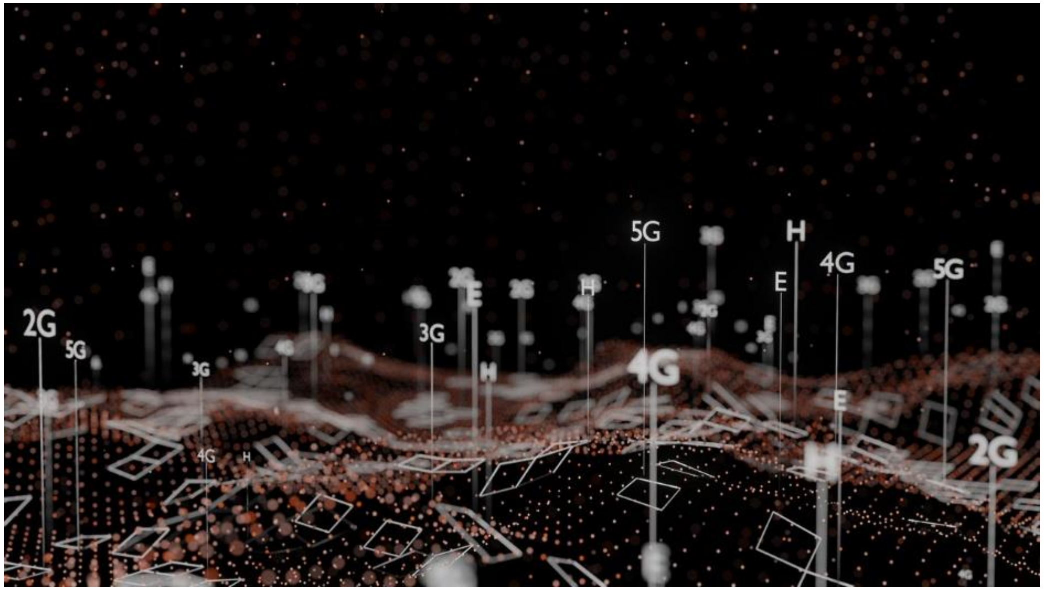
4^{th} Generation Cellular Network Planning



Cellular Network Generations

- It is useful to think of cellular Network/telephony in terms of *generations*:
  - 0G: Briefcase-size mobile radio telephones
  - 1G: *Analog* cellular telephony
  - 2G: *Digital* cellular telephony
  - 3G: *High-speed* digital cellular telephony (including *video telephony*)
  - LTE (4G): IP-based "anytime, anywhere" voice, data, and multimedia telephony at *faster* data rates than 3G

INTRODUCTION : 4G

- Latest and Fastest Generation of mobile phone communication.
- Based on same 3G Technology with improvements named as LTE.
- First used in 2008 in Sweden.
- Range: 100MB/s to 1GB/s.

4G TECHNOLOGY

- High-speed data access
- High quality streaming video
- Combination of wi-fi and wi-max
- Capable of providing 100Mbps – 1Gbps speed.
- One of the basic term used to describe 4G is MAGIC.
- MAGIC:
  - Mobile Multimedia
  - Anytime Anywhere
  - Global Mobility Support
  - Integrated Wireless Solution
  - Customized Personal Services .

DRAWBACKS OF 4G

- Battery uses is more
- Hard to implement
- Need complicated hardware
- Expensive equipment required to implement next generation network.
- New technology which makes it more expansive than 3G
- It is impossible to make our current equipment to be compatible with 4G

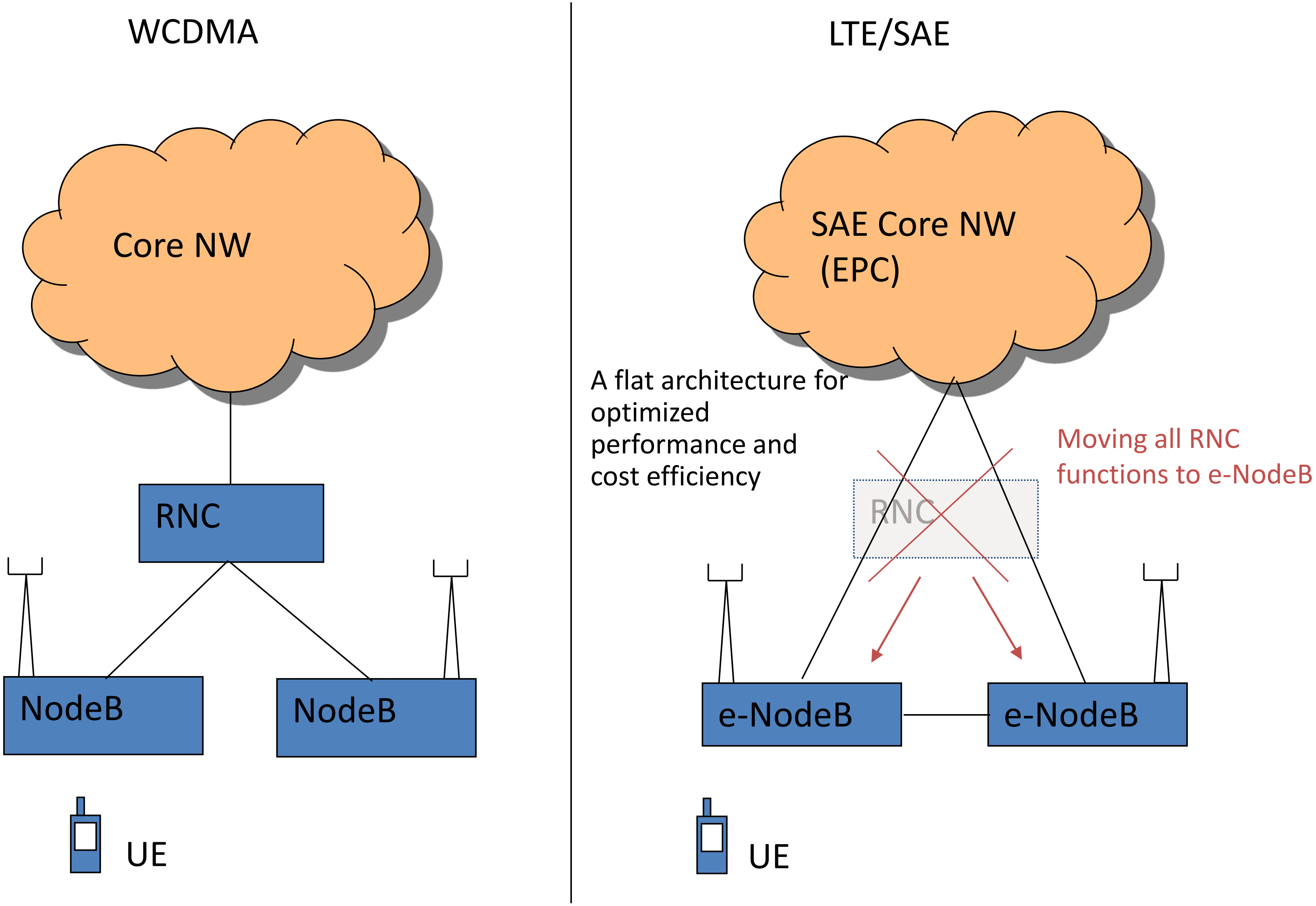
4G Long Term Evolution (LTE)

- Long Term Evolution (LTE) – Standard created by the 3rd Generation Partnership Project
  - Deployed globally
  - All packet switched network
  - High throughput and QoS considerations
  - Provides wireless retransmissions of lost data

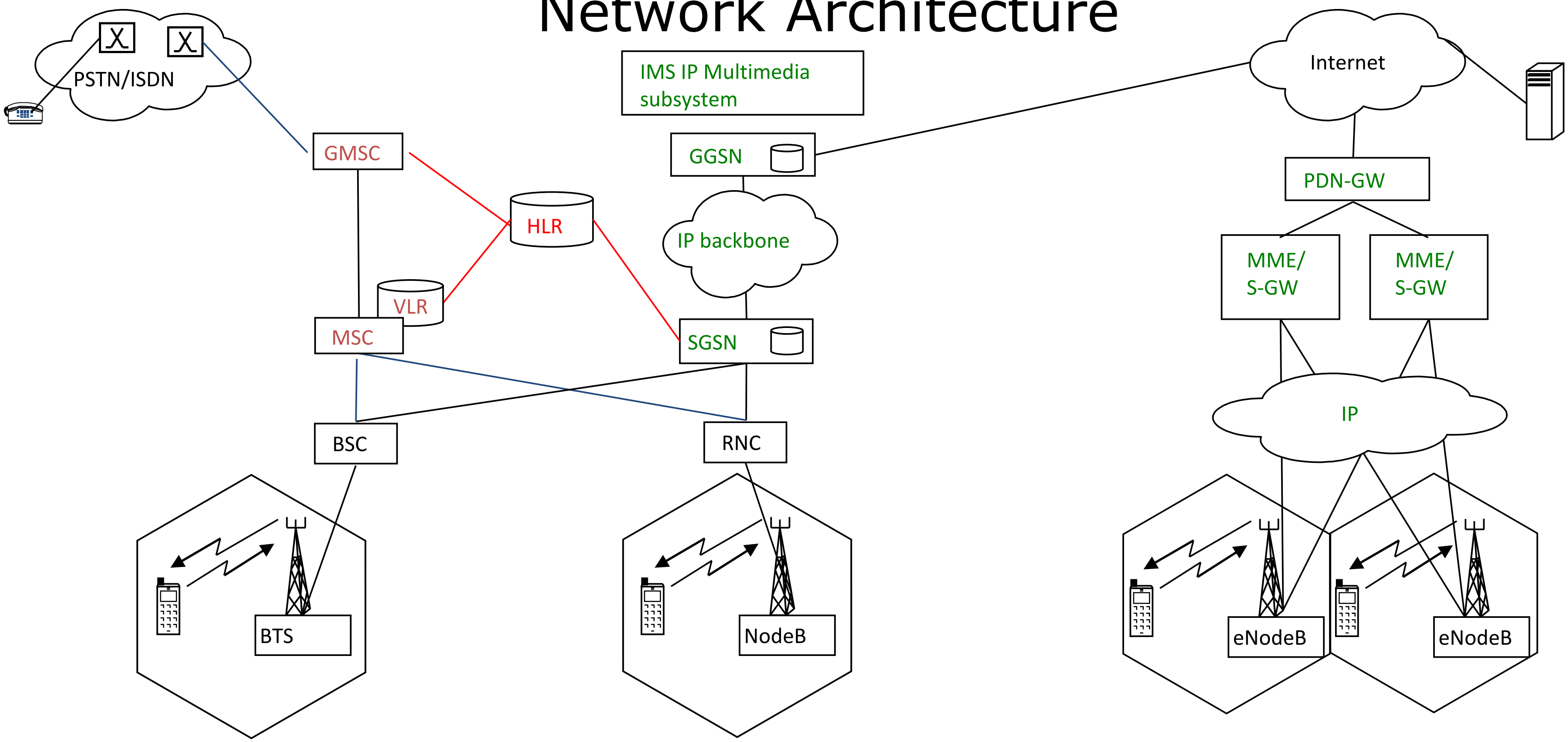
LTE – Targets

- High data rates
  - Downlink: >150 Mbps
  - Uplink: >50 Mbps
- Low delay/latency
  - User plane RTT: < 10 ms RAN RTT (fewer nodes, shorter TTI)
  - Channel set-up: < 100 ms idle-to-active (fewer nodes, shorter messages, quicker node resp.)
- High spectral efficiency
  - Targeting 3 X HSPA Rel. 6 (@ 2006)
- Spectrum flexibility
  - Operation in a wide-range of spectrum allocations, new and existing
  - Wide range of Bandwidth: 1.4, 1.6, 3.0/3.2, 5, 10, 15 and 20 MHz, FDD and TDD
- Simplicity – Less signaling, Auto Configuration e-NodeB
  – ”PnP”, ”Simple as an Apple”
- Cost-effective migration from current/future 2/3G systems
- State-of-the-art towards 4G
- Focus on services from the packet-switched domain

Simplified Network Architecture



Network Architecture

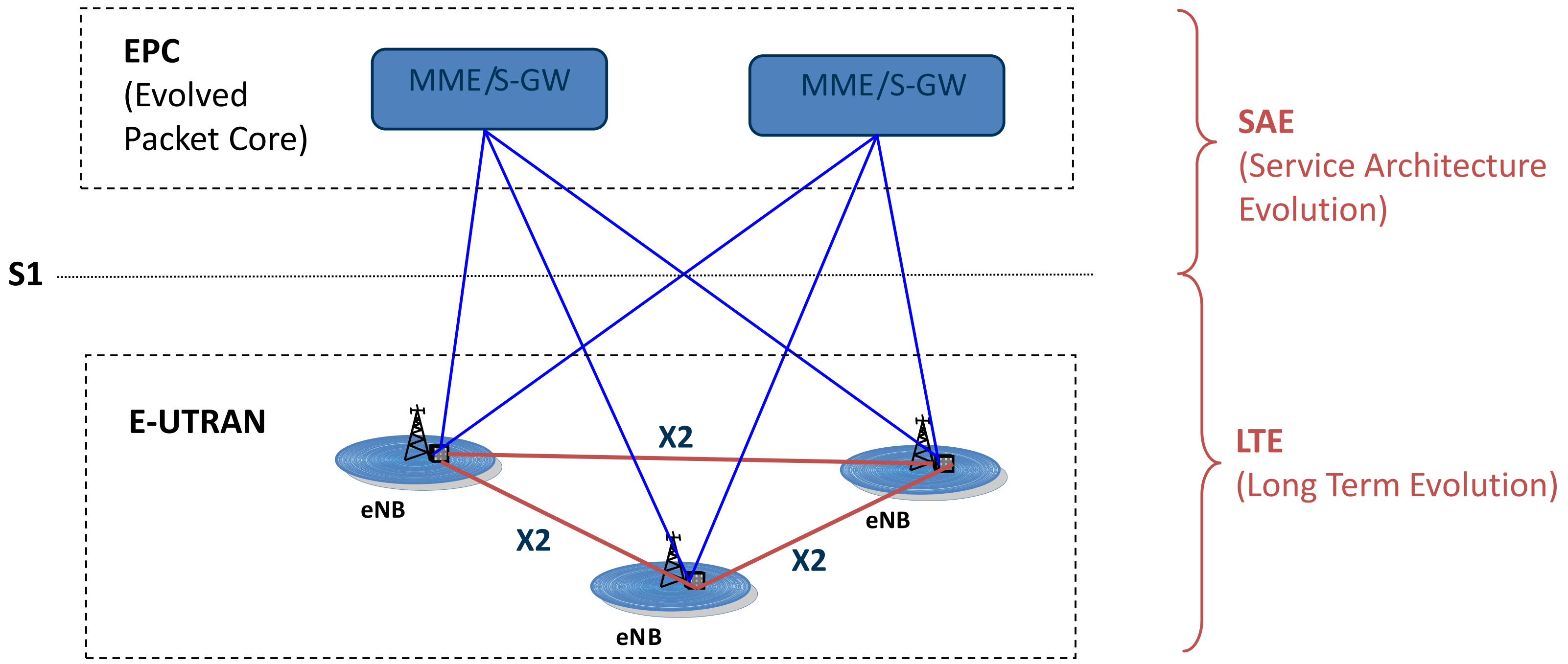


2G, GSM and GPRS
Duplex techinque: FDD
Freq band: 900MHz, 1800MHz, 1900MHz
Bandwidth per carrier: 200 kHz
Multiple access: TDMA

3G, UMTS with WCDMA
Duplex techinque: FDD (and TDD)
Freq band: 2 GHz 15 bands
Bandwidth per carrier: 5 MHz BW
Access tech: CDMA

LTE/SAE 4G
Duplex technique: FDD or TDD
Freq band: 450MHz up to 2.6GHz 15 bands
Bandwidth 1.25 – 20 MHz BW
Multiple access: OFDM (OFDMA DL and SC-FDMA UL)

E-UTRAN Architecture



MME (Mobility Management Entity)	Distribution of paging messages to the eNBs, Security control, Idle state mobility control, SAE bearer control, Ciphering and integrity protection of NAS signalling
S-GW (Serving Gateway)	Termination of U-plane packets for paging reasons; Switching of U-plane for support of UE mobility
eNB (e-NodeB)	RRM: Radio Bearer Control, Admission Control, Connection Mobility Control Scheduling, IP Header Compression, encryption of user data streams, Scheduling and transmission of paging messages, Selection of an MME at UE attachment, Routing of user plane data towards serving GW, Scheduling and transmission of broadcast information, Measurements and reporting

LTE basics

Radio resources

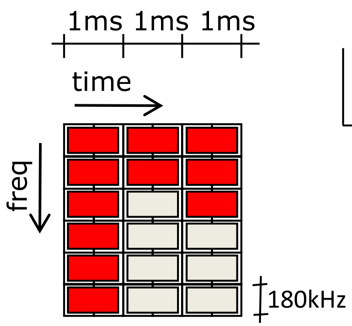
FDD:

TDD:

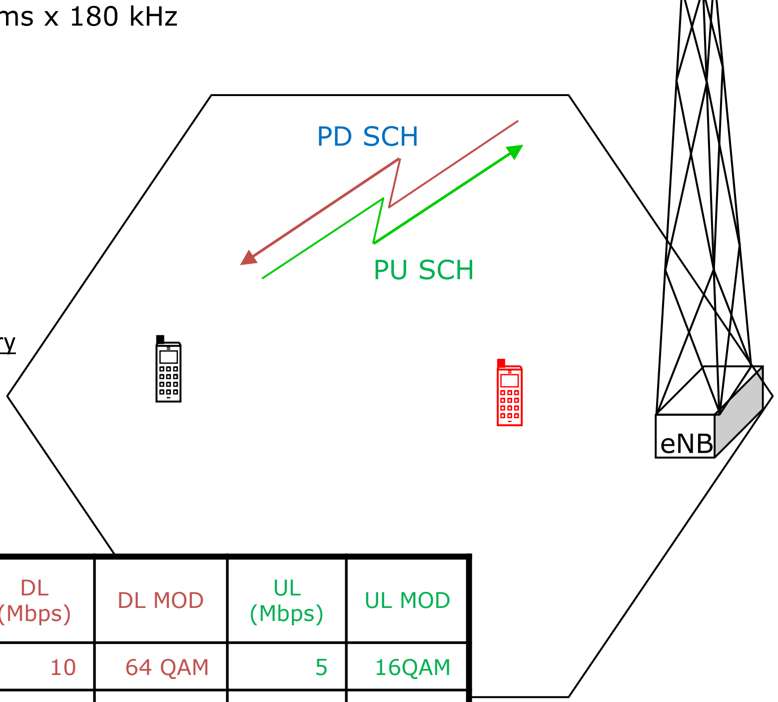
DL: OFDMA

UL: SC-FDMA

Sharing: frequency & time



Physical Resource Block (PRB): 0.5 ms x 180 kHz



Scheduling

Scheduling: Allocation of Physical resource blocks (PRB) and which Modulation Scheme to use

Alt 1 Round robin, red, black, red

Alt 2 Best quality red, red, red ...

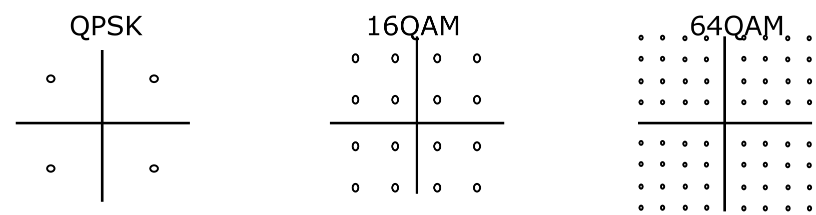
Alt 3 Proportional fairness, quality/data volume, red , red , black, red

Also take into account the QoS of the service and UE category

UE category

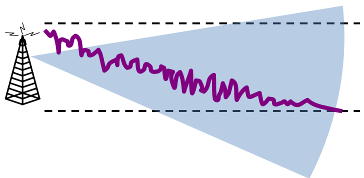
Category	DL (Mbps)	DL MOD	UL (Mbps)	UL MOD
1	10	64 QAM	5	16QAM
2	50	64 QAM	25	-
3	100	64 QAM	50	-
4	150	64 QAM	50	-
5	300	64 QAM	75	64QAM

Modulation

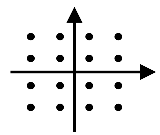


Key Radio features of LTE

Many similarities with HSPA/HSPA+....

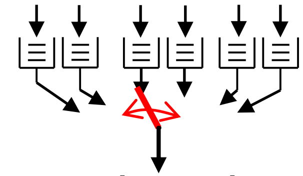


Fast Link Adaptation due to channel bahaviour



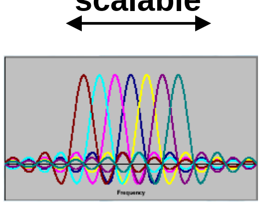
Up to 64QAM Modulation

Short TTI = 1 ms Transmission time interval



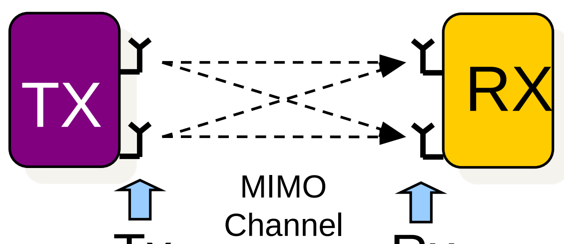
Advanced Scheduling Time & Freq.

scalable



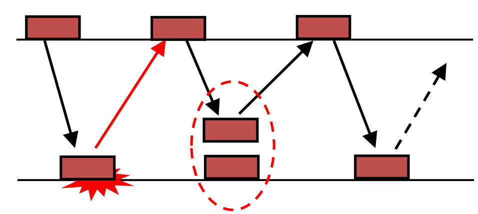
DL: OFDMA

UL: SC-FDMA



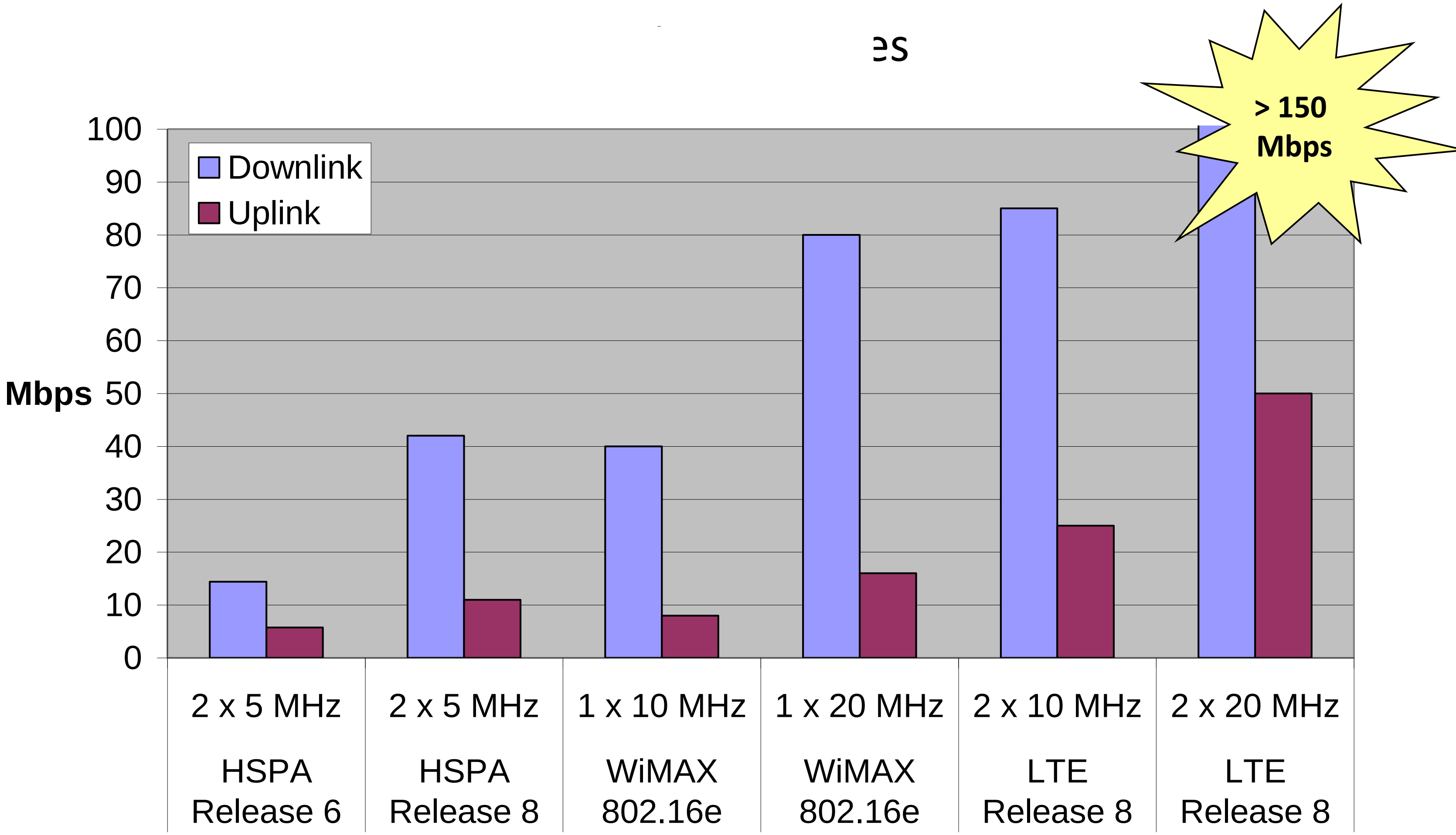
ARQ

Automatic Repeat Request



Frequency re-use 1

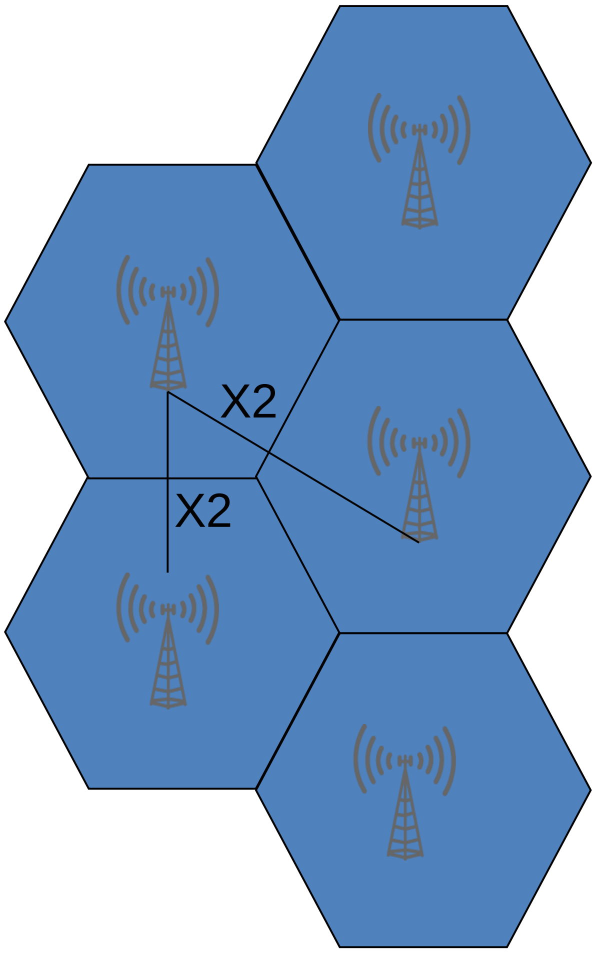
Performance Numbers



- **Rather similar Peak Data Rates for HSPA evolution and WiMAX**
- **LTE provides outstanding Data Rates beyond 150 Mbps in 2 x 20 MHz Bandwidth due to less overhead**
- **WiMAX uses asymmetric 29:18 TDD in 10/20 MHz, whereas HSPA and LTE use FDD with 2 x 5 and 2 x 10/20 MHz**
- **Prerequisite: 2x2 MIMO with 64-QAM in Downlink**

Frequency Reuse One in LTE

- LTE is designed for frequency reuse of one $\Rightarrow$ no frequency planning required
- Inter-site interference coordination is possible by exchanging load information over X2 interface = soft frequency reuse
- Current simulations show no clear performance gains in downlink from inter-site interference coordination
- Some performance potential in uplink by exchanging overload indicator information



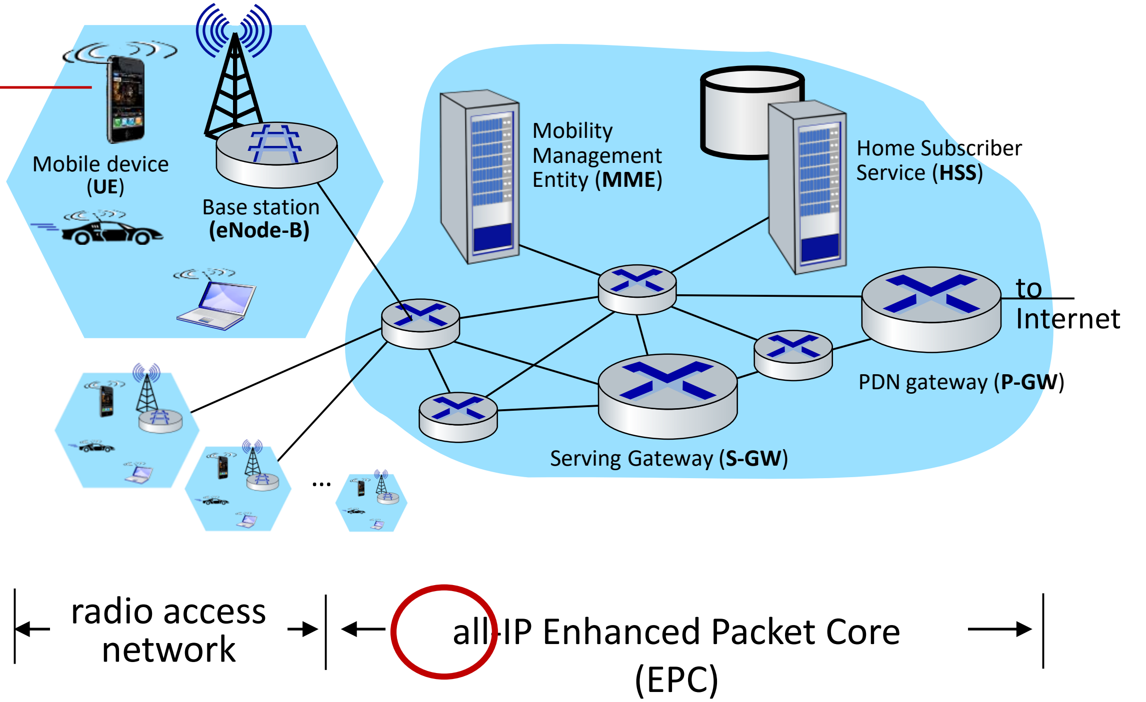
LTE Frequency Variants in 3GPP – FDD

	Total [MHz]	Uplink [MHz]	Downlink [MHz]	Europe	Japan	Americas	
1	2x60	1920-1980	2110-2170	●	●		UMTS core
2	2x60	1850-1910	1930-1990			●	US PCS
3	2x75	1710-1785	1805-1880	●			1800
4	2x45	1710-1755	2110-2155			●	US AWS
5	2x25	824-849	869-894			●	US 850
6	2x10	830-840	875-885		●		Japan 800
7	2x70	2500-2570	2620-2690	●			2600
8	2x35	880-915	925-960	●			900
9	2x35	1749.9-1784.9	1844.9-1879.9		●		Japan 1700
10	2x60	1710-1770	2110-2170			●	Extended AWS
11	2x25	1427.9-1452.9	1475.9-1500.9		●		Japan 1500
12	2x18	698-716	728-746			●	US700
13	2x10	777-787	746-756			●	US700
14	2x10	788-798	758-768			●	US700
xx	2x30?	790-820	832-862?	●			UHF (TV)

Elements of 4G LTE architecture

Mobile device:

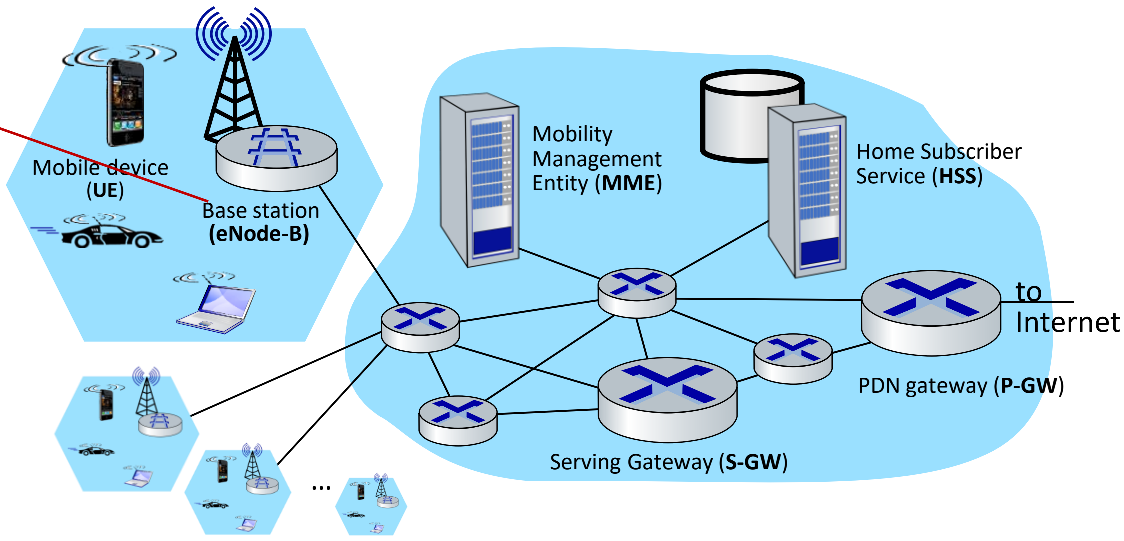
- smartphone, tablet, laptop, IoT, ... with 4G LTE radio
- 64-bit International Mobile Subscriber Identity (IMSI), stored on SIM (Subscriber Identity Module) card
- LTE jargon: User Equipment (UE)



Elements of 4G LTE architecture

Base station:

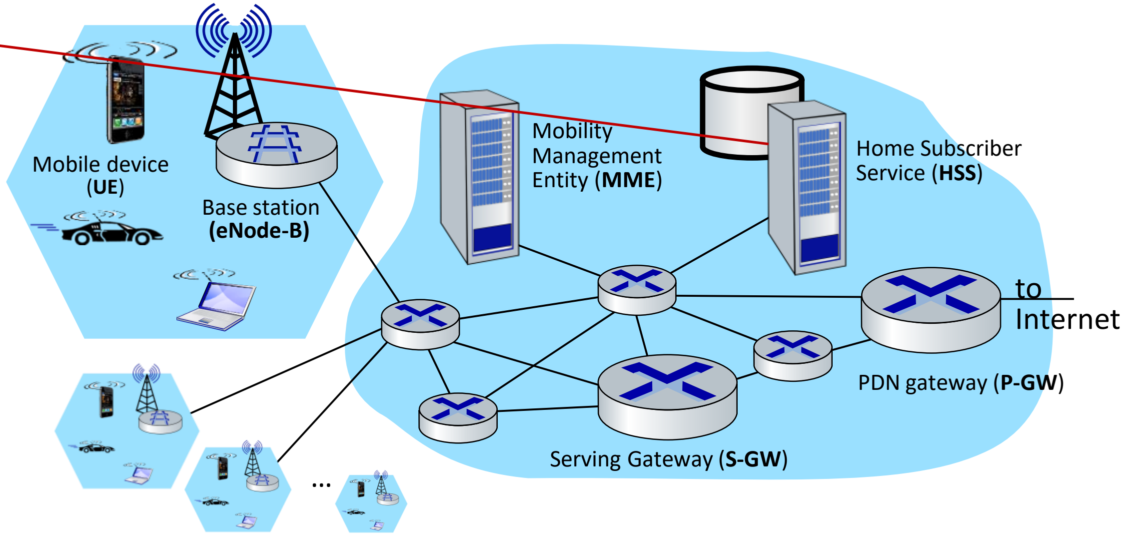
- at "edge" of carrier's network
- manages wireless radio resources, mobile devices in its coverage area ("cell")
- coordinates device authentication with other elements
- similar to WiFi AP but:
  - active role in user mobility
  - coordinates with nearly base stations to optimize radio use
- LTE jargon: eNode-B



Elements of 4G LTE architecture

Home Subscriber Service

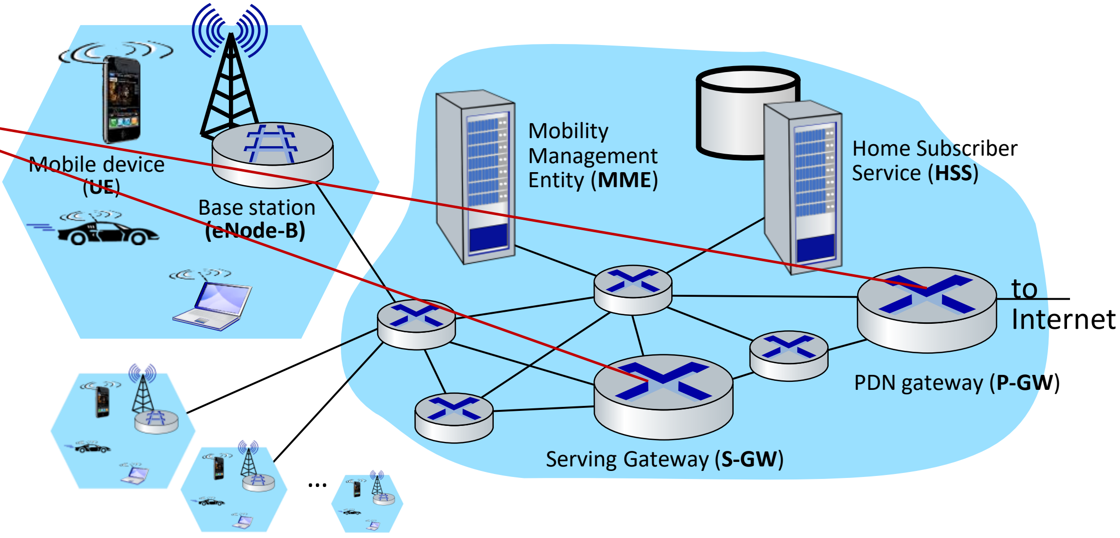
- stores info about mobile devices for which the HSS's network is their "home network"
- works with MME in device authentication



Elements of 4G LTE architecture

Serving Gateway (S-GW), PDN Gateway (P-GW)

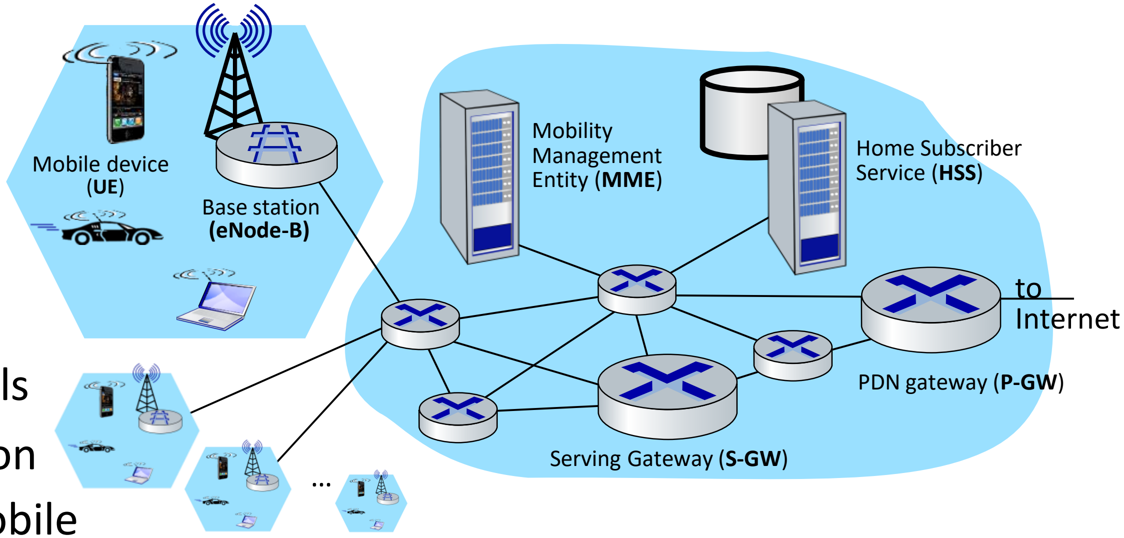
- lie on data path from mobile to/from Internet
- P-GW
  - gateway to mobile cellular network
  - Looks like any other internet gateway router
  - provides NAT services
- other routers:
  - extensive use of tunneling



Elements of 4G LTE architecture

Mobility Management Entity

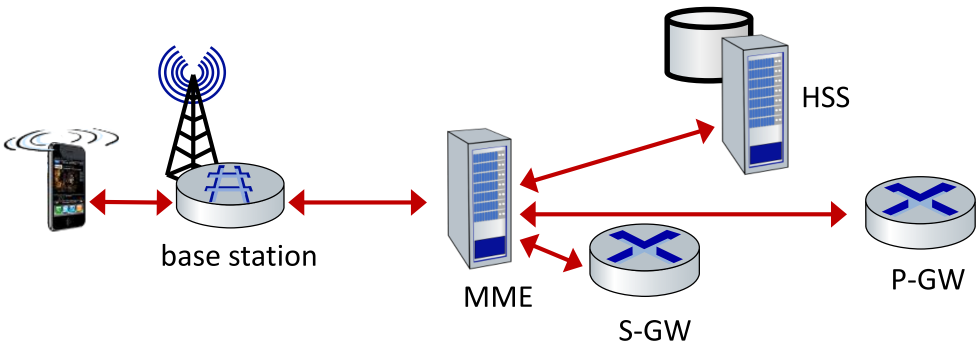
- device authentication (device-to-network, network-to-device) coordinated with mobile home network HSS
- mobile device management:
  - device handover between cells
  - tracking/paging device location
- path (tunneling) setup from mobile device to P-GW



LTE SGW | Serving Gateway

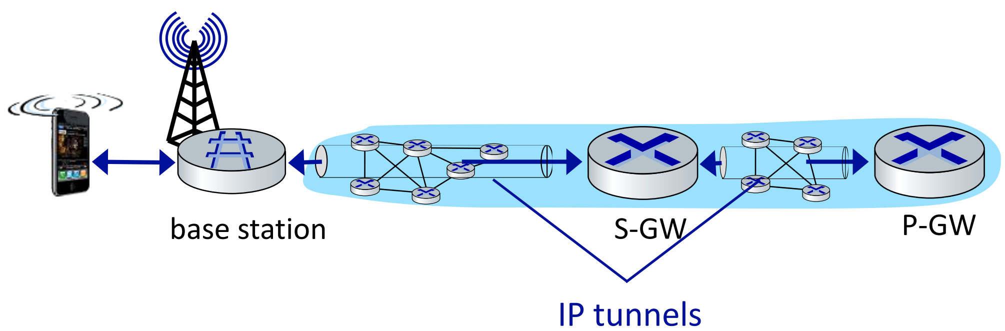
- One or more SGWs will serve given group of eNBs for user plane data.
- Single UE is served by one S-GW at any time.
- It receives instructions from MME to set up and tear down sessions for particular UE.
- It acts as interface module for signalling between PGW and MME.
- It takes care of user IP packets between P-GW and eNB.

LTE: data plane control plane separation



control plane

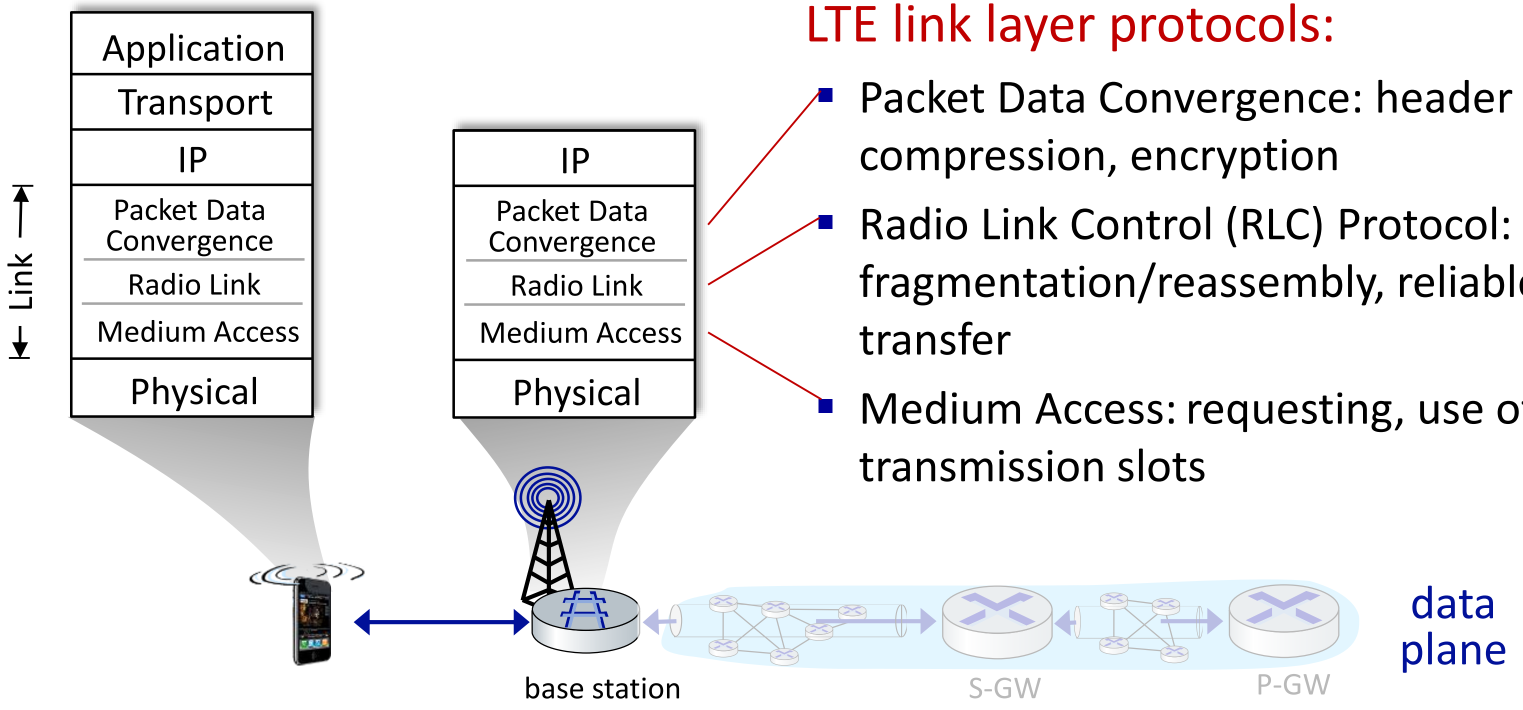
- new protocols for mobility management , security, authentication (later)



data plane

- new protocols at link, physical layers
- extensive use of tunneling to facilitate mobility

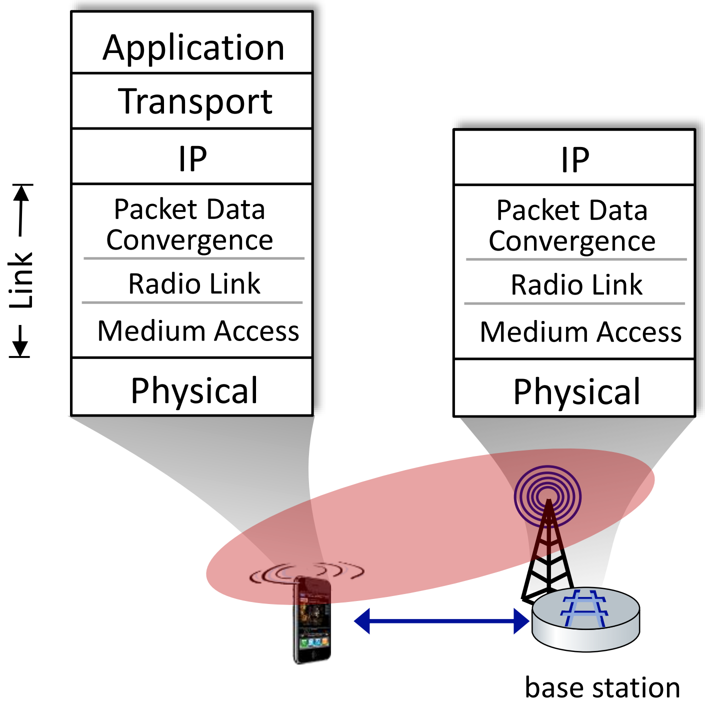
LTE data plane protocol stack: first hop



LTE link layer protocols:

- Packet Data Convergence: header compression, encryption
- Radio Link Control (RLC) Protocol: fragmentation/reassembly, reliable data transfer
- Medium Access: requesting, use of radio transmission slots

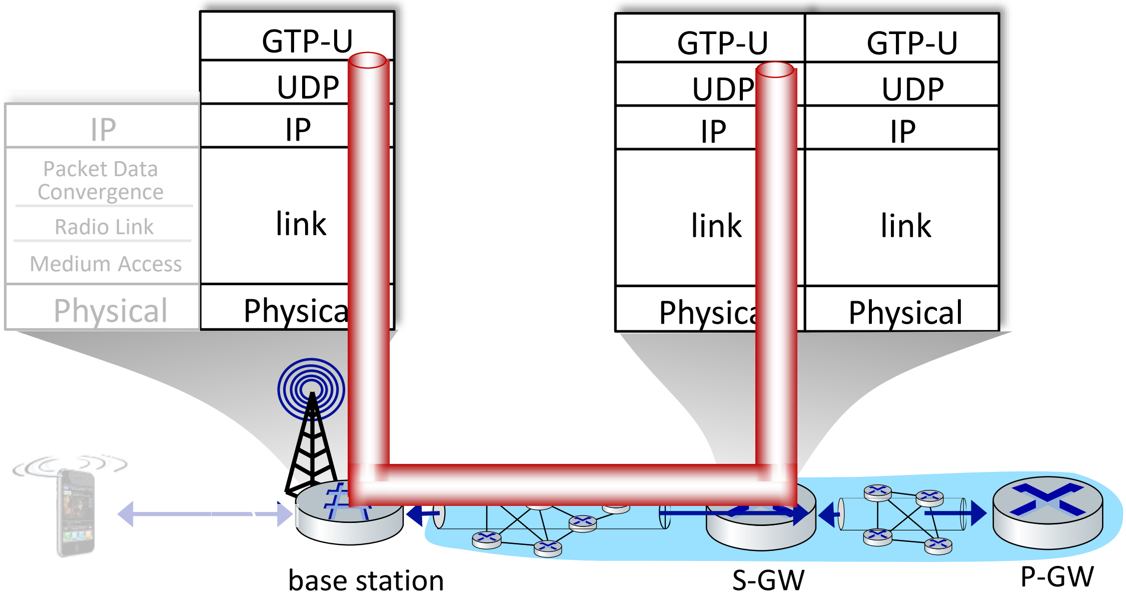
LTE data plane protocol stack: first hop



LTE radio access network:

- downstream channel: FDM, TDM within frequency channel (OFDM - orthogonal frequency division multiplexing)
  - "orthogonal": minimal interference between channels
  - upstream: FDM, TDM similar to OFDM
- each active mobile device allocated two or more 0.5 ms time slots over 12 frequencies
  - scheduling algorithm not standardized – up to operator
  - 100's Mbps per device possible

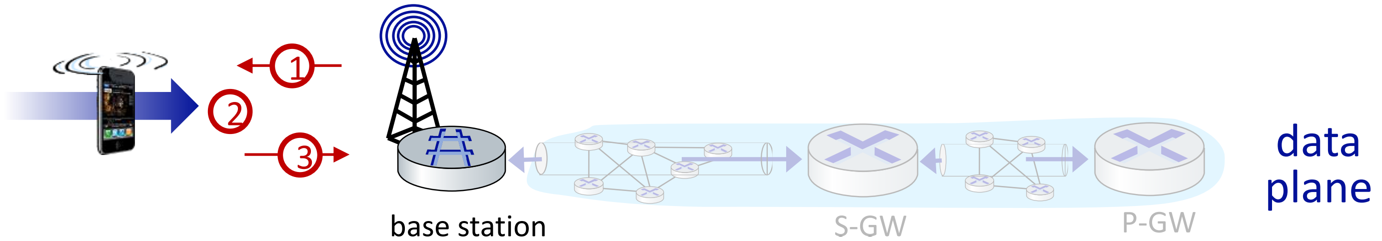
LTE data plane protocol stack: packet core



tunneling:

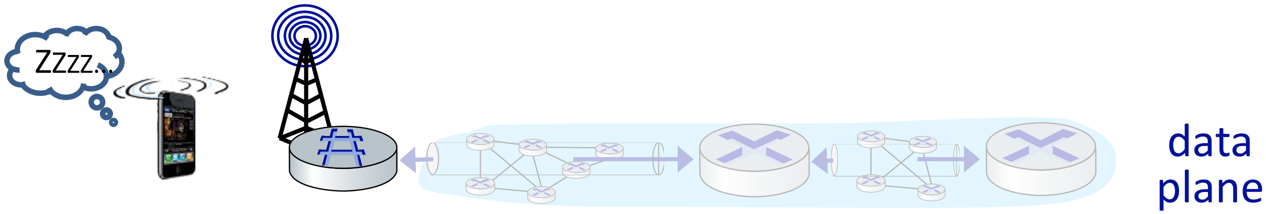
- mobile datagram encapsulated using GPRS Tunneling Protocol (GTP), sent inside UDP datagram to S-GW
- S-GW re-tunnels datagrams to P-GW
- supporting mobility: only tunneling endpoints change when mobile user moves

LTE data plane: associating with a BS



1. BS broadcasts primary synch signal every 5 ms on all frequencies
   - BSs from multiple carriers may be broadcasting synch signals
2. mobile finds a primary synch signal, then locates 2nd synch signal on this freq.
   - mobile then finds info broadcast by BS: channel bandwidth, configurations; BS's cellular carrier info
   - mobile may get info from multiple base stations, multiple cellular networks
3. mobile selects which BS to associate with (*e.g.,* preference for home carrier)
4. more steps still needed to authenticate, establish state, set up data plane

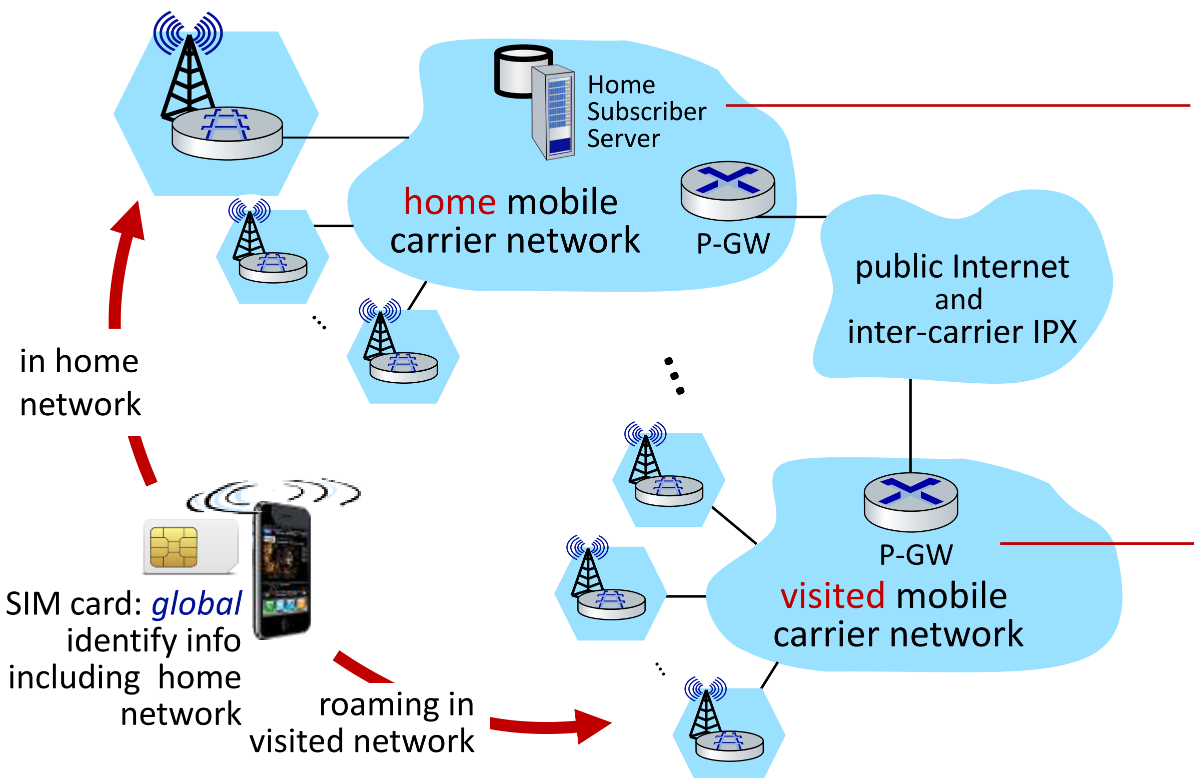
LTE mobiles: sleep modes



as in WiFi, Bluetooth: LTE mobile may put radio to "sleep" to conserve battery:

- light sleep: after 100's msec of inactivity
  - wake up periodically (100's msec) to check for downstream transmissions
- deep sleep: after 5-10 secs of inactivity
  - mobile may change cells while deep sleeping – need to re-establish association

Home network, visited network: 4G



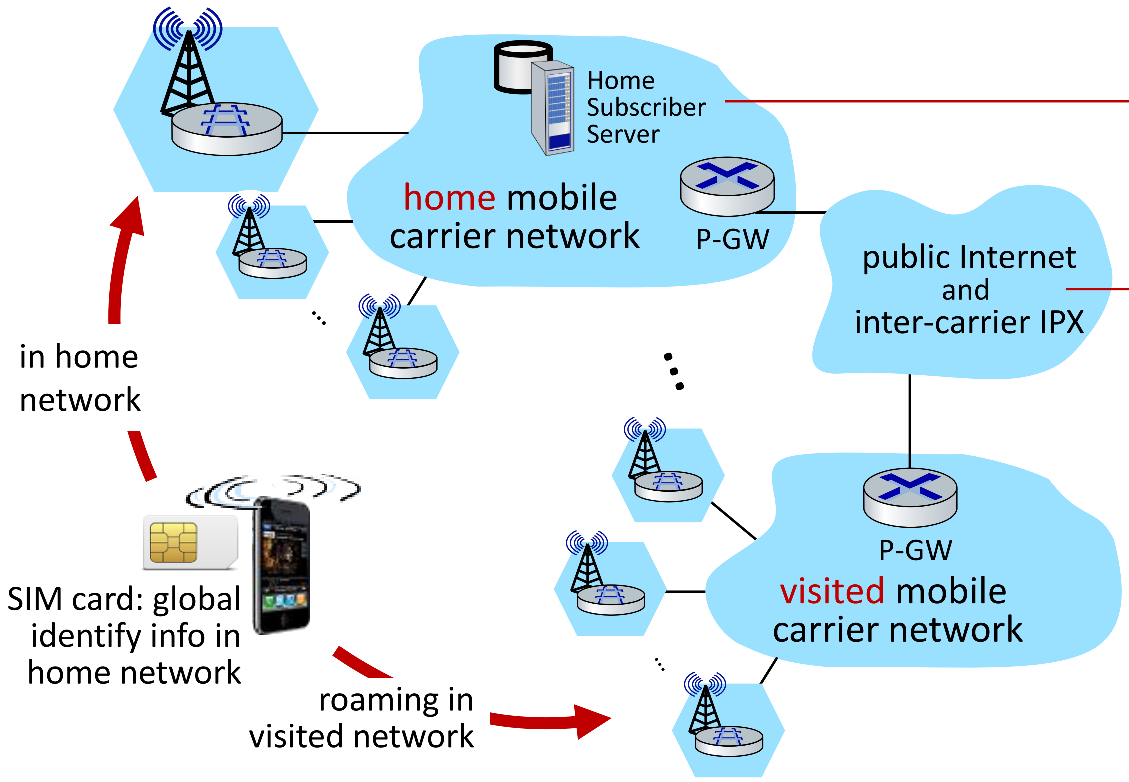
home network:

- (paid) service plan with cellular provider, e.g., Verizon, Orange
- home network HSS stores identify & services info

visited network:

- any network other than your home network
- service agreement with other networks: to provide access to visiting mobile

Global cellular network: a network of IP networks



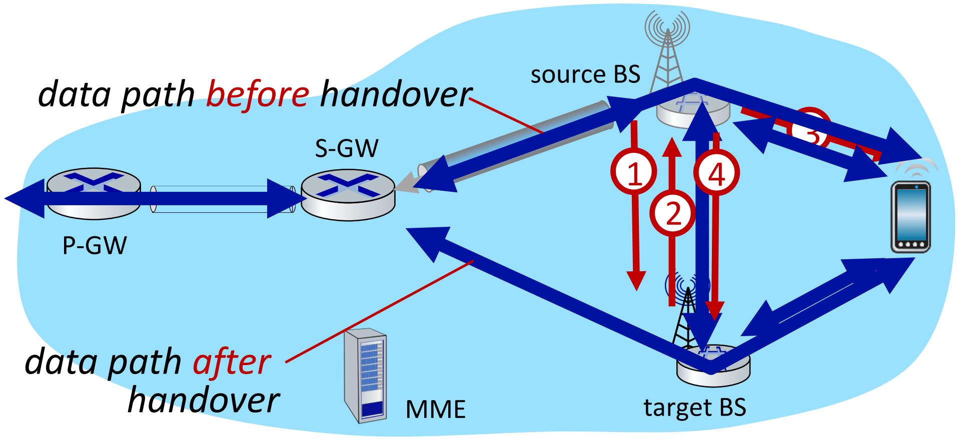
home network HSS:

- identify & services info, while in home network and roaming

all IP:

- carriers interconnect with each other, and public internet at exchange points
- legacy 2G, 3G: not all IP, handled otherwise

Handover between BSs in same cellular network



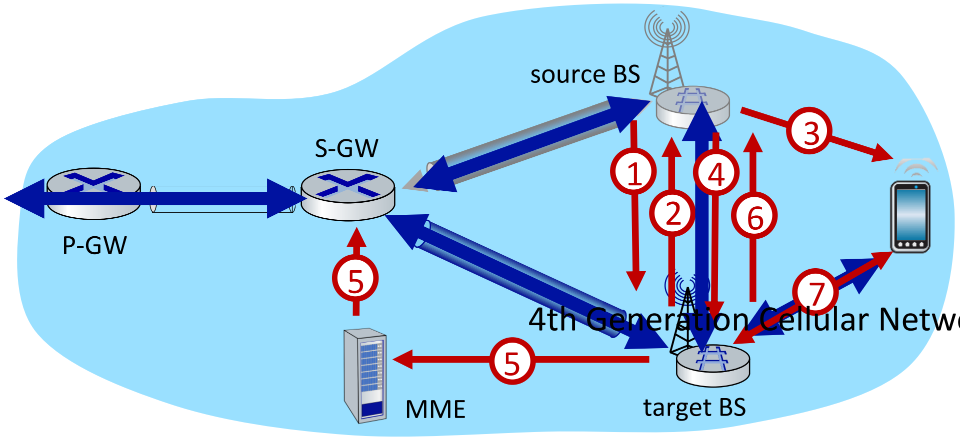
① current (source) BS selects target BS, sends *Handover Request message* to target BS

② target BS pre-allocates radio time slots, responds with HR ACK with info for mobile

③ source BS informs mobile of new BS
- mobile can now send via new BS - handover *looks* complete to mobile

④ source BS stops sending datagrams to mobile, instead forwards to new BS (who forwards to mobile over radio channel)

Handover between BSs in same cellular network



5 target BS informs MME that it is new BS for mobile

- MME instructs S-GW to change tunnel endpoint to be (new) target BS

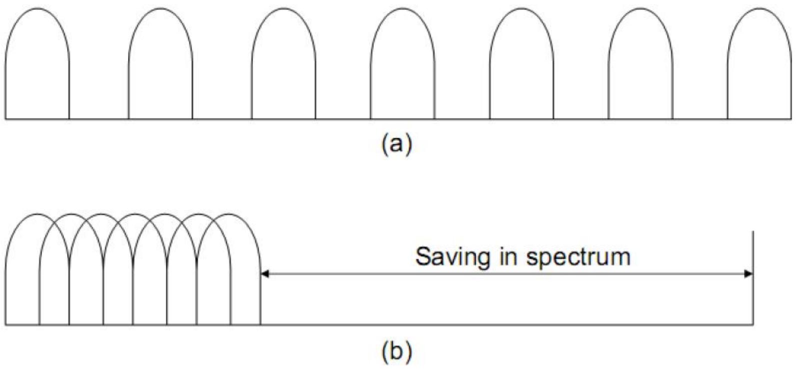
6 target BS ACKs back to source BS: handover complete, source BS can release resources

7 mobile's datagrams now flow through new tunnel from target BS to S-GW

Orthogonal Frequency Division Multiplexing

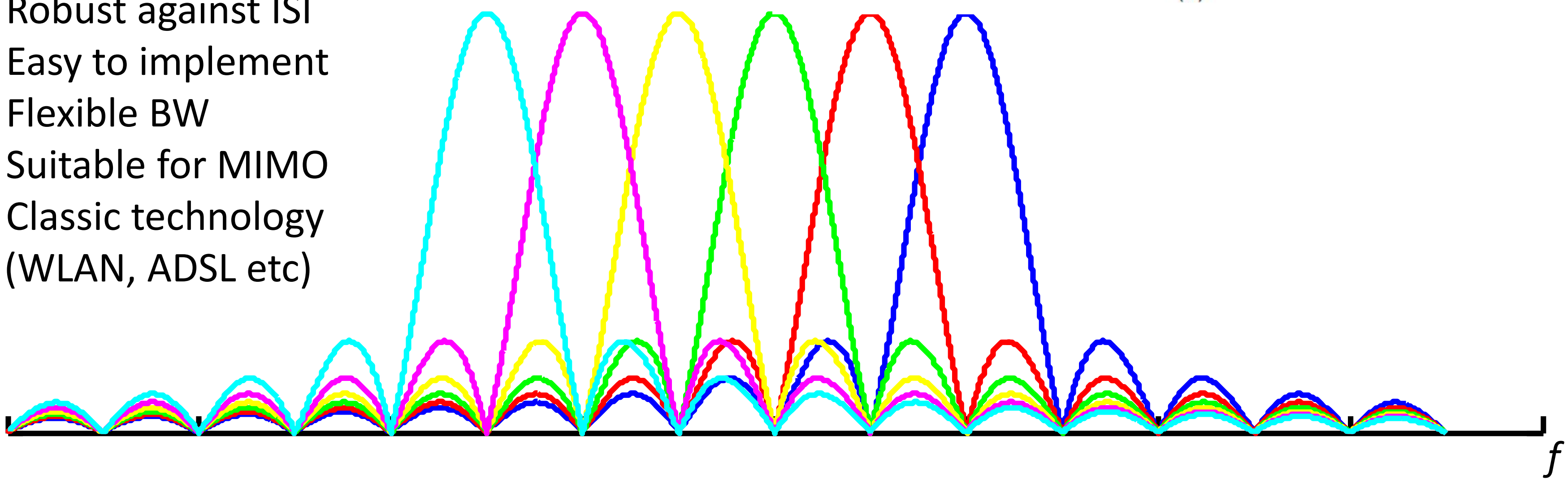
- Orthogonal: all other subcarriers zero at sampling point
- Sub carrier spacing 15 kHz

OFDM vs Single Carrier



Benefits

+ Frequency diversity
+ Robust against ISI
+ Easy to implement
+ Flexible BW
+ Suitable for MIMO
+ Classic technology (WLAN, ADSL etc)

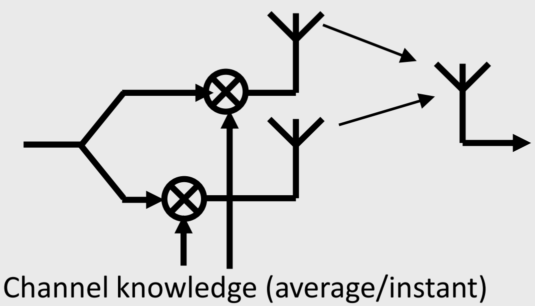


Multi Antenna Possibilities

Directivity

Antenna/Beamforming gain

Example

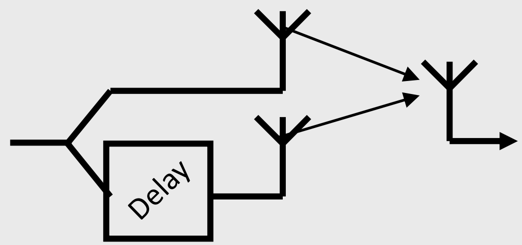


Transmit the signal in the best direction

Diversity

"Reduce fading"

Example

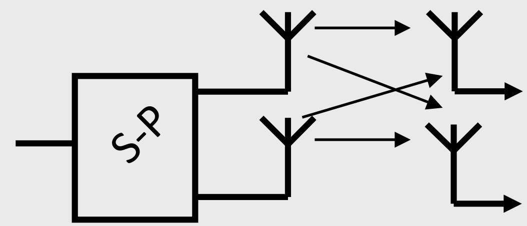


Transmit the signal in all directions

Spatial Multiplexing

"Data Rate multiplication"

Example

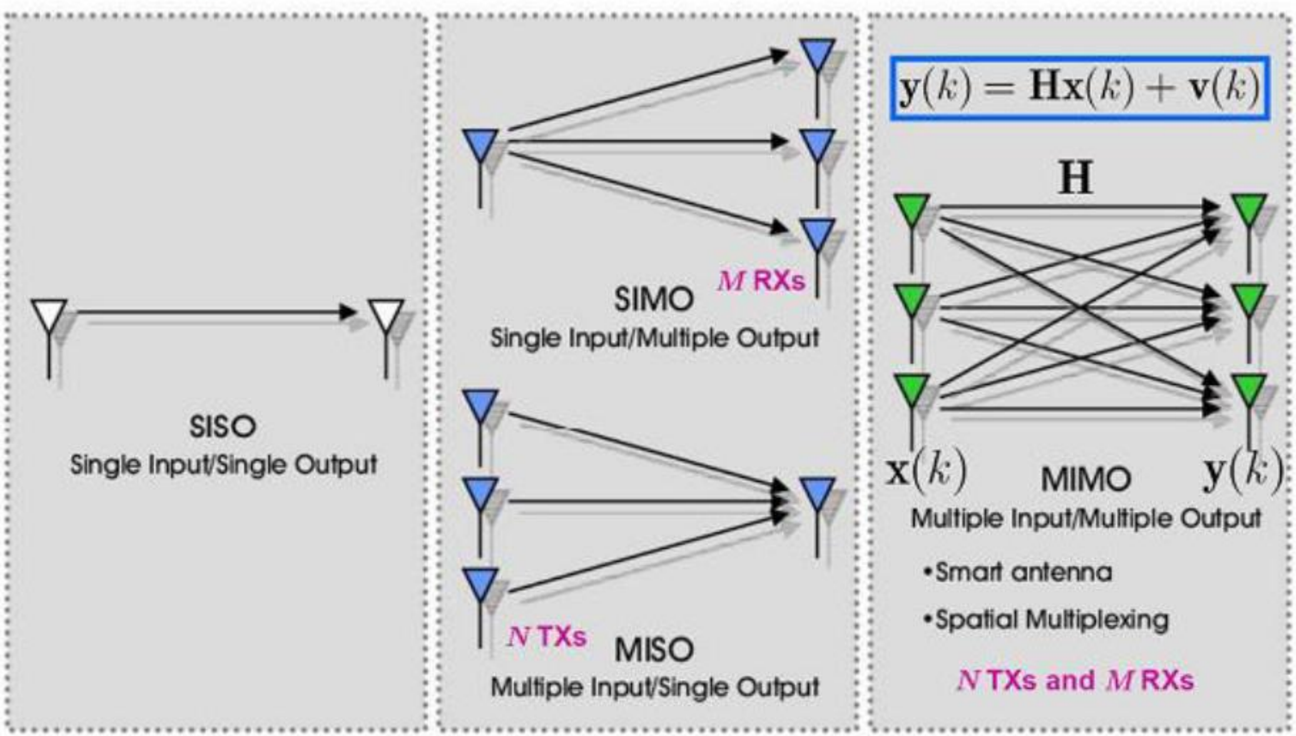


Transmit several signals in different directions

- ***Different techniques make different assumptions on channel knowledge at rx and tx***
- ***Many technqiues can realize several benefits***
- ***Realized benefit depends on channel (incl. antenna) and interference properties***

Multiple Antenna Technique

Existing Tech | **Smart Antenna** | **MIMO Antenna**



Note:

$$\mathbf{H} = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1N} \\ h_{21} & h_{22} & \cdots & h_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ h_{M1} & h_{M2} & \cdots & h_{MN} \end{bmatrix}$$

LTE Network Planning

LTE Dimensioning Concept

Dimensioning Procedures should follow information gathering job about the nature of the subscriber and the area

Both capacity and coverage dimensioning process should be balanced

Dimensioning could be divided into two main steps as following

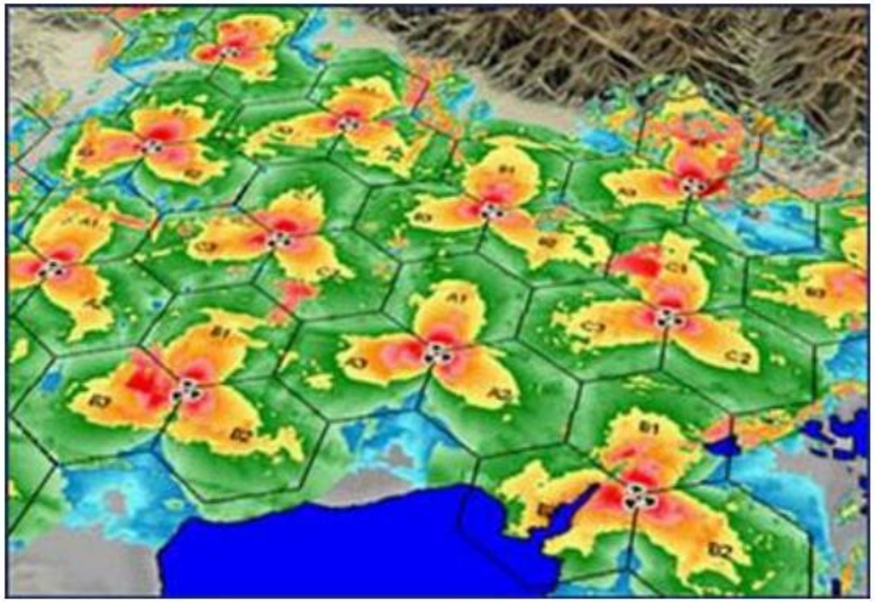
- Capacity dimensioning
- Coverage dimensioning

N = Total Area / Site Area (A)

$A = 1.94 * R^2$ … directional antenna or

$A = 2.5 * R^2$ … omni antenna

$D = 1.5 * R$

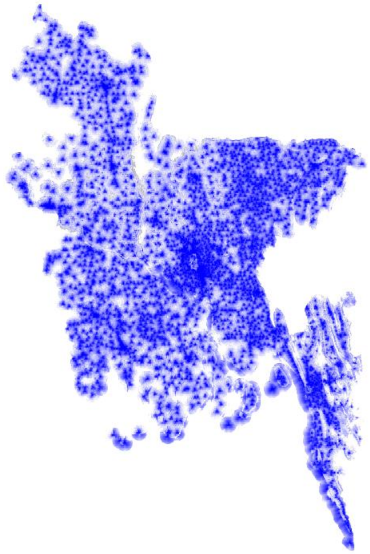


LTE coverage area

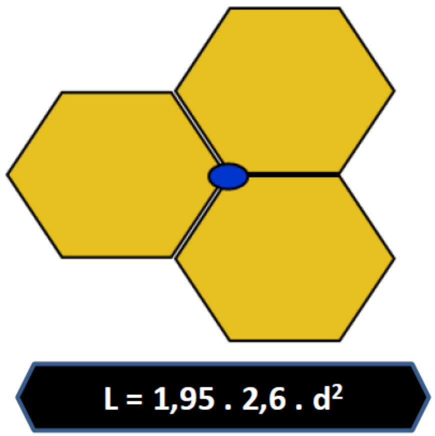
After determiation of cell range (radius) d
we can estimate the site coverage area

*	Omni	2-sectors	3-sectors
Site_area	$2.6 * d^2$	$1.3 * d^2$	$1.95 * d^2$
Intersite_distance	0.87 * d	2* d	1.5 * d

#sites = deployment_area / site_area



For trisectoral



$$L = 1.95 \times 2.6 \times (1)^2$$

$$L = 5.07\ km^2$$

Number of eNodeB

- Urban Area (Trisector)
  - total area 242.928 km^2
  - $N_{eNodeB} = 242.928 / 5.07$
  - $N_{eNodeB} = 48$

Capacity Plan

Calculation steps:

1. Number of user
2. User density
3. Services and Type
4. Penetration : building, vehicular, pedestrian
5. BHCA and call duration
6. OBQ
7. Site calculation

Number of User

$$Un = Uo\,(1 + gf)^n$$

Uo is Uo_u or Uo_{sub}

$$Uo_u = u \times Uo_N$$

$$Uo_{sub} = sub \times Uo_N$$

Where:

$$Uo_N = a \times b \times d \times N$$

- Un : num of user on year 'n'
- Uo : initial num of user (based on urban/sub-urban)
- a : percent of cellular user (%)
- b : penetration of operator A (%)
- d : Percent of LTE user
- N : num of civilian in the object area
- gf : num of user growth factor
- n : planned year
- u/sub : urban or sub-urban penetration (%)

Customer Prediction Parameter

Ex :

- Population = 1445892 people
- Cellular penetration = assumption 80%
- LTE penetration = assumption 10 %
- LTE provider A penetration = assumption 50 %

Population	1445892	people
Customer cellular (80%)	1156713	user
Customer LTE (10%)	115671	user
Customer LTE provider A (50%)	57835	user

User prediction in 5th years

- $U5 = 57835 (1 + 0.05)^5$ →assumption fp=5%

  = **73814** user

User Density

$L_u = L \times u$

$L_{sub} = L \times sub$

- L_u : urban area wide
- L_{sub} : sub-urban area wide
- L : object area wide

$C_u = Un/L_u$

$C_{sub} = Un/L_{sub}$

- C_u : Urban area density
- C_{sub} : sub-urban area density

Example User Density Calculation

Ex :

- urban area penetration = assumption 40 %
- suburban area penetration = assumption 40 %
- Openarea = assumption 20 %

=>

Urban area wide (Lu) : 242,928 km^2

Sub-urban area wide (Lsub) : 242,928 km^2

=>

C_u = 44288 / 242,928 = 182,31232 user/km^2

C_{sub} = 29525 / 242,928 = 121,54155 user/km^2

Propagation Model

- **LTE – 700 MHz**
  - Okumura-Hatta

$$Lp = 69{,}55 + 26{,}16 \log f - 13{,}82 \log hB - CH + [44{,}9 - 6{,}55 \log hB] \log d$$

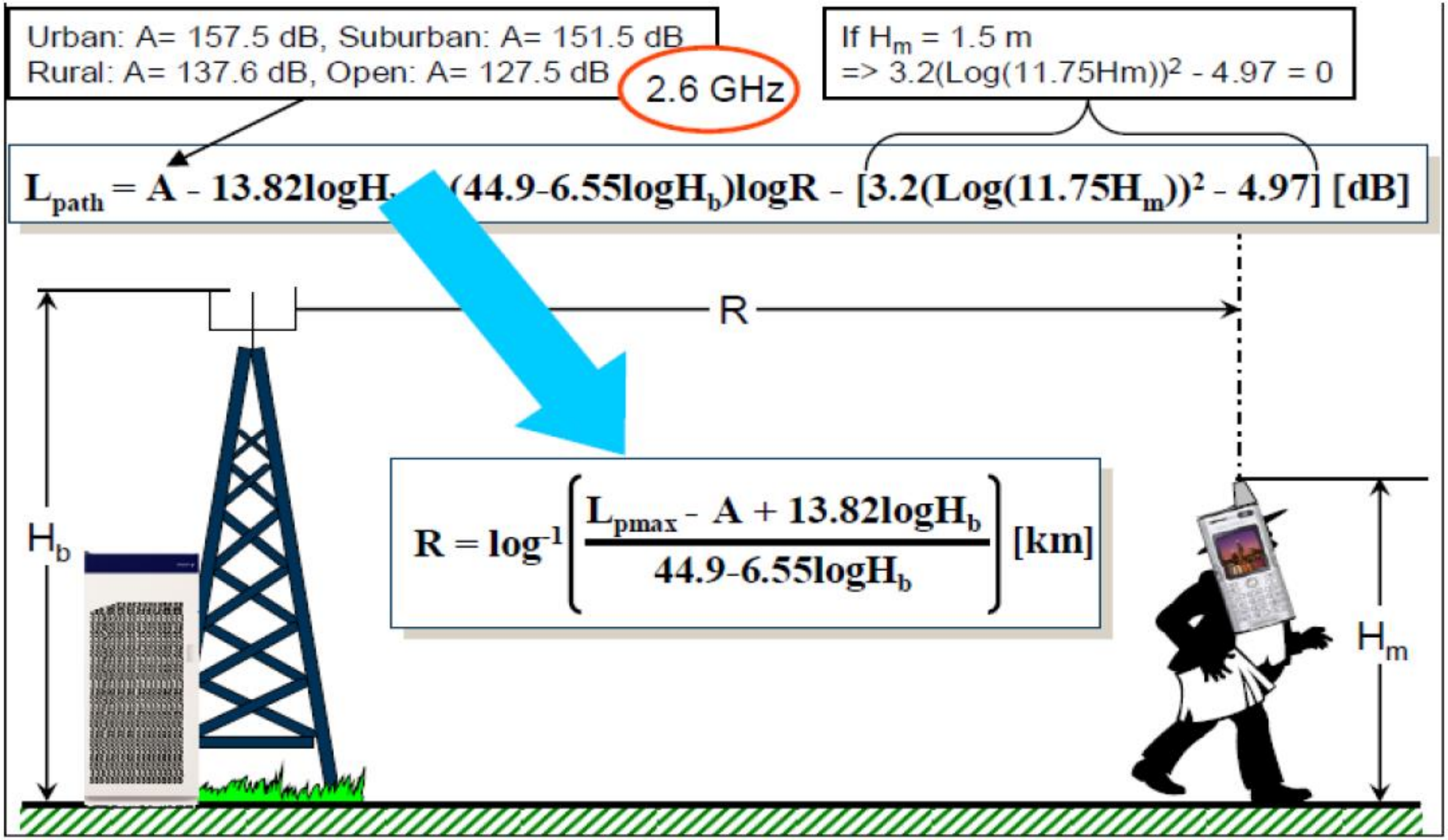
- **LTE – 2100 MHz**
  - Cost 231-Hatta

$$L_p = 46{,}3 + 33{,}9\,(\log f_c) + 13{,}82 \log h_T - a(h_R) + (44{,}9 - 6{,}55 \log h_T) \log d + C_M$$

- **LTE – 2600 MHz**
  - SUI

$$Lp = 109.78 + 47.9 \log (d/100)$$

- Get limited MAPL then substitute in propagation model equation to get R

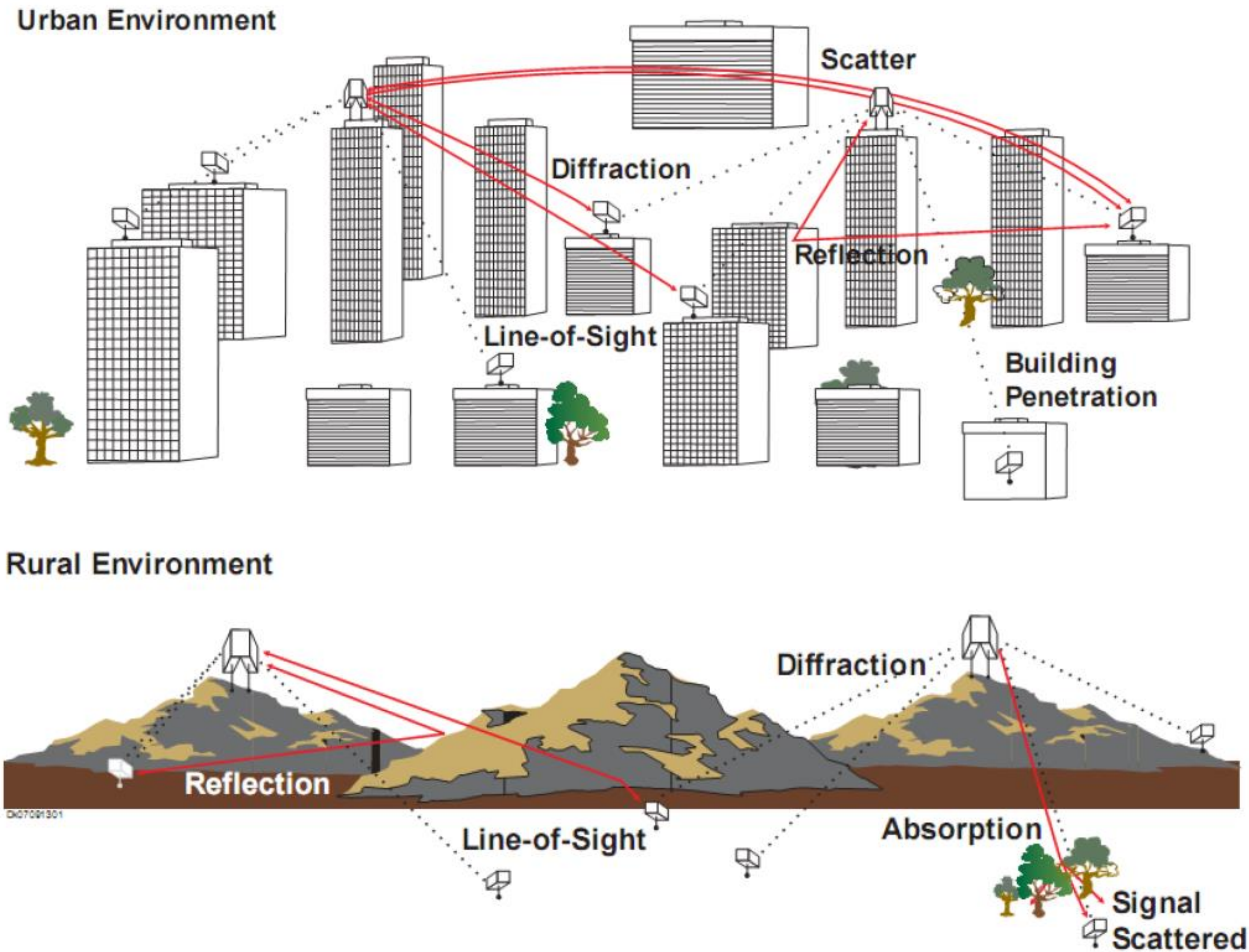


Uplink Link Budget

Uplink Link Budget			
	GSM Voice	HSPA	LTE
Data Rate (kbps)	**12.2**	**64**	**64**
Transmitter - UE			
a. Tx Power (dBm)	33	23	23
b. Tx Antenna Gain (dBi)	0	0	0
c. Body Loss (dB)	3	0	0
d. EIRP (dBm)			
Receiver – BTS/NodeB/eNodeB			
e. Noise Figure (dB)	-	2	2
f. Thermal Noise (dB)	-	-108.2	-118.4
g. Receiver Noise (dBm)	-	-106.2	-116.4
h. SINR (dB)	-	-17.3	-7
i. Receiver Sensitivity	**-114**		
j. Interference Margin (dB)	0	3	1
k. Cable Loss (dB)	0	0	0
l. Rx antenna gain (dBi)	18	18	18
m. Fast Fade margin (dB)	0	1.8	0
n. Soft Handover gain (dB)	0	2	0

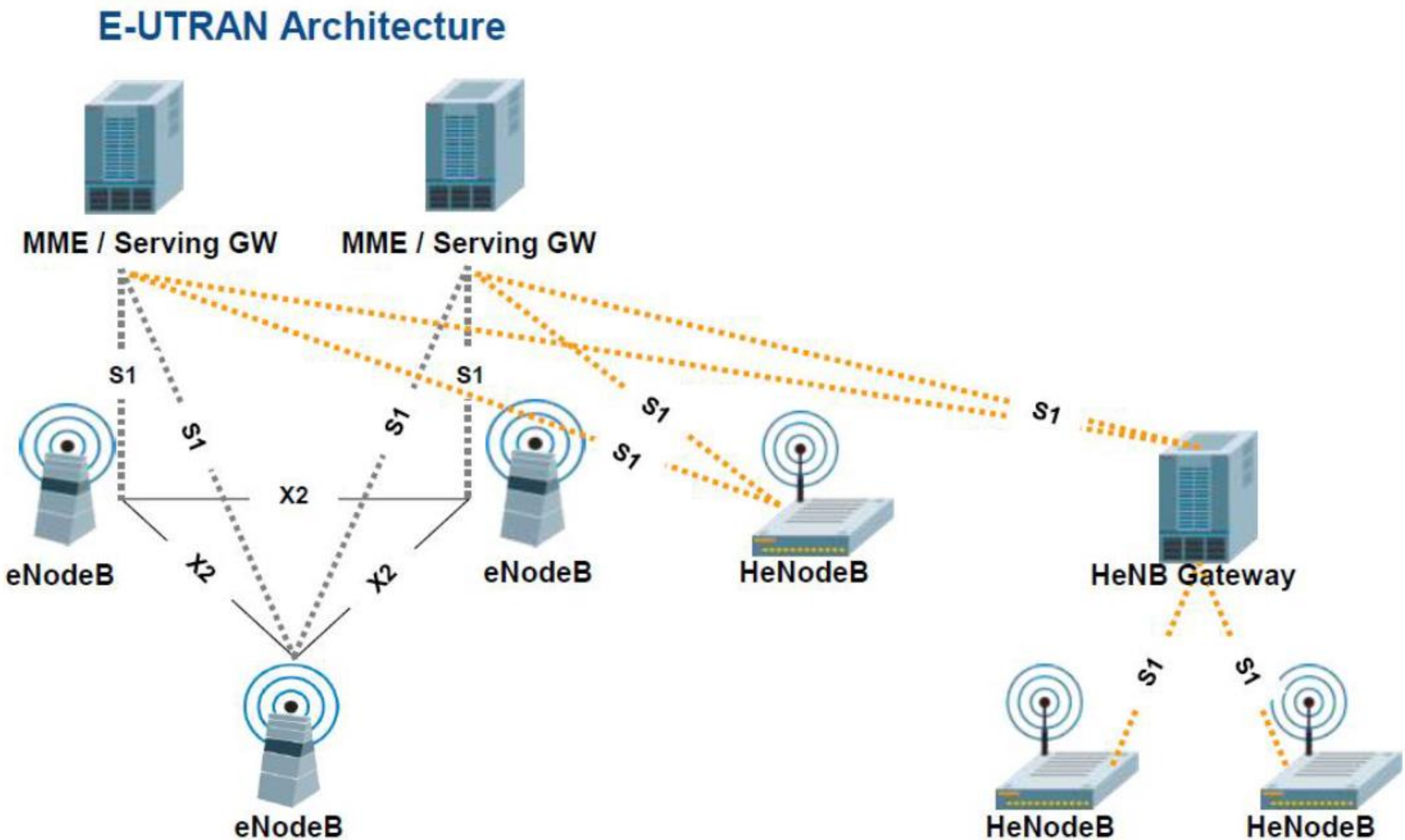
Downlink Link Budget

Downlink Link Budget			
	GSM Voice	HSPA	LTE
Data Rate (kbps)	**12.2**	**1024**	**1024**
Transmitter - BTS/NodeB/eNodeB			
a. Tx Power (dBm)	44.5	46	46
b. Tx Antenna Gain (dBi)	18	18	18
c. Cable Loss (dB)	2	2	2
d. EIRP (dBm)			
Receiver – UE			
e. UE Noise Figure (dB)	-	7	7
f. Thermal Noise (dB)	-119.7	-108.2	-104.5
g. Receiver Noise floor (dBm)	-	-101.2	-97.5
h. SINR (dB)	-	-5.2	-9
i. Receiver Sensitivity	**-104**		
j. Interference Margin (dB)	0	4	4
k. Control channel overhead (%)	0	20	20
l. Rx antenna gain (dBi)	0	0	0
m. Body Loss(dB)	3	0	0



Urban Environment
Scatter
Diffraction
Reflection
Line-of-Sight
Building
Penetration
Rural Environment
Diffraction
Reflection
Line-of-Sight
Absorption
Signal
Scattered

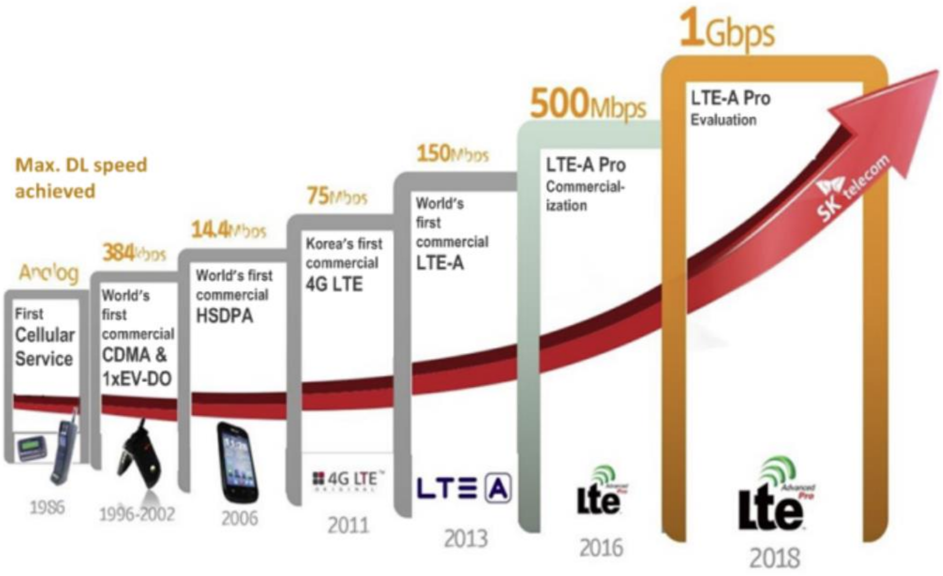
Femtocell @ LTE



Pricing - Example Network #1

700 MHz	LTE
Base Stations	50
Subscribers Supported	9000
Total Investment	$9,827,500
Investment per Subscriber	$1,092

LTE -Advanced



COMPARISON OF LTE-A WITH OTHER CELLULAR TECHNOLOGIES

	WCDMA (UMTS)	HSPA HSDPA / HSUPA	HSPA+	LTE	LTE ADVANCED (IMT ADVANCED)
Max downlink speed bps	384 k	14 M	28 M	100M	1G
Max uplink speed bps	128 k	5.7 M	11 M	50 M	500 M
Latency round trip time approx	150 ms	100 ms	50ms (max)	~10 ms	less than 5 ms
3GPP releases	Rel 99/4	Rel 5 / 6	Rel 7	Rel 8	Rel 10
Approx years of initial roll out	2003 / 4	2005 / 6 HSDPA 2007 / 8 HSUPA	2008 / 9	2009 / 10	2014 / 15
Access methodology	CDMA	CDMA	CDMA	OFDMA / SC-FDMA	OFDMA / SC-FDMA