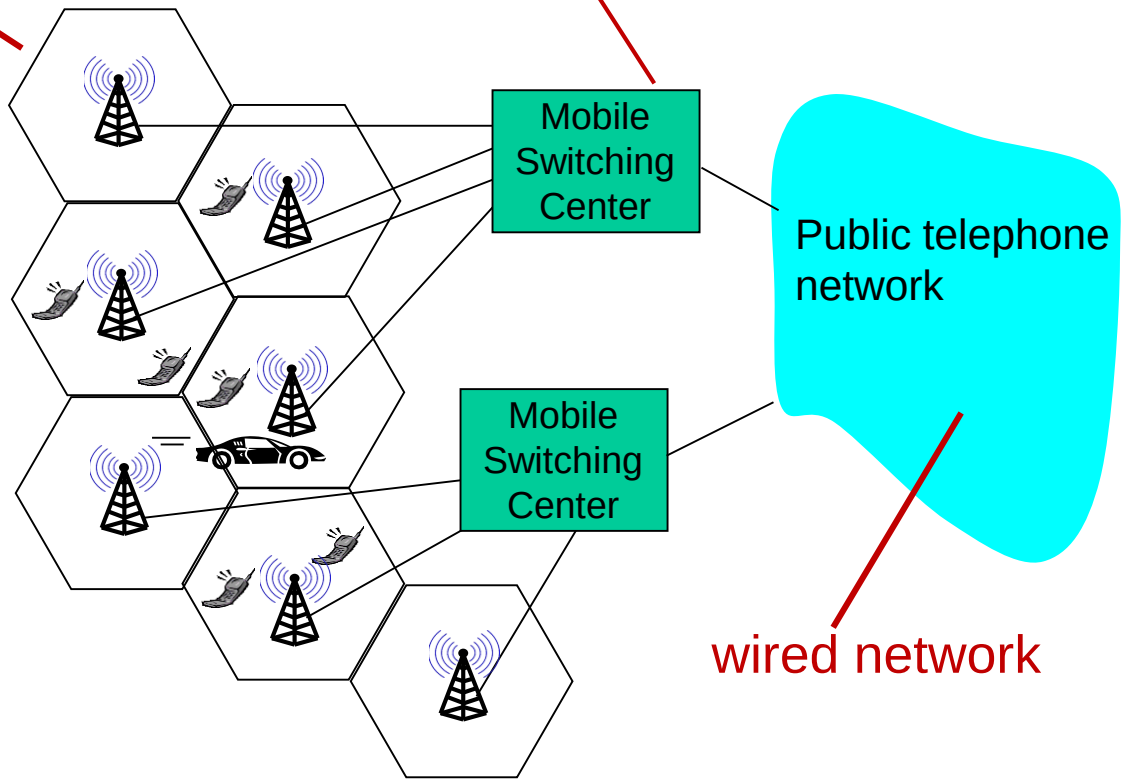
Background: Cellular network technology

- Overview
  - 1G: Analog voice (no global standard …)
  - 2G: Digital voice (again … GSM vs. CDMA)
  - 3G: Digital voice and data
    - Again … UMTS (WCDMA) vs. CDMA2000 (both CDMA-based)
    - and … 2.5G: EDGE (GSM-based)
  - 4G: LTE, LTE-Advanced …
    - OFDM (OFDMA for downlink and SC-OFDM for uplink)
- Trends
  - More data, packet-based switching, shared channel, directional (spatial reuse), multi-antenna, etc.
  - Other goals: Seamless with other technologies, QoS for multimedia, etc.

Components of cellular network architecture

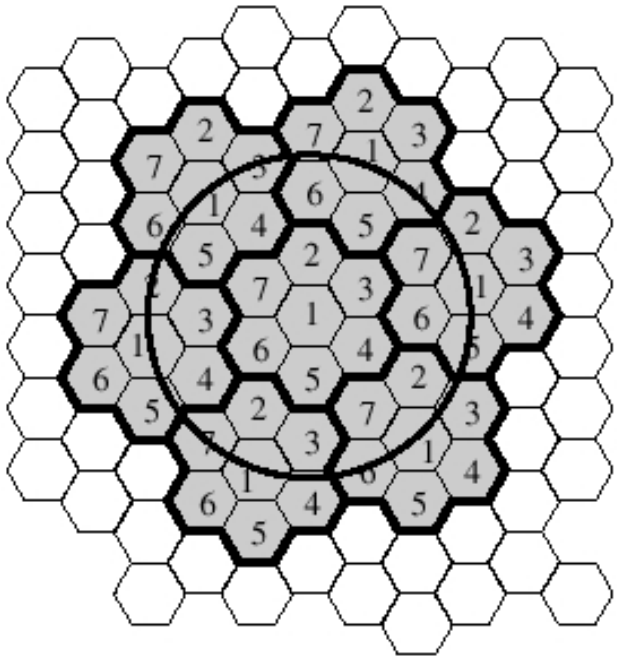
MSC
- connects cells to wired tel. net.
- manages call setup (more later!)
- handles mobility (more later!)

cell
- covers geographical region
- *base station* (BS) analogous to 802.11 AP
- *mobile users* attach to network through BS
- *air-interface:* physical and link layer protocol between mobile and BS



Components of cellular networks, cont'd

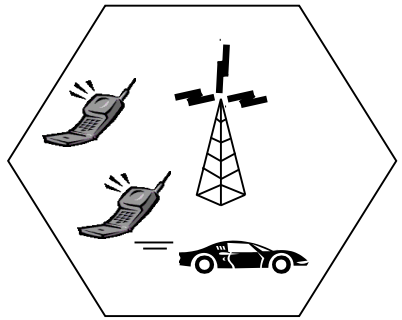
- Frequency reuse: use the same frequency spectrum in different set of cells
- Cells that reuse the same frequency must be distant enough for avoiding interference
- Transmission power control
- Migration of a mobile station from one cell to another with continuance of communication -> *handoff*



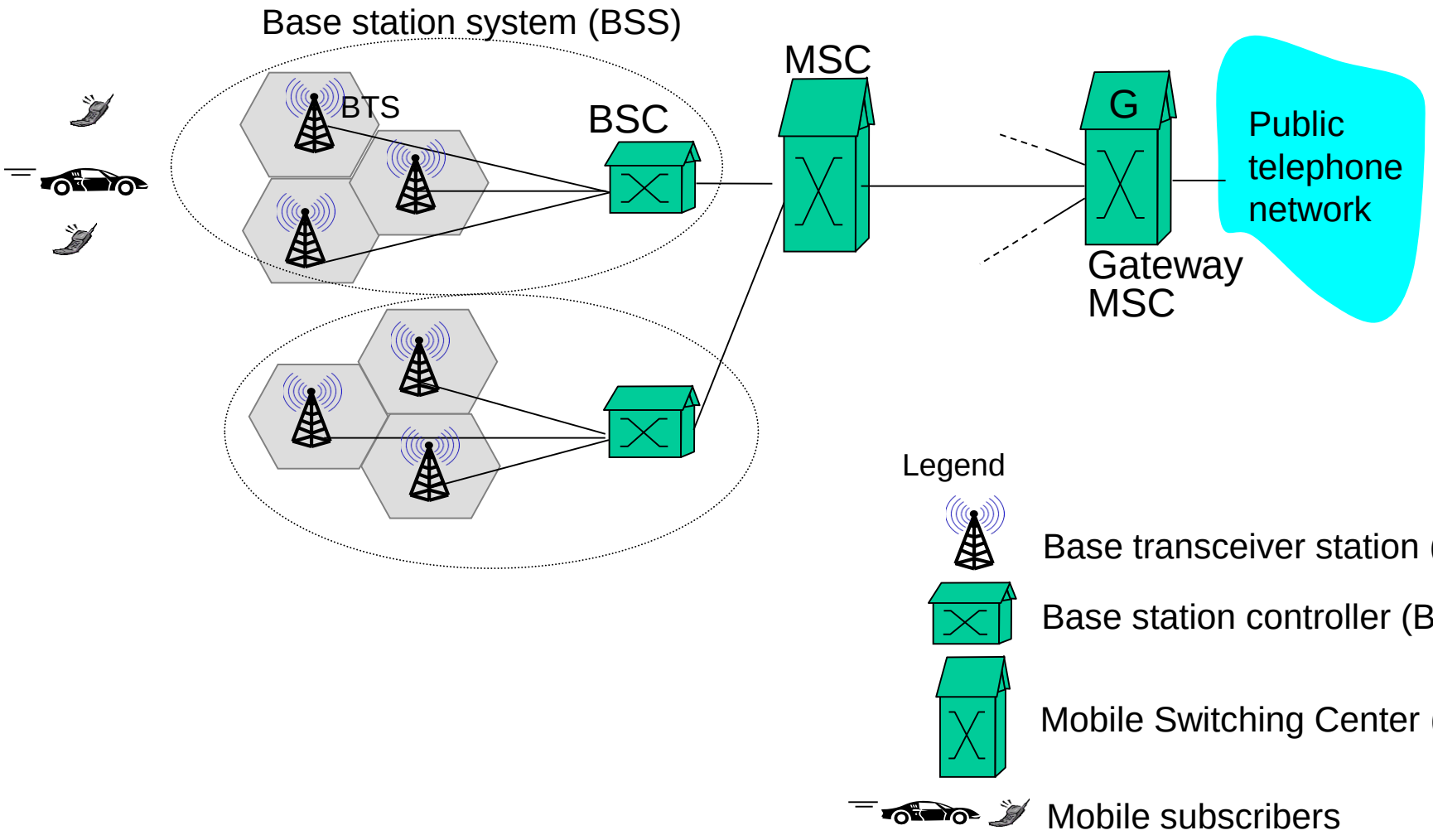
Cellular networks: the first hop

Techniques for sharing mobile-to-BS radio spectrum

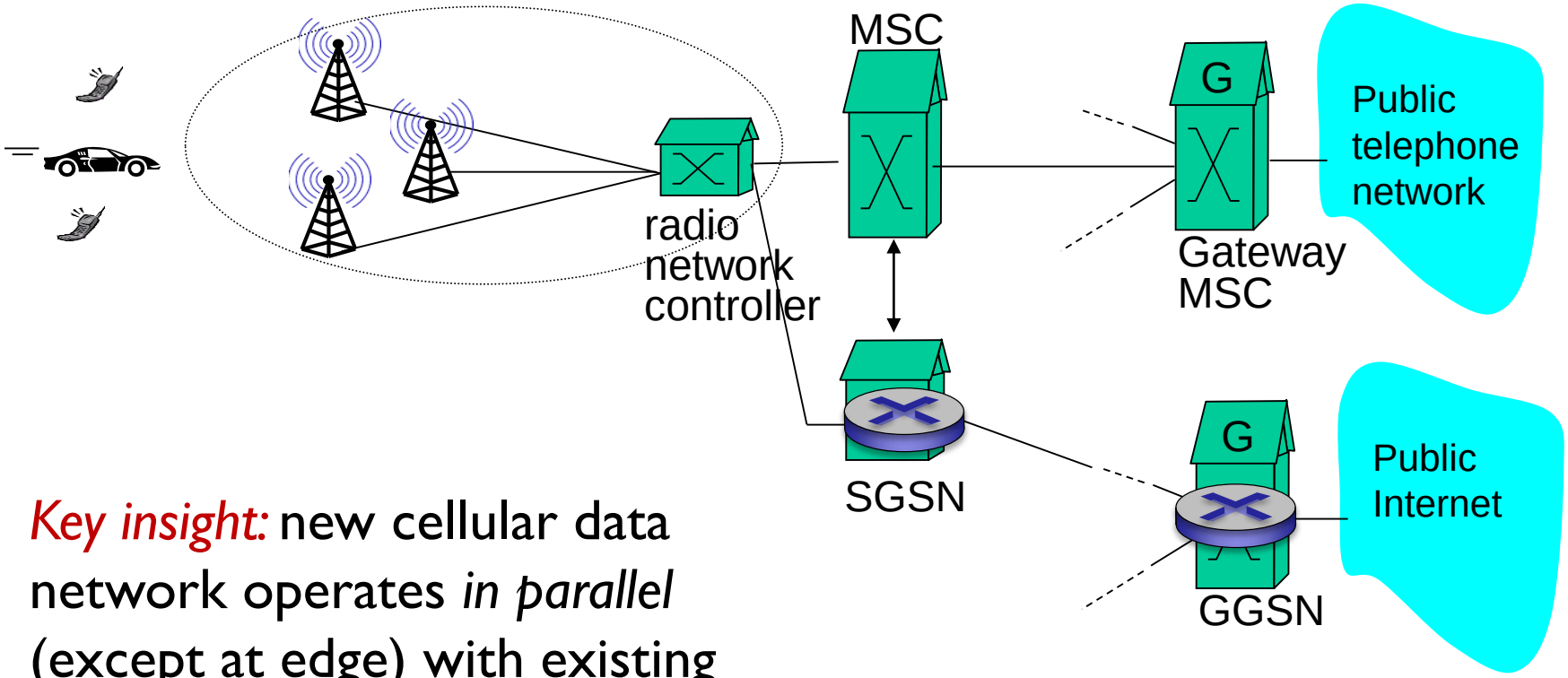
- combined FDMA/TDMA: divide spectrum in frequency channels, divide each channel into time slots
- CDMA: code division multiple access
- SDMA: space division multiple access
- OFDMA-based: orthogonal frequency division



2G (voice) network architecture



3G (voice+data) network architecture



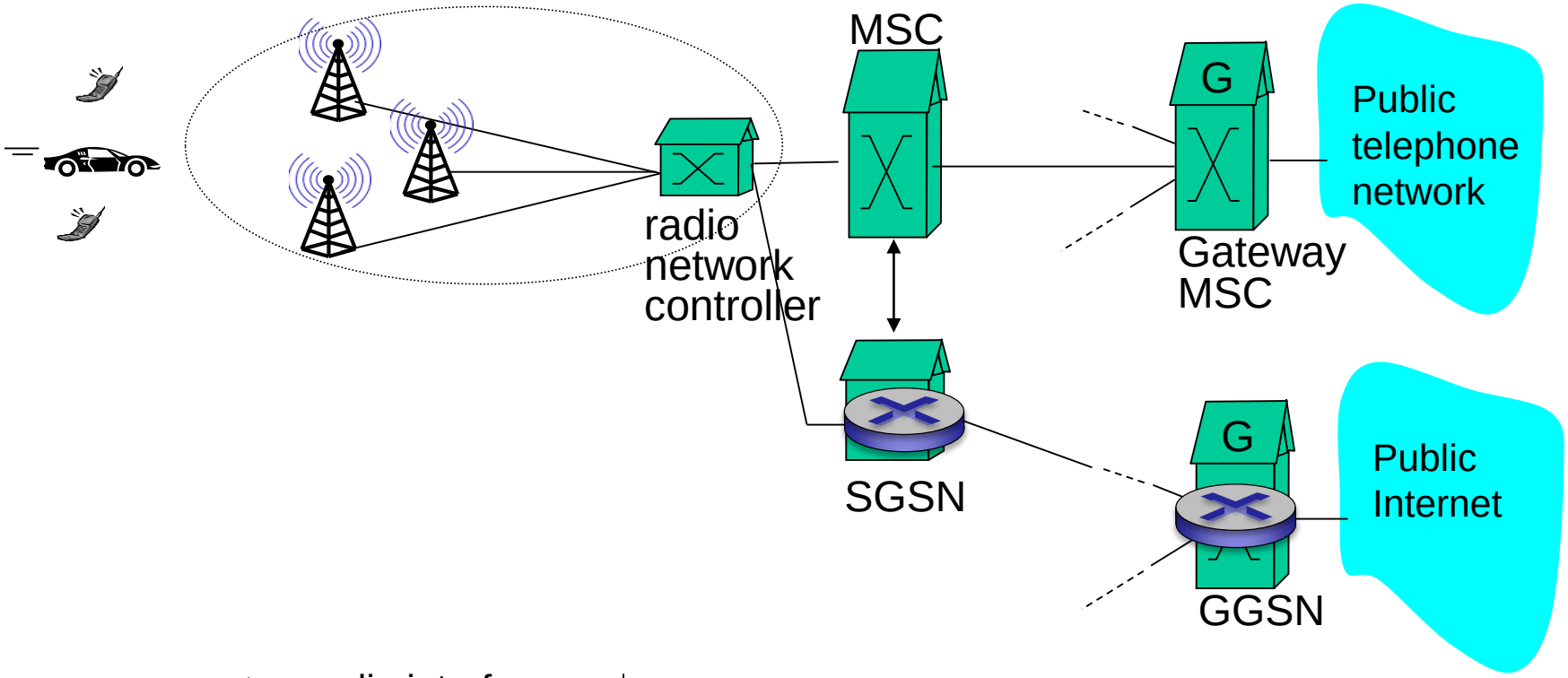
Key insight: new cellular data network operates *in parallel* (except at edge) with existing cellular voice network

- voice network *unchanged* in core
- data network operates in parallel

Serving GPRS Support Node (SGSN)

Gateway GPRS Support Node (GGSN)

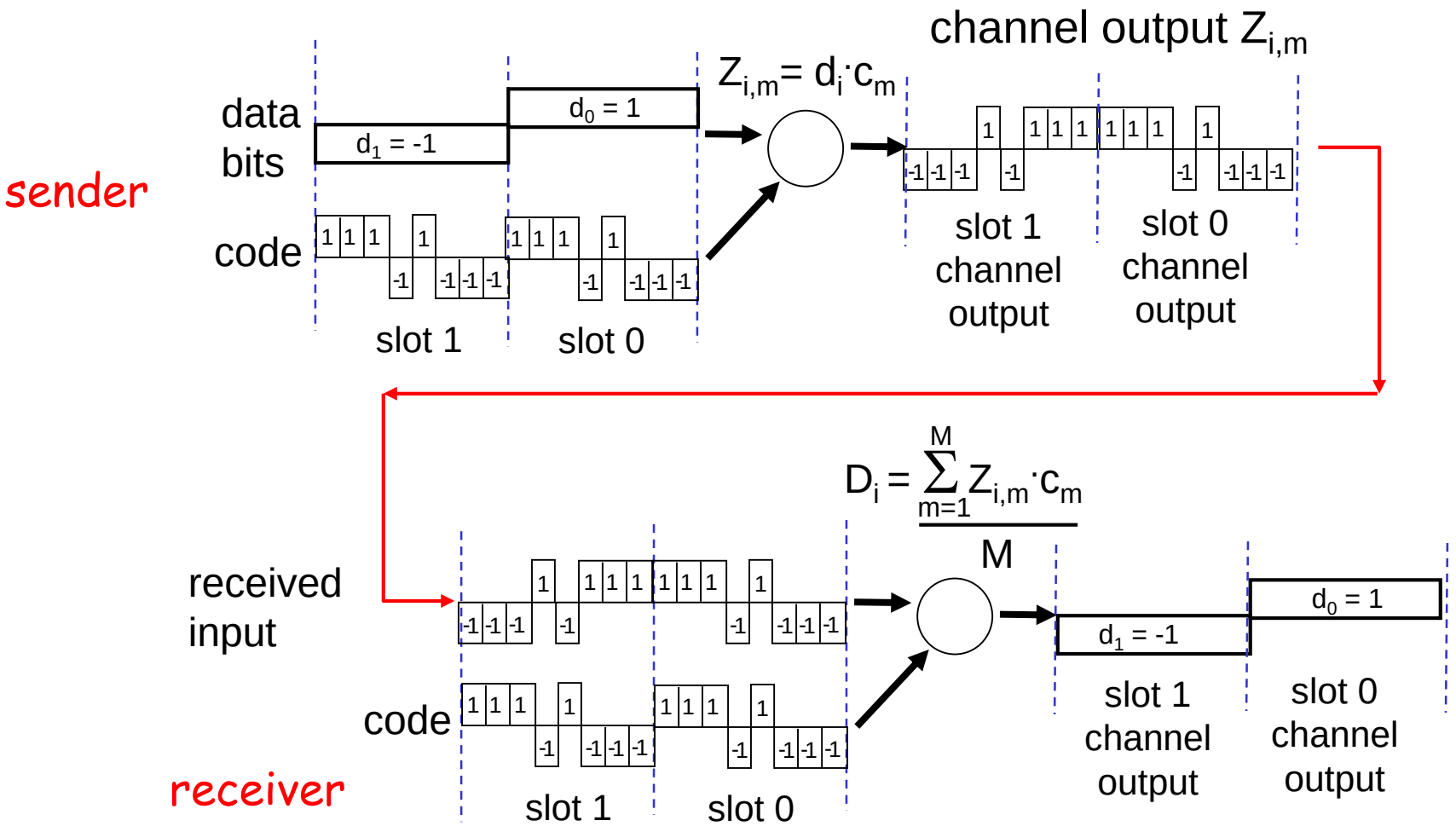
3G (voice+data) network architecture



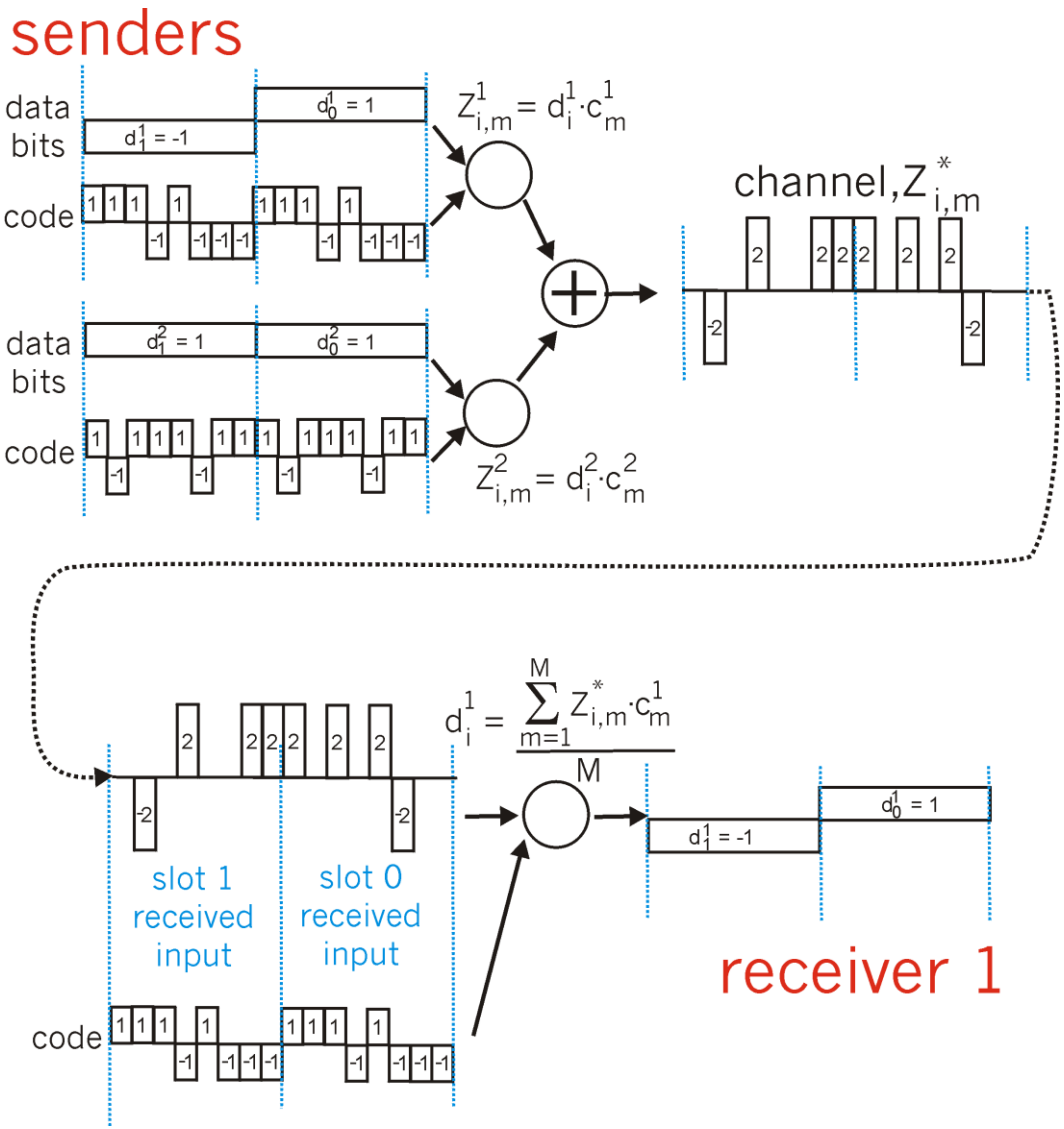
Code Division Multiple Access (CDMA)

- used in several wireless broadcast channels (cellular, satellite, etc) standards
- unique "code" assigned to each user; i.e., code set partitioning
- all users share same frequency, but each user has own "chipping" sequence (i.e., code) to encode data
- *encoded signal* = (original data) X (chipping sequence)
- *decoding:* inner-product of encoded signal and chipping sequence
- allows multiple users to "coexist" and transmit simultaneously with minimal interference (if codes are "orthogonal")

CDMA Encode/Decode



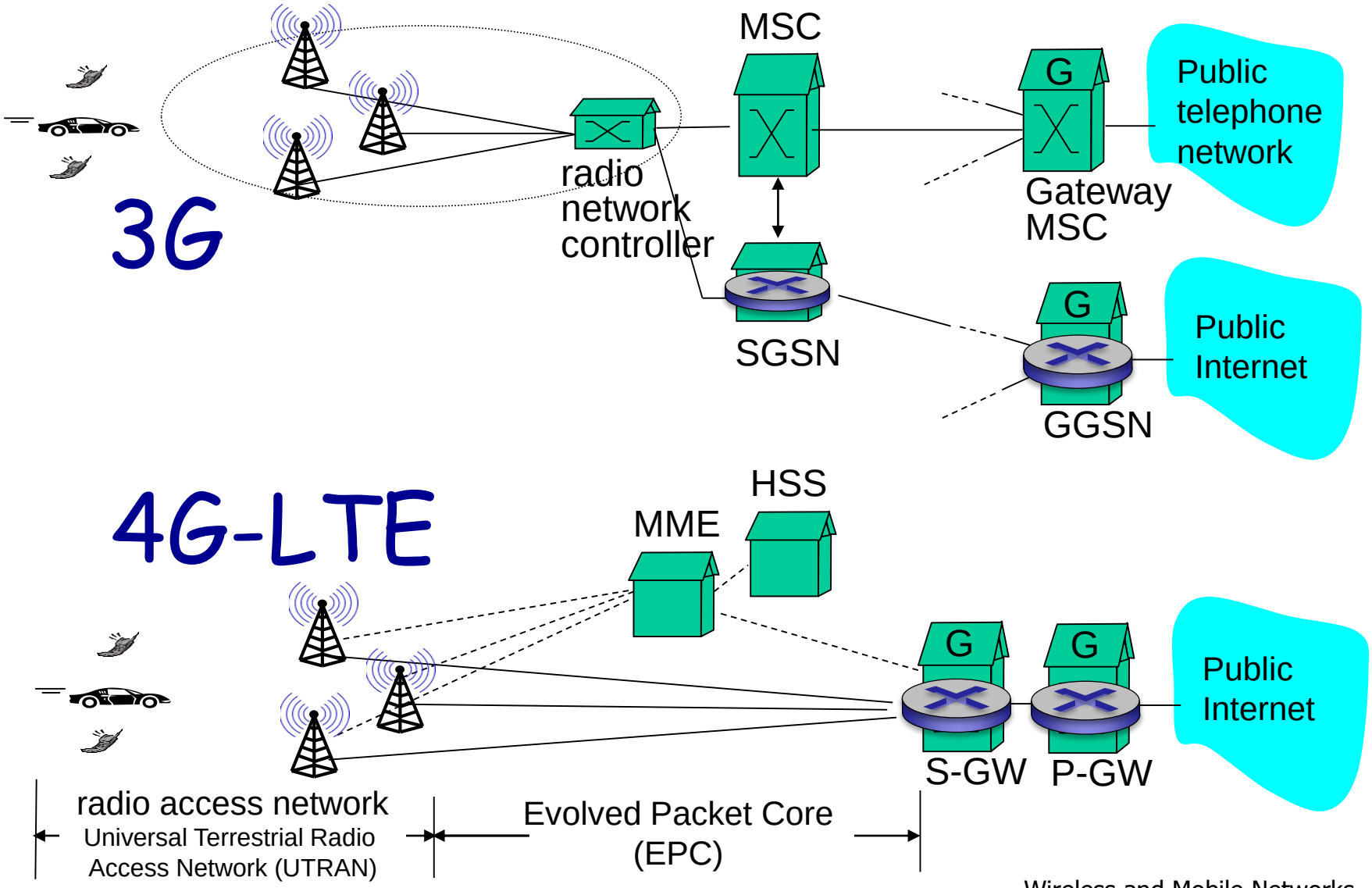
CDMA: two-sender interference



Practical chipping codes …

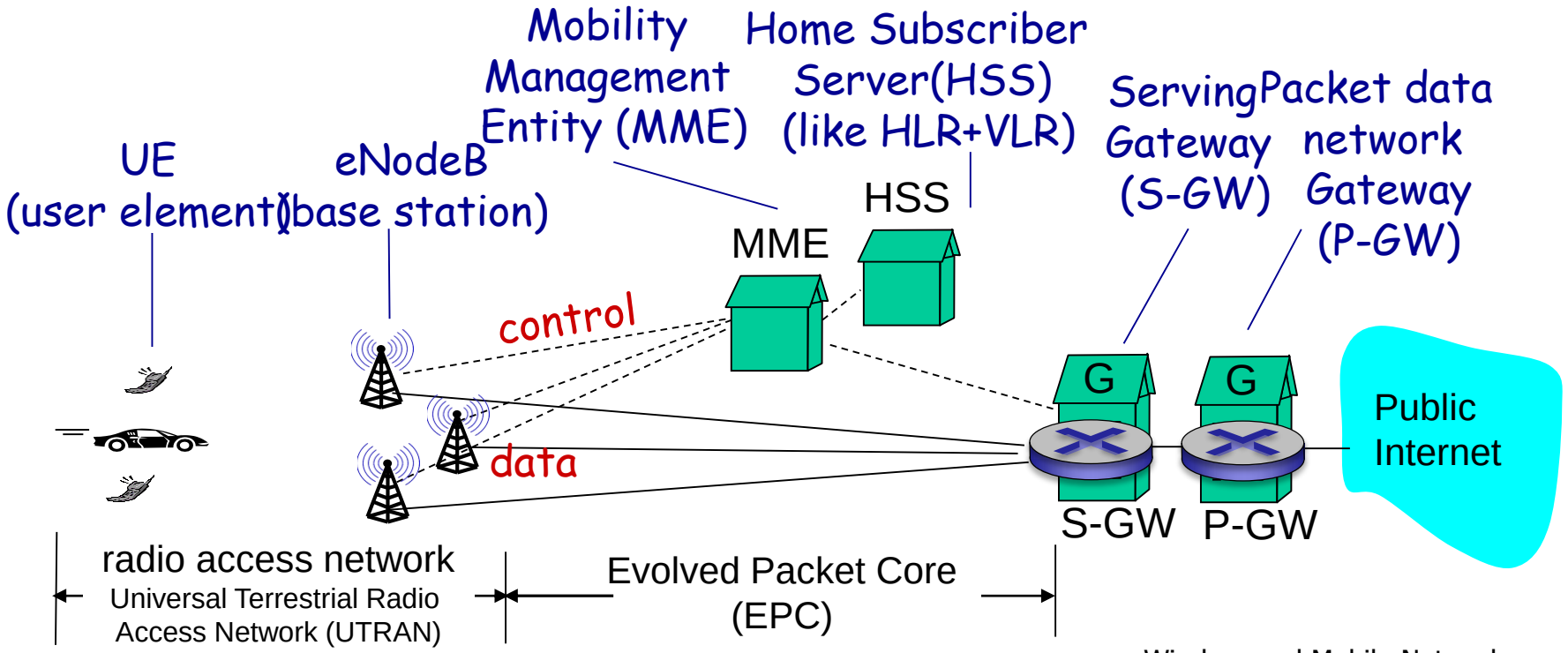
- Orthogonal even under offset?
  - No synchronization …
  - Random sequence; high probability low cross-correlation
- Different chip lengths?
  - different rates, take advantage of silence, more calls

3G versus 4G LTE network architecture



4G: differences from 3G

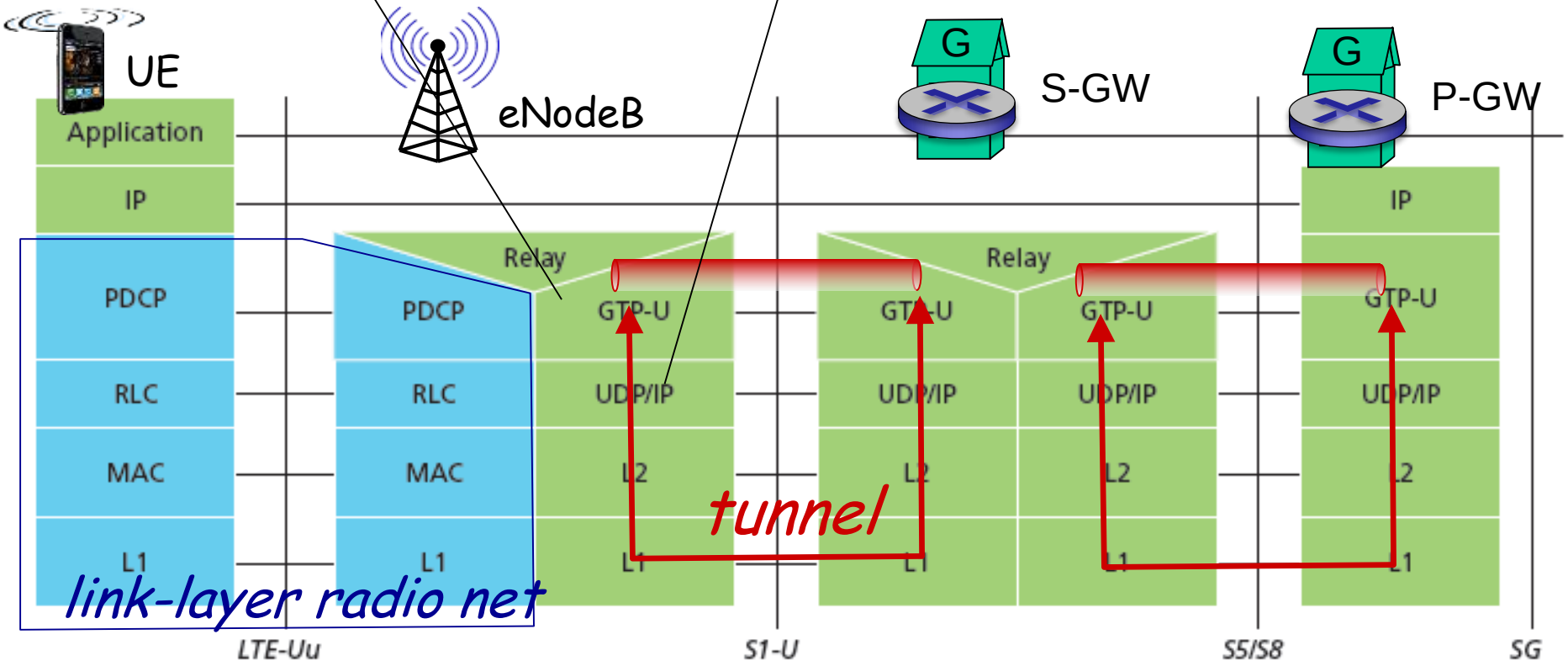
- all IP core: IP packets tunneled (through core IP network) from base station to gateway
- no separation between voice and data – all traffic carried over IP core to gateway



Radio+Tunneling: UE – eNodeB – PGW

IP packet from UE encapsulated in GPRS Tunneling Protocol (GTP) message at ENodeB

GTP message encapsulated in UDP, then encapsulated in IP. large IP packet addressed to SGW

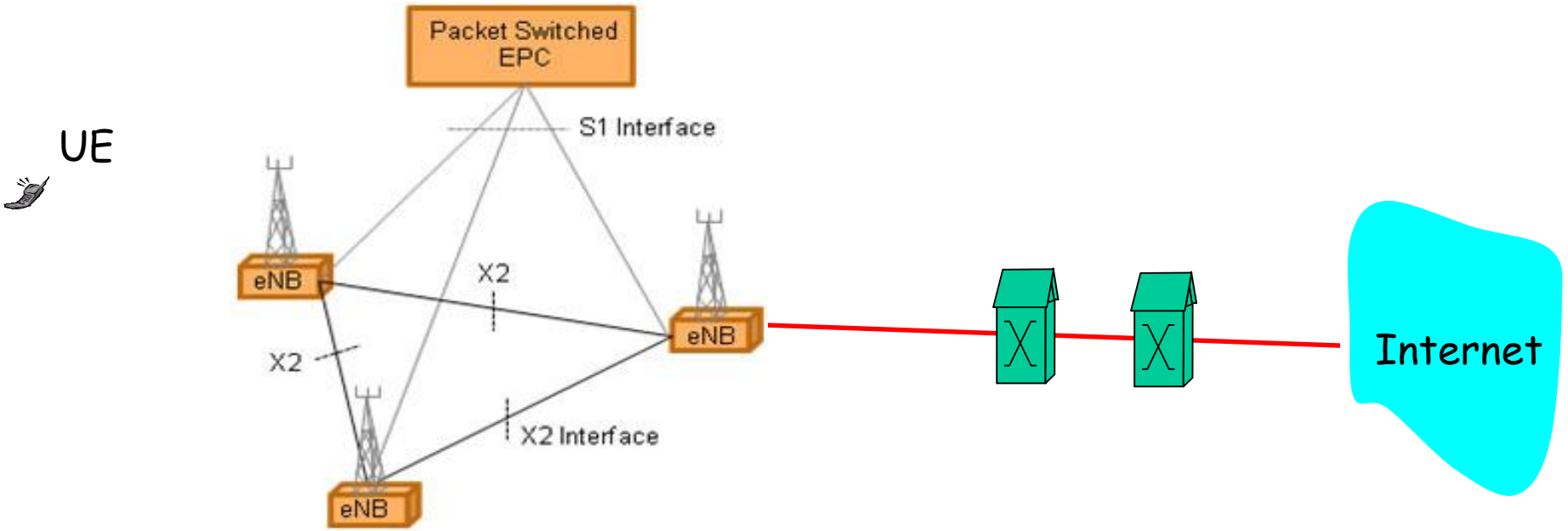


Quality of Service in LTE

- QoS from eNodeB to SGW: min and max guaranteed bit rate
- QoS in radio access network: one of 12 QCI values

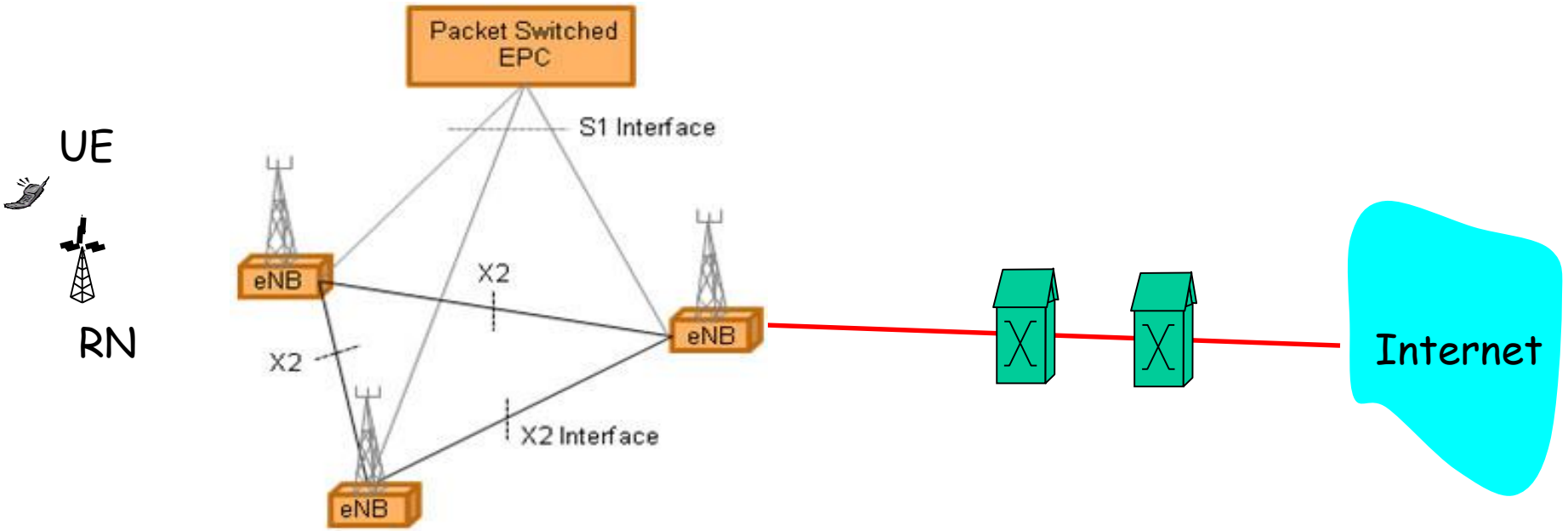
QCI	RESOURCE TYPE	PRIORITY	PACKET DELAY BUDGET (MS)	PACKET ERROR LOSS RATE	EXAMPLE SERVICES
1	GBR	2	100	10^{-2}	Conversational voice
2	GBR	4	150	10^{-3}	Conversational video (live streaming)
3	GBR	5	300	10^{-6}	Non-conversational video (buffered streaming)
4	GBR	3	50	10^{-3}	Real-time gaming
5	Non-GBR	1	100	10^{-6}	IMS signaling
6	Non-GBR	7	100	10^{-3}	Voice, video (live streaming), interactive gaming
7	Non-GBR	6	300	10^{-6}	Video (buffered streaming)
8	Non-GBR	8	300	10^{-6}	TCP-based (for example, WWW, e-mail), chat, FTP, p2p file sharing, progressive video and others
9	Non-GBR	9	300	10^{-6}	

LTE and LTE-Advanced



- ITU, IMT-advanced, 3GPP, and LTE-Advanced ...
- All traffic is IP-based
- Base station called enhanced NodeB, eNodeB or eNB

LTE and LTE-Advanced



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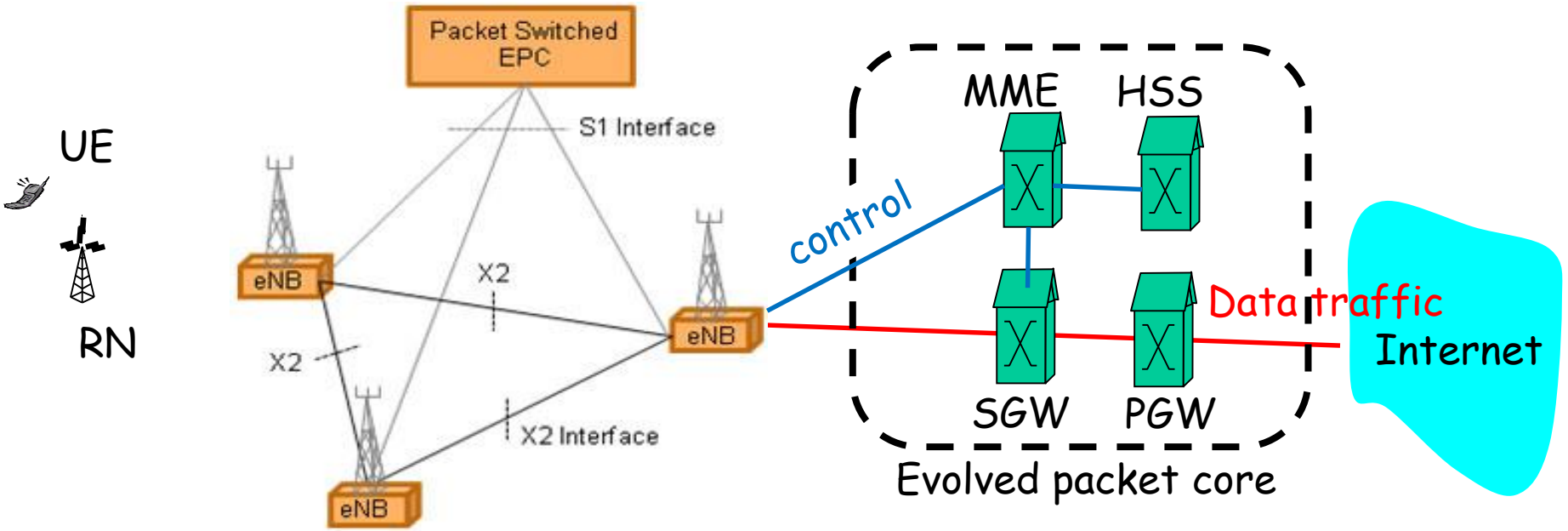
LTE and LTE-Advanced



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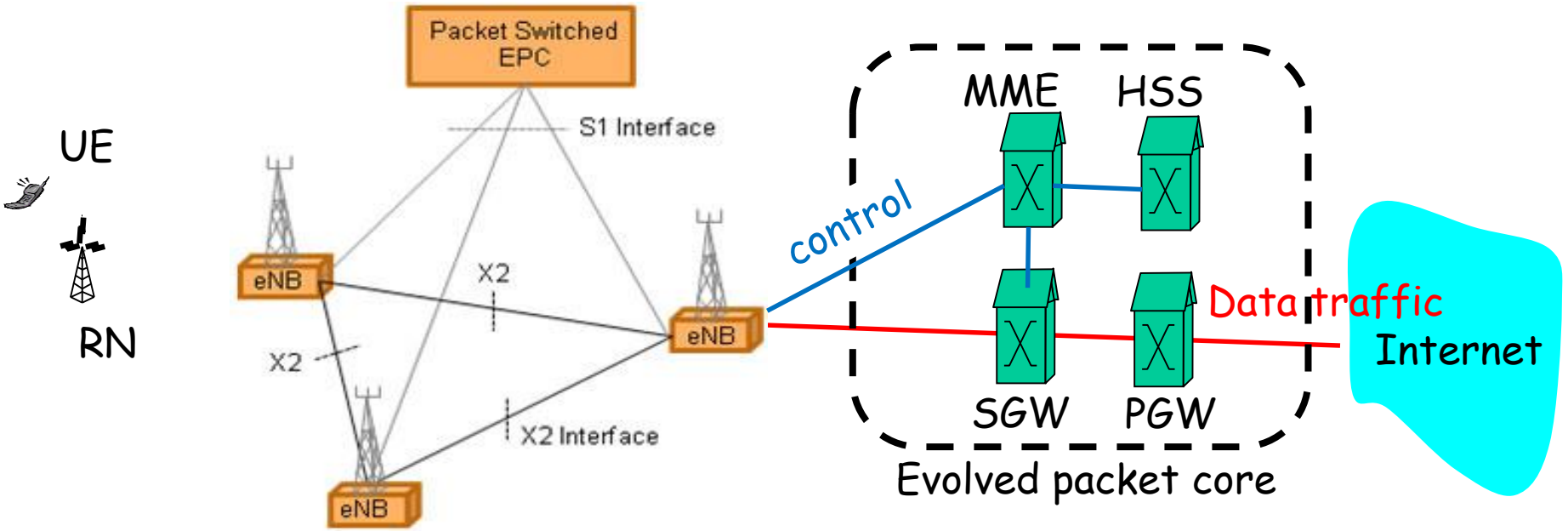
LTE and LTE-Advanced



- ITU, IMT-advanced, 3GPP, and LTE-Advanced ...
- All traffic is IP-based
- Base station called enhanced NodeB, eNodeB or eNB
- Downlink (OFDMA) vs uplink (SC-OFDM)

LTE downlink (OFDMA-based)

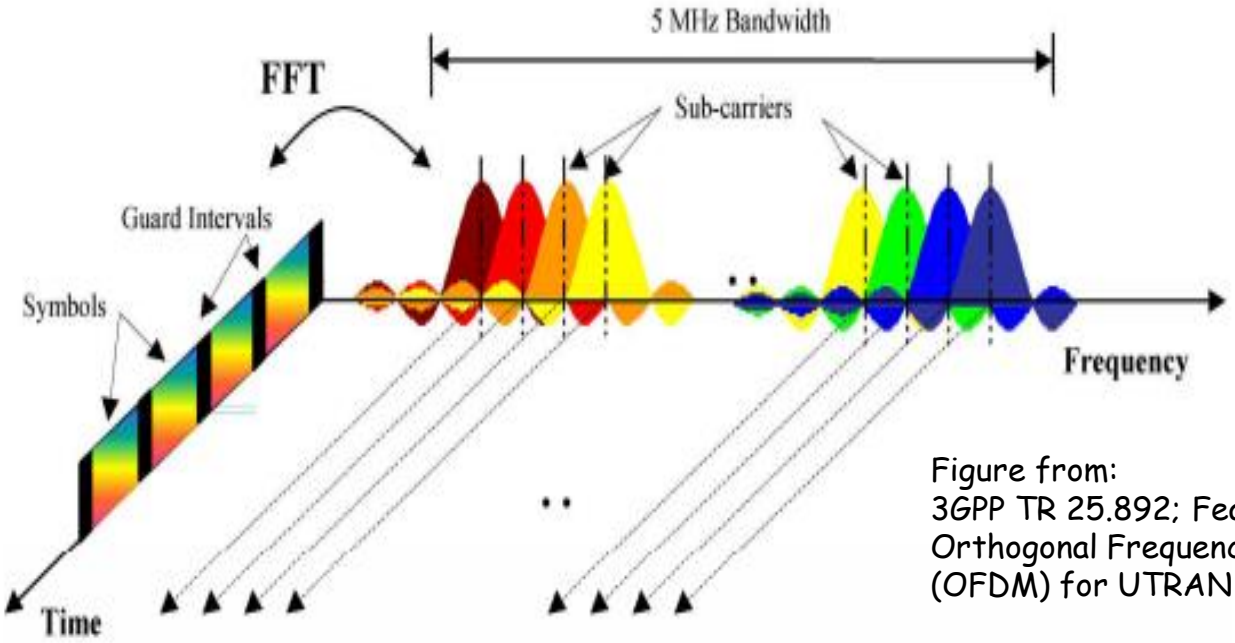


Figure from:
3GPP TR 25.892; Feasibility Study for Orthogonal Frequency Division Multiplexing (OFDM) for UTRAN enhancement (Release 6)

- Data symbols are independently modulated and transmitted over a high number of closely spaced orthogonal subcarriers.
- Available modulation schemes for E-UTRA downlink: QPSK, 16QAM, and 64QAM
- OFDM signal is generated using Inverse Fast Fourier Transform (IFFT) digital signal processing

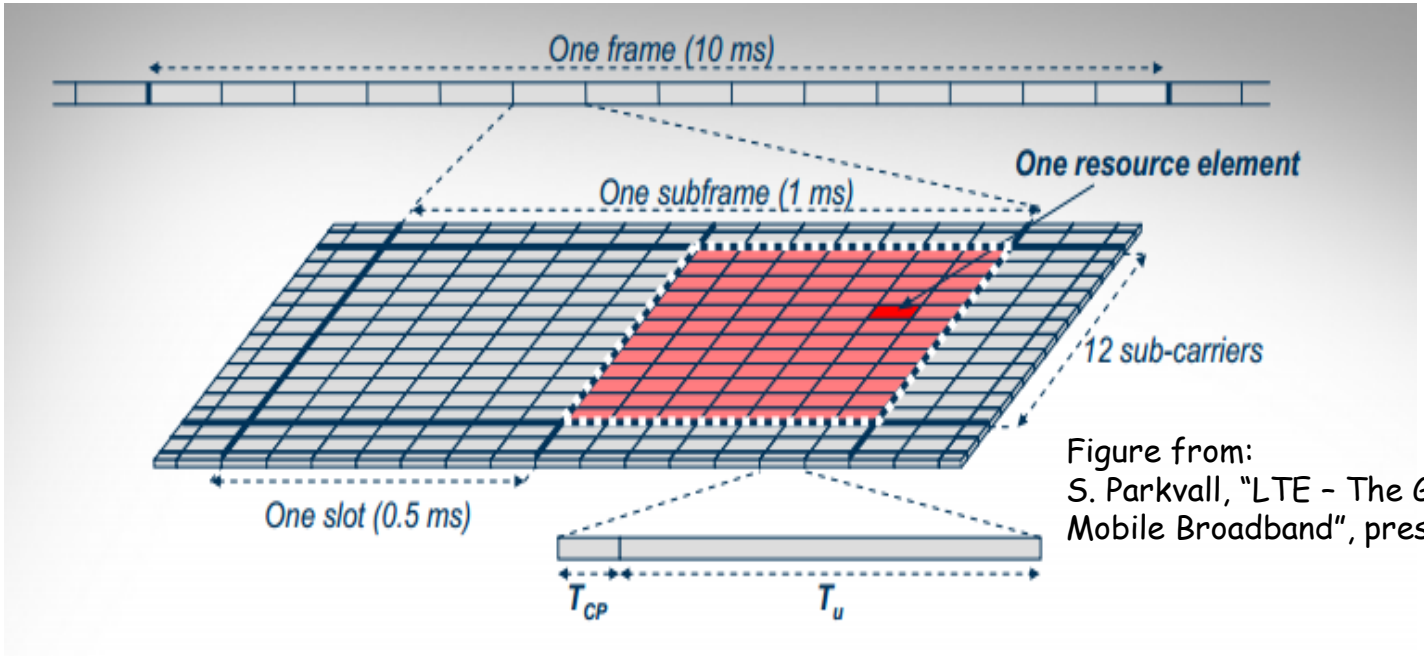
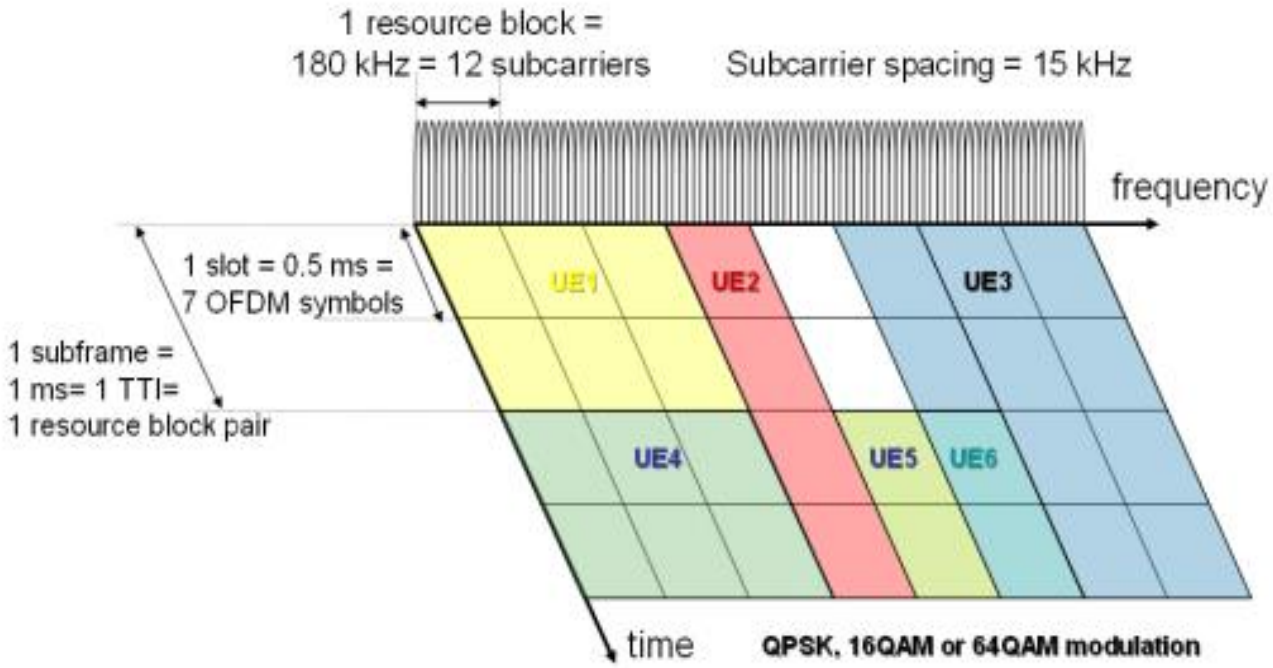


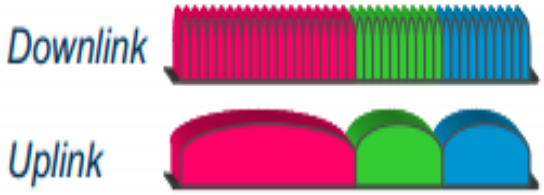
Figure from:
S. Parkvall, "LTE – The Global Standard for Mobile Broadband", presentation, Ericsson Research

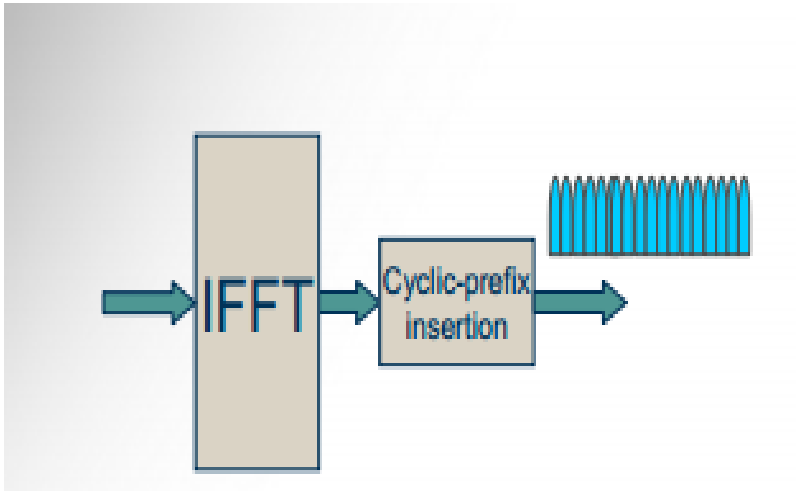
- Time domain structure:
  - 10 ms frame consisting of 10 subframes of length 1 ms
  - Each subframe consists of 2 slots of length 0.5 ms
  - Each slot consists of 7 OFDM symbols (6 symbols in case of extended CP)
- Resource element (RE)
  - One subcarrier during one OFDM symbol
- Resource block (RB)
  - 12 subcarriers during one slot (180 kHz × 0.5 ms)

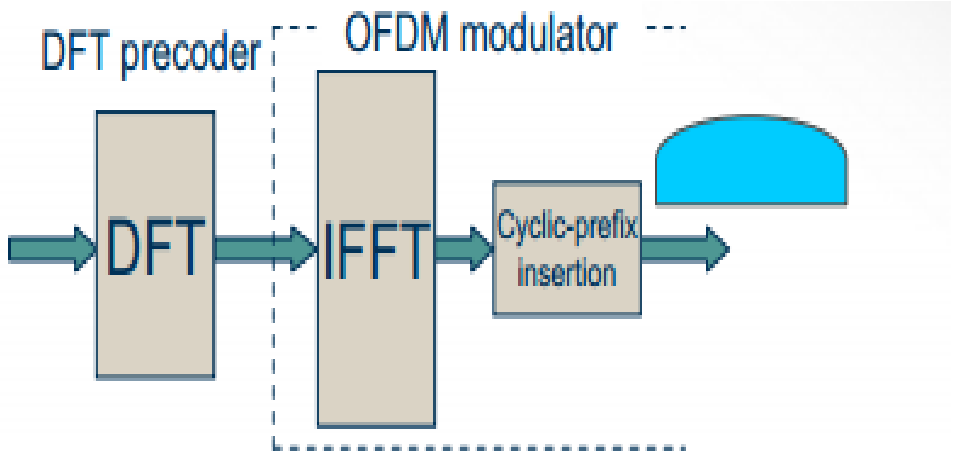


- Scheduling decisions done in the base station
- Scheduling algorithm is a vendor-specific, but typically takes into account
  - Radio link quality situation of different users
  - Overall interference situation
  - Quality of Service requirements
  - Service priorities, etc.

Downlink vs uplink







- Parallel transmission on large number of narrowband subcarriers
- Avoids own-cell interference
- Robust to time dispersion
- Bad power-amplifier efficiency

- Single carrier properties
- Better battery lifetime at phones/sender (reduced power-amplifier power)
- More complexity at receiver (equalizer needed)
- Lower throughput

Current LTE status

- OLD reference numbers: GSA Fast Facts based on their "Evolution to LTE Report" (updated September 2014):
  - 526 operators are investing in LTE in 156 countries
  - Over 21% of operators are deploying LTE-Advanced technologies. 16 operators have commercially launched LTE-Advanced systems.
  - 66 operators in 35 countries are investing in VoLTE studies, trials, deployments
  - 10 operators have commercially launched HD voice service using VoLTE
  - GSA forecasts there will be at least 350 commercially launched LTE networks by end 2014

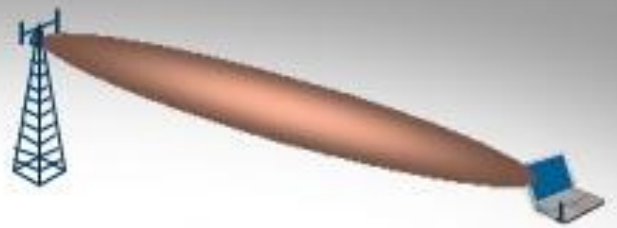
  Have a look at 2016 numbers …. (e.g., wiki suggest that 14% -> 78% in Sweden between 2013 and 2015)

- More material later … (e.g., eMBMS and MIMO)

Multi-antenna (*slide from Ericsson)

Multi-Antenna Transmission Techniques

Diversity for improved system peformance



Beam-forming for improved coverage (less cells to cover a given area)

SDMA for improved capacity (more users per cell)

Multi-layer transmisson ("MIMO") for higher data rates in a given bandwidth

The multi-antenna technique to use depends on what to achieve

Evolved Multimedia Broadcast/Multicast Service (eMBMS) in LTE-advanced

Evolved Multimedia Broadcast/Multicast Service (eMBMS) in LTE-advanced

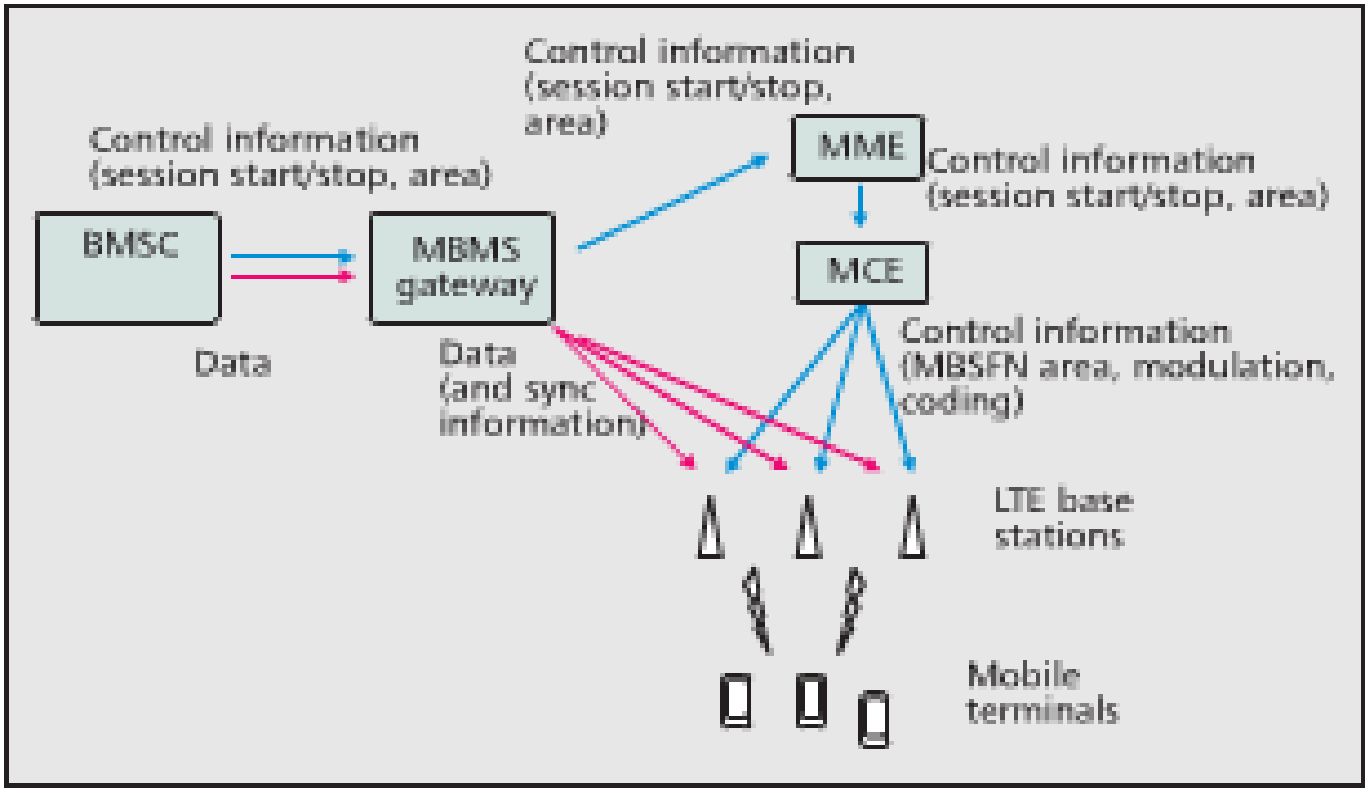


Figure 4. *RAN architecture for SFN across LTE base stations.*

- Separation of control plane and data plane

Image from: Lecompte and Gabin, Evolved Multimedia Broadcast/Multicast Service (eMBMS) in LTE-Advanced: Overview and Rel-11 Enhancements, IEEE Communications Magazine, Nov. 2012.

Evolved Multimedia Broadcast/Multicast Service (eMBMS) in LTE-advanced

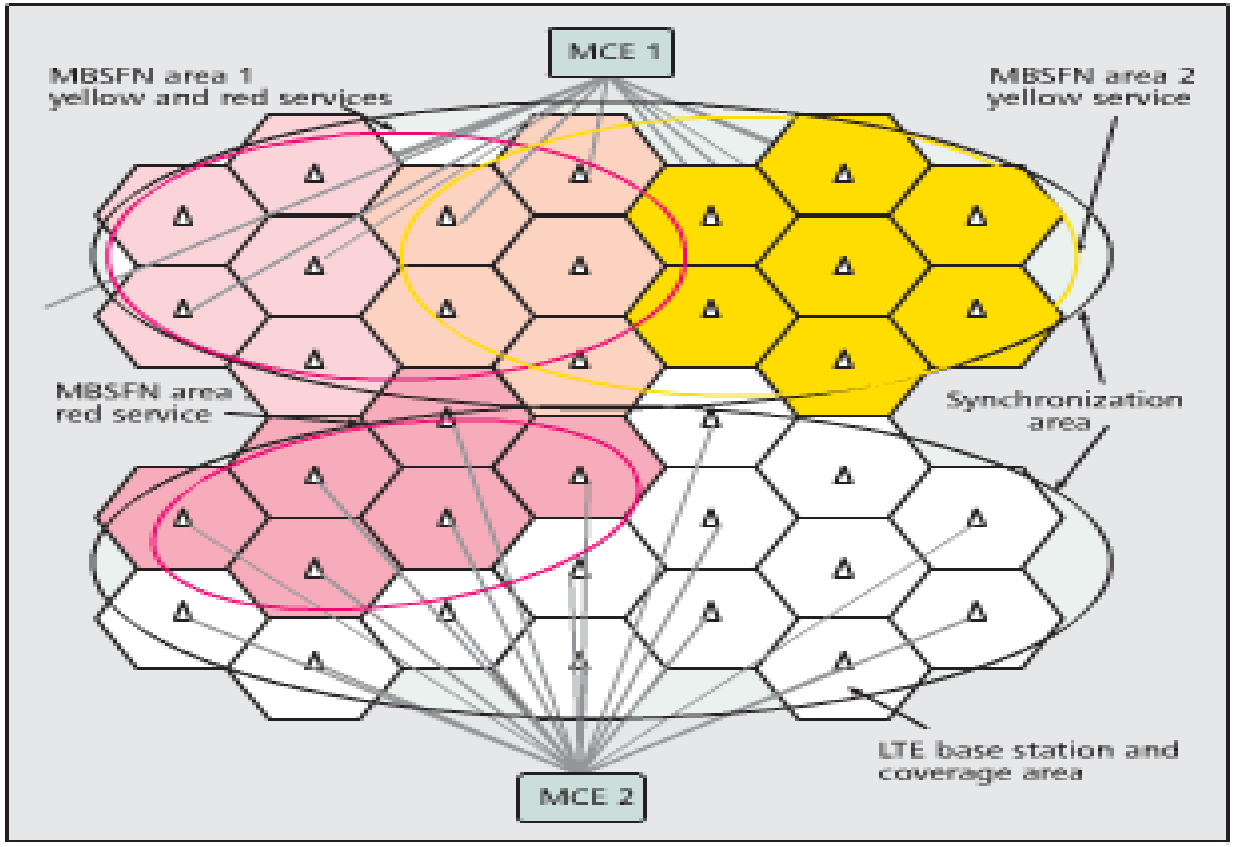


Figure 5. *Example with two MBMS services with different services areas.*

- MBMSFN and use of services areas

Image from: Lecompte and Gabin, Evolved Multimedia Broadcast/Multicast Service (eMBMS) in LTE-Advanced: Overview and Rel-11 Enhancements, IEEE Communications Magazine, Nov. 2012.

More slides …

Functional split of major LTE components