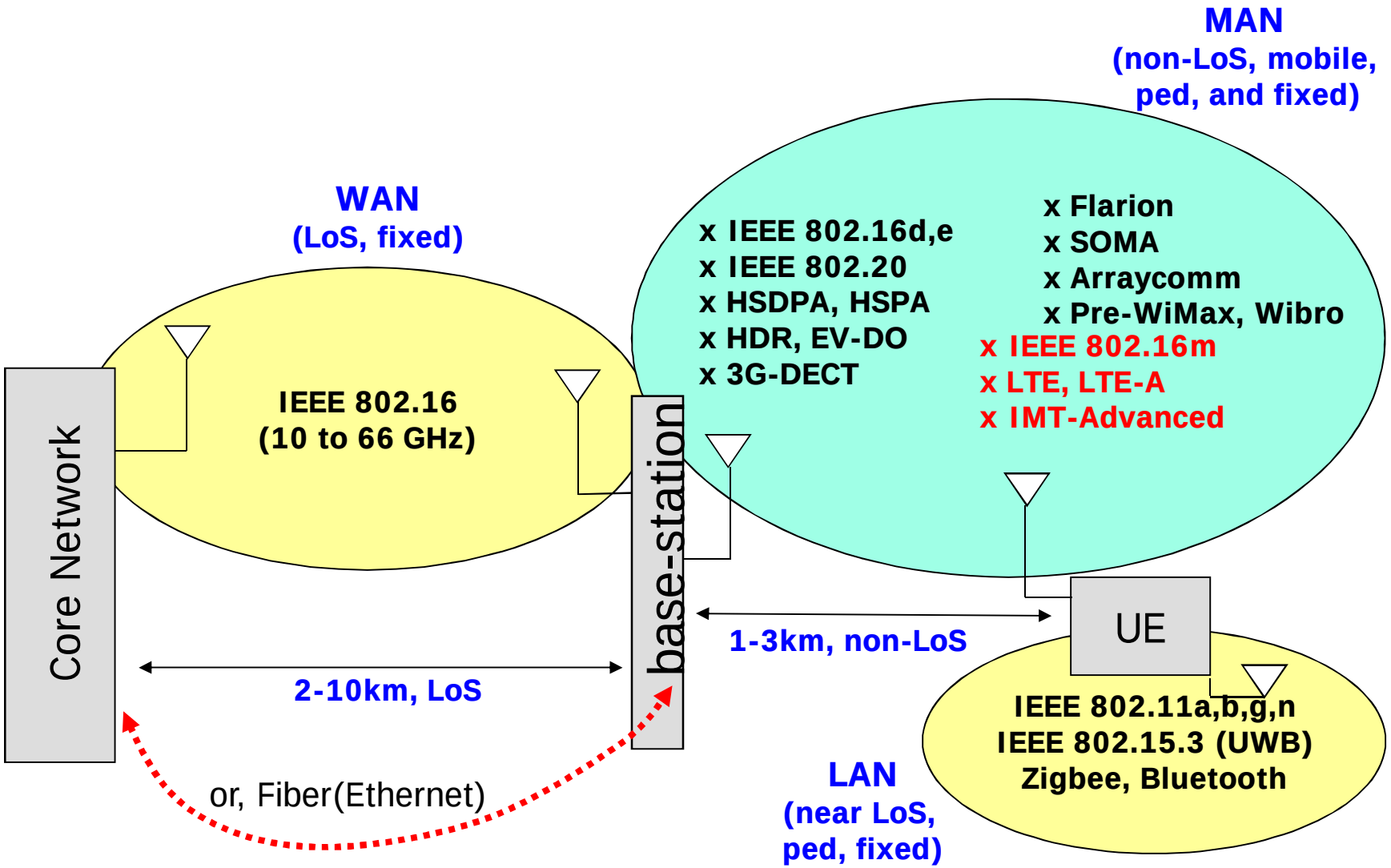

Outline

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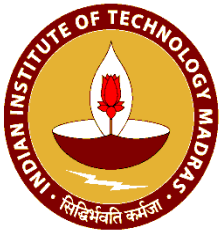


- **Key drivers for 4G evolution**
  - Relevance to India

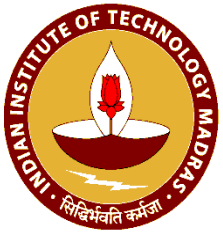
- **Case-study : Het-nets (small cells)**

The "Mobile Broadband Pie"

- Mobile/Broadband Technology
  - User equipment (handset, dongle)
  - Infra equipment (base-station, towers, antennas)
  - Core network (authentication, backhaul, management, switching)

- Players vs Earnings (% of total lifetime revenue)
  - Air-interface Algorithms and Protocol developers — **1%**
  - Chip vendors — **3%**
  - Equipment vendors (user-side, infra-side) — **6%**
  - Operators — **15%**
  - Technology Services — **15-20%**
  - Applications developers — **25-30%**
  - Regulators and Govt ----------→ — **20-30%**

- Innovation is possible (& is vital for India) at all levels, by all players



How "broad" should Broadband be?

- DoT and TRAI consider broadband access to be 512kbps to 1Mbps *sustained* connections

- For 95% of Indian consumers, broadband internet has to be only "wirelessly" delivered

- Bit-rate per link, scales with Bandwidth
  - 2G → GSM in 200KHz : 14kbps; GPRS in 200KHz: up to 112kbps
  - 2.5G → EDGE in 200KHz: up to 384kbps
  - 3G/3.5G → EVDO in 1.25MHz: up to 2Mbps; HSPA in 5MHz: up to 14Mbps
  - 4G → WiMax/802.16m & LTE/LTE-A in 10MHz: up to 40Mbps
  - 4G+ → > LTE-Rel.13 40MHz and up to 100MHz (peak bit rates of 1GBps !)

Question and Answer

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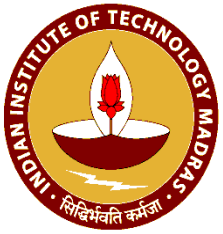
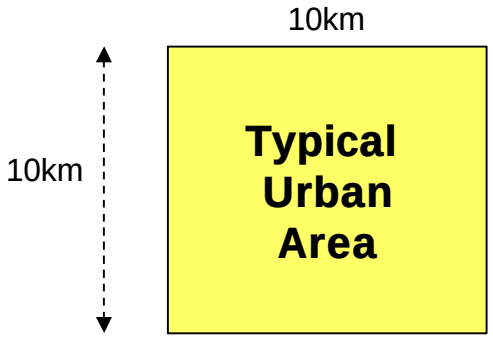


- When the bandwidth (BW) of a digitally modulated signal increases
  - Bit-rate R increases linearly with BW – T / F
  - Range (link budget) decreases – T / F / Can't Say
  - Spectral efficiency (R/BW) ratio cannot be changed– T / F
  - Transceiver complexity increases – T / F
  - Transmit power has to be increased – T / F

- The number of users that can be supported per square km (for a given bit-rate per user)
  - Increases with spectral efficiency
  - Increases by using small cells (underlay)

Relevance to India

- India is the 2nd largest market for 4G broadband wireless (200million+ customers)



→ 2000 users per 1 sq.km
→ 1Mbps per user
→ Total rate to be supported
Over the city =100x2000x1=200 Gbps
→ With 1Gbps per base-station every 1sq.km, we will required 200 BS
→ Key Question: Is 1Gbps per BS possible?

- For 4G, every operator in India has only 20MHz spectrum
  - With universal reuse of spectrum, how many bits/sec can be supported per base-station?
    - With max-rate allocation to only "cherry picked'" users – perhaps **60**Mbps
    - With fairness and latency constraints brought in – getting **40**Mbps is very tough!

- Then, how to evacuate (even merely!) 1Gbps per base-station?
  - Create more BS per sq.km → small cells with 20-25 of them per 1 sq.km

Relevance to India – contd.

- Are there other India-specific requirements for mobile internet?
  - Mostly indoor fixed users -- many from 3-storey to 5-storey apts
  - Voice+Text remains as (if not more) important
  - Highly power efficient networks & subscriber equipment
  - Low to very low ARPU

- Are these requirements reflected in the International wireless standards?

IMT-A Requirements from ITU *

* Test environments are described in Report ITU-R M.2135

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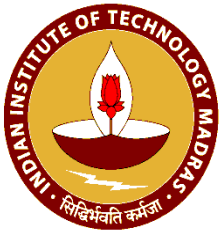


Average Spectral Efficiency

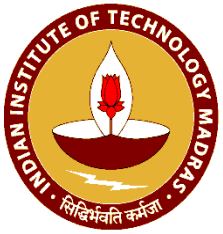
Test environment (1)	*Downlink (bit/s/Hz/sector)*	*Uplink (bit/s/Hz/sector)*
Indoor (10 Kmph)	**3**	**2.25**
Microcellular (30 Kmph)	**2.6**	**1.80**
Base urban (120 Kmph)	**2.2**	**1.4**
High speed (350 Kmph)	**1.1**	**0.7**

Recall that Avg. SE for:
2G GSM – 0.4 to 0.6;
3G WCDMA – 0.8 to 1.0;

Cell-edge SE

t (1)	*Downlink (bit/s/Hz/sector)*	*Uplink (bit/s/Hz/sector)*
Indoor	**1.0**	**0.70**
Microcellular	**0.75**	**0.50**
Base urban	**0.60**	**0.30**
High speed	**0.40**	**0.15**

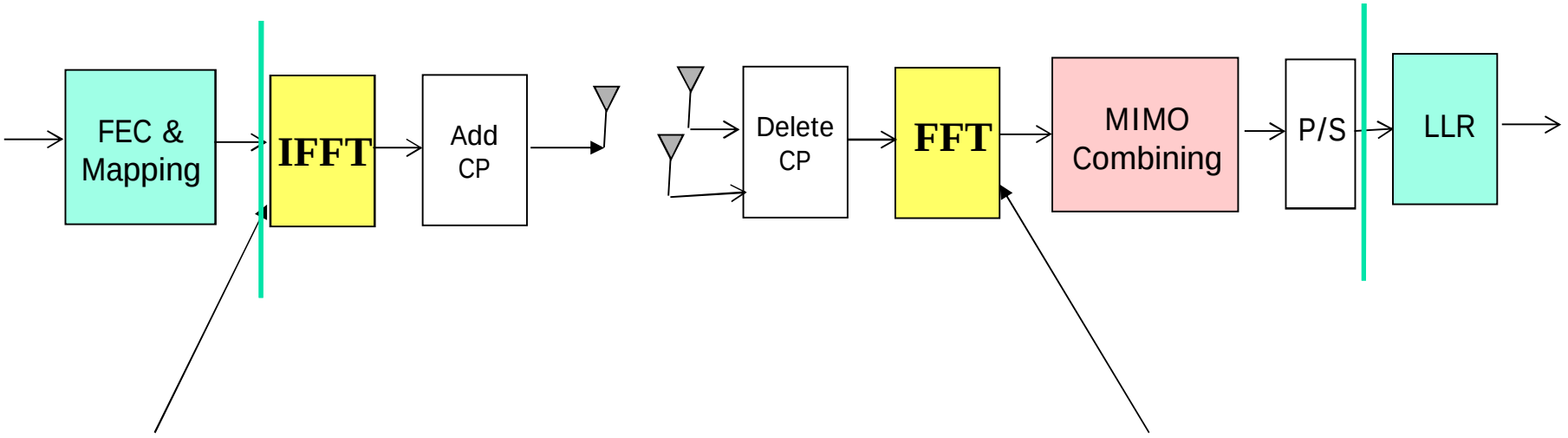
Key Elements of Mobile Broadband Systems



- Five key elements of BWA technology are:
  - → Broadband OFDM
  - → MIMO
  - → Interference mitigation
  - → Heterogeneous networks
  - → Link (Rate) Adaptation

Coded OFDM

- **Nearly all new and emerging wireless standards use OFDM – Why?**
  - Flexibility in resource allocation
  - Ability to scale with bandwidth easily



If $x(k)$ modulates the k^{th} subcarrier

measurement on the k^{th} subcarrier is $y(k) = H(k)x(k) + v(k)$

MIMO-OFDM →
Technology Enablers for Mobile Broadband

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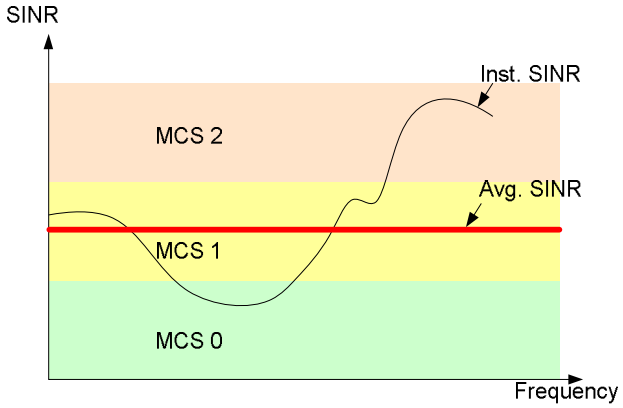

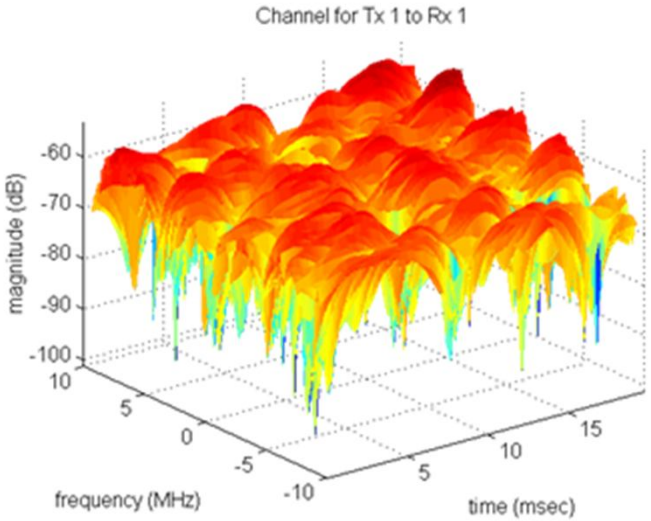

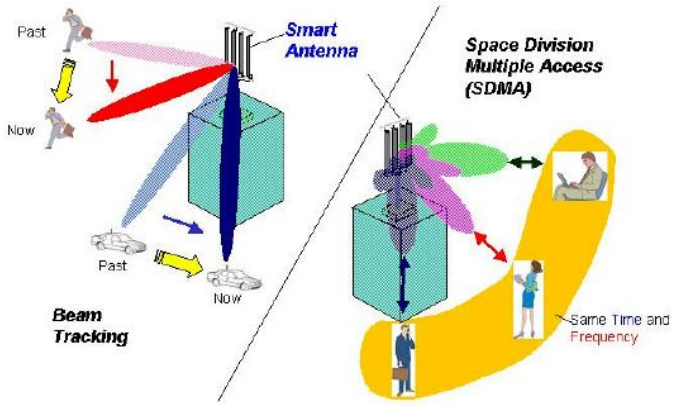

Smart Antenna Technology

Evolved 3G - Terminology

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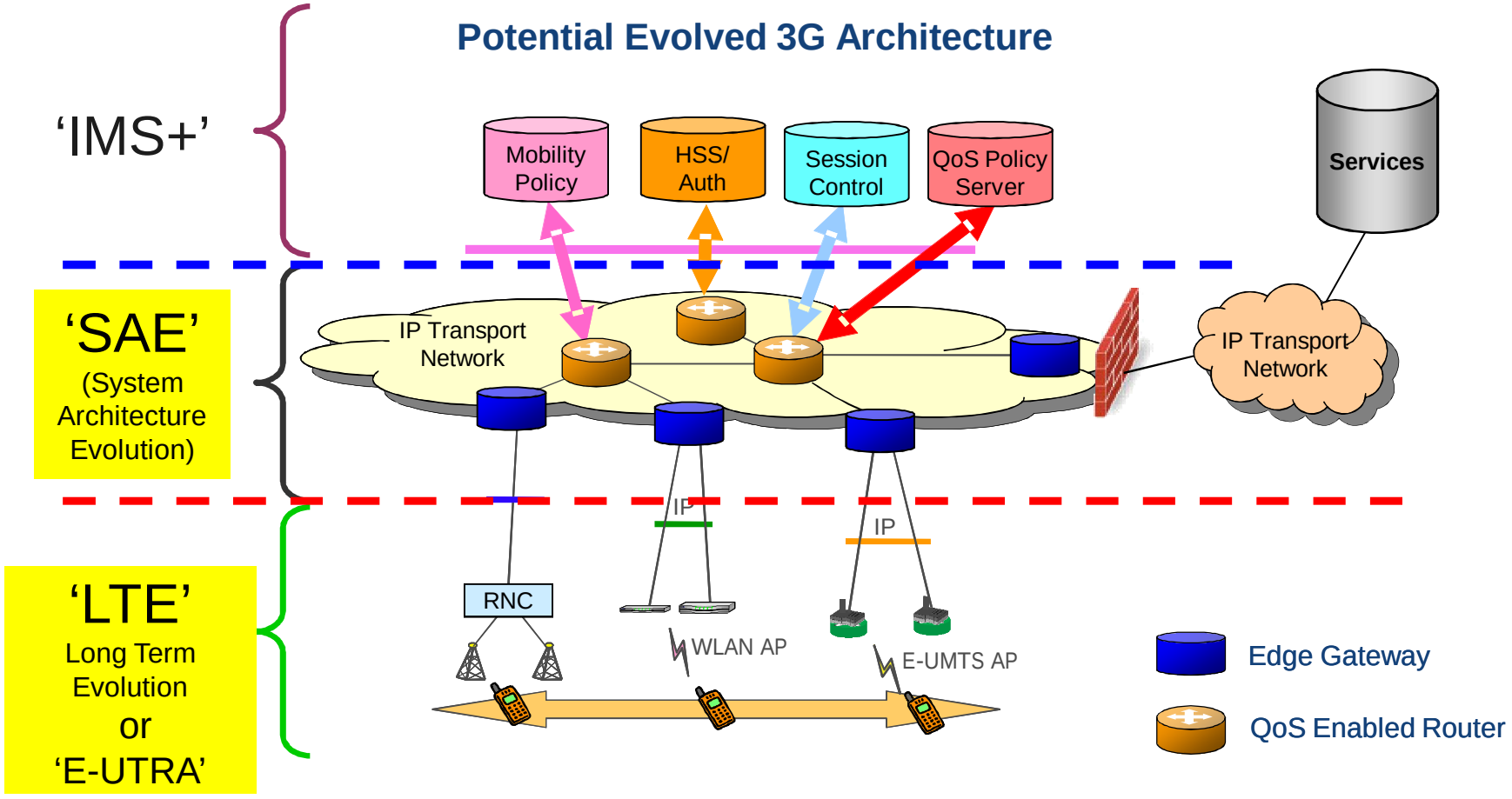

Courtesy: Dr. Amitava Ghosh, Motorola Labs

802.16m Frame(s)

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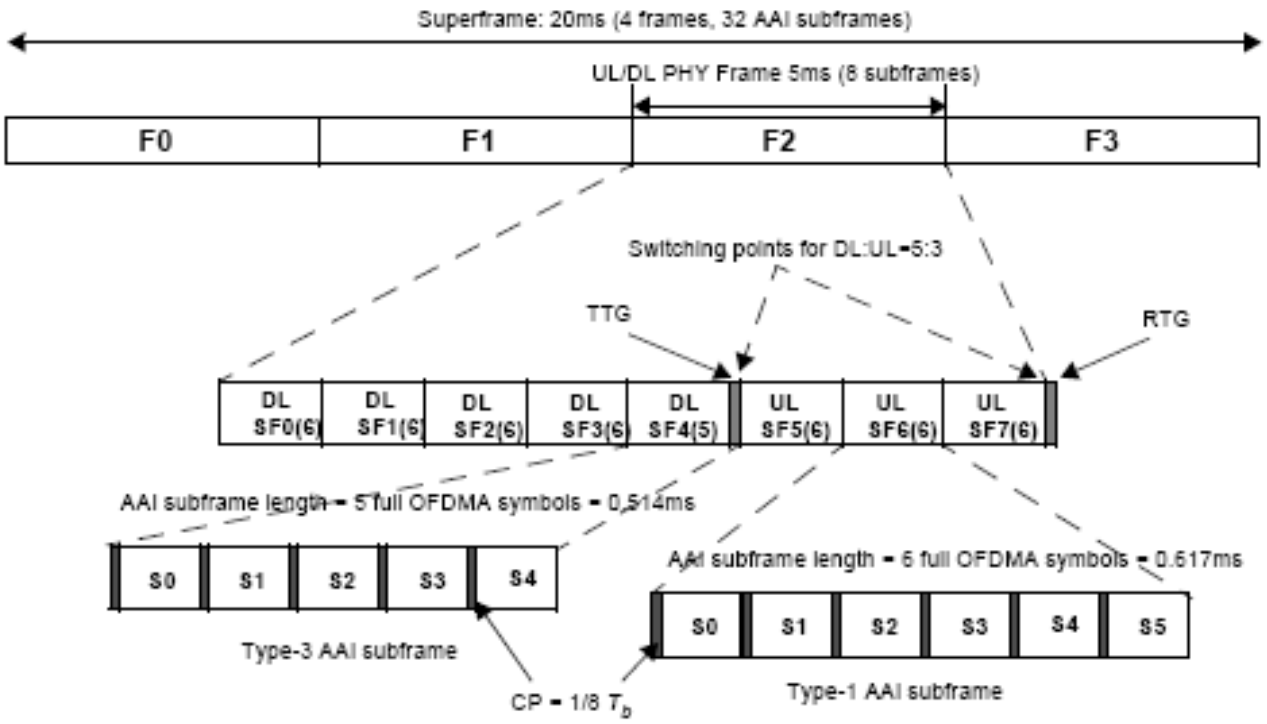
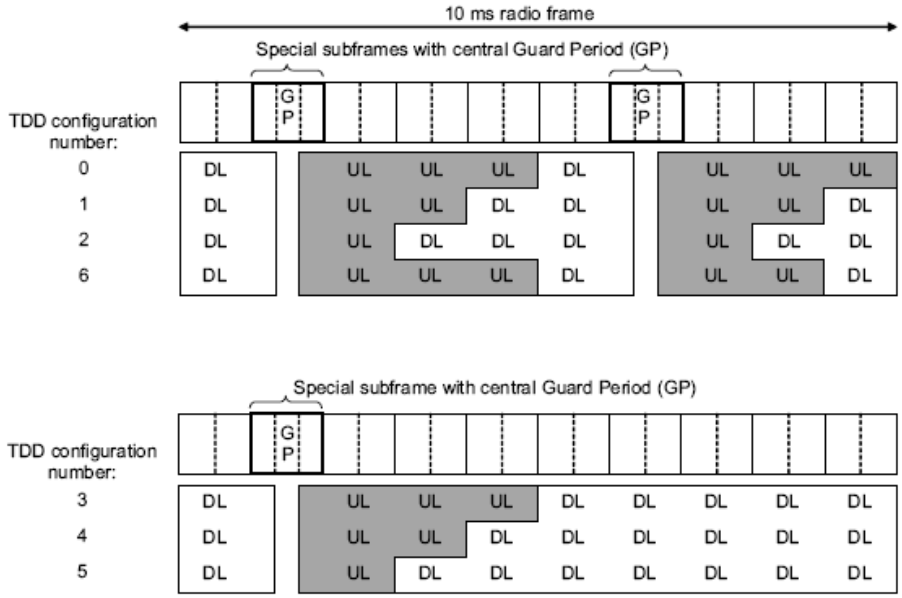


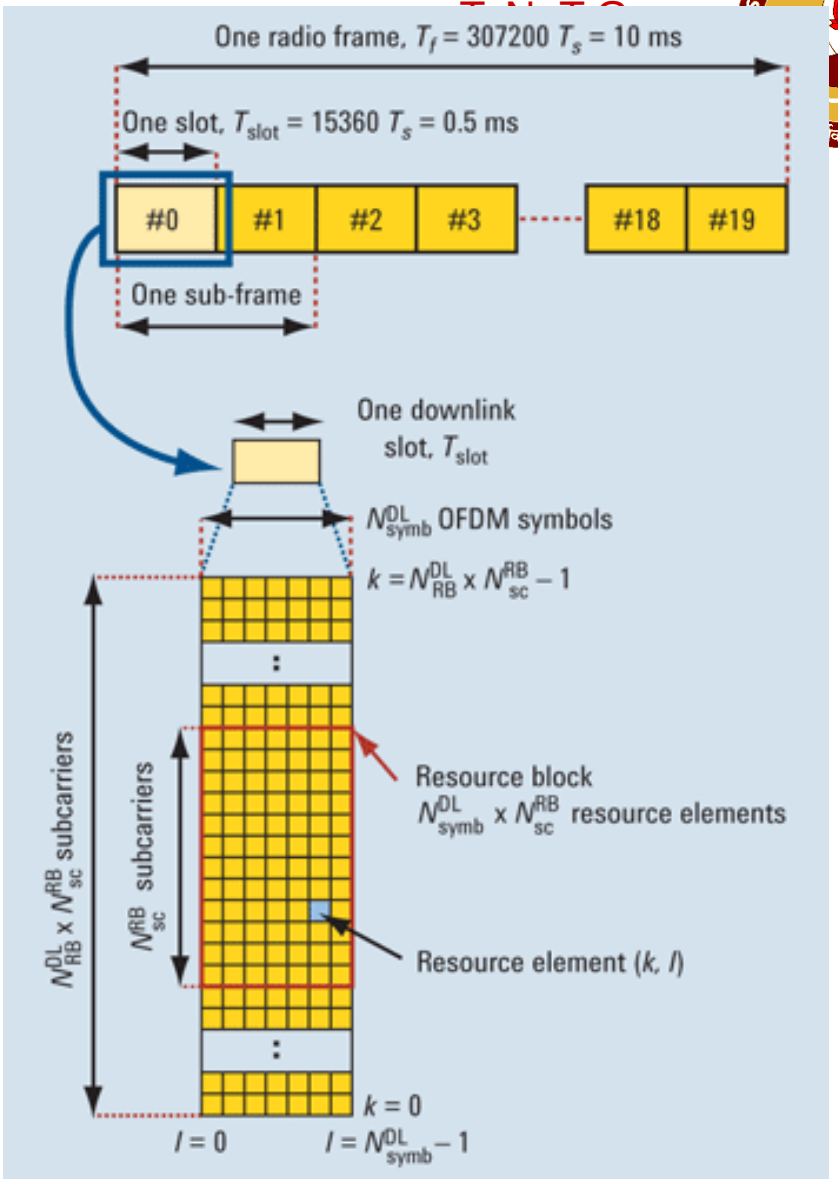
Frame structure with type-1 and type-3 AAI subframes in TDD mode for 5, 10, and 20 MHz channel bandwidths (CP=1/8 T_b)

Figure 465—Frame structure for 5/10/20 MHz mode

Fig illustrates an example TDD frame structure with D:U = 5:3, which is applicable to the nominal channel bandwidths of 5, 10, and 20 MHz with G = 1/8. In Figure 465 the last DL AAI subframe, i.e. DL SF4, is a type-3 AAI subframe and the other AAI subframes are type-1 AAI subframes. TTG and RTG are 105.714 µs and 60µs, respectively. (*Courtesy: IEEE 802.16m WMAN*)

LTE Frame(s)





Courtesy: Agilent

802.16m OFDM/OFDMA Parameters

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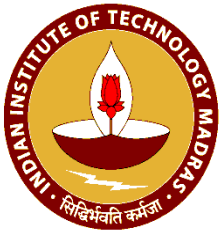
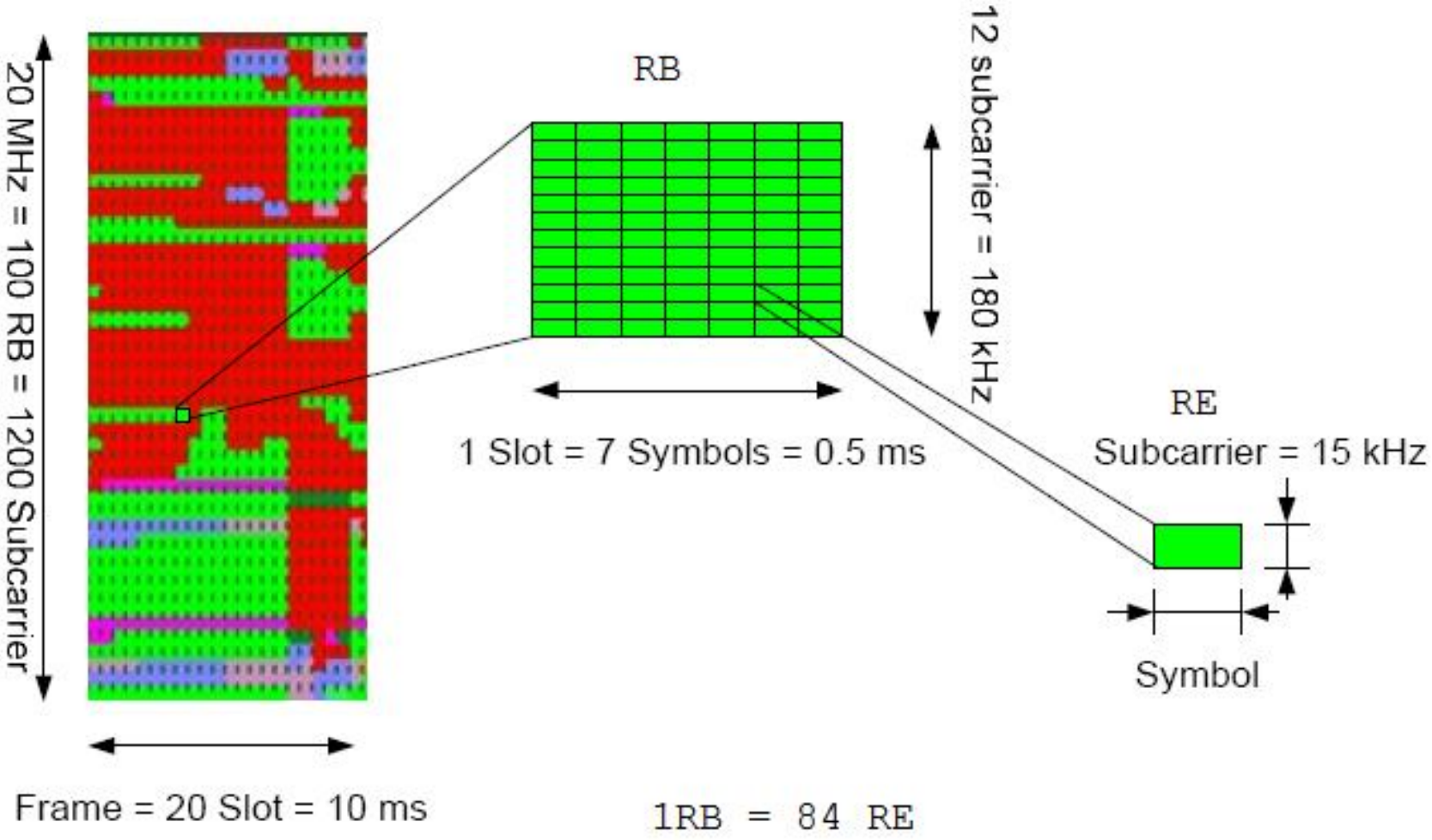


Table 766—OFDMA parameters

The nominal channel bandwidth, BW (MHz)			5	7	8.75	10	20
Sampling factor, n			28/25	8/7	8/7	28/25	28/25
Sampling frequency, F_s (MHz)			5.6	8	10	11.2	22.4
FFT size, N_{FFT}			512	1024	1024	1024	2048
Subcarrier spacing, Δf (kHz)			10.94	7.81	9.77	10.94	10.94
Useful symbol time, T_b (μs)			91.4	128	102.4	91.4	91.4
CP ratio, G = 1/8	OFDMA symbol time, T_s (μs)		102.857	144	115.2	102.857	102.857
	FDD	Number of OFDMA symbols per 5ms frame	48	34	43	48	48
		Idle time (μs)	62.857	104	46.40	62.857	62.857
	TDD	Number of OFDMA symbols per 5ms frame	47	33	42	47	47
		TTG + RTG (μs)	165.714	248	161.6	165.714	165.714

LTE Resource Structure



What can MIMO do?

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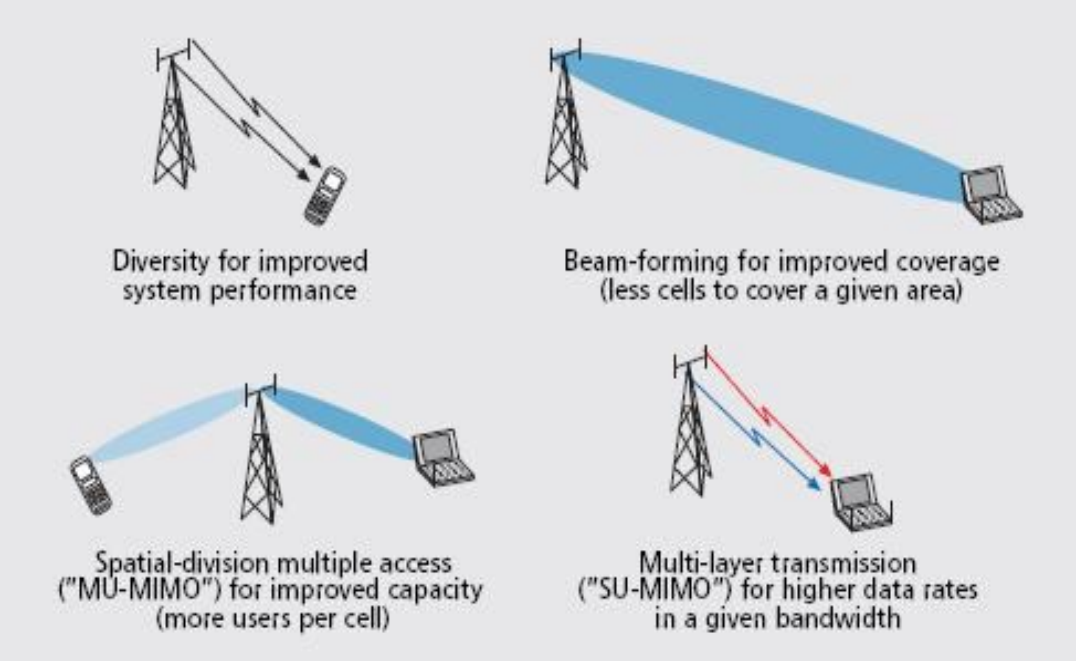

Courtesy: E. Dahlman, IEEE Comm Mag, Apr 2009

Bits to Waveforms – How complex can it get?

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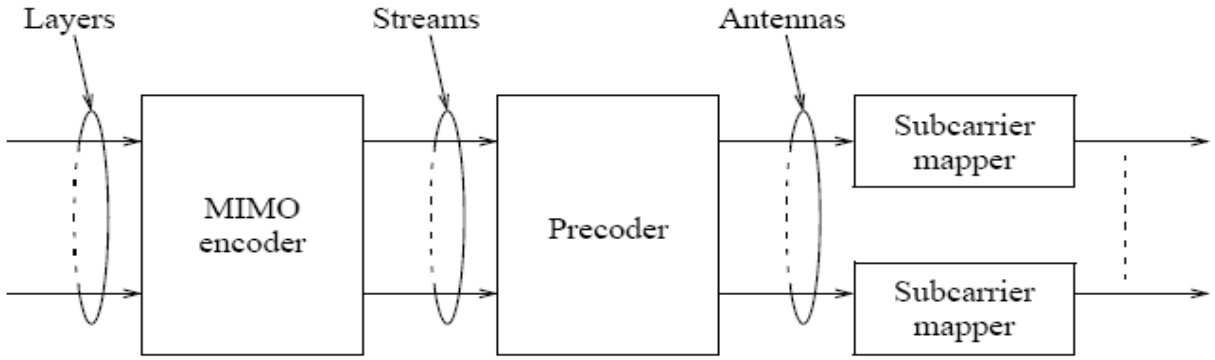


A layer → is a codeword (as seen by UE)

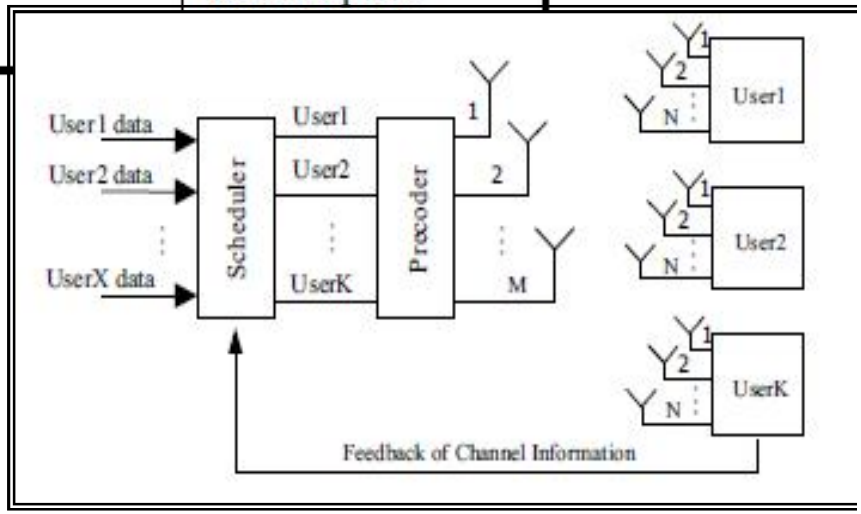
A stream → is what goes into a Tx antenna

Example: DL-MIMO in .16m

Mode index	Description	MIMO encoding format (MEF)	MIMO precoding
Mode 0	OL SU-MIMO (Tx diversity)	SFBC	non-adaptive
Mode 1	OL SU-MIMO (SM)	VE	non-adaptive
Mode 2	CL SU-MIMO (SM)	VE	adaptive
Mode 3	OL MU-MIMO (SM)	HE	non-adaptive
Mode 4	CL MU-MIMO (SM)	HE	adaptive
Mode 5	OL SU-MIMO (Tx diversity)	CDR	non-adaptive

All MIMO modes supported for 2,4,8 Ants.
- Modes 0,1,2 support for single layer only
- Mode 1 and 2 support upto 8-streams
- Modes 3 and 4 support 2,3,4 layers

- **LTE has similar choices**



Performance of Downlink Scheduler
(Homogeneous Network -- LTE)

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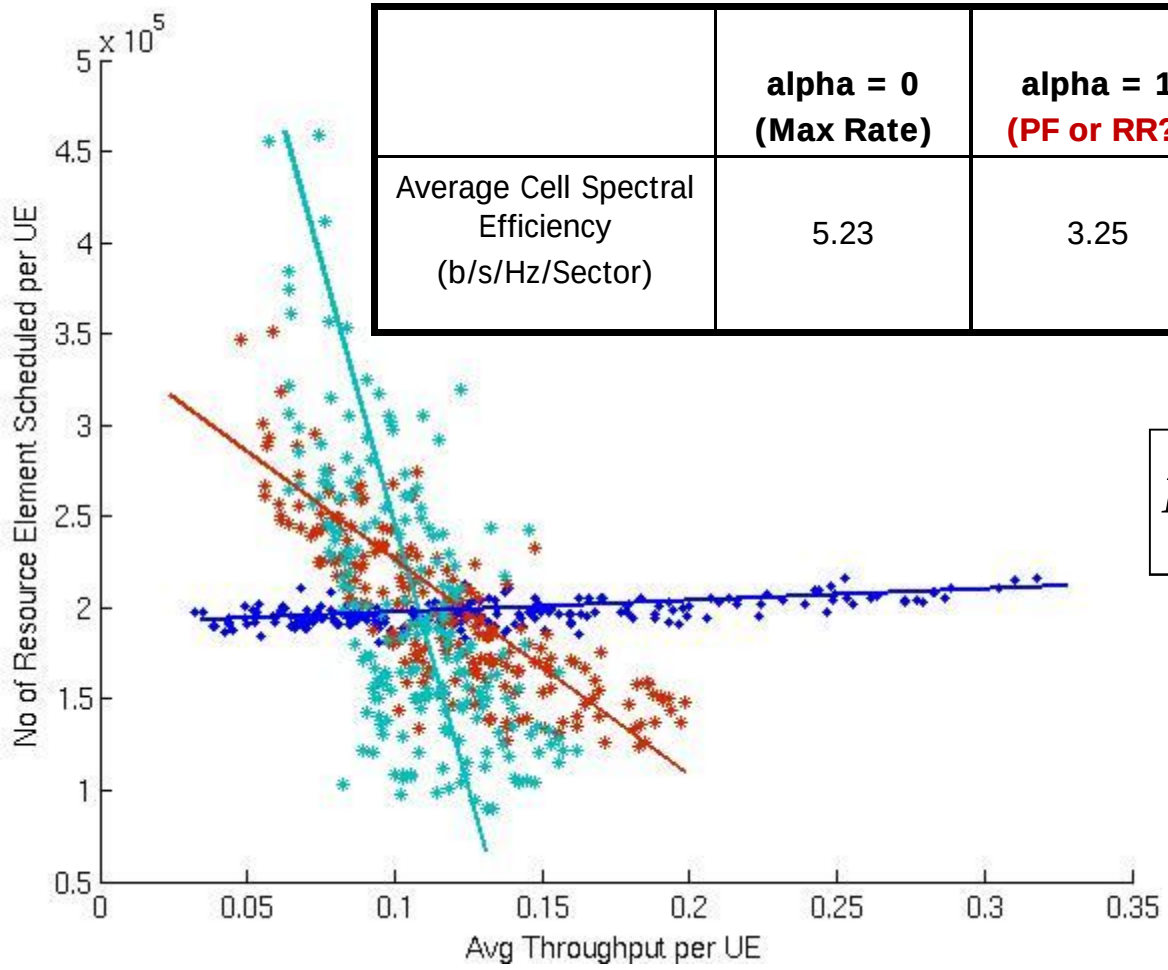

	alpha = 0 (Max Rate)	alpha = 1 (PF or RR?)	alpha = 2	alpha = 4
Average Cell Spectral Efficiency (b/s/Hz/Sector)	5.23	3.25	2.82	2.58

$$PF_{metric} = \frac{R}{(E[R])^{\text{alpha}}}$$

Freq. Reuse and SINR Distribution

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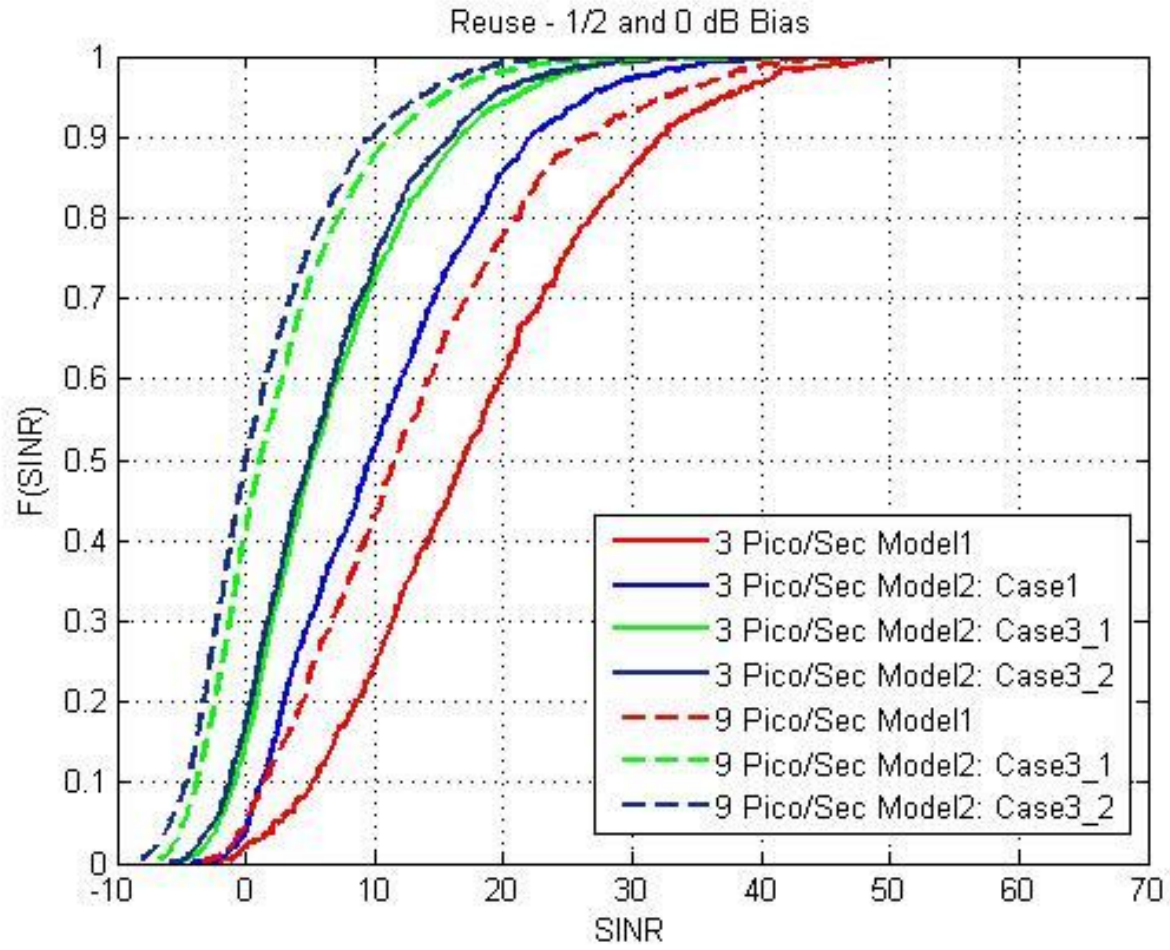
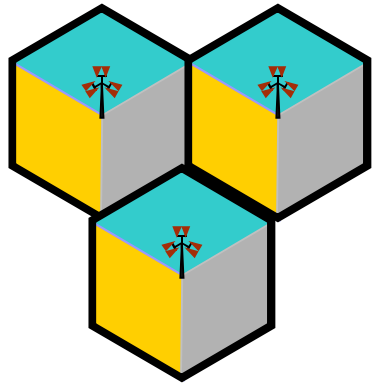
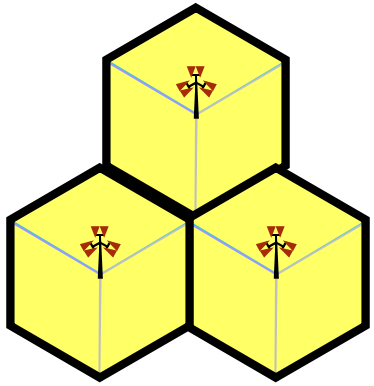


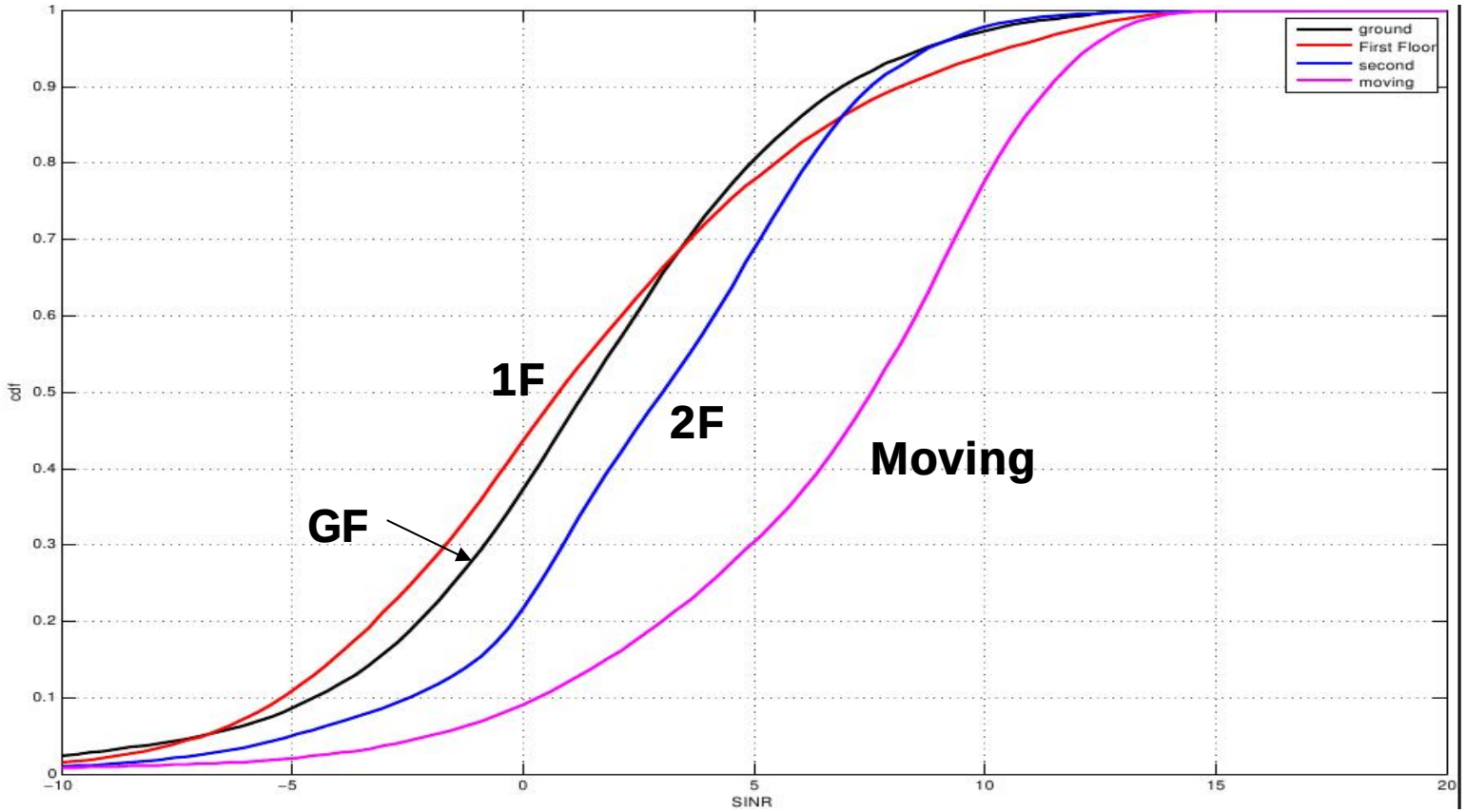


Reuse 1/3



Reuse 1/1

SINR Distribution Measured
(at Velachery, near IITM campus)



Footprint of the IITM 4G/4G+ Testbed

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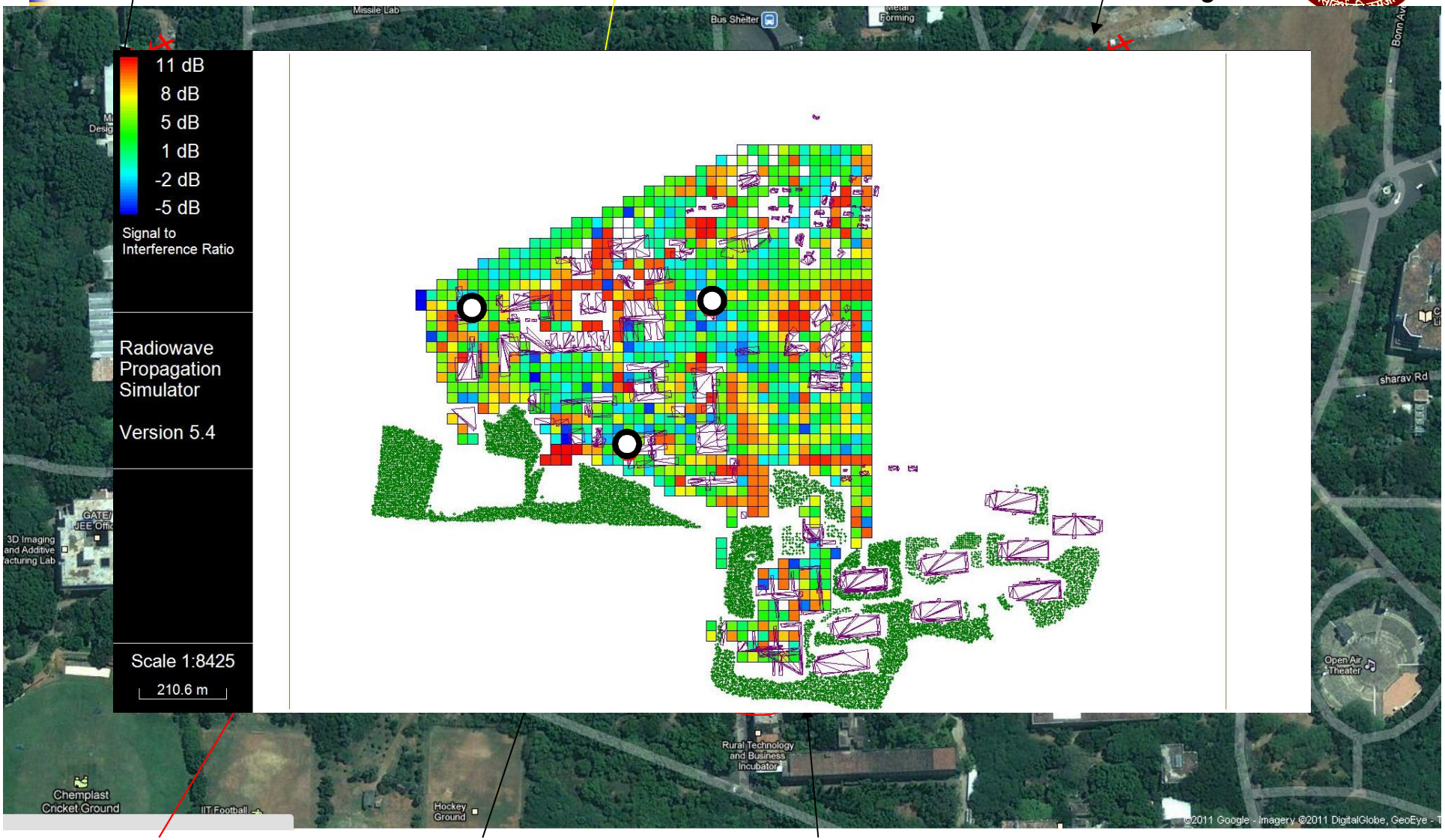

Snapshot of the Baseband Platform

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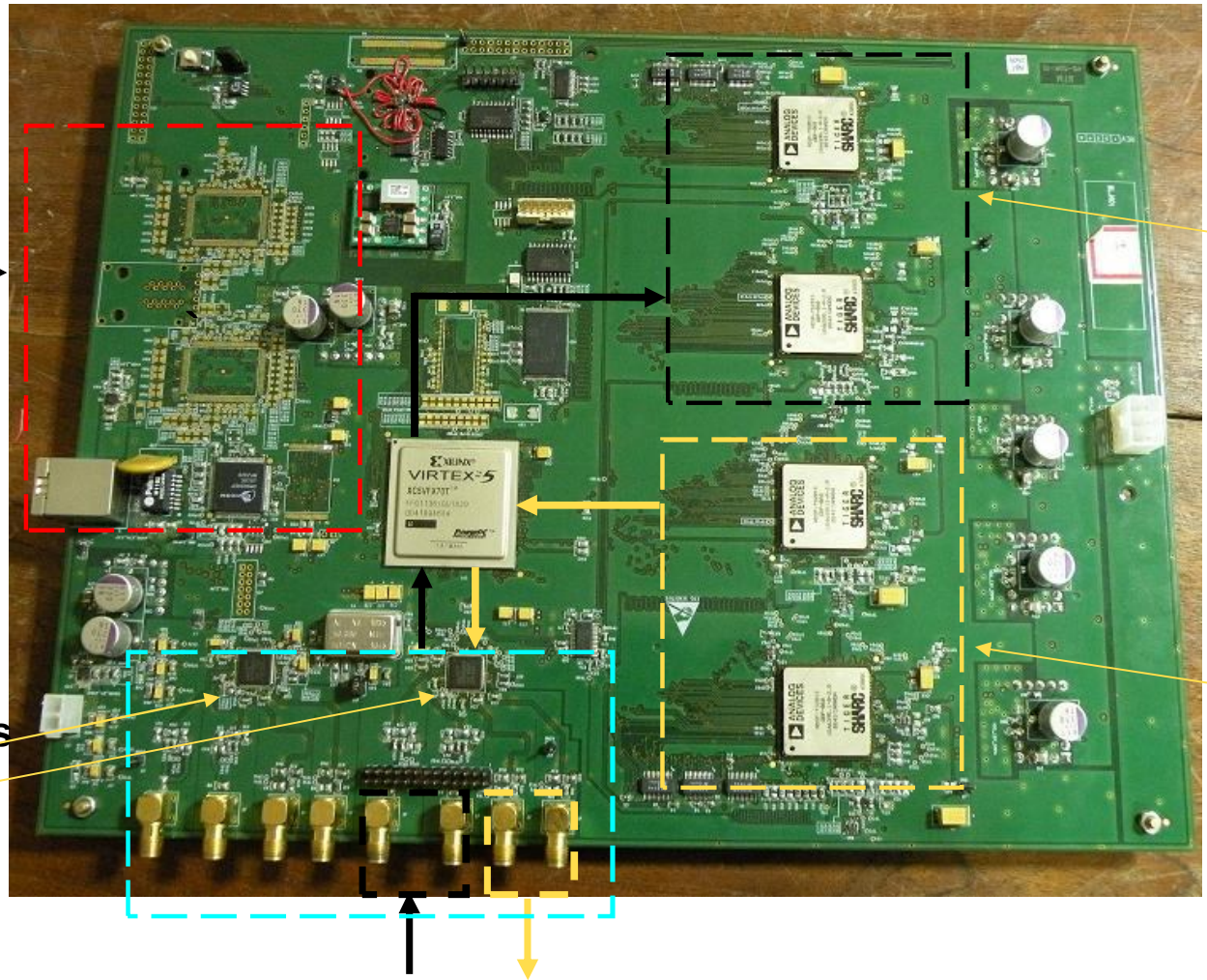

Lab Testing -- Setup

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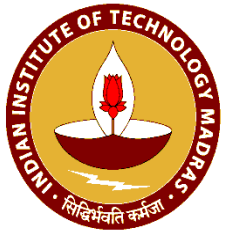
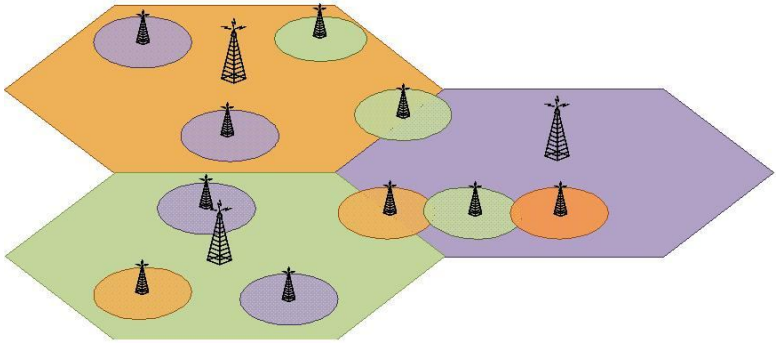


Case Study : Heterogeneous Network → Macro +

- Pico
- Femto
- Relay



Placement of Macro and Pico
(inter-Pico distance >40m or 20m)

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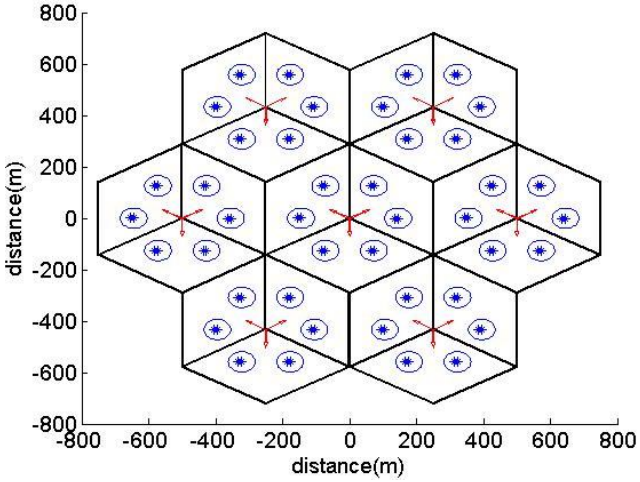

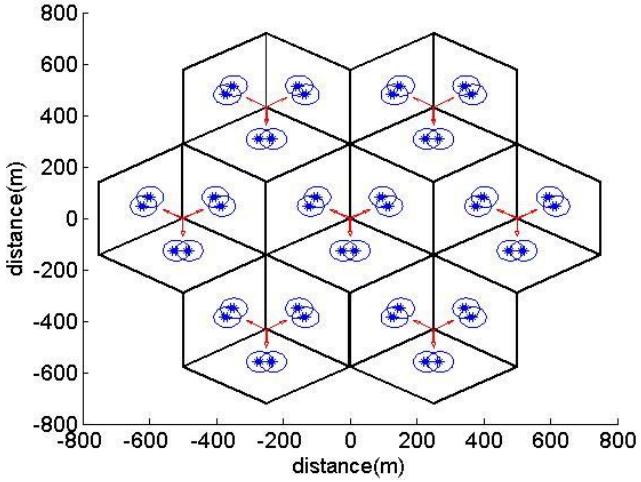

Macro-Pico Resource Partitioning

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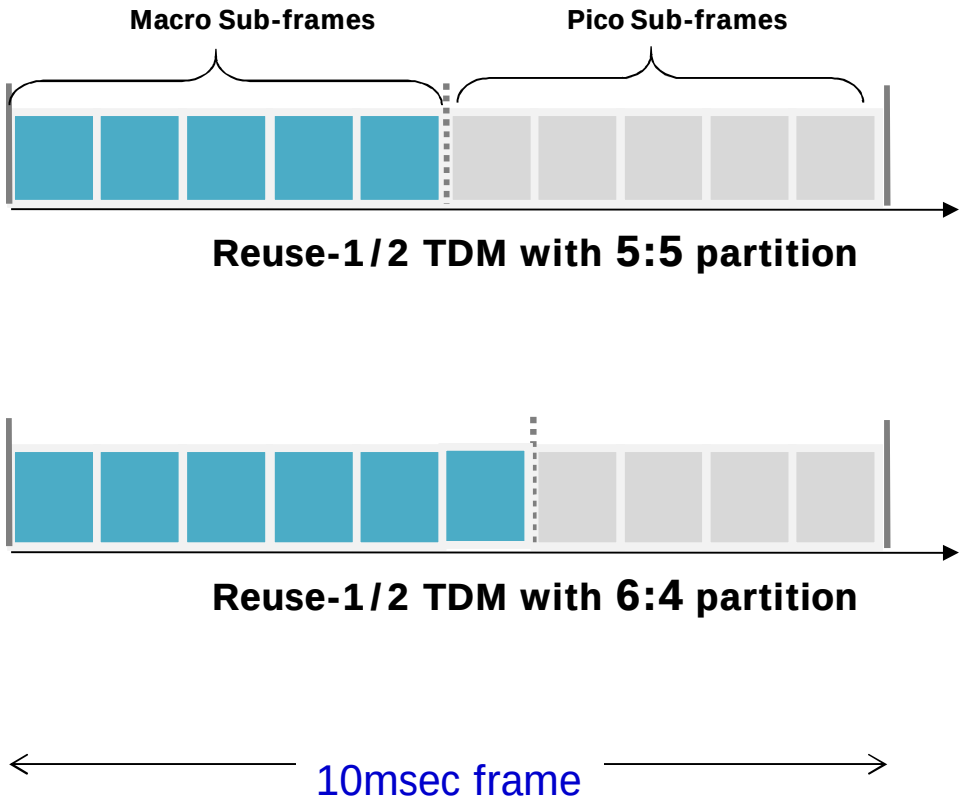
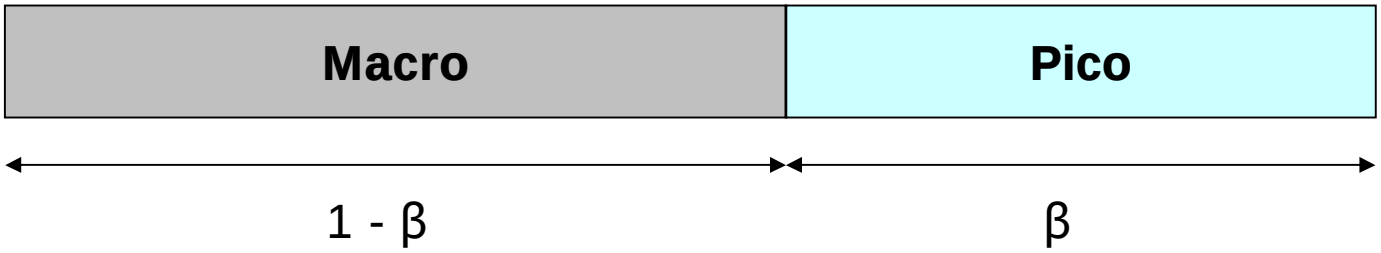


Actually, Picos can use all 10 subframes; Macros will be "blanked out" during the last 4 or 5 subframes

Resource Sharing in Het-Nets

Resources will be divided between macro and pico divided based on the average load seen by a pico



If **M** is the avg. thruput of macro/sector, **P** is the avg. thruput per pico and **N** is the number of picos/sector, then the thruput/sector will be,

$$T = (1-\beta)\mathbf{M} + \mathbf{N}\,\beta\mathbf{P}$$

Since β is a system wide parameter, some picos may not be able to serve all their users while some picos may have surplus resources

Reuse – 1 vs Reuse – ½
(Model 2: Case 3_1 of LTE-A)

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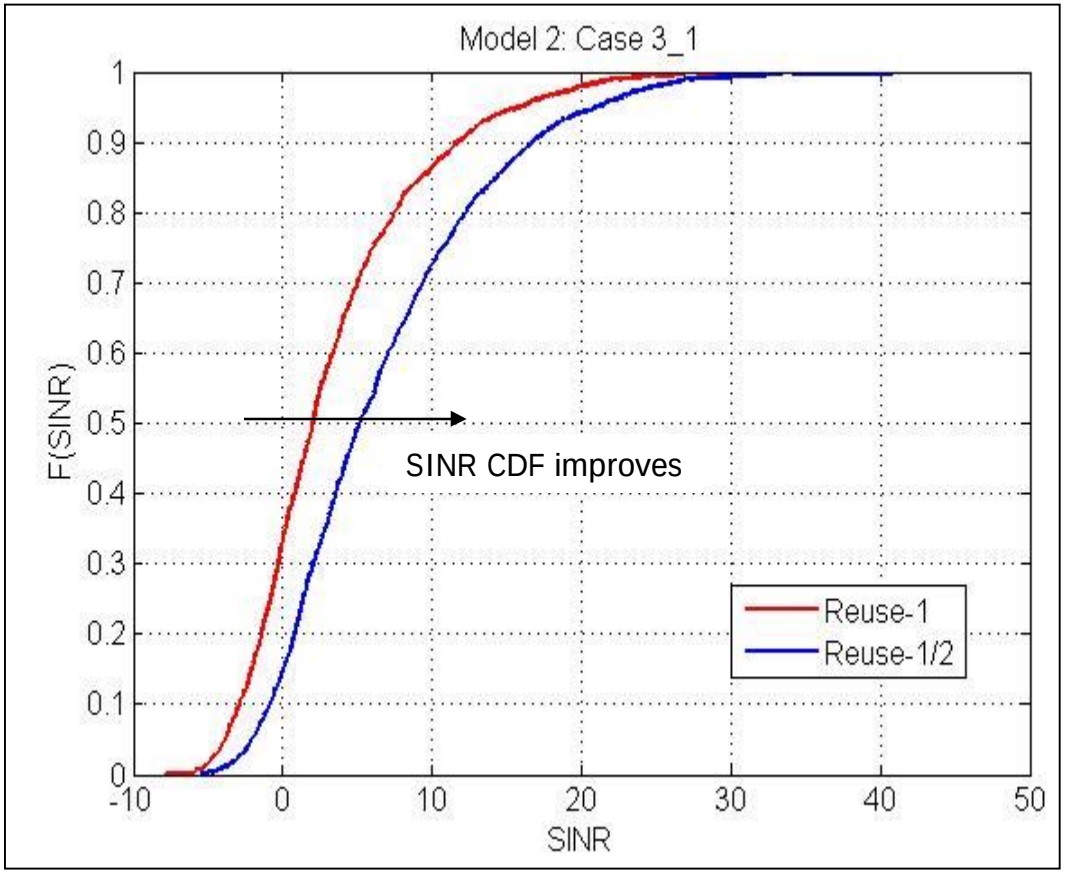
- When Macro and pico eNodeBs **do not** operate simultaneously in the same resource
- There are 3 picos per sector



Average Cell Spectral Efficiency

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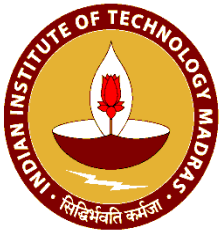

	Urban Macro (No Pico)	**Het-Net Model 2 Case 3_1 (3 Pico/Sec)**
Average Cell Spectral Efficiency (b/s/Hz/Sector)	1.423	3.25

Points to ponder:

A) How to cover "hot-spots" or coverage holes?

B) How to handoff more users to picos?

*** Model 2 Case 3_1: Pico Tx power – 37dBm Bias – 6dB**

Range Extension

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- **Range Extension (by using Bias)**
  - UE attaches to a Pico as long as Pico Rx power + x > Macro Rx power
  - x (in dB) is called the bias .

Het-net Model	Pico Tx Power (dBm)	No of UE Attached to Pico(%)		
		0dB	3dB	18dB
Model 2 Case 3_1	37	49.39	58.41	92.12

Number of UEs attached to a pico increases as bias increases

Effect of Bias → on SINR cdf

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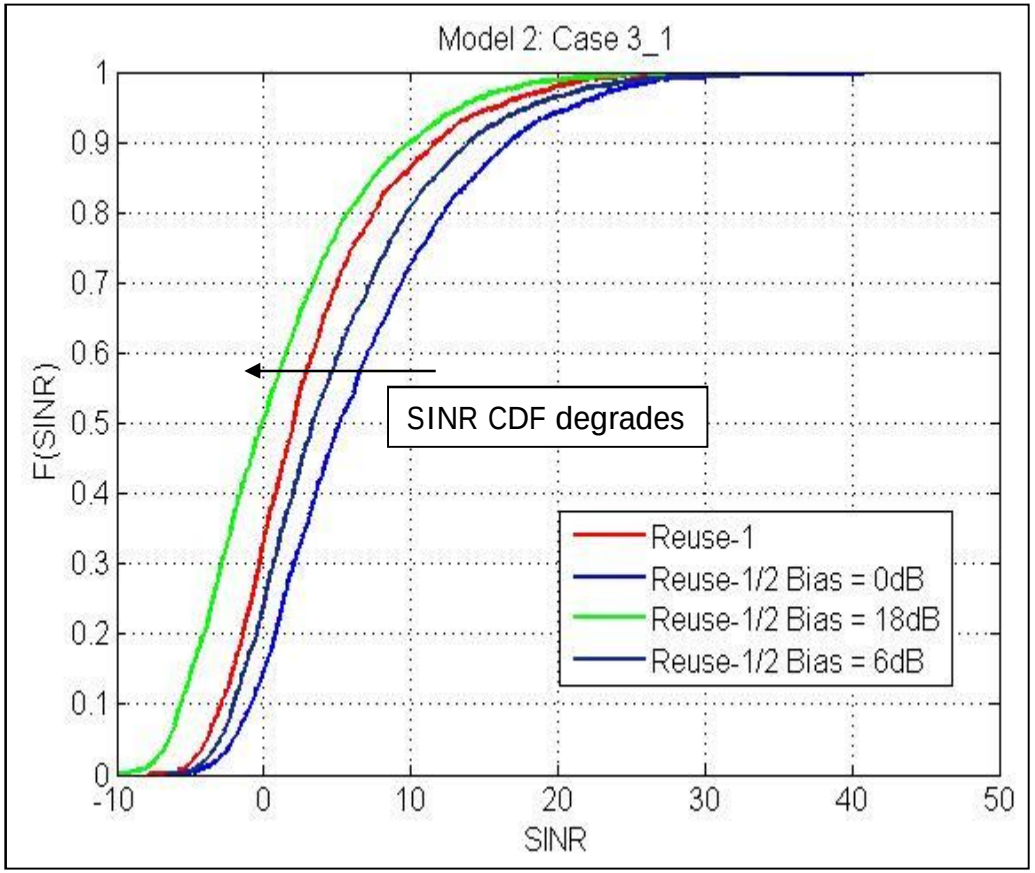
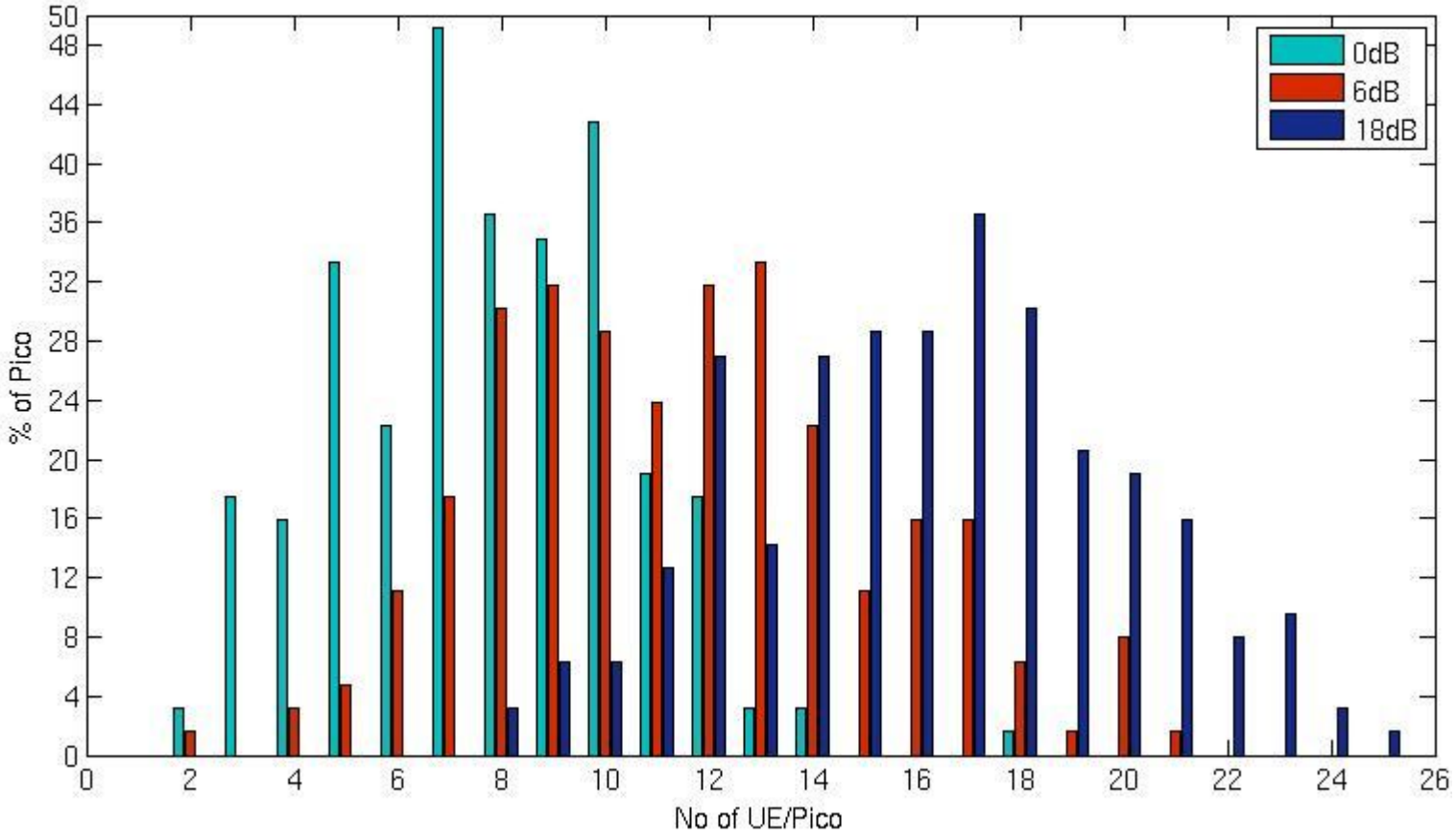
- 3 picos / sector

Pico-Pico and Macro-Pico interference starts increasing with increase in bias



Effect of Bias → on loading of Picos

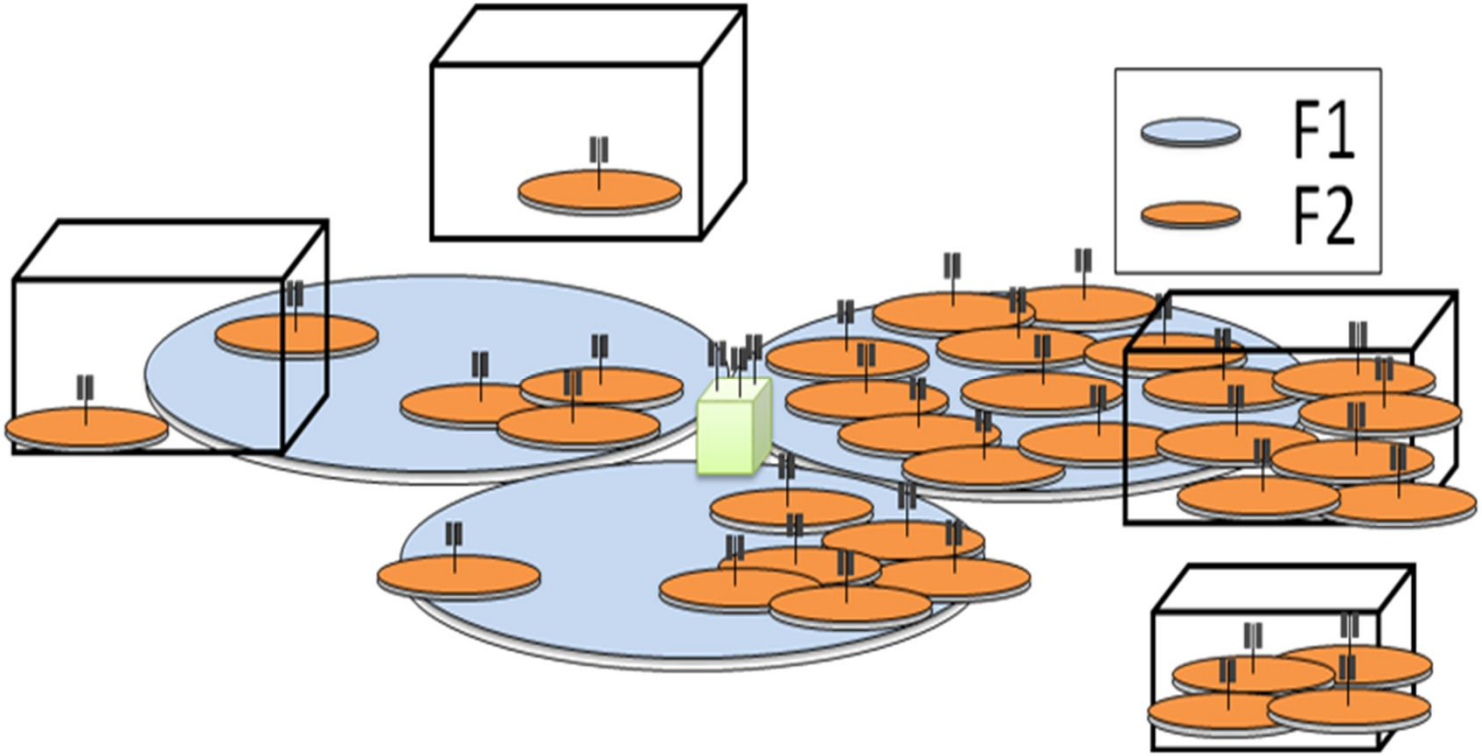
Histogram of No. of UE/pico for different biases



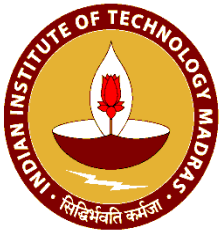
There is a large variation in the number of UEs/pico

Alternative to Range Extension : Pico eNodeBs as Under-lay

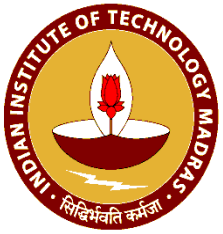
TeNeT Group
IIT Madras



Concluding Remarks



- BWA is the only way to give broadband internet to 200mil homes !!
- Magic sauce in 4G/4G+ is
  - Wideband OFDM
    - With narrow-banding to get range and also to fight interference
    - But, 20MHz-40MHz processing increases equipment cost
  - Small cells
    - But this increases the CAPEX and OPEX costs!
- 4G/4G+ should take at least a decade of learning
  - India should learn thro R&D, Deployment, Applications; if possible, contribute to standards and/or disruptive technologies
- Equitable access to all parts of India is vital for inclusive development
  - **For sustainable development of India, equitable access is necessary; but, is it sufficient?**



Perspective on LTE-A HetNets

THANK YOU!

October 25, 2014