Mobile Communications

EENG473

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Outline

- Instructor
- Course Description
- Lecture Schedule
- Exams, Homework and Project
- Grading
- General Policies

Course Description

The cellular concept, Propagation modeling, frequency planning, Link control,Handoffs, Power Control, Traffic capacity, wireless networking, Examples of current mobile systems standards.

Course outline

- Overview
- Fundamentals of cellular systems: Basic building blocks, the cellular concept, handovers, power control, traffic engineering.
- Propagation aspects: large-scale effects
- small-scale effects, propagation models.
- Mitigation Techniques: Equalization, diversity
- Multiple access techniques: FDMA, TDMA, CDMA.
- Wireless standards and systems GSM, UMTS, 5G

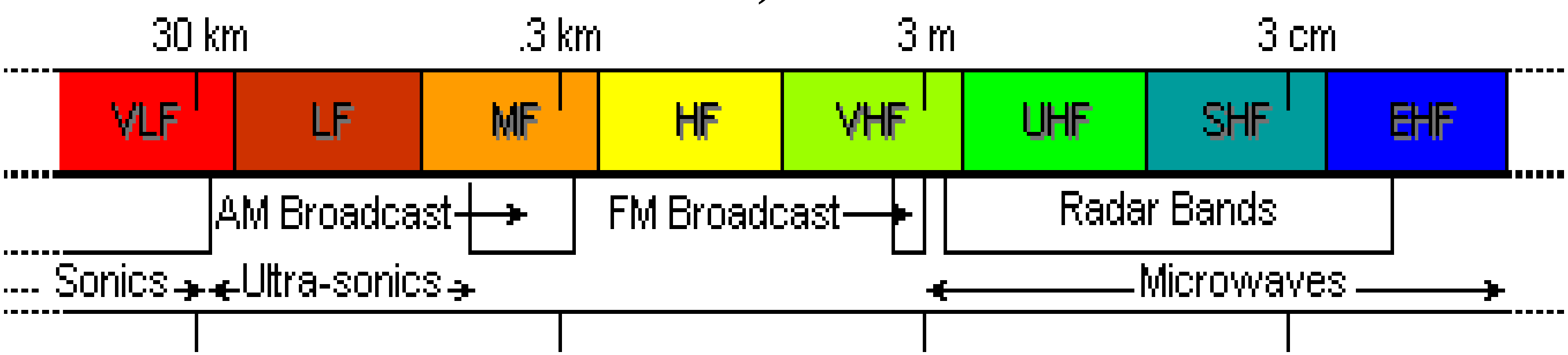
Textbook

T. S. Rappaport, *Wireless Communications: Principles and Practice*, (Second Edition), Prentice Hall, 2002.

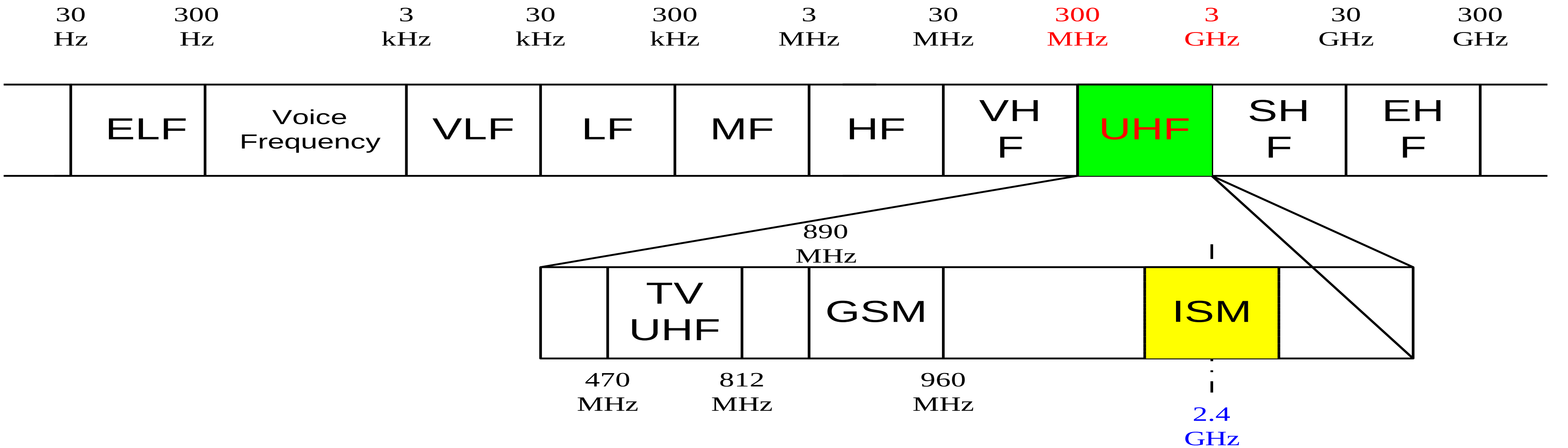
Background and Radio Frequency Spectrum Issues

Spectrum Regulations

- Spectral Allocation in US controlled by FCC (commercial) or OSM (defense)
  In Europe, ETSI
- FCC auctions spectral blocks for set applications.
- Some spectrum set aside for universal use
- Worldwide spectrum controlled by ITU-R (International Telecommunication Union Radio communication Sector)



Spectrum Allocation



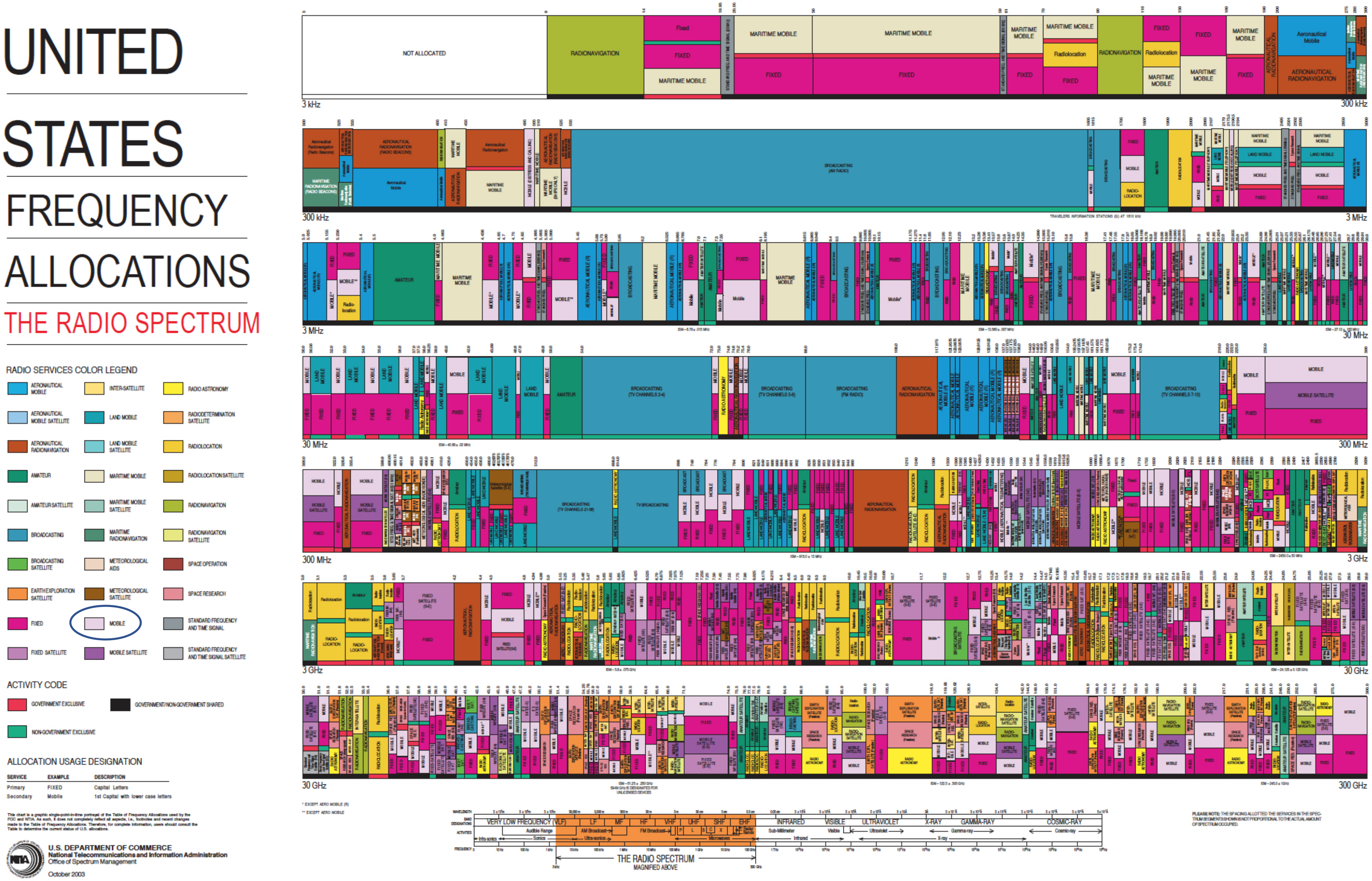
Note: The **Industrial, Scientific and Medical (ISM)** radio bands were originally reserved internationally for non-commercial use of RF electromagnetic fields for industrial, scientific and medical purposes.

Bluetooth and IEEE 802.11b : 2.45 GHz band (wavelength =12.2 cm)

–Standard for **5.2 GHz** NII band (300 MHz)

–**Unlicensed National Information Infrastructure (U-NII) band , USA**

Very Crowded RF spectrum



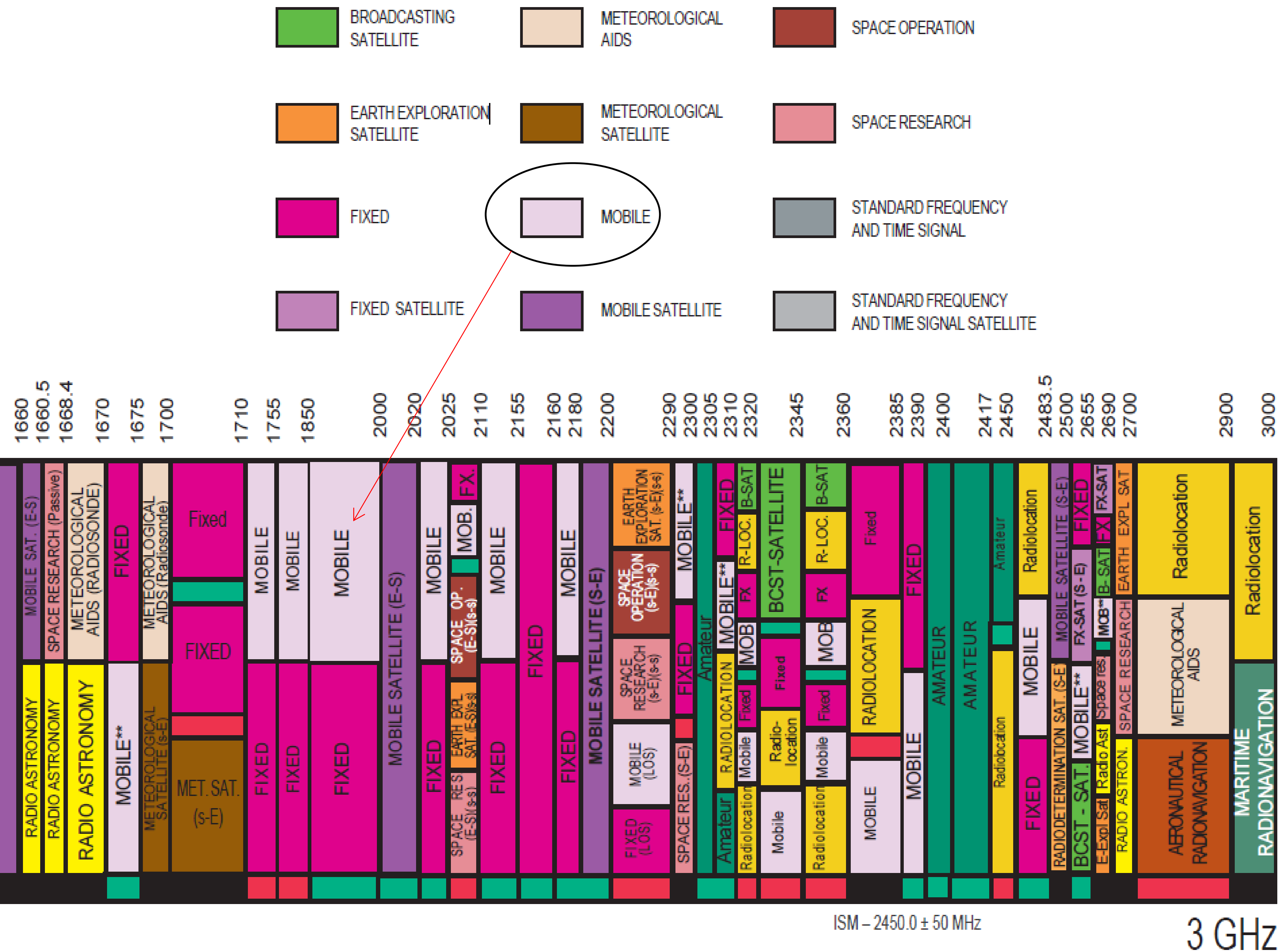

BROADCASTING SATELLITE
METEOROLOGICAL AIDS
SPACE OPERATION
EARTH EXPLORATION SATELLITE
METEOROLOGICAL SATELLITE
SPACE RESEARCH
FIXED
MOBILE
STANDARD FREQUENCY AND TIME SIGNAL
FIXED SATELLITE
MOBILE SATELLITE
STANDARD FREQUENCY AND TIME SIGNAL SATELLITE
1660 1660.5 1668.4 1670 1675 1700 1710 1755 1850 2000 2020 2025 2110 2155 2160 2180 2200 2290 2300 2305 2310 2320 2345 2360 2385 2390 2400 2417 2450 2483.5 2500 2655 2690 2700 2900 3000
ISM – 2450.0 ± 50 MHz
3 GHz

TABLE 1.1 Frequency Band Designations

Frequency range, GHz	Band designati
0.1–0.3	VHF
0.3–1.0	UHF
1.0–2.0	L
2.0–4.0	S
4.0–8.0	C
8.0–12.0	X
12.0–18.0	Ku
18.0–27.0	K
27.0–40.0	Ka
40.0–75	V
75–110	W
110–300	mm
300–3000	µm

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History of Mobile phones

1. 1940s - Early Concepts

- Development of mobile radio systems for police departments in the United States and Europe
- Introduction of hand-held radios, such as the "Handie-Talkie" used in WWII.

2. 1947 - Bell Labs' Cellular Concept

- Bell Labs proposed the concept of cellular networks, which involved dividing coverage areas into smaller cells to reuse frequencies and increase capacity.

3. 1960s - Early Mobile Communication Systems

- Development of car-based mobile telephony systems, primarily used by wealthy individuals and businesses.
- Introduction of Improved Mobile Telephone Service (IMTS), which provided better call quality and more channels than previous systems.

4.1973 - First Mobile Phone Call

- Martin Cooper of Motorola made the first public mobile phone call on April 3, 1973, using a prototype of the Motorola DynaTAC.

5. **1980s - First Generation (1G) Mobile Networks**
   - Launch of the first 1G mobile networks, including the Advanced Mobile Phone System (AMPS) in the United States in 1983.
   - Introduction of the first commercially available mobile phone, the Motorola DynaTAC 8000X, in 1983.

6. **1990s - Second Generation (2G) Mobile Networks**
   - Launch of 2G networks in the early 1990s, introducing digital encryption of conversations and SMS text messaging.
   - Introduction of GSM (Global System for Mobile Communications) as a standard in Europe, leading to global adoption.
   - Rise of mobile phones as consumer products, with smaller, more affordable devices.

7. **1996 - Introduction of the First Smartphone**
   - Release of the Nokia 9000 Communicator, combining mobile phone functionality with PDA features.

8. **Late 1990s - Early 2000s - Third Generation (3G) Mobile Networks**

- Launch of 3G networks, providing faster data transmission and enabling mobile internet access, video calls, and multimedia messaging.

- Popularization of smartphones with the introduction of devices like the BlackBerry and early Windows Mobile phones.

9. **2007 - Introduction of the iPhone**

- Apple released the first iPhone, revolutionizing the mobile phone industry with its touch screen interface, app ecosystem, and design.

- Rapid growth of the smartphone market, with Android emerging as a major competitor.

10. **2010s - Fourth Generation (4G) Mobile Networks**

- Rollout of 4G LTE networks, providing even faster data speeds and enabling high-quality video streaming and advanced mobile applications.

- Proliferation of smartphones globally, with increasing affordability and accessibility.

11. **2020s - Fifth Generation (5G) Mobile Networks**

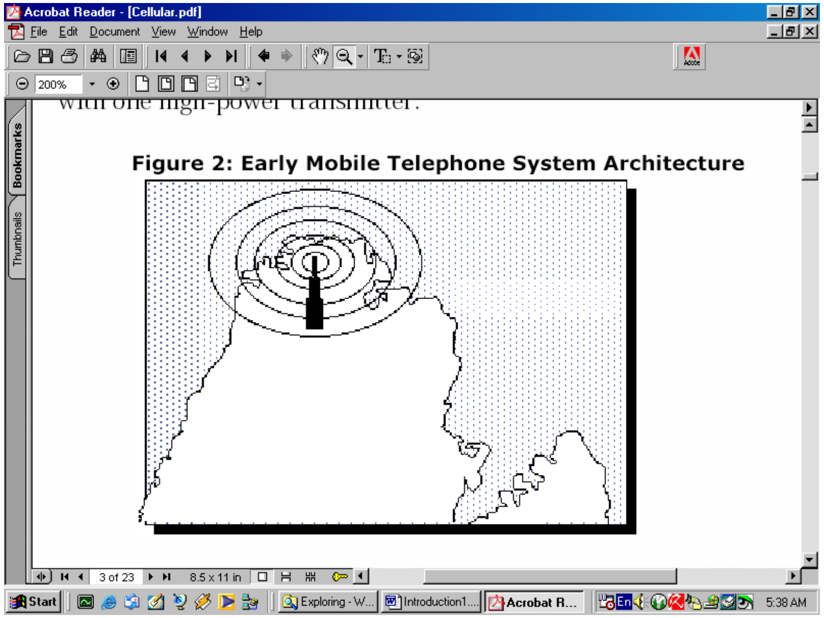
- Launch of 5G networks, offering significantly faster speeds, lower latency, and support for advanced applications like IoT, autonomous vehicles, and smart cities.

- Continued evolution of mobile phones with innovations in AI, augmented reality, foldable screens, and more.

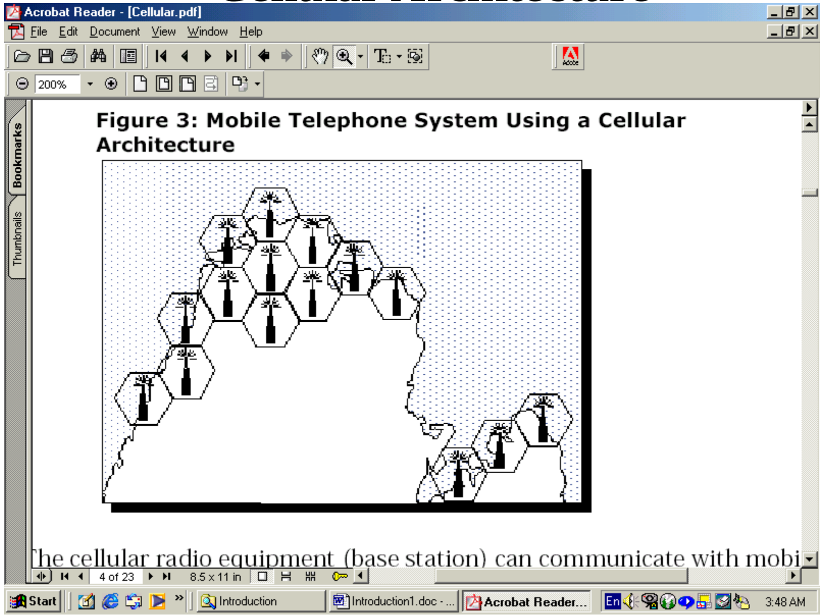
Cellular mobile phone networks basics

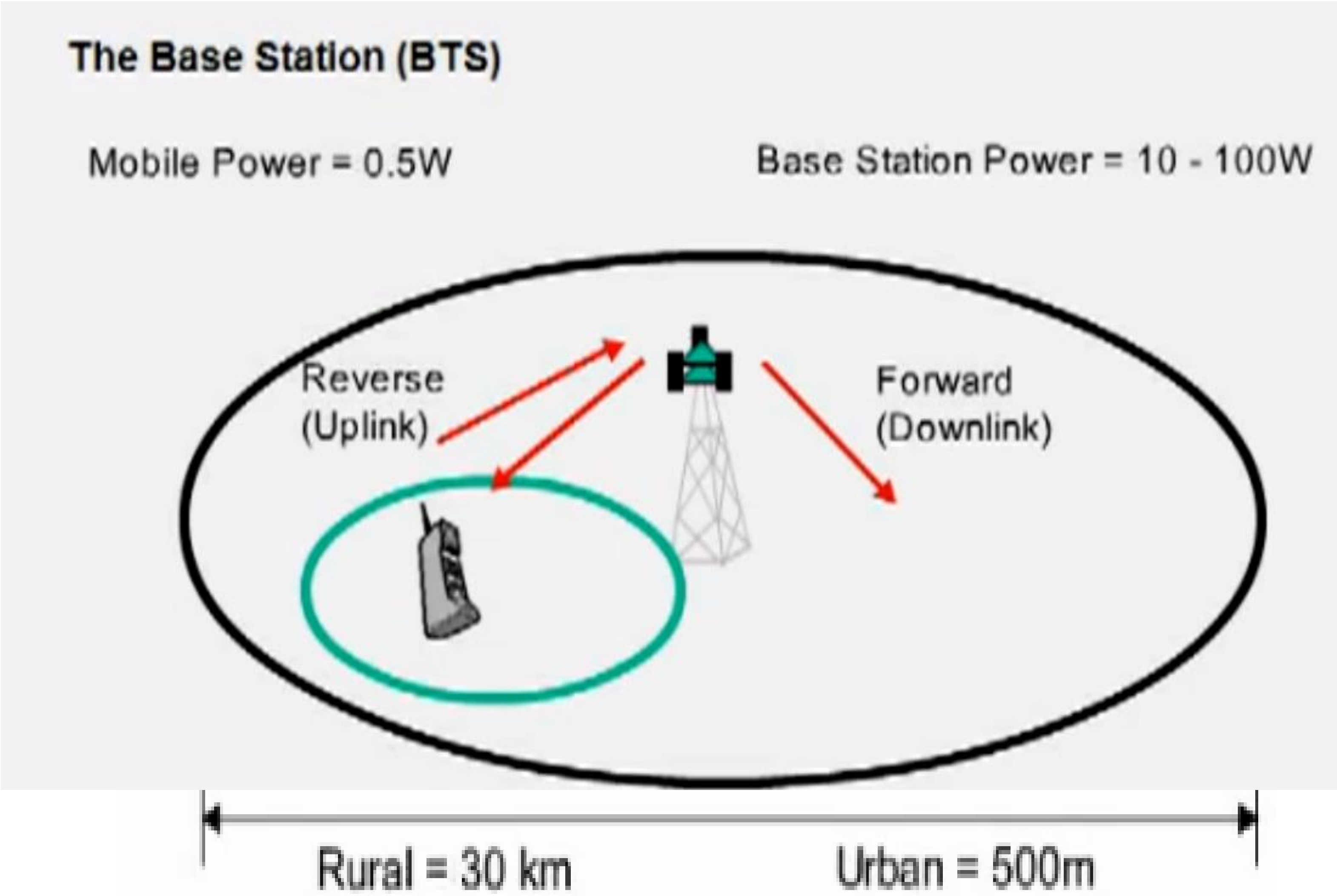
Cellular Telephone Systems

Early Mobile Telephone System Architecture



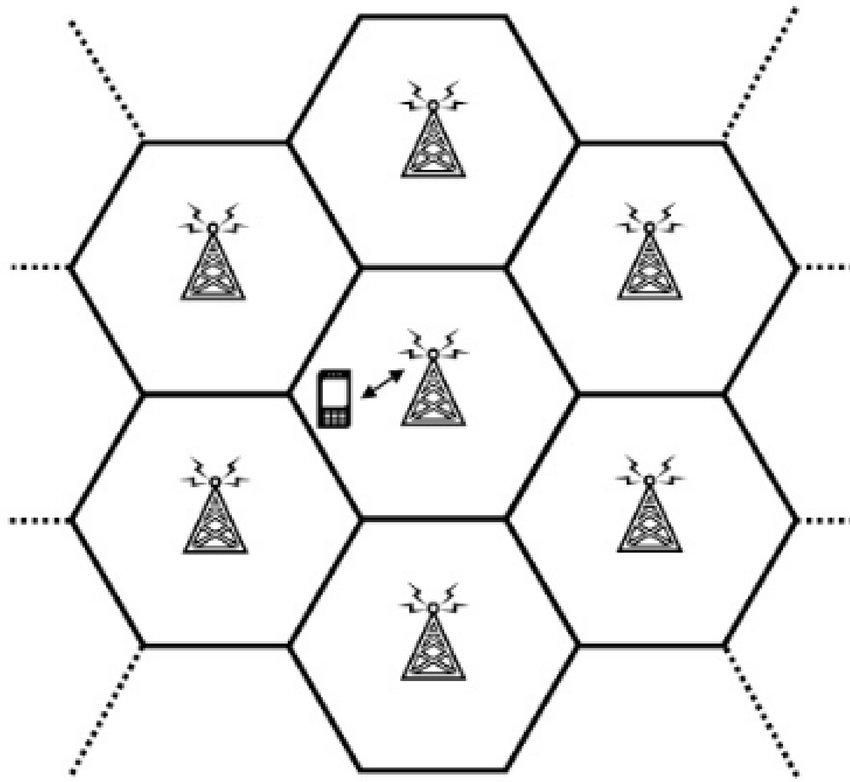
Mobile Telephone System Using Cellular Architecture

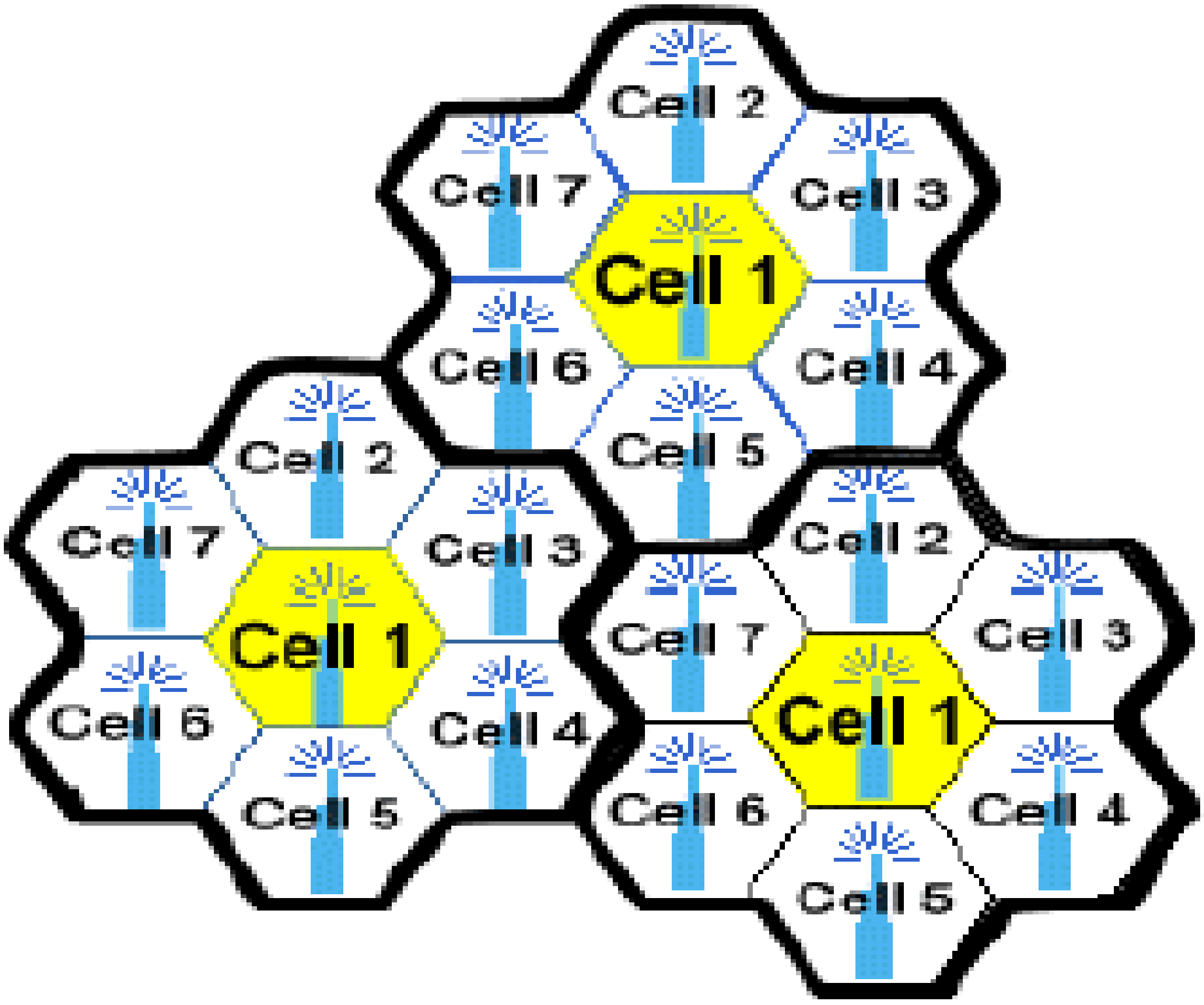



The Base Station (BTS)
Mobile Power = 0.5W
Base Station Power = 10 - 100W
Reverse
(Uplink)
Forward
(Downlink)
Rural = 30 km
Urban = 500m

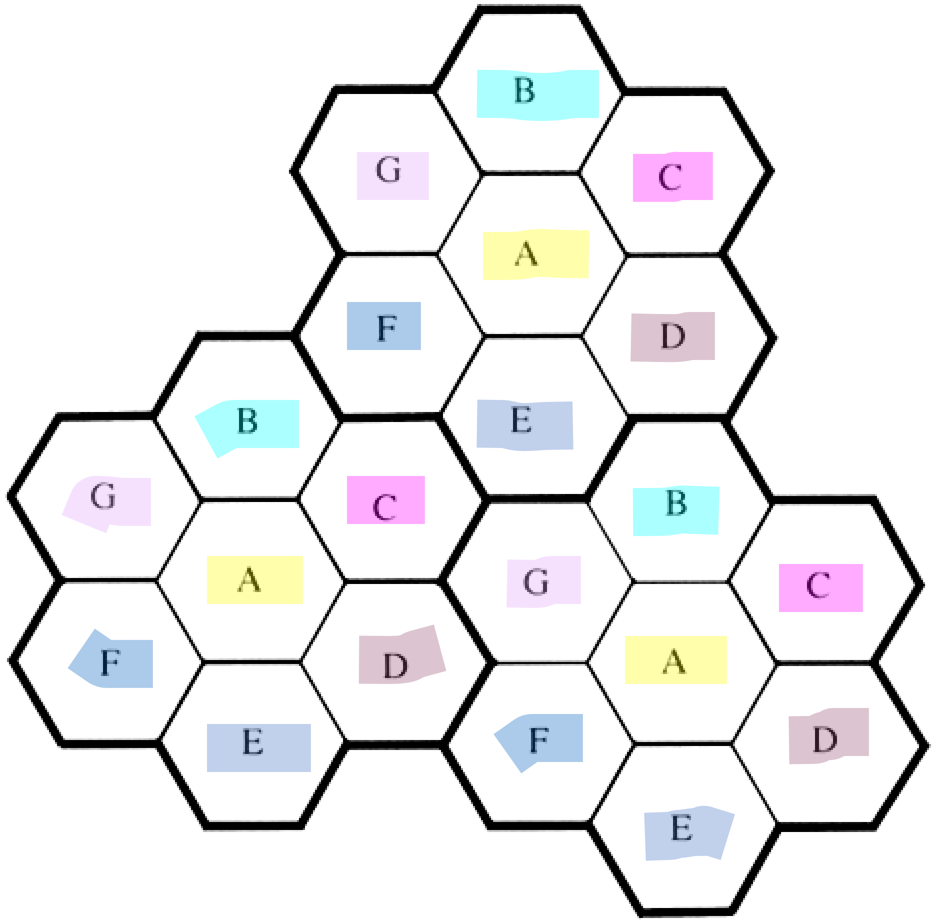
Cellular Wireless System

- A large geographical region is segmented into smaller "cell"s.
  - Transmit power limitation
  - Facilitates frequency spectrum re-use
- Cellular network design issues
  - Inter-cell synchronization
  - Handoff mechanism
  - Frequency planning

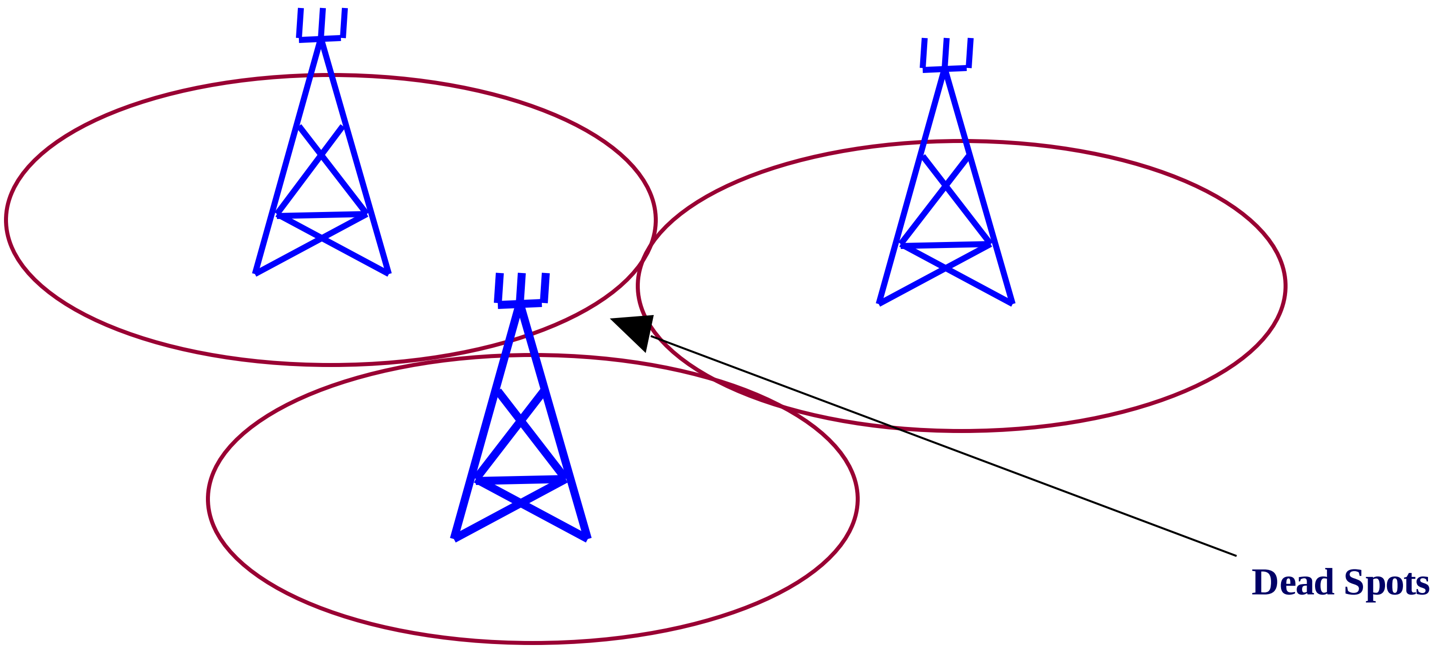



Cell 2
Cell 7
Cell 3
Cell 1
Cell 6
Cell 4
Cell 5
Cell 2
Cell 7
Cell 3
Cell 1
Cell 6
Cell 4
Cell 5
Cell 2
Cell 7
Cell 3
Cell 1
Cell 6
Cell 4
Cell 5

The Cellular Concept



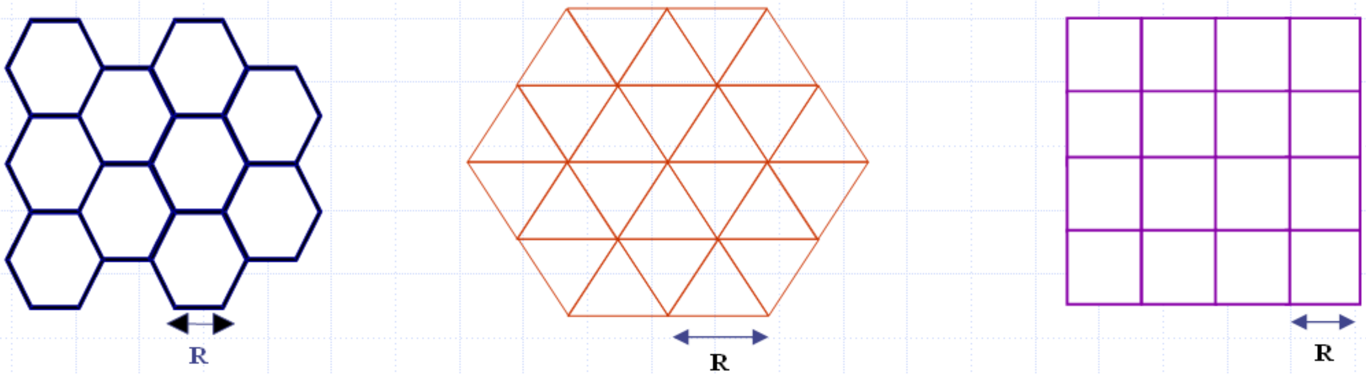
Cell Geometry, Radio Coverage



Problem of omni directional antennas

Cell Geometrical Shape

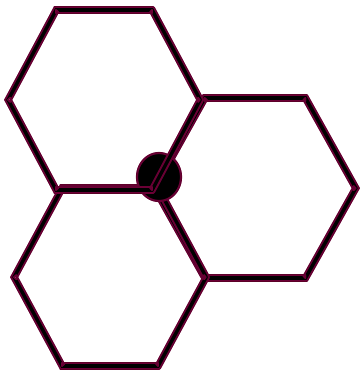
To solve the dead spot problem



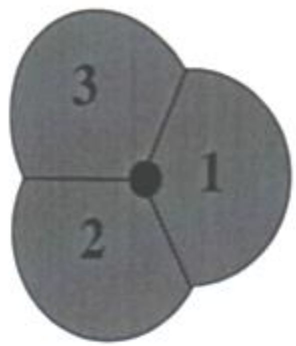
Tradeoffs

- The number of cells required to cover a given area.
- The cell transceiver power.

Sectorial Antenna



Sectorial Antenna



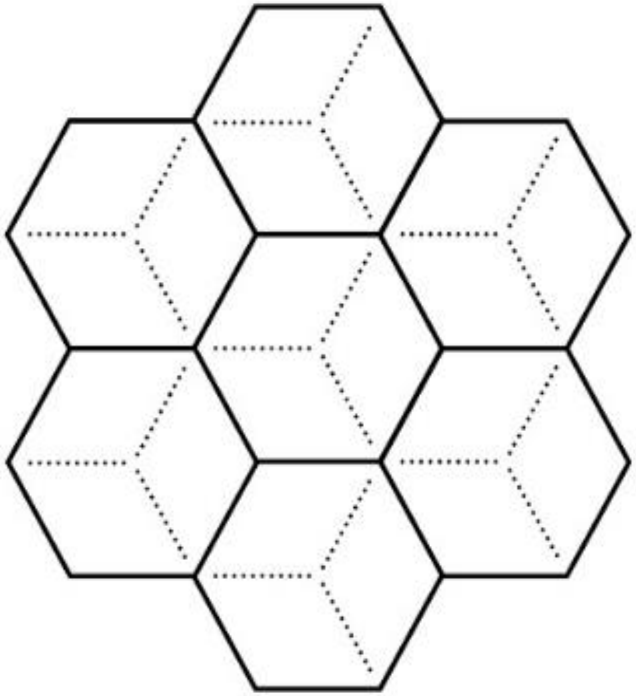
Theoretical

Actual

The cells will take the form of overlapping circles.

Due to the obstacles in the coverage area the actual shape of the cells would be Random.

- Sectorized cells



Cellular system

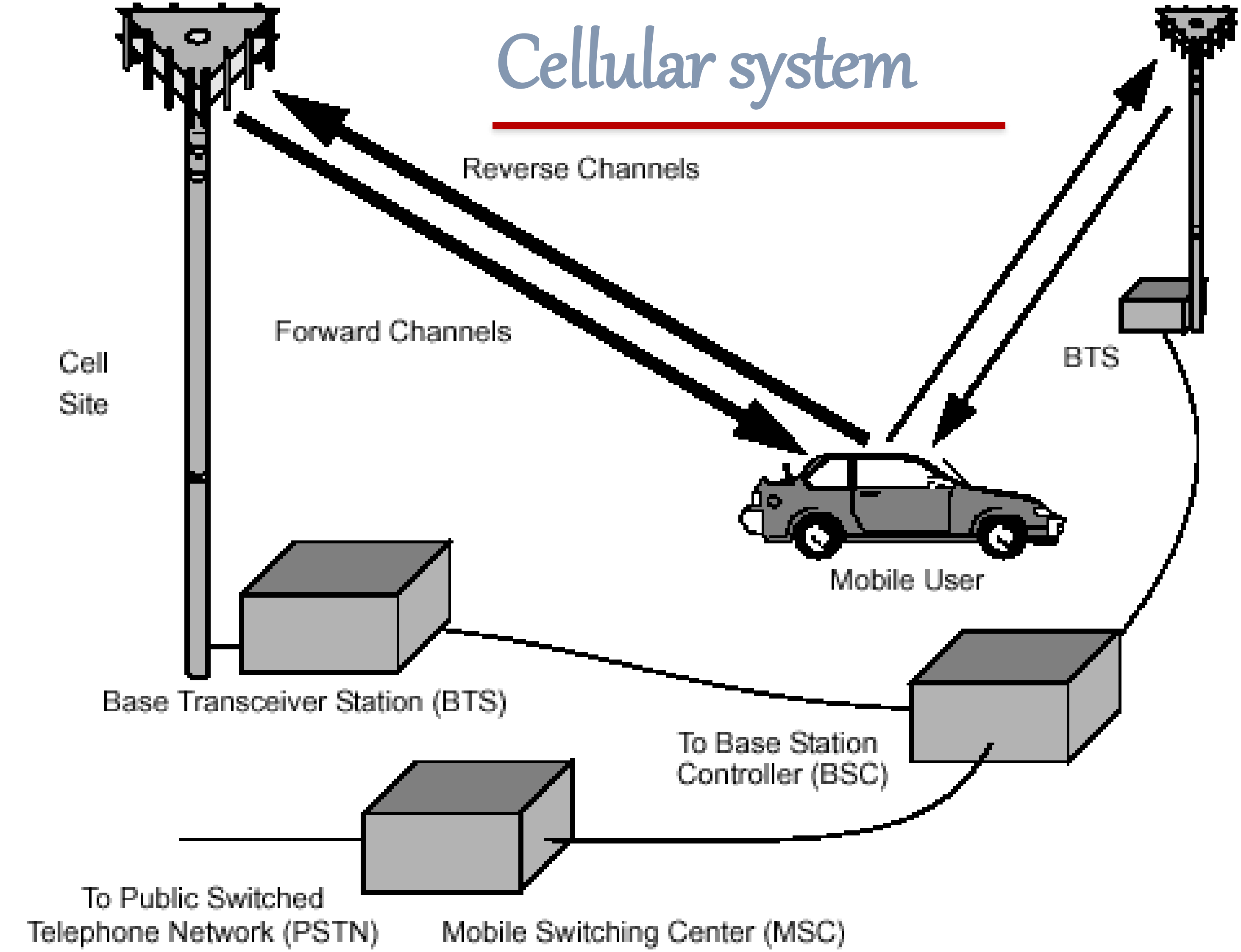


Figure 1–3 There are two main types of forward channels. Control and access channels are used to set up calls and provide security and management functions. Traffic channels are used to carry voice traffic. The reverse channels are also divided into access channels and traffic channels. In some systems, the Base Station Controller (BSC) may be integrated directly into the cell site. In other systems, as shown here, the Base Transceiver Stations (BTSs) are connected to a Base Station Controller.

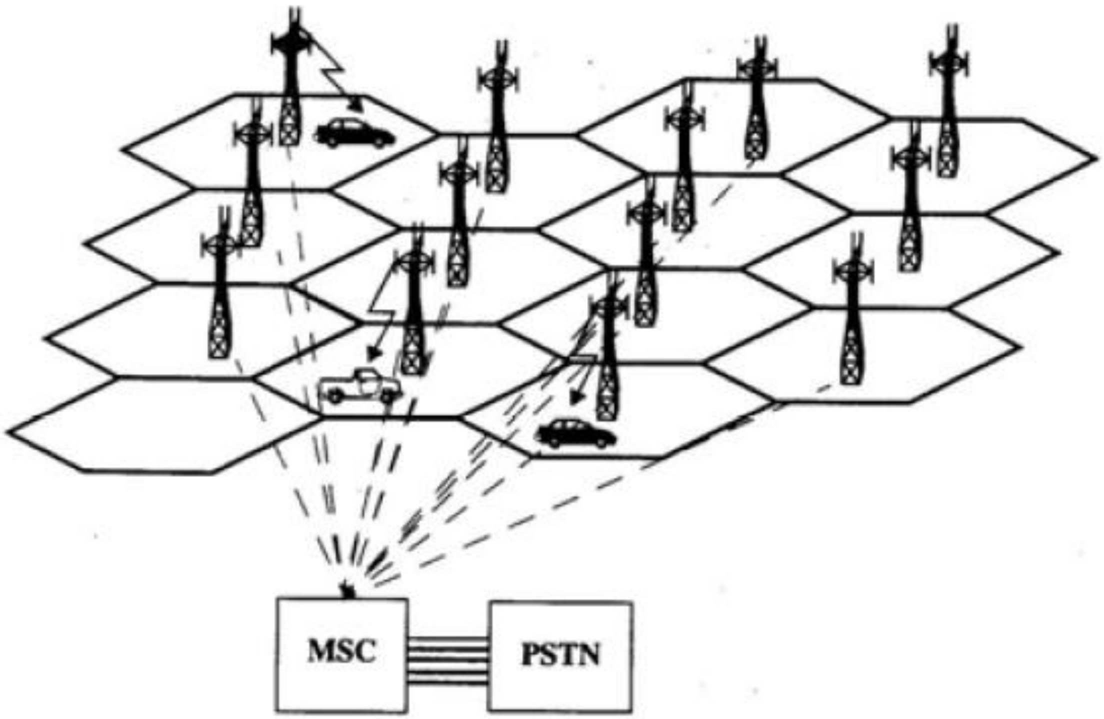


Figure 1.5 A cellular system. The towers represent base stations which provide radio access between mobile users and the mobile switching center (MSC).

Evolution of Mobile Networks

	First Generation Systems	Second Generation Systems	Third Generation Systems
Time Frame	1984-1996	1996-2000	2000-2010
Services	Analog Mobile Telephony Voice Band Data	Digital voice, messaging	High speed data Broadband video Multimedia
Architecture	Macrocellular	Microcellular, Picocel-lular Wireless Local Loop	
Radio Technology	Analog FM, FDD-FDMA	Digital modulation, CDMA, TDMA using TDD and FDD	CDMA, possibly com-bined with TDMA, with TDD and FDD variants
Frequency Band	800 MHz	800+1900 MHz	2 GHz+
Examples	AMPS TACS ETACS NMT450/900 NTT JTACS/NTACS	cdmaOne (IS-95) GSM/DCS-1900 US TDMA IS-136 PACS PHS	cdma2000 WCDMA

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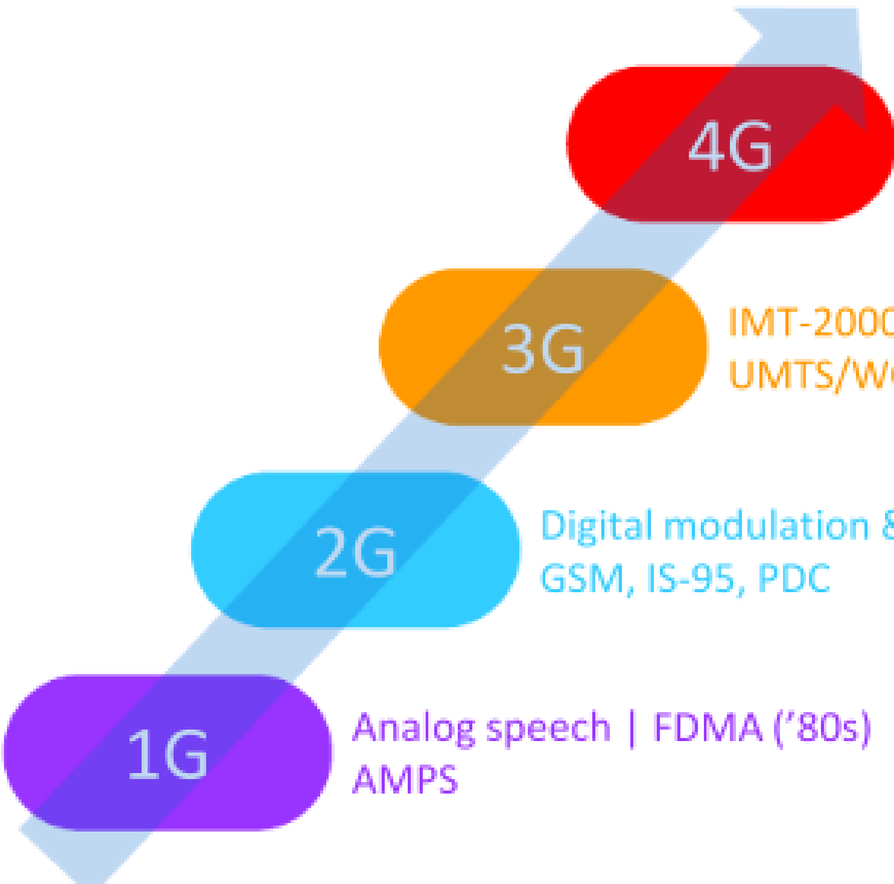
Cellular system Evolution

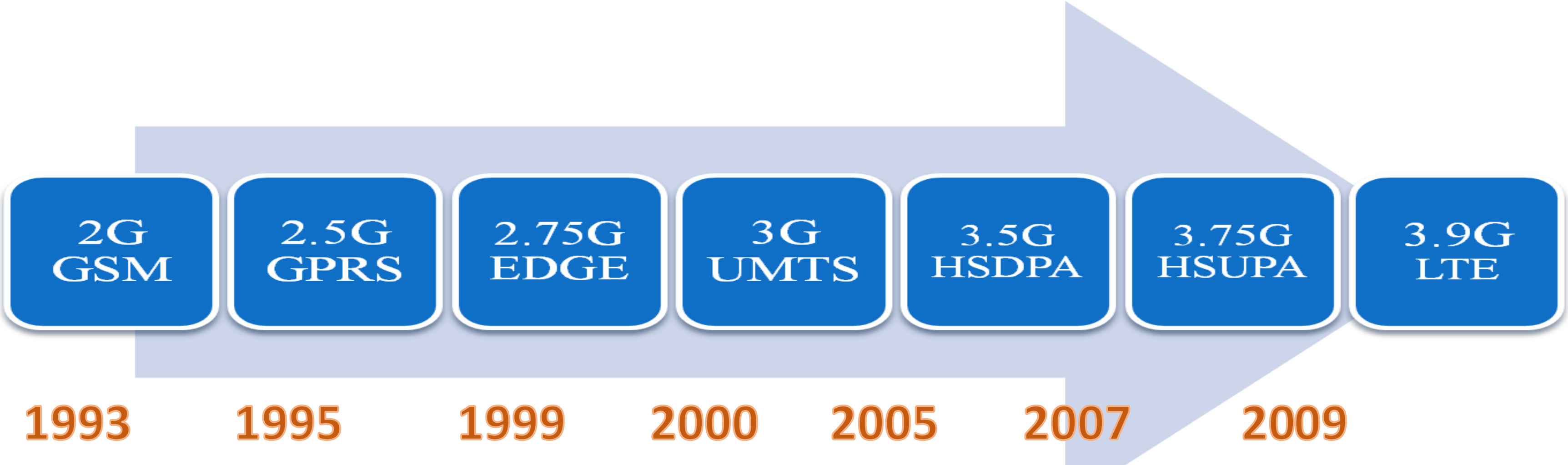


Systems beyond IMT-2000 (IMT-Advanced)
LTE/LTE-Advanced, WiMAX (802.16m)

IMT-2000 global standard | Wideband CDMA ('00s)
UMTS/WCDMA/HSPA, CDMA2000, TD-SCDMA

Digital modulation & roaming | TDMA & CDMA ('90s)
GSM, IS-95, PDC

Analog speech | FDMA ('80s)
AMPS

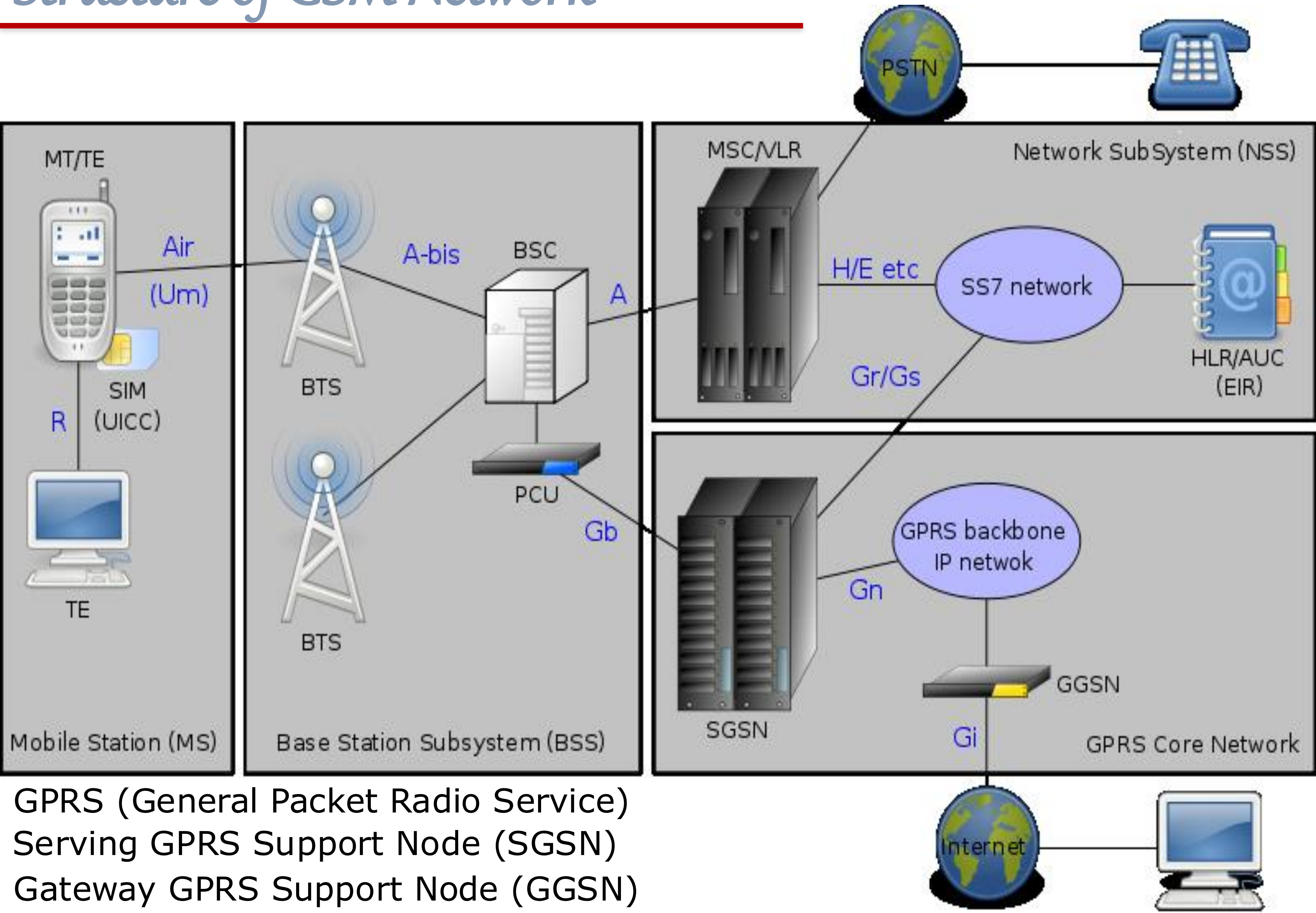


- 1G (Early 1980s)
  - Analog speech communications.
  - Analog FDMA.
  - Ex: AMPS
- 2G (Early 1990s)
  - Digital modulation of speech communications.
  - Advanced security and roaming.
  - TDMA and narrowband CDMA.
  - Ex: GSM, IS-95 (cdmaOne), and PDC
- 3G (Late 1990s)
  - Global harmonization and roaming.
  - Wideband CDMA
  - Ex: UMTS, cdma2000, and TD-SCDMA

- **2.5G – GPRS (General Packet Radio Service)**
- 2.75G- Enhanced Data Rates for GSM Evolution (EDGE)
- 3.5G- High Speed Downlink Packet Access (HSDPA)
- 3.75G- High Speed Uplink Packet Access (HSUPA)
- 3.9G- Evolved High Speed Packet Access (HSPA+)

Generation	Frequency	Definition	throughput	Technology
1G (1981-1996)	800-900 MHz (BW = 30 kHz)	Analog (FM) Voice	14.4 Kbps (peak)	AMPS, NMT, TACS ETACS
2G (1996-2000)	900/1800 MHz 850/1900 MHz (BW = 200KH)	Digital Narrowband Circuit Switching Data Voice Messaging (SMS)	9.6 / 14 Kbps	GSM/DCS - 1900 TDMA(IS-136) CDMA (IS95- CDMA-one)
2.5G, 2.75G		Packet Switching Data WAP +MMS	56 kbit/s up to 115 kbit/s	GPRS, EDGE
3G (2001-2010) (wideband-Global)	2GHz + 1920 - 2170MHz (BW=5MHz)	Digital Broadband Packet Switching Data (High speed data Multimedia)	3.1 Mbps (Peak) 500-700 Kbps	CDMA2000 (Verizon, Sprint) UMTS, WCDMA (AT&T, T-Mobile+ Europe)
3.5G 3.75G		>2 Mbps	14.4 Mbps (peak) 1-3 Mbps 42 Mbps (peak)& 28 Mbps 2x2 MIMO 672 Mbps	HSPA: HSDPA, HSUPA HSPA+
4G (2012+) (Broadband) 5G=Gigabit	LTE (3GPP) LTE-A (3GPP2)	Digital Broadband All IP (voice+data) Very High	100-300 Mbps (peak) 100 -1000 Mbps (peak) 3-5 Mbps	LTE (WCDMA) Mobile WIMAX, IEEE802.16 (d,e,m) UBM (IP networks)

Structure of GSM Network



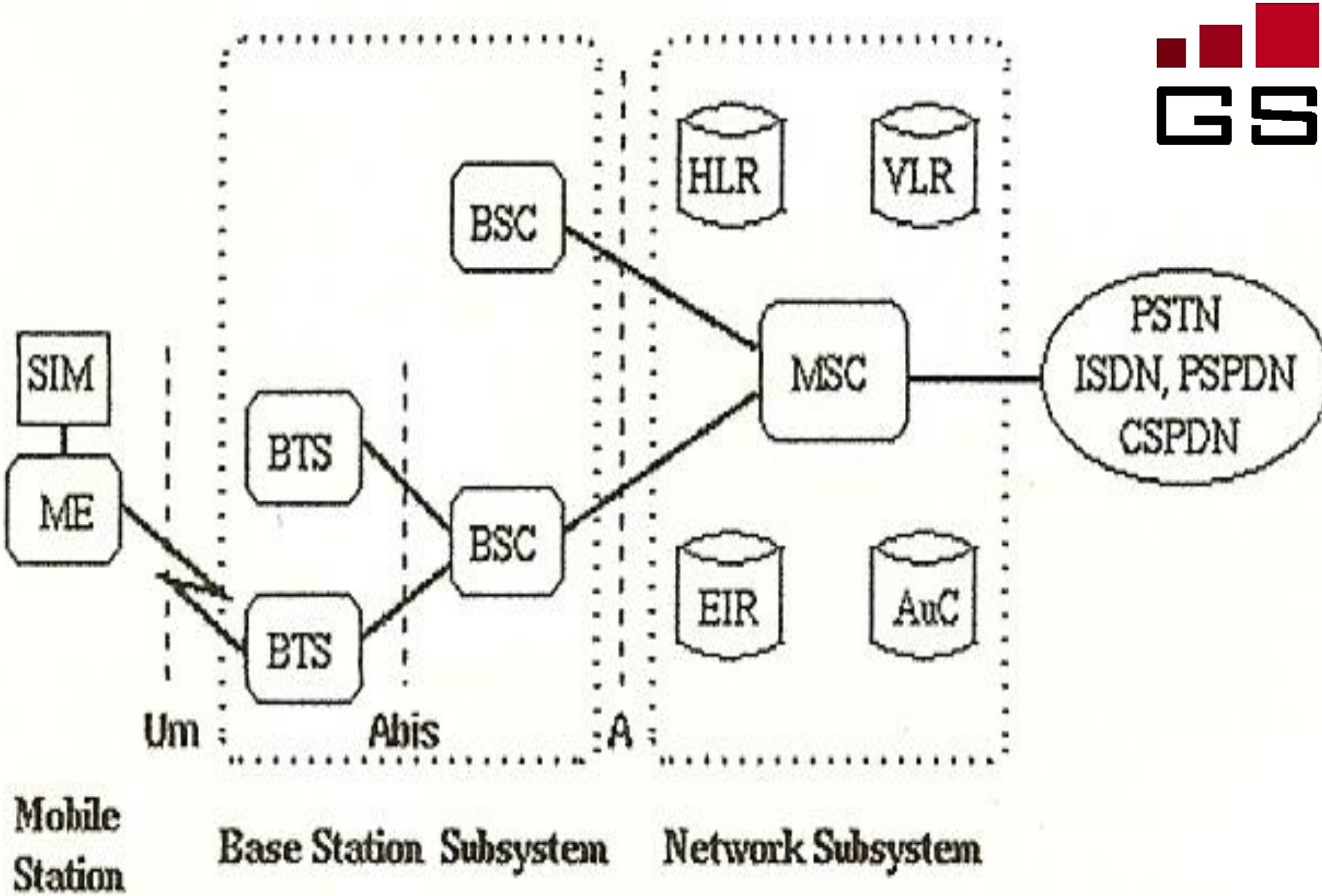
GPRS (General Packet Radio Service)

Serving GPRS Support Node (SGSN)

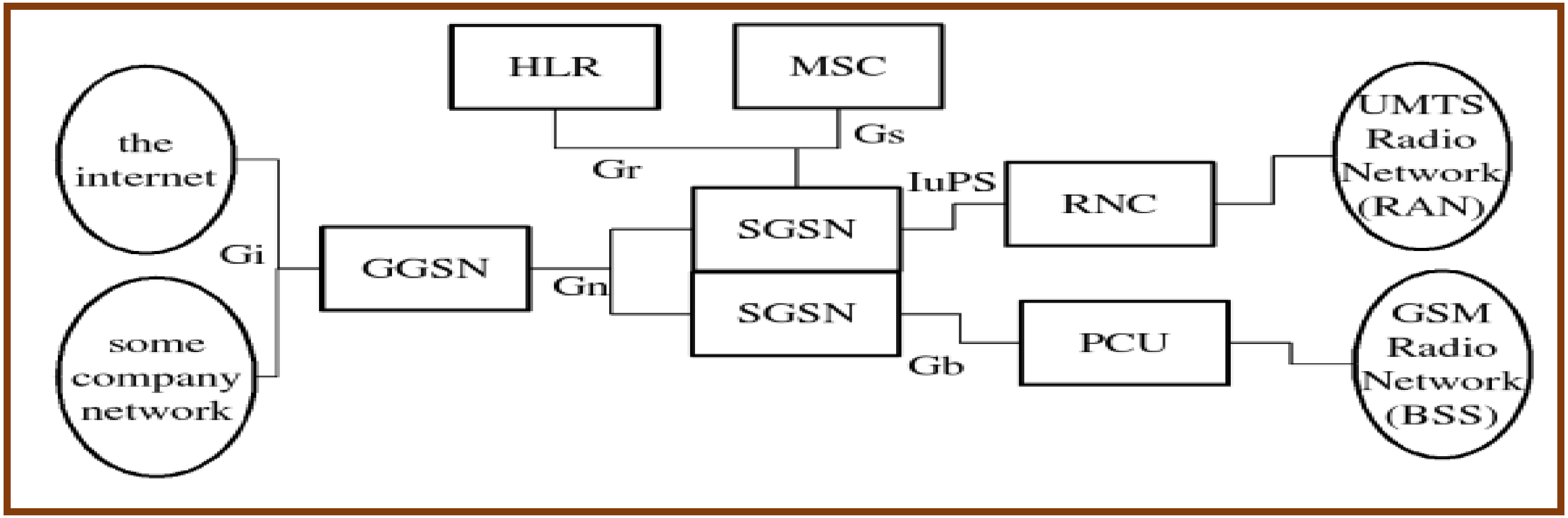
Gateway GPRS Support Node (GGSN)

System Architecture

- Mobile Station (MS)
  - Mobile Equipment (ME)
  - Subscriber Identity Module (SIM)
- Base Station Subsystem (BBS)
  - Base Transceiver Station (BTS)
  - Base Station Controller (BSC)
- Network Subsystem
  - Mobile Switching Center (MSC)
  - Home Location Register (HLR)
  - Visitor Location Register (VLR)
  - Authentication Center (AUC)
  - Equipment Identity Register (EIR)



SIM Subscriber Identity Module
ME Mobile Equipment
BTS Base Transceiver Station
BSC Base Station Controller
HLR Home Location Register
VLR Visitor Location Register
MSC Mobile services Switching Center
EIR Equipment Identity Register
AuC Authentication Center



The GPRS core network is the central part which allows 2G, 3G and WCDMA mobile networks to transmit IP packets to external networks such as the Internet provides mobility management, session management and transport for Internet Protocol packet services in GSM and WCDMA networks.

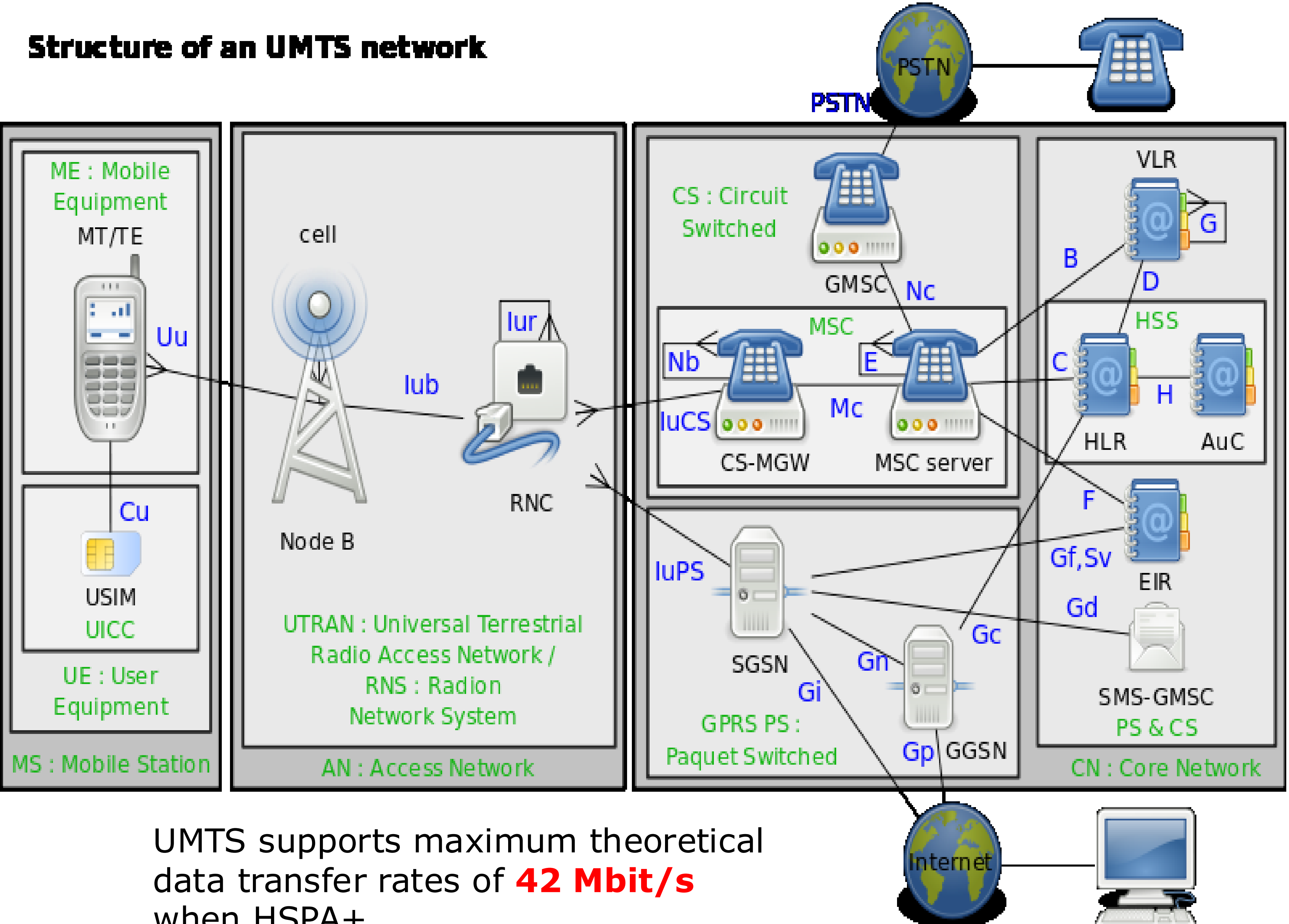
Gateway GPRS Support Node (GGSN): is responsible for the interworking between the GPRS network and external packet switched networks

Serving GPRS Support Node (SGSN): is responsible for the delivery of data packets from and to the mobile stations within its geographical service area.

Packet control unit: The allocation of channels between voice and data is controlled by the base station, but once a channel is allocated to the PCU, the PCU takes full control over that channel.

The Radio Network Controller (or RNC): is a governing element in the UMTS radio access network (UTRAN) and is responsible for controlling the Node Bs that are connected to it..

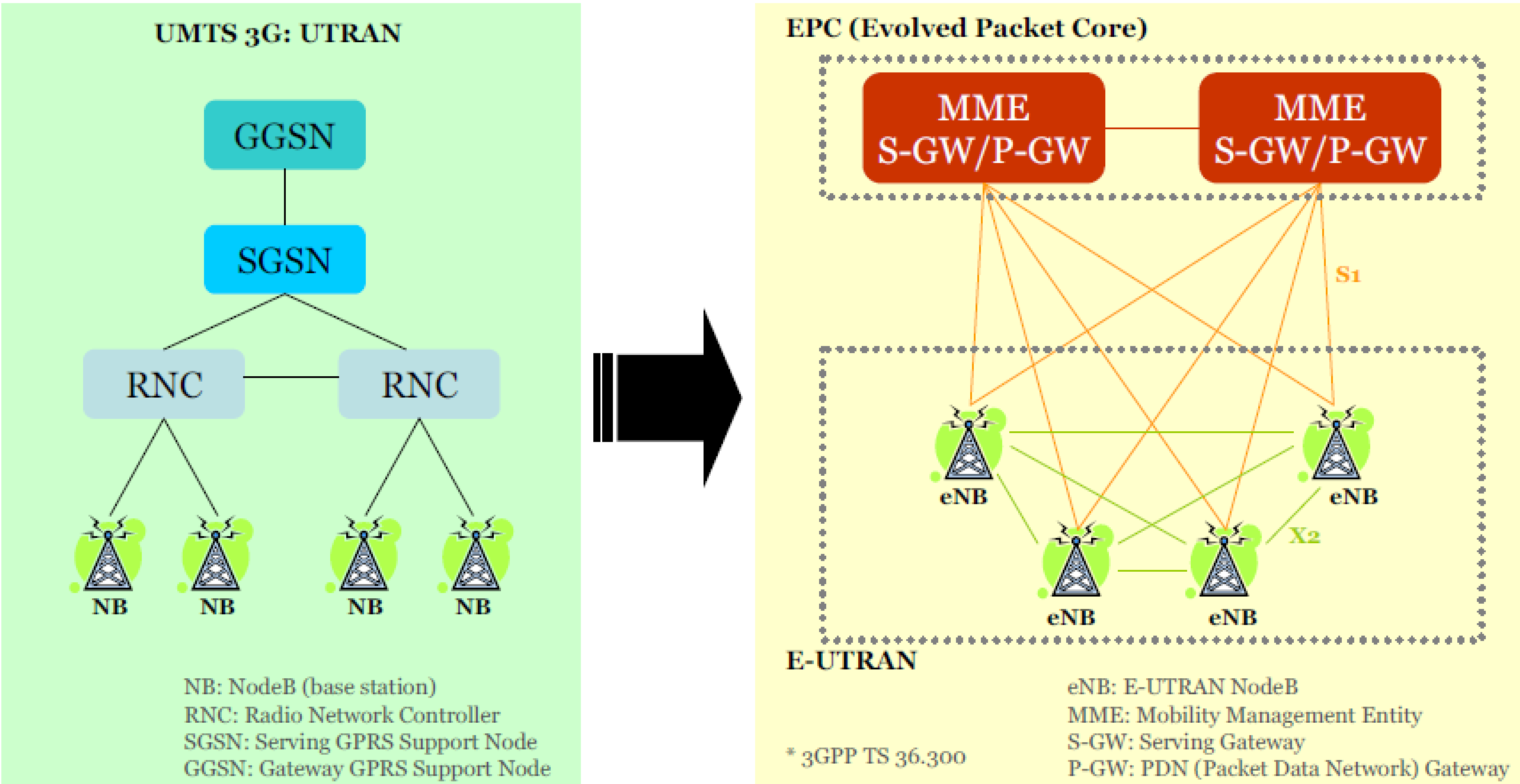
Structure of an UMTS network



UMTS supports maximum theoretical data transfer rates of **42 Mbit/s** when HSPA+

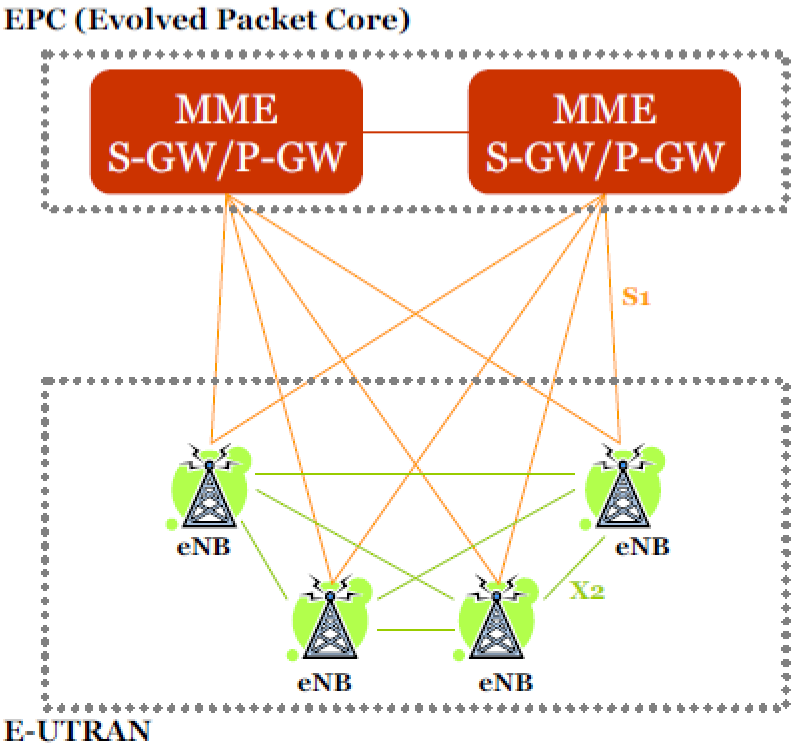
LTE Network Architecture

- E-UTRAN (Evolved Universal Terrestrial Radio Access Network)



LTE Network Architecture

- eNB
  - All radio interface-related functions
- MME
  - Manages mobility, UE identity, and security parameters.
- S-GW
  - Node that terminates the interface towards E-UTRAN.
- P-GW
  - Node that terminates the interface towards PDN.



* 3GPP TS 36.300

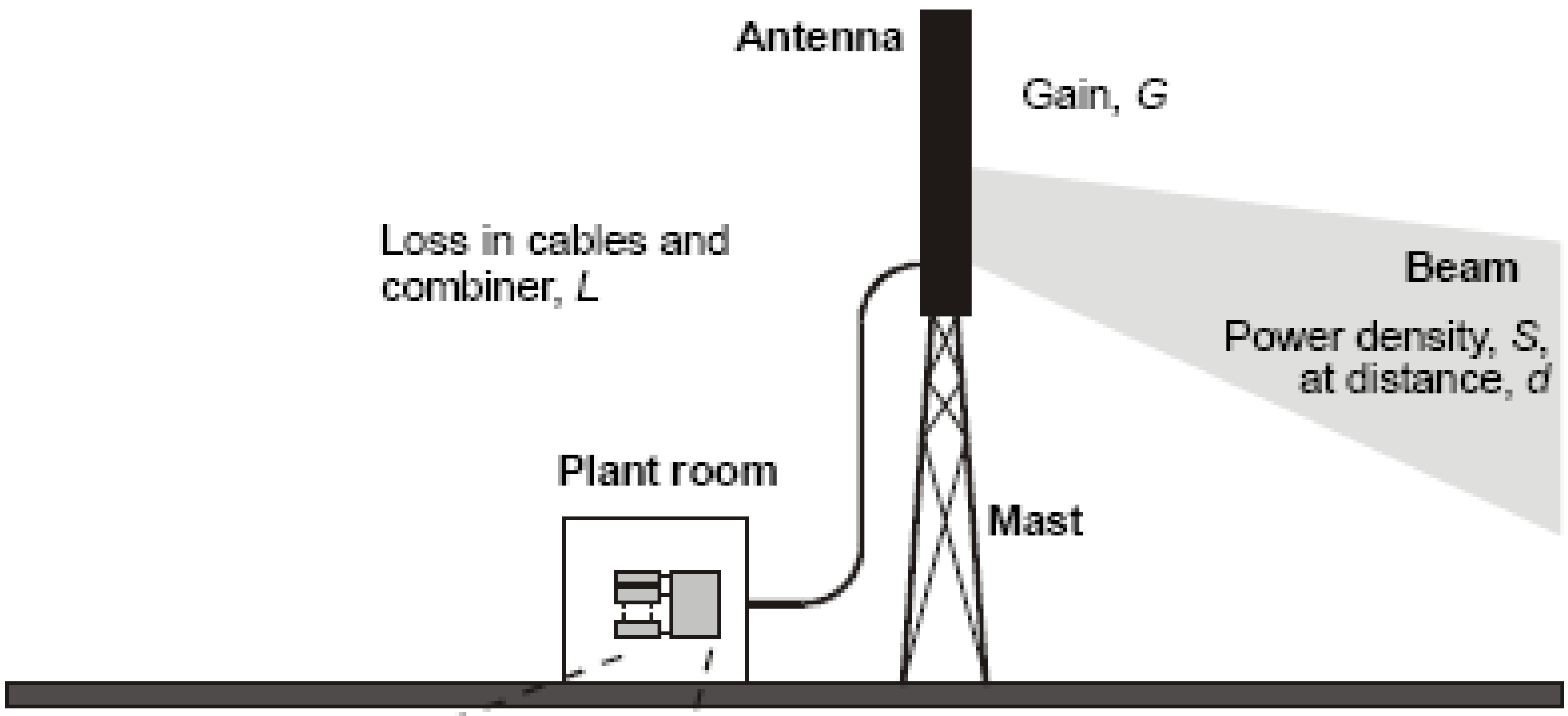
eNB: E-UTRAN NodeB
MME: Mobility Management Entity
S-GW: Serving Gateway
P-GW: PDN (Packet Data Network) Gateway

Types and Structure of Base Station

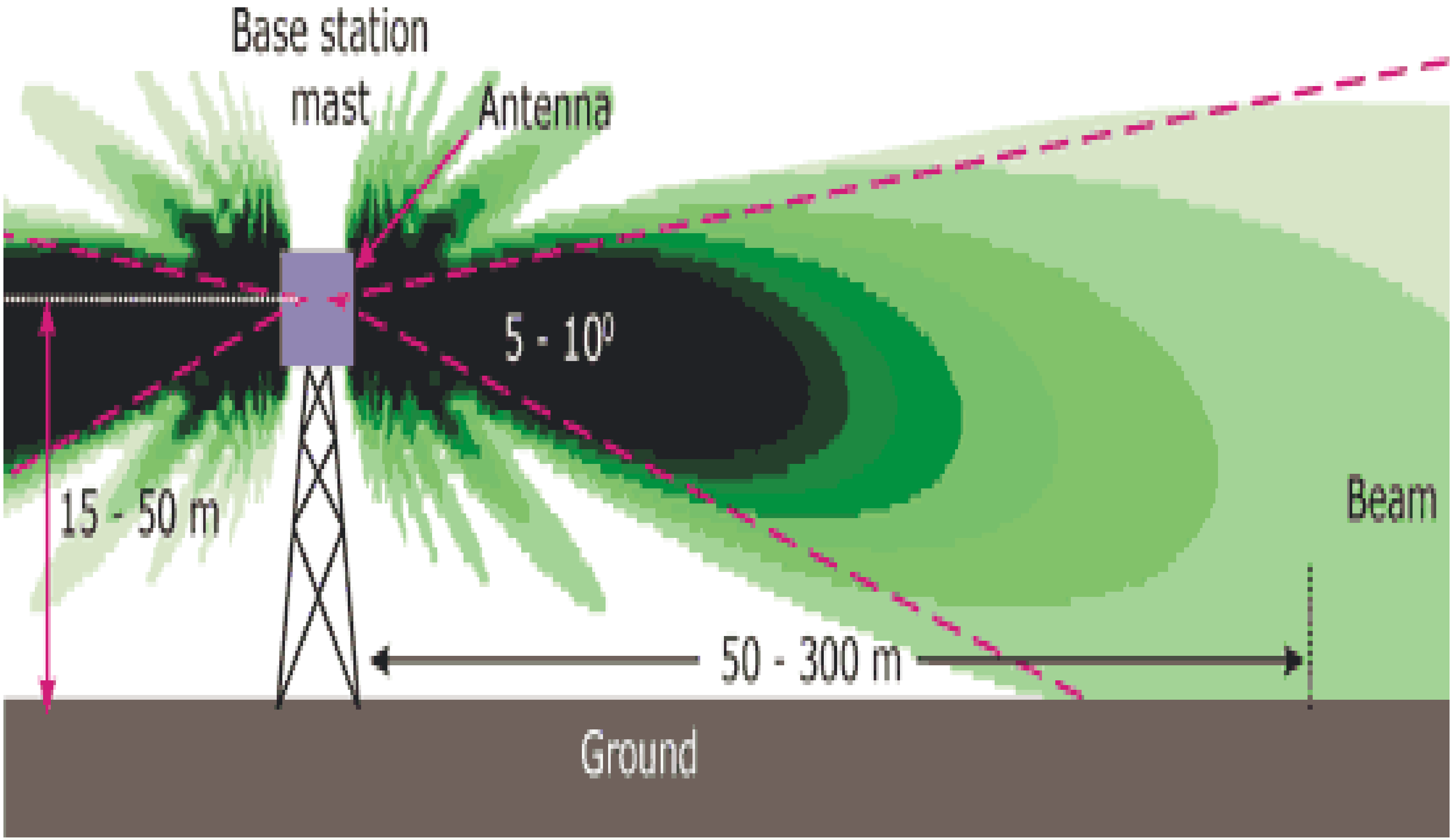
types of Base stations:

- Macro-cell
- Micro-cells
- Pico-cell
- Femto cell

The base station consists of : **plants room, mast, Antenna and cables.**



RF Beamfrom the Base Station



Base Station Antenna 1800 MHz PCS & GSM (Sectored cells)

Frequency Range	1710-1990 MHz
Bandwidth	170 MHz
Gain	12.5 dBi
VSWR	≤ 1.5
Nominal Impedance	50 ohm
Polarization	Vertical
Maximum Power	100 W
Connector	N Female
3dB Beamwidth Horizontal Plane	120°
3dB Beamwidth Vertical Plane	16°
F/B	> 25 dB
Dimension	600 x 100 x 80 mm
Weight	6 kg / 13.23 lb

Main characteristics of a GSM hand-held terminal transmitter

	GSM 900	DCS 1800
Frequency band	890 – 915 MHz	1710 – 1785 MHz
Channel width	200 kHz	200 kHz
Peak radiated power	2 W	1 W
Multiple access technique	FDMA + TDMA	FDMA + TDMA
Modulation scheme	GMSK	GMSK
Maximum average radiated power	250 mW	125 mW

Main characteristics of a GSM base-station transmitter

	GSM 900	DCS 1800
Frequency band	935 – 960 MHz	1805 – 1880 MHz
Channel width	200 kHz	200 kHz
Peak radiated power (typical)	30 W	30 W
Multiple access technique	FDMA + TDMA	FDMA + TDMA
Modulation scheme	GMSK	GMSK


base station antenna in Mexico City, Mexico. There are three antennas: each serves a 120-degree segment of the horizon. The microwave dish links the site with the telephone


492 F High Point Road in Gaffney, South Carolina.


Two GSM base stations disguised as trees in Dublin, Ireland.


Cell tower disguised as a palm tree in Tucson, Arizona










The Beginning

Dyna-Tac

New Take-Along Telephones Give You Pushbutton Calling to Any Number

This amazing phone system could handle thousands of calls simultaneously, patching yours directly into a phone exchange

By JOHN R. FREE

Handsets Evolution (from the brick to the slick)

1983: Motorola DynaTAC 8000X

Analog voice

World's first handheld cellular phone call in public

On April 3, 1973, Motorola installed a base station to handle the first public demonstration of a phone call over the cellular network

weighed about 2.5 lb (1.1 kg).

Cooper and Motorola took the cellular phone technology to **New York** to demonstrate it to reporters and the public, standing on **Sixth Avenue** in New York City near the New York Hilton hotel, Cooper made a phone call from a prototype **Dyna-Tac** handheld cellular phone before going to a press conference upstairs in the

Mobile phone systems Evolution (the road to 4Gand What is LTE?)

2012: The year LTE becomes a standard, not a luxury

4G LTE. The fastest cellular network.

What is LTE?

Wifi+ 4G

Fundamental Constraints

- Shannon's capacity upper bound
  - Achievable data rate is fundamentally limited by bandwidth and signal -to-noise ratio (SNR).

Signal power

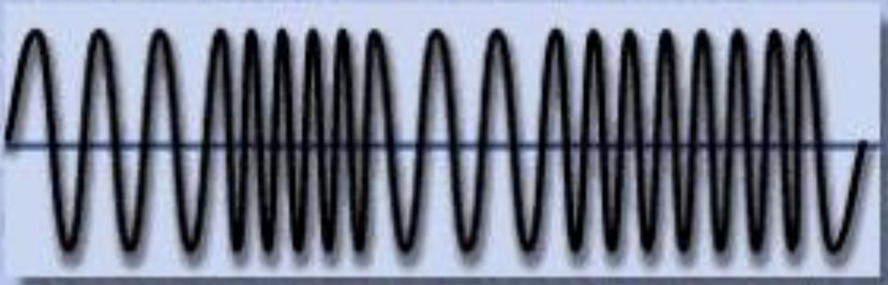
$$C = \underbrace{BW}_{\text{Channel bandwidth}} \cdot \log_2\left(1 + \frac{S}{N}\right) \text{ [bits per second]}$$

Noise power

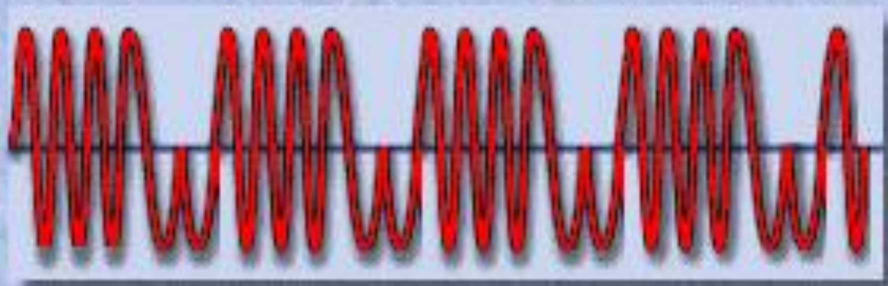
$$\eta = \frac{\text{Transmission Rate}}{\text{Channel Bandwidth } W} \ [\text{bits}/s/Hz].$$

- PSK requires too wide a bandwidth
- Gaussian Minimum Shift Keying (GMSK) is actually used on the GSM air interface

AMPLITUDE MODULATION



FREQUENCY MODULATION

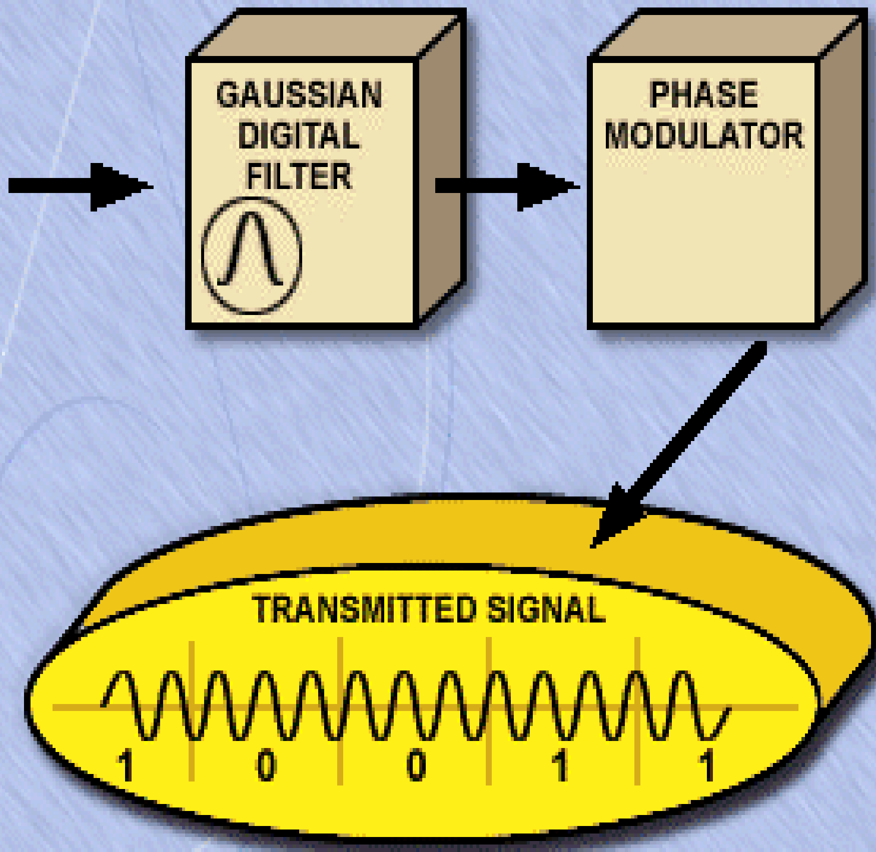


PHASE SHIFT KEYING (PSK)

By: Dr.Mohab Mangoud

Gaussian Minimum Shift Keying:

- Digital signal filtered through a Gaussian Filter
- Filtering distorts the signal, rounding off the corners and removing abrupt phase changes
- Distorted signal is used to phase shift the carrier signal
- Phase change occurs over a period of time
- Frequency components are lowered, reducing the bandwidth requirement



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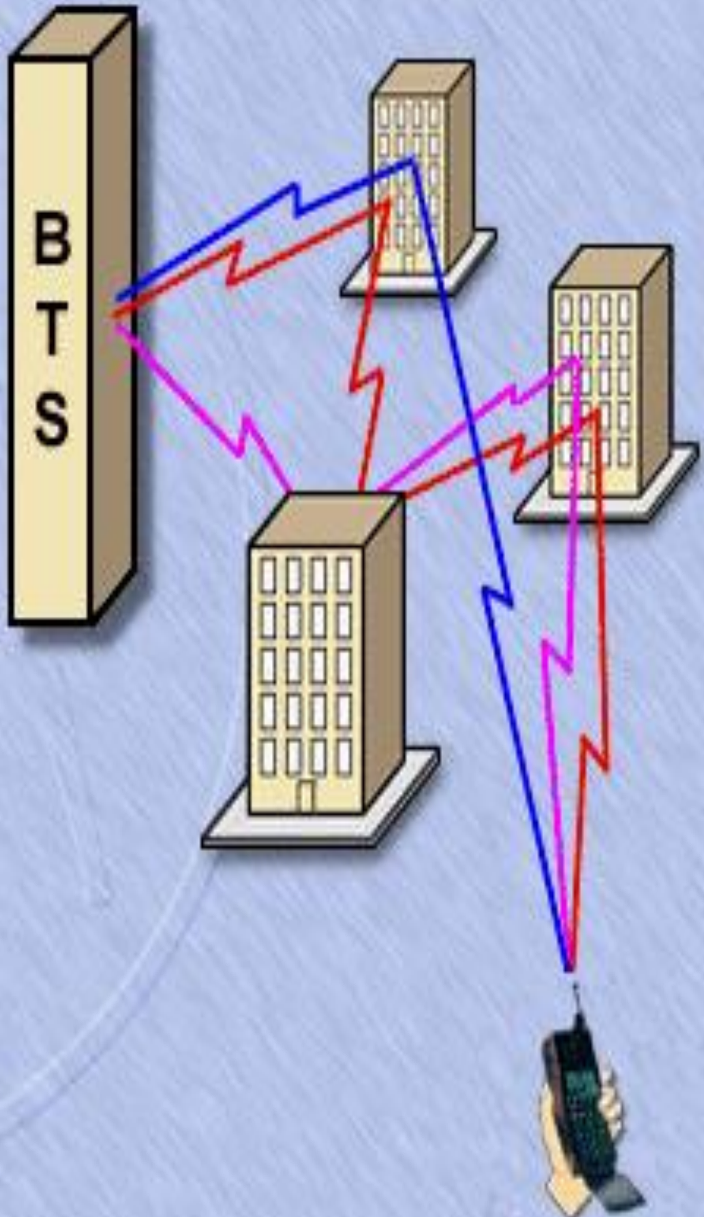
MULTIPATH FADING

- Signals travel from transmitter to receiver by different routes and experience time dispersion
- Signals combine again at receiver, constructively or destructively
- Combined signal strength also changes when receiver moving



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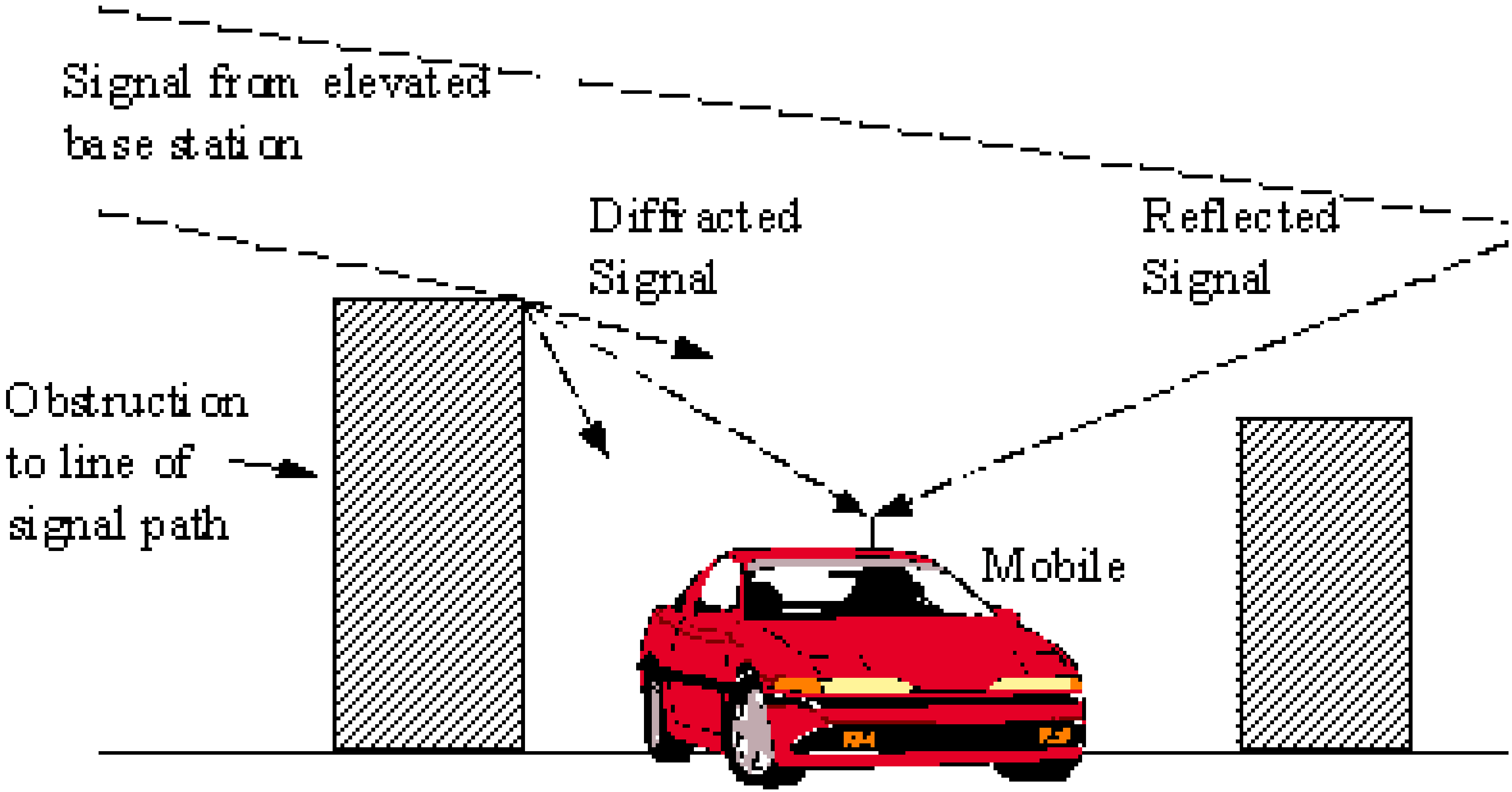
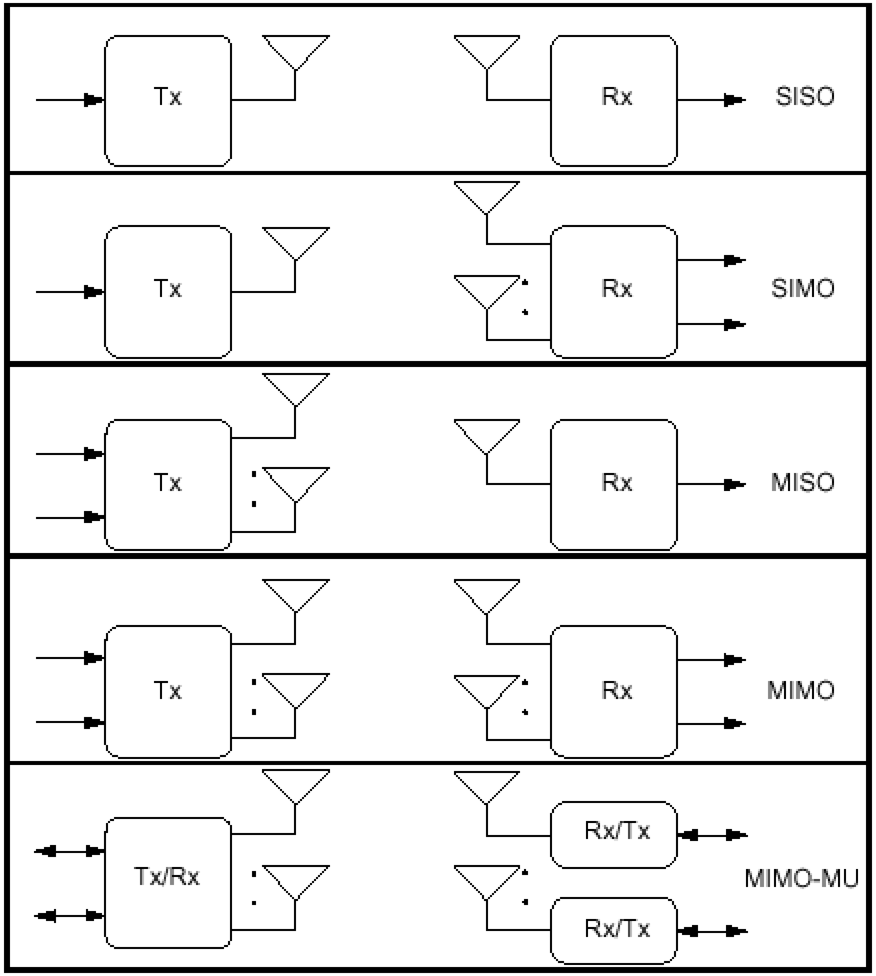


Figure 2 Radio Propagation Effects

By: Dr.Mohab Mangoud

- GSM combats multipath fading with:
  - Equalisation
  - Diversity
  - Frequency Hopping
  - Interleaving
  - Channel Coding

By: Dr.Mohab Mangoud



SISO: Single input Single output
SIMO: Single input Multiple output
MISO: Multiple input Single output
MIMO: Multiple input Multiple output
MIMO-MU: Multiple input Multiple output (multiuse

Beamforming

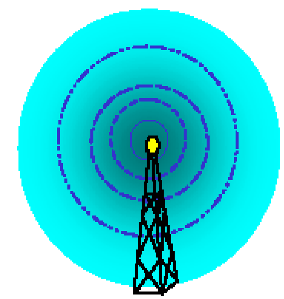
- Traditional cellular systems
- Idea of smart antenna

It consists of

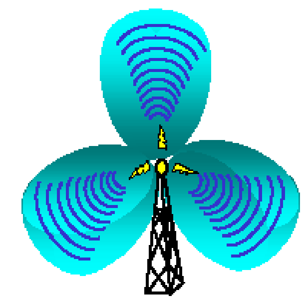
a number of radiating elements (antenna array)

a combining/dividing network (Beamforming unit)

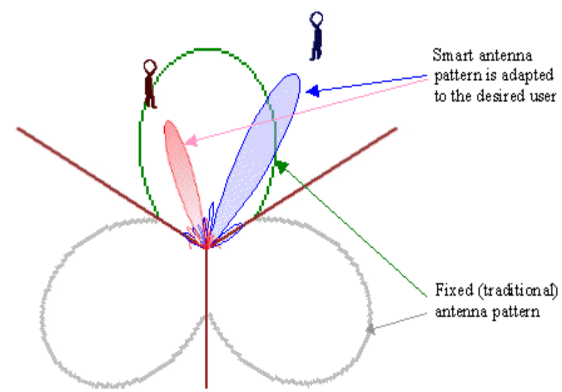
control unit, realized using DSP



Omnidirectional antenna

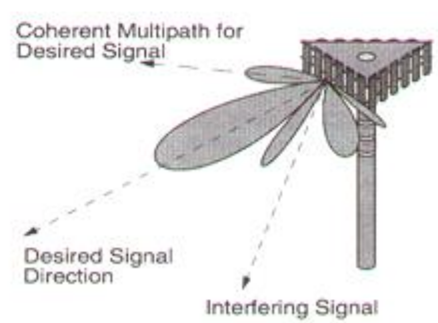


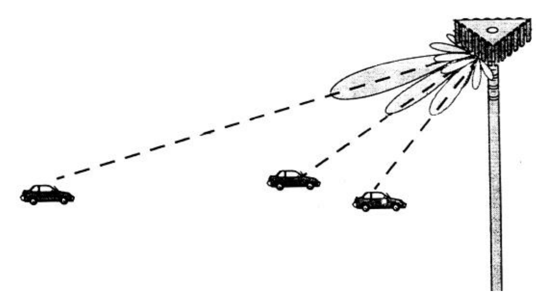
Multibeam antenna array



Beamforming

- to increase the system capacity and to increase the signal quality (system performance
- to avoid problems associated with multipath

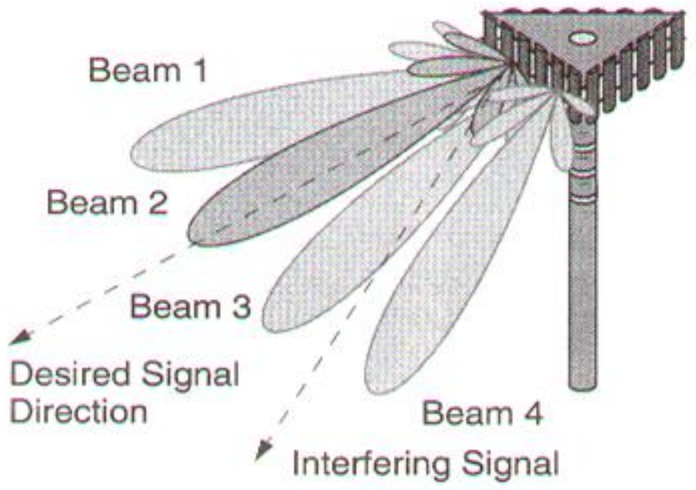




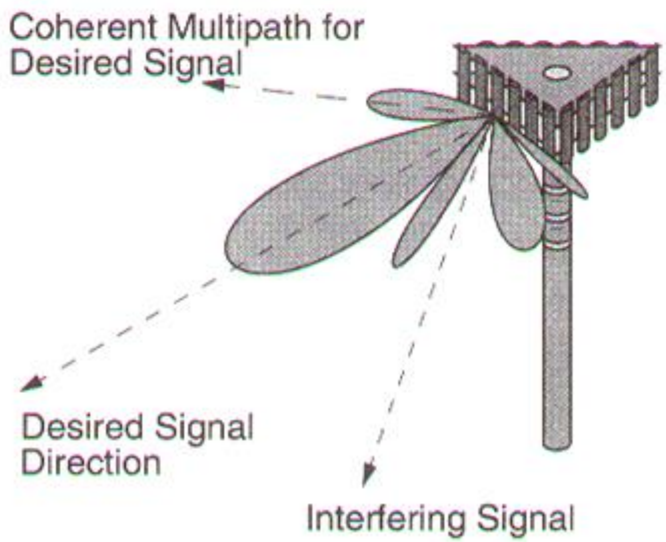
By: Dr.Mohab Mangoud

Types of Smart Antennas

- Switched-Beam Antennas



- Adaptive-Array Antennas



•Disadvantages:

Signal strength degradation

The desired signal and interfering signals can not be distinguished (Reduced S/N)

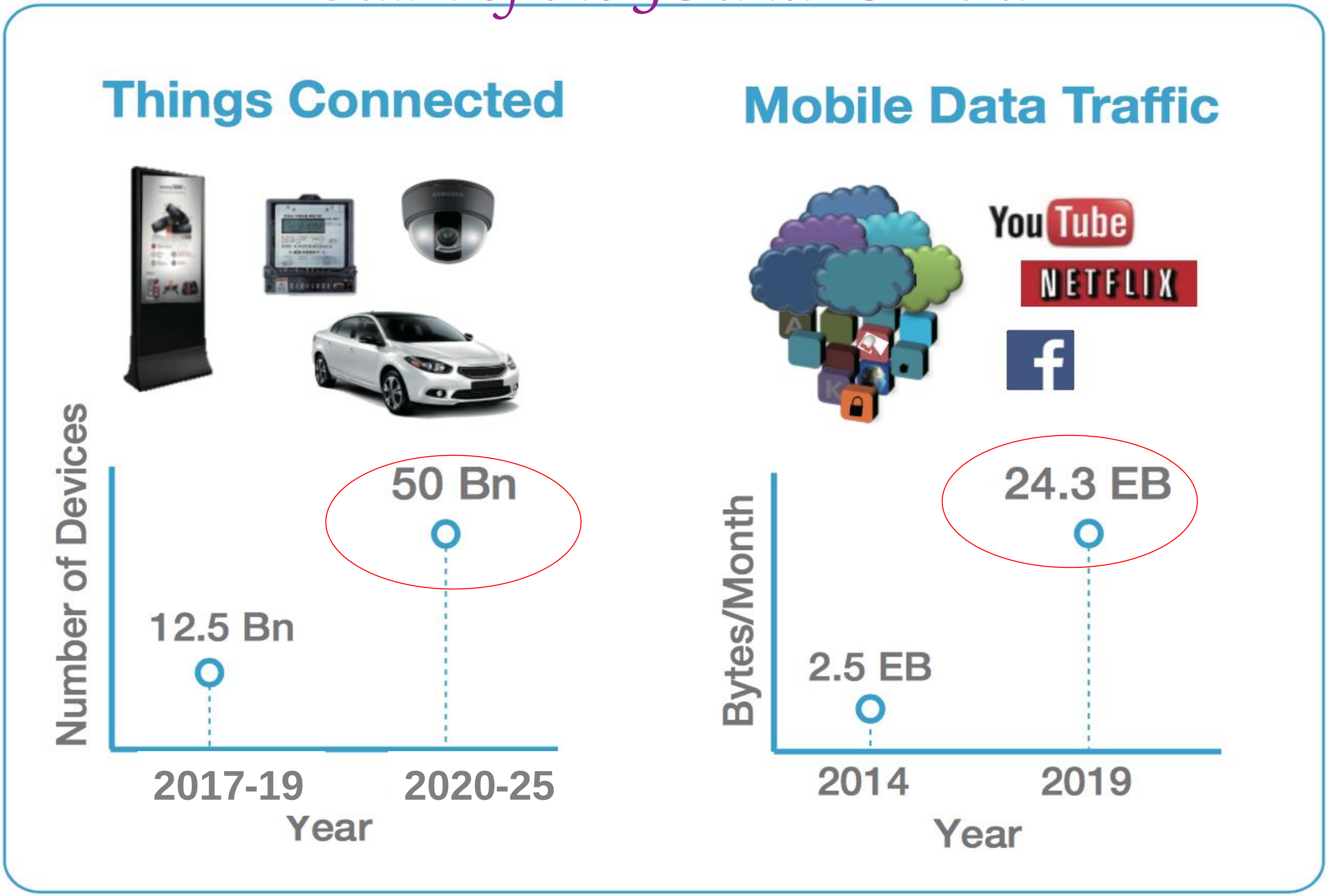
•A direction of arrival (DOA) algorithm for determining signal direction & interference sources is needed.

•The beam pattern is adapted (steered) based on changed in both the desired and interfering signal locations.

By: Dr.Mohab Mangoud

5G Technologies

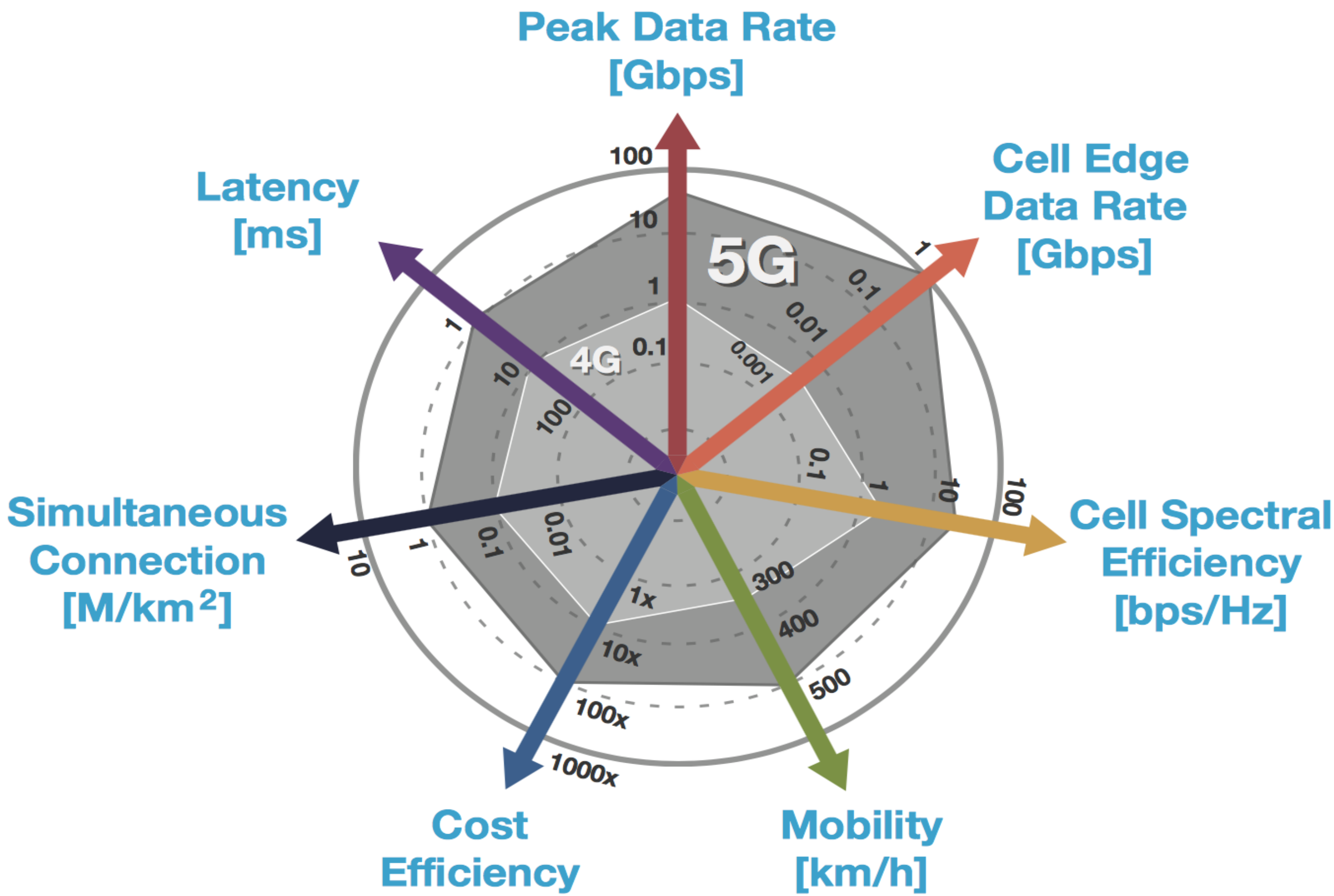
Dawn of the 5G and IOT Era



Source: 5G Samsung Report

Exabytes = 10^{18} = one bilion of gigabytes

5G



2G : digital voice, 3G : first data services, 4G : mobile broadband

5G : designed to serve not only phones but for connecting everything else

(5G Isn't About the Smartphone @ IEEE Spectrum March 2019)

4G vs 5G

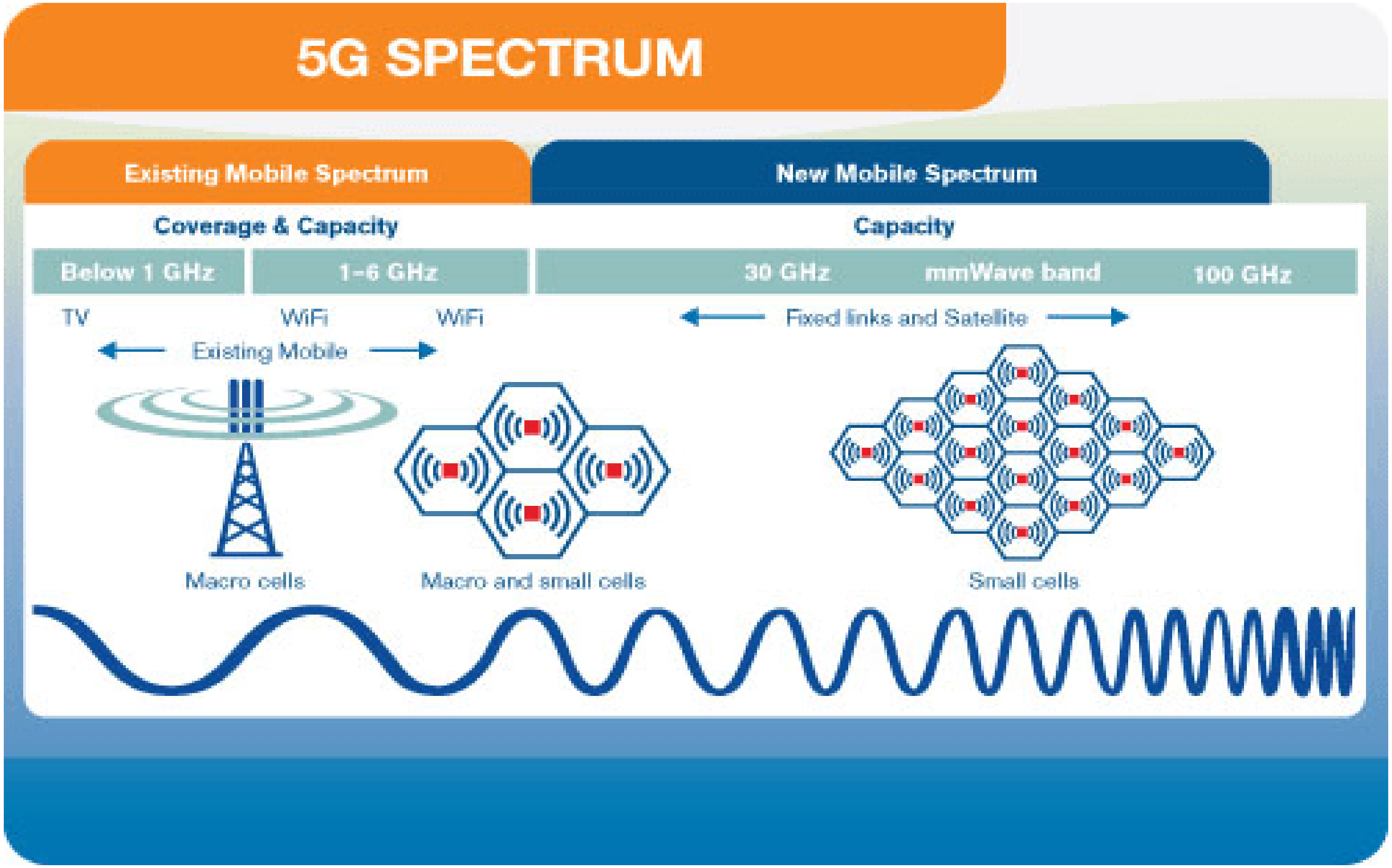
Performance Metrics	4G	5G
Peak data rate (Gbps)	1	20
User experienced data rate (Mbps)	10	100
Connection density (devices/km^2)	10^5	10^6
Mobility support (kmph)	350	500
Area traffic capacity (Mbit/s/m^2)	0.1	10
Latency (ms)	10	1
Reliability (%)	99	99.99
Positioning accuracy (m)	1	0.01
Spectral efficiency (bps/Hz)	3	10
Network energy efficiency (J/bit)[1]	1	0.01

IEEE Communications Surveys & Tutorials (Volume: 20 , Issue: 2 , 2018)

Key Technologies of 5G & IoT

- Millimeter waves
- Massive MIMO
- Multi-RAT (Radio Access Technology)
- Advanced D2D (Device to Device), M2M
- Dense Small Cell deployment

Why Millimeter wave (mmwave) ?



5G will use spectrum:

600 MHz to **6 GHz** + mmWave bands (24–86 GHz).

New 5G spectrum

The growing momentum behind millimetre wave bands

24.25-27.5 GHz
31.8-33.4 GHz
37-43.5 GHz
45.5-50.2 GHz
50.4-52.6 GHz
66-71 GHz
71-76 GHz
81-86 GHz

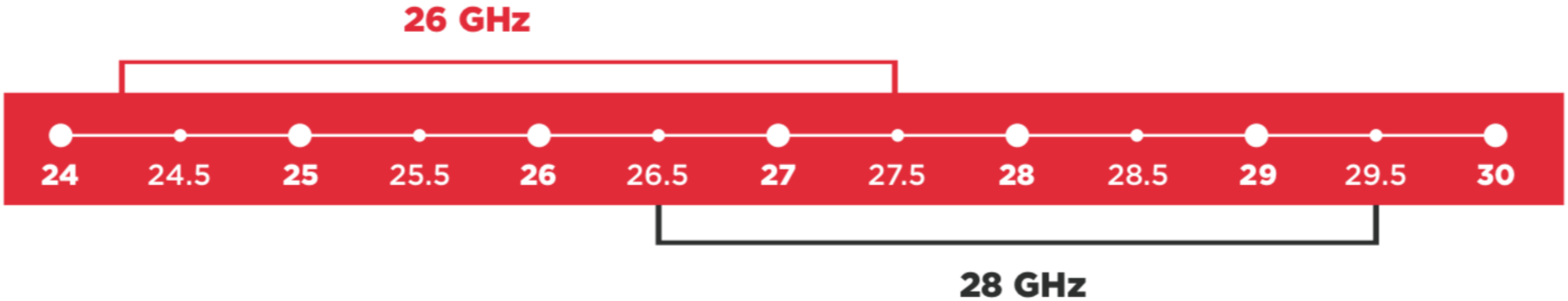


Table II: Comparison of available bandwidth at μWave and mmWave frequencies[2]

Band	Generation	Frequency (GHz)	Wavelength (m)	Frequency Range (GHz)	Bandwidth (GHz)	Available Bandwidth (GHz)[3]
μWave	2G	0.8	0.3750	0.791 - 0.862	1.117[4]	2.5
		0.9	0.3333	0.880 - 0.959		
	3G	1.8	0.1667	1.710 - 1.880		
	4G	2.1	0.1429	1.920 - 2.169		
		2.6	0.1154	2.500 - 2.690		
	5G	0.6	0.500	0.470 – 0.694		
		0.7	0.4286	0.694 - 0.790		
		1.5	0.2000	1.427 – 1.518		
		3.5	0.0857	3.300 - 3.800		
		4.7	0.0638	4.500 – 4.990		
		5.6	0.0536	5.500 – 5.700		
mmWave	5G	23	0.0130	22.55 - 23.55	1.0	23
		28	0.0107	27.50 - 31.23	1.3	
		38	0.0079	38.6 - 40.0	1.4	
		40	0.0075	40.5 - 42.5	2.0	
		46	0.0065	45.5 - 46.9	1.4	
		47	0.0064	47.2 - 48.2	1.0	
		49	0.0061	48.2 - 50.2	2.0	
		73	0.0041	71 - 76	5.0	
		83	0.0036	81 - 86	5.0	
		93	0.0032	92 - 95	2.9	

DOI 10.1109/COMST.2017.2787460, IEEE Communications Surveys & Tutorials

mmWaves Propagation Characteristics

mmWaves {wavelength <<<} therefore they experience :

- higher pathloss (with increasing frequency)
- lesser penetrating power through solids and buildings,
- significantly more prone to the effects of shadowing, diffraction and blockage
- mmWave signals suffer more attenuation due attenuations due to atmospheric/molecular absorption and rain as a function of carrier frequency are presented in following Figs

mmWaves

- (**Disadvantage)** Overall, losses in mmWave systems are higher than those of μWave systems.

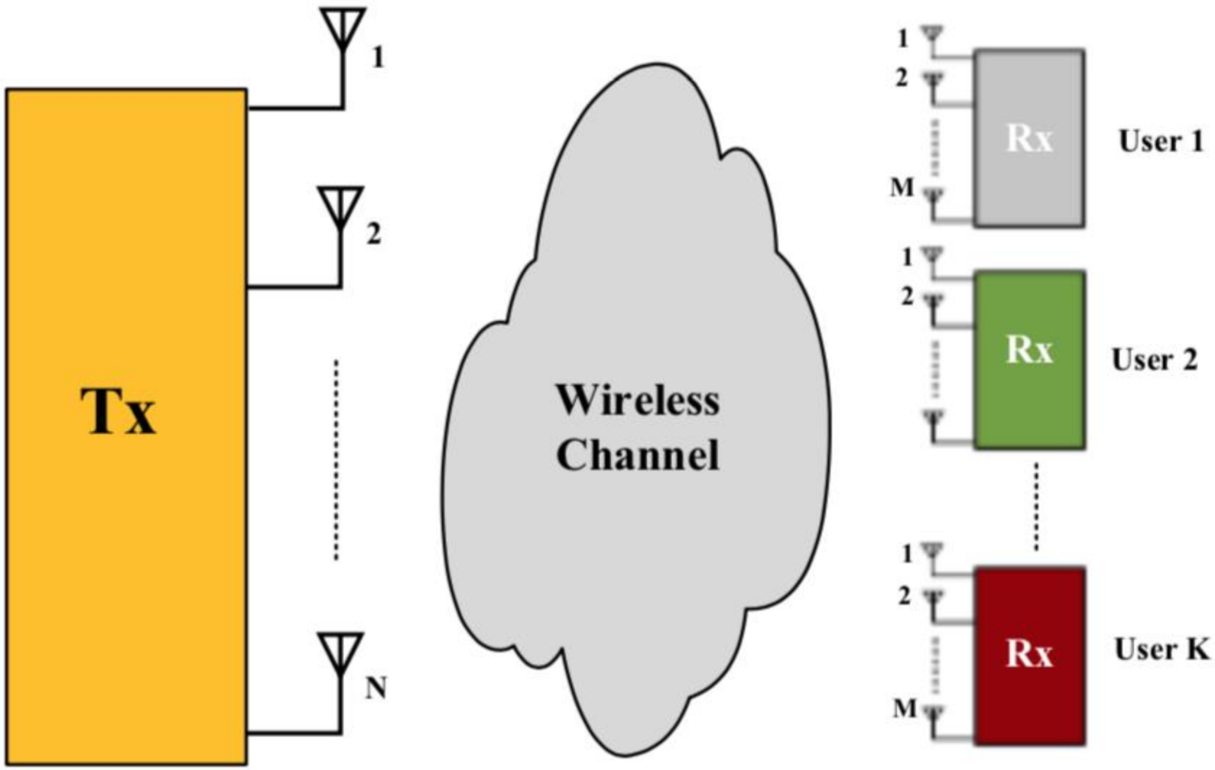
- (**Advantages**) Smaller wavelength (which enables massive antenna arrays

- Huge available bandwidth in the bands can **compensate** for the losses

- Beter spectral and energy efficiencies and performance gain (with the evolving computational complexity, signal processing).

Massive MIMO and Beamforming technology

SISO, Single-user MIMO (SU-MIMO), Multi-user MIMO (MU-MIMO) , Massive MIMO



$$C_{massive\ MIMO} \approx \mathrm{N} \log_2\left(1 + \frac{\rho M}{N}\right)$$

Capacity grows linearly with the number of the antenna at the BS or UE

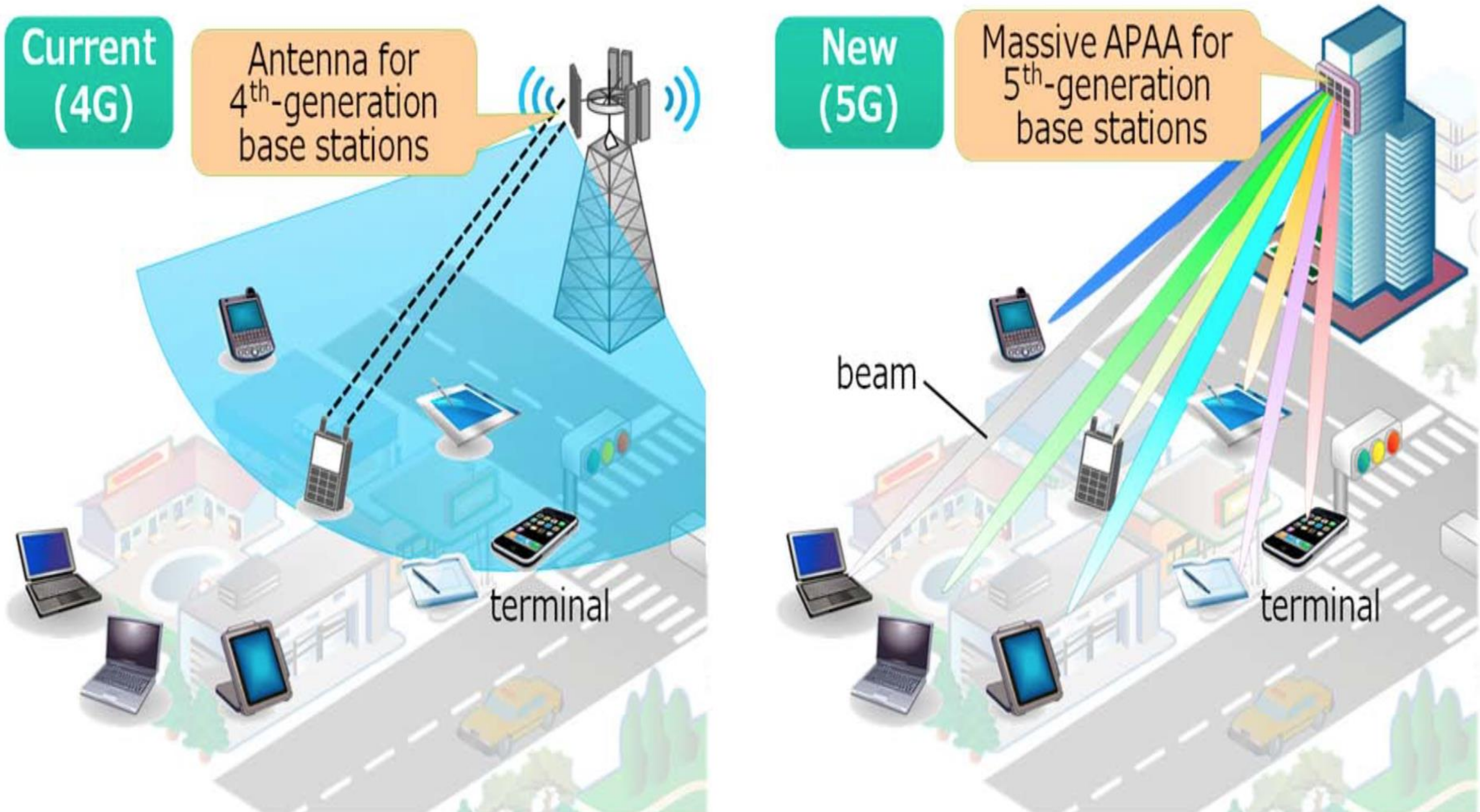
Massive MIMO Prototypes

Lund University / NTT Docomo massive MIMO prototype

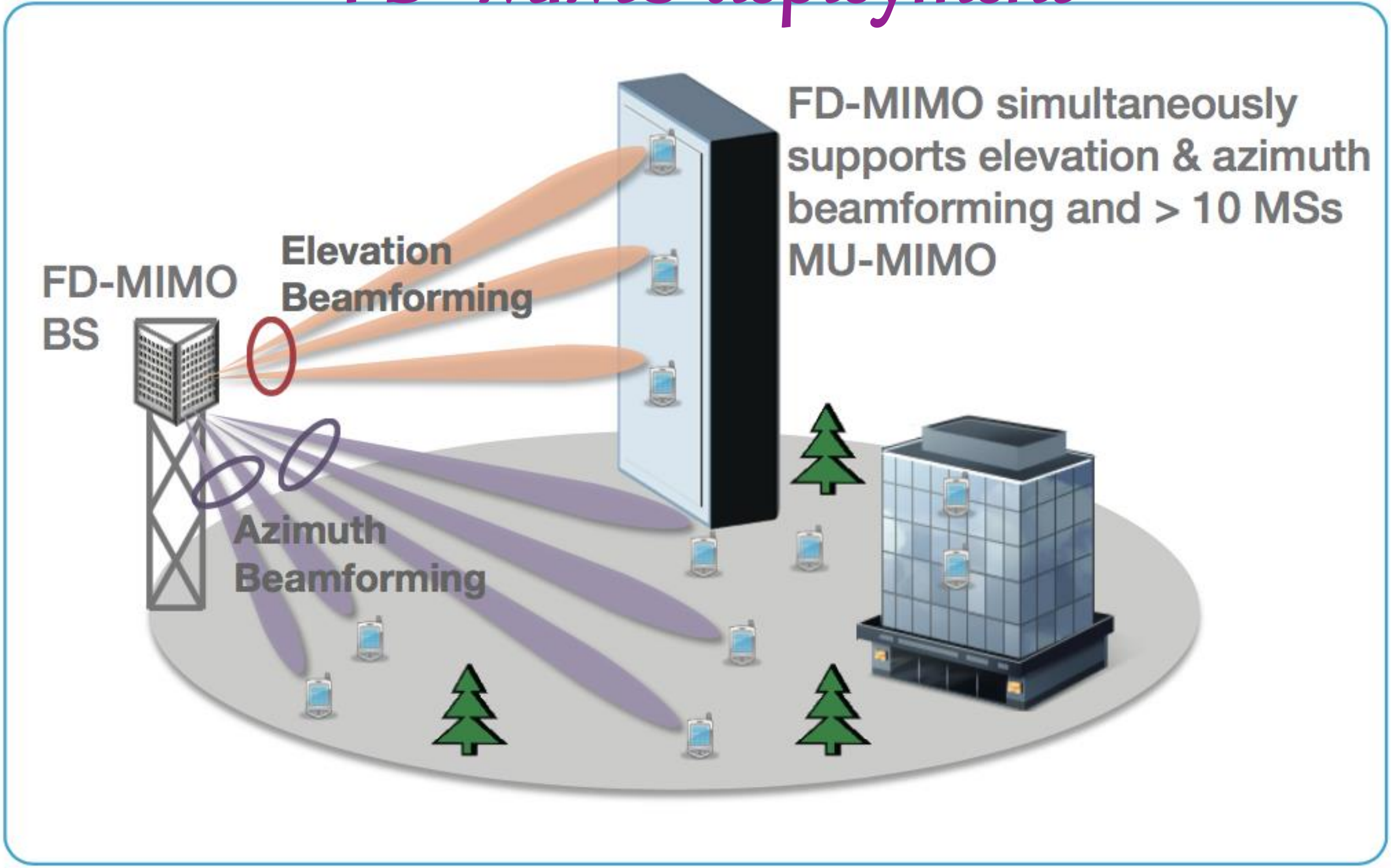
Up to 1024 and 64 for the BSs and UEs, respectively.

(with RF chains, the maximum numbers are 32 and 8 for the BSs and UEs)

Evolution of Multi-antenna Technology From 4G MIMO to 5G Massive MIMO

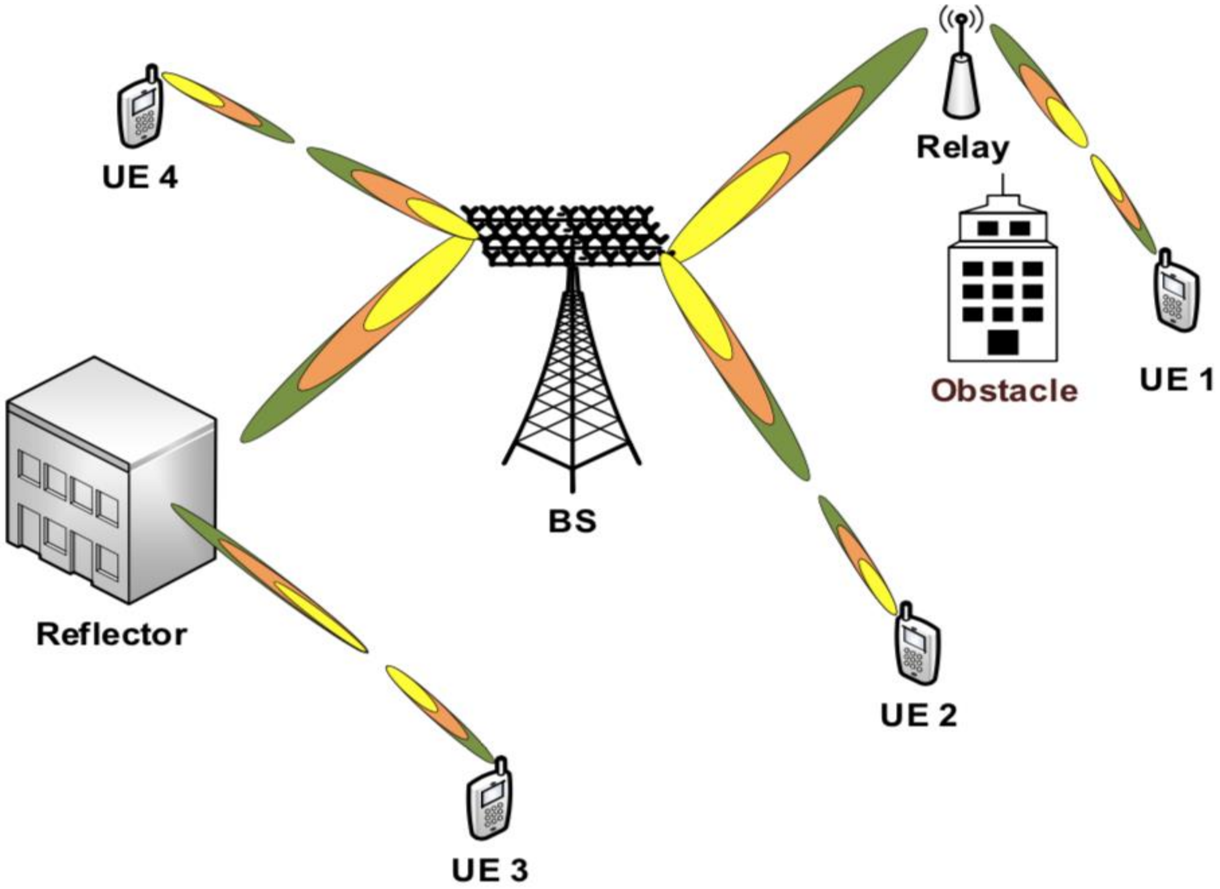


FD- MIMO deployment



Large Scale Antenna Systems (LSAS), Full Dimension MIMO (FD-MIMO), Very Large MIMO , Hyper MIMO.

Directional communications in 5G HetNets



- Employing adaptive **beamforming** to suppress interference
- Use relay stations to bypass obstacles and avoiding blockages

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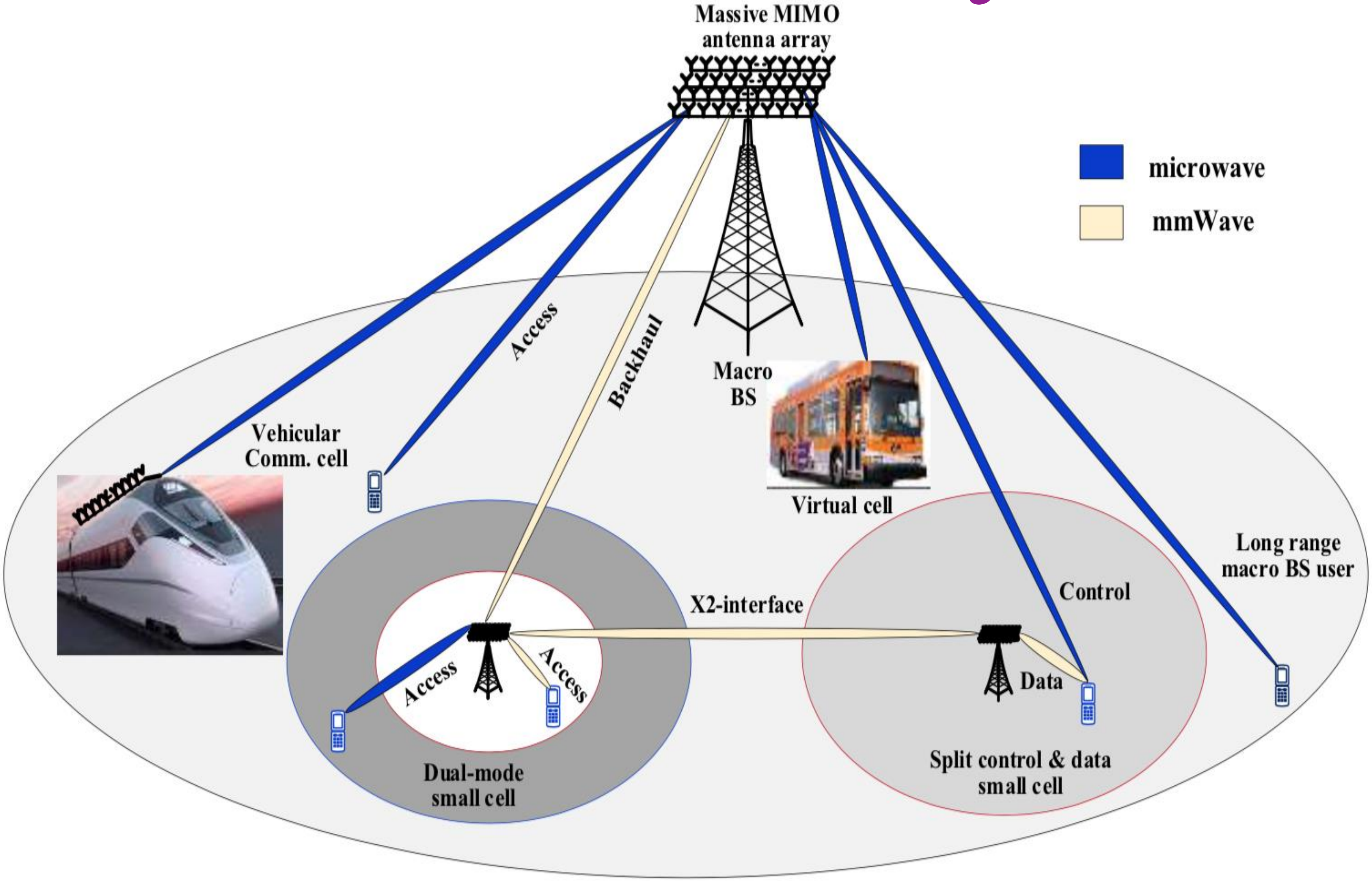
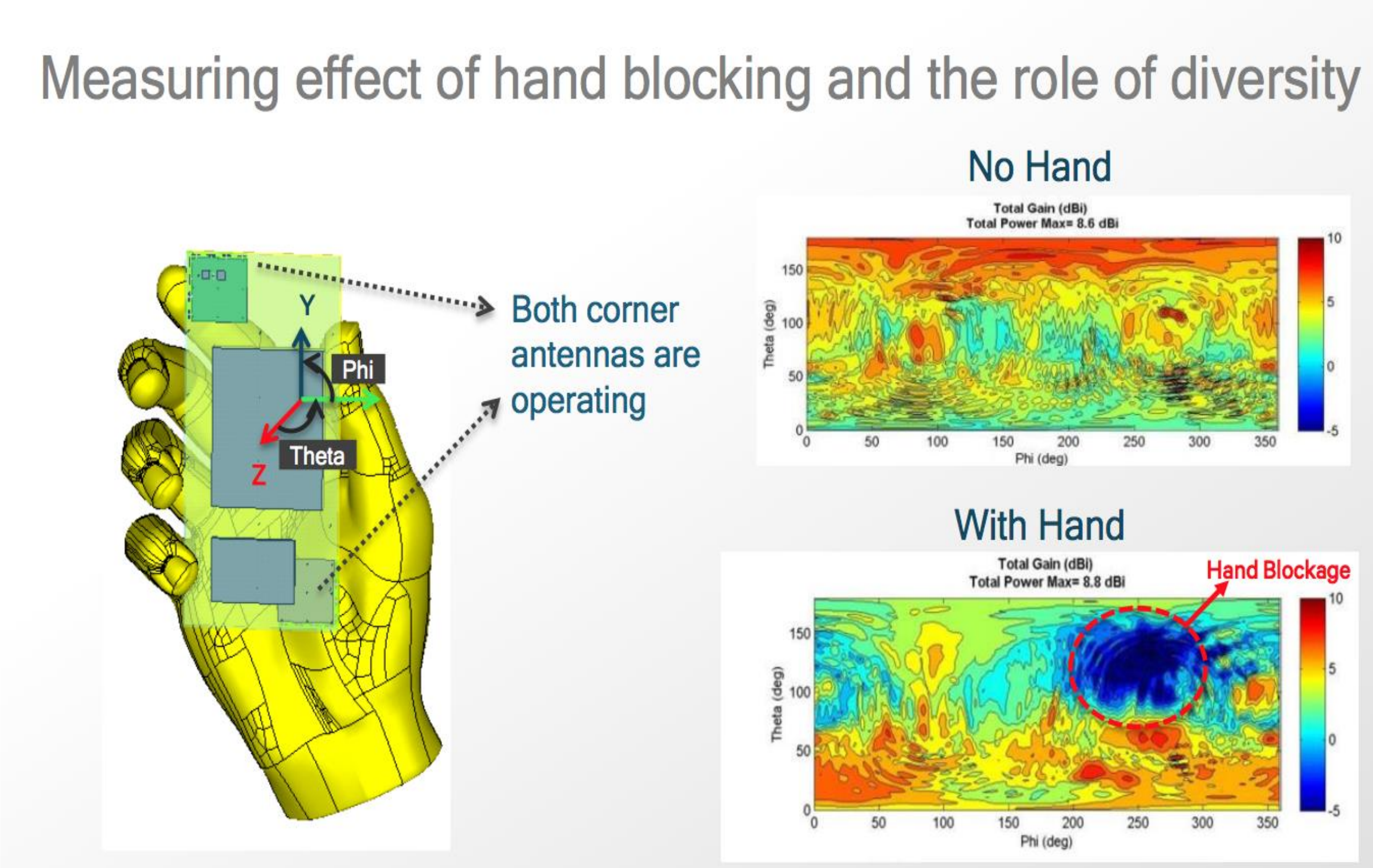
A candidate architecture for the mmWave massive MIMO- based 5G network



Research Project: 5G mmwave



By Qualcomm

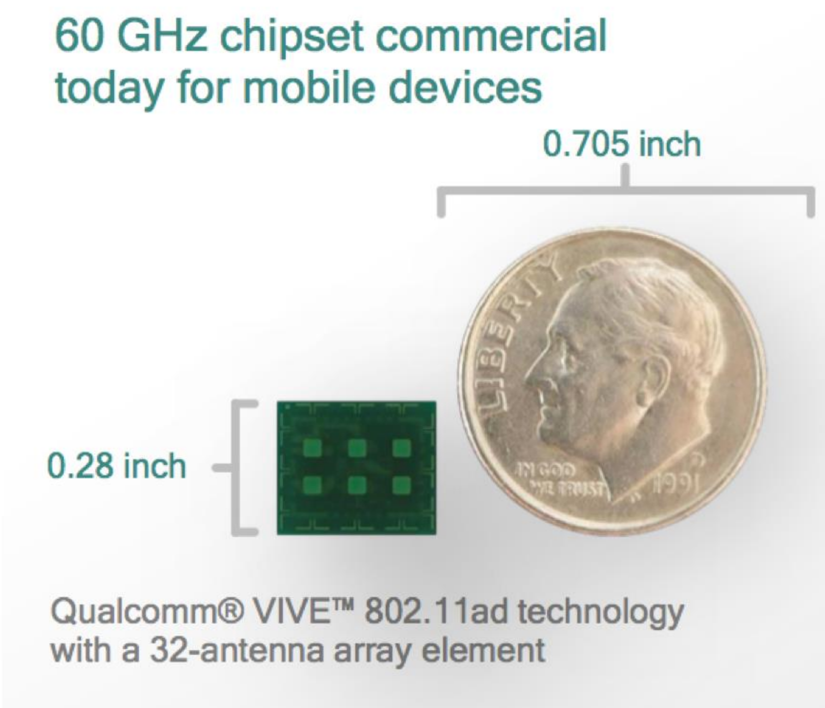
5G Handset Antennas

Samsung's Galaxy S8 includes antennas for :
1 Bluetooth, 1 GPS, 1 Wi-Fi,
1 NFC communications,
4 LTE cellular antennas

Apple Watch antennas for: 1 Wi-Fi, 1 Bluetooth, and 1 GPS;

Source : Building Smartphone Antennas That Play Nice Together {IEEE Spectrum March 2019}

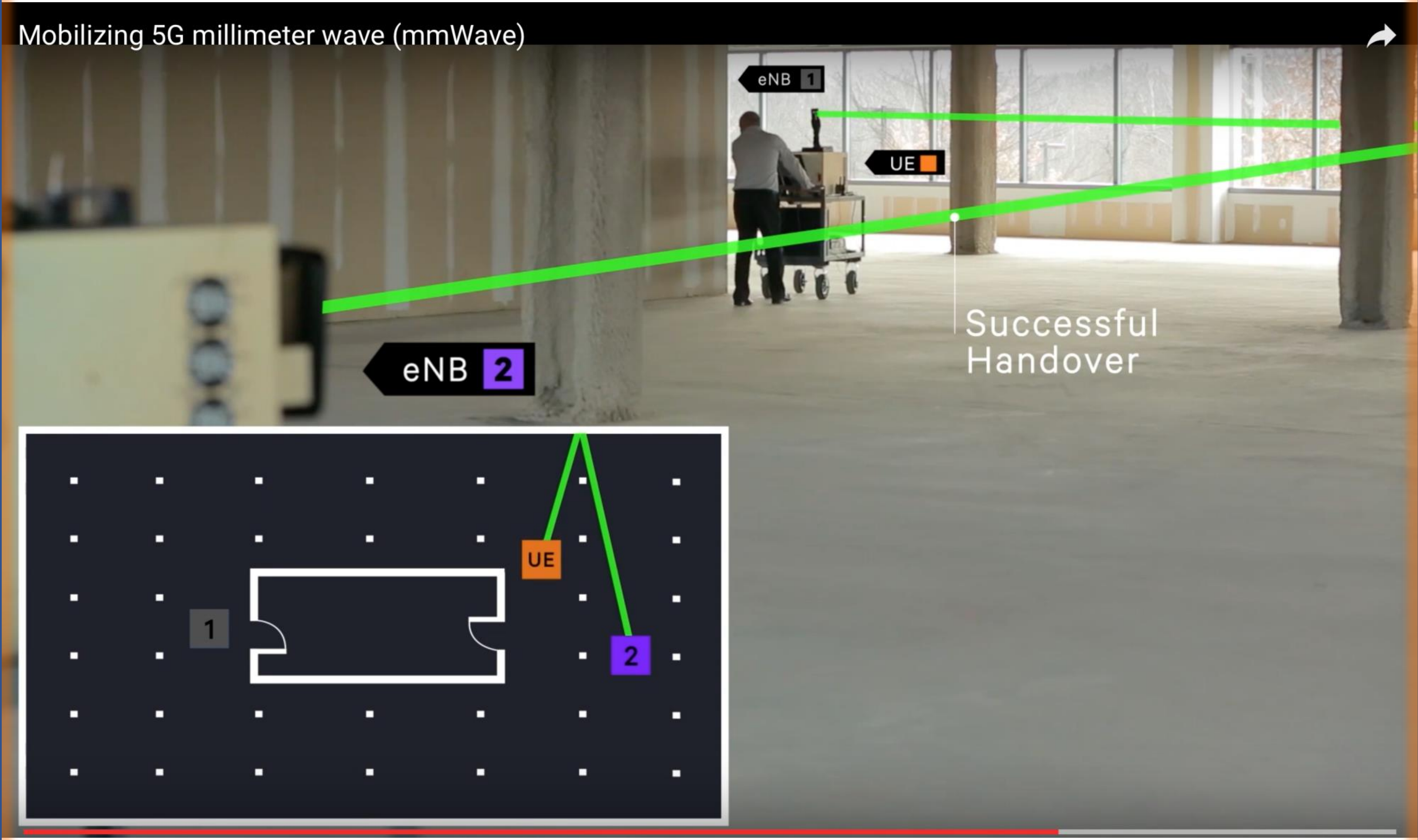
Design concept : Massive MIMO on Handset



16-antenna arrays at the top
and bottom of a prototype
Samsung phone
CREDIT: SAMSUNG

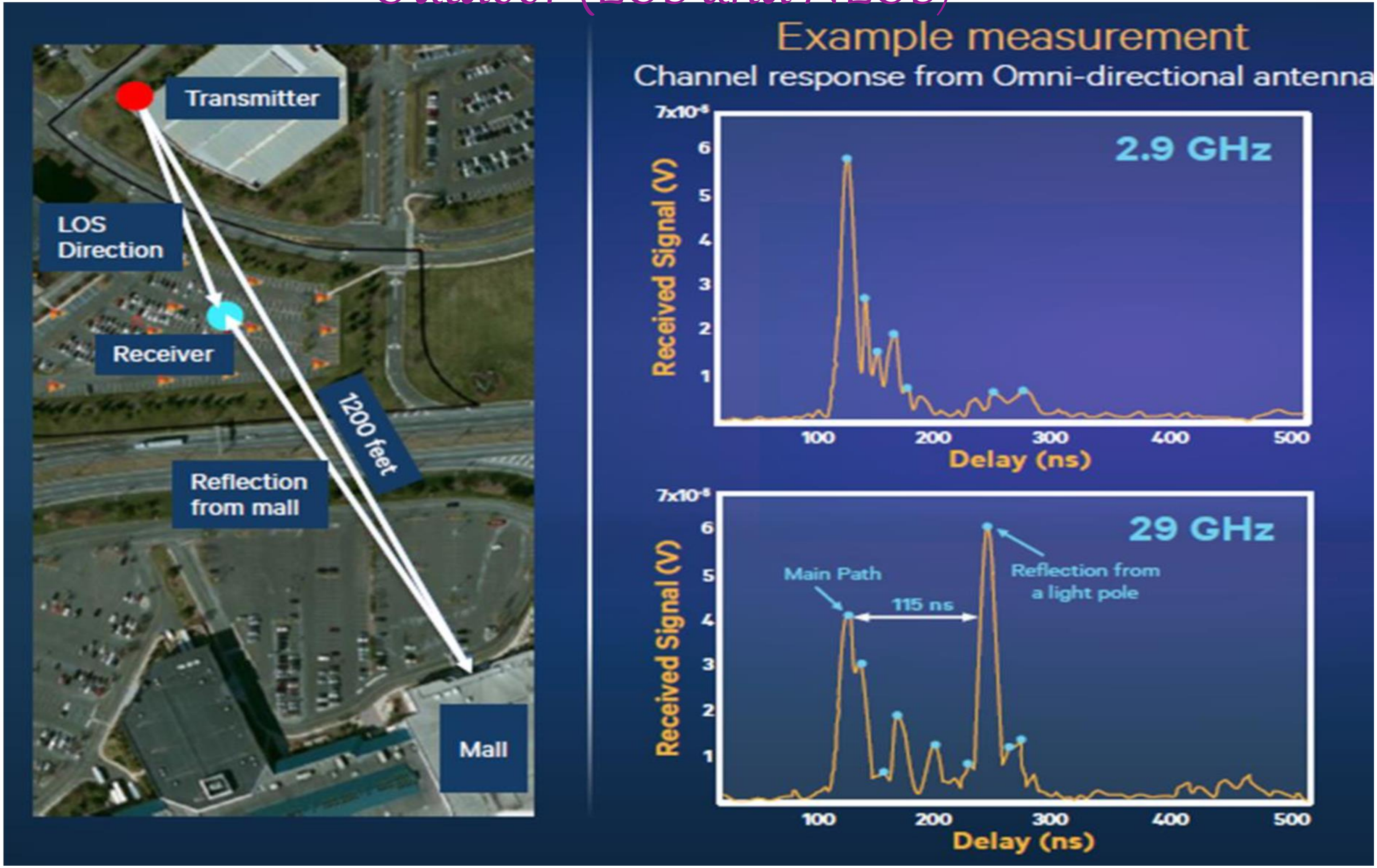
The challenge of fitting multiple antennas into the tiny space available in a typical IoT device is even more overwhelming

Qualcomm Project : **5G** mmwave (eNB handover)



Measurement Experiments of 5G mmwave

Outdoor (LOS and NLOS)



Qualcomm

ERICSSON-LG Project – 5G mm-wave

PUSHES 5G DOWNLOAD SPEED to 26.3 GBIT/S

2020 Tokyo Olympics

Conclusion : Ericsson, Samsung and Nokia will conduct trials at 15GHz, 28GHz and 70GHz, respectively. NTT Docomo describes as "massive MIMO";

NTT- DOCOMO a cumulative **20Gbp**s of data throughput in an outdoor environment using the 15GHz frequency band with two simultaneously

Network type	Theoretical download speed (Mbps)	Typical download speed (Mbps)	Theoretical upload speed (Mbps)	Typical upload speed (Mbps)
3G	7	3	2	0.4
3G HSPA+	42	6	22	3
4G LTE	150	20	50	5
4G LTE-Advanced	300	42	150	10
5G	10,000	200	1000	12.0-20.0

(Source: 4G)