Beyond 3G Wireless Technologies

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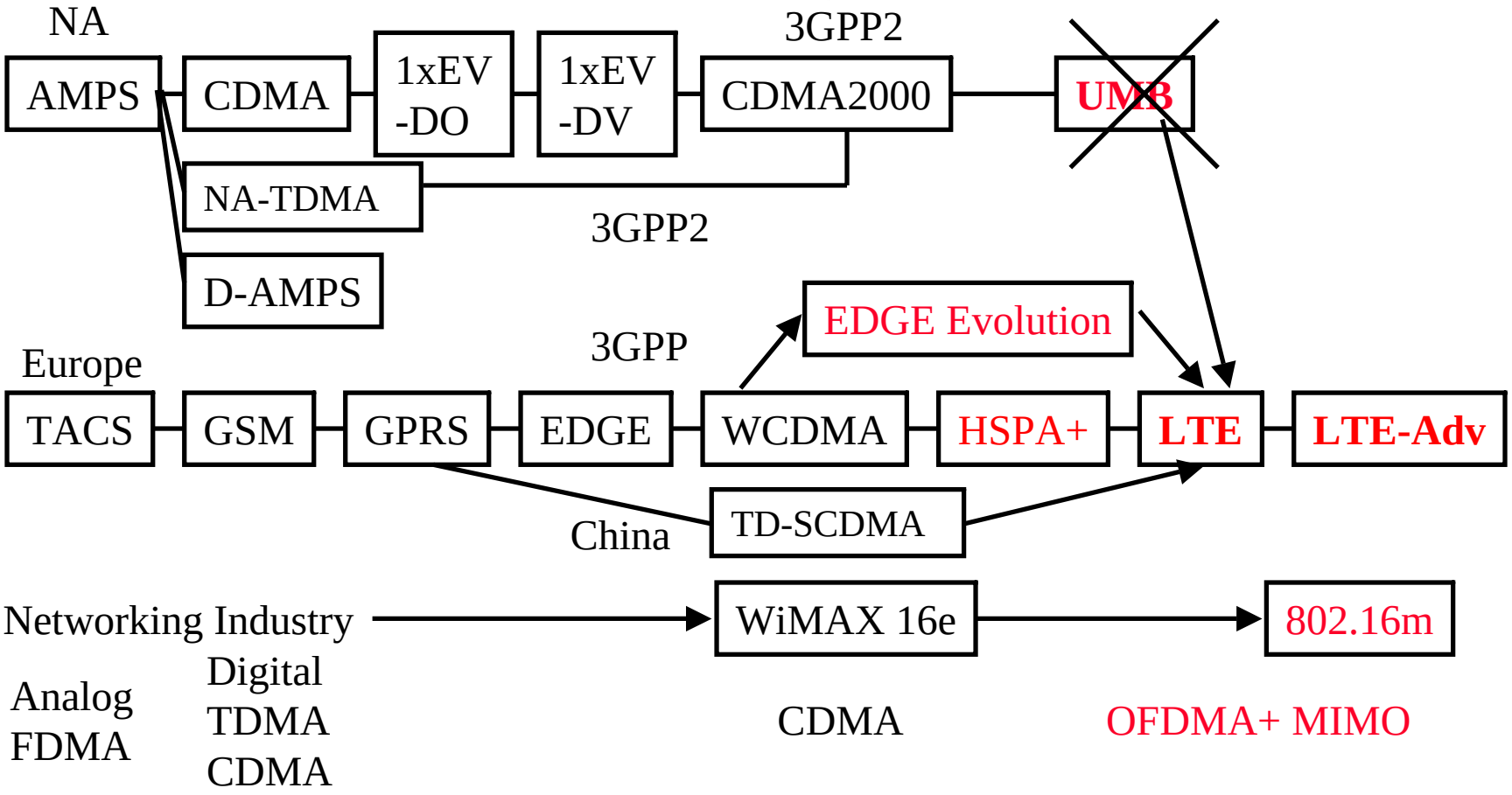
Audio/Video recordings of this lecture are available at:

http://www.cse.wustl.edu/~jain/cse574-10/

Overview

- Cellular Telephony Generations
- 3G+: HSDPA, HSUPA, MBMS, HSPA
- Long Term Evolution (LTE)
- FemtoCells
- 4G: IEEE 802.16m and LTE-Advanced

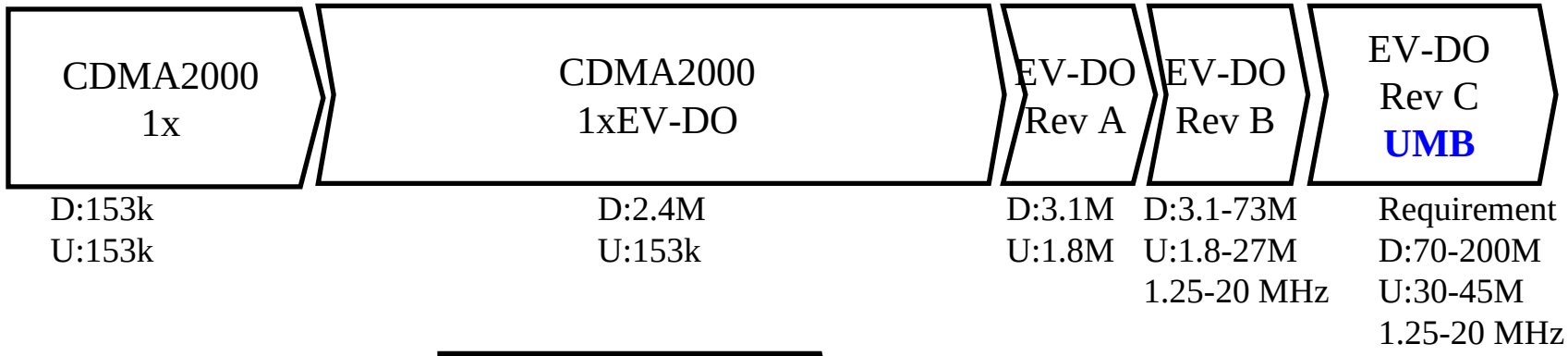
Cellular Telephony Generations



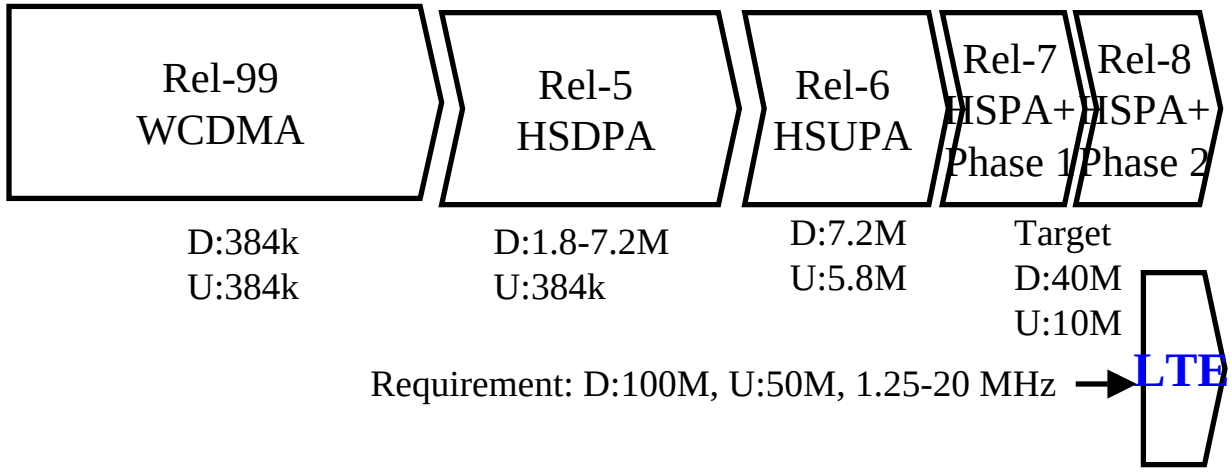
Voice	Voice	Voice+Data	Voice+Data	Voice+HS Data	All-IP
1G	2G	2.5G	3G	3.5G	4G

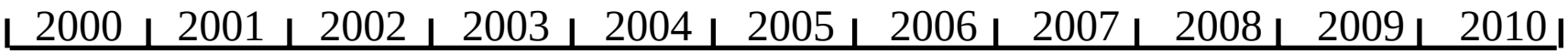
3G Technologies: Bit Rates

CDMA2000 Path (1.25 MH FDD Channel)



WCMDA Path (5 MHz FDD Channel)



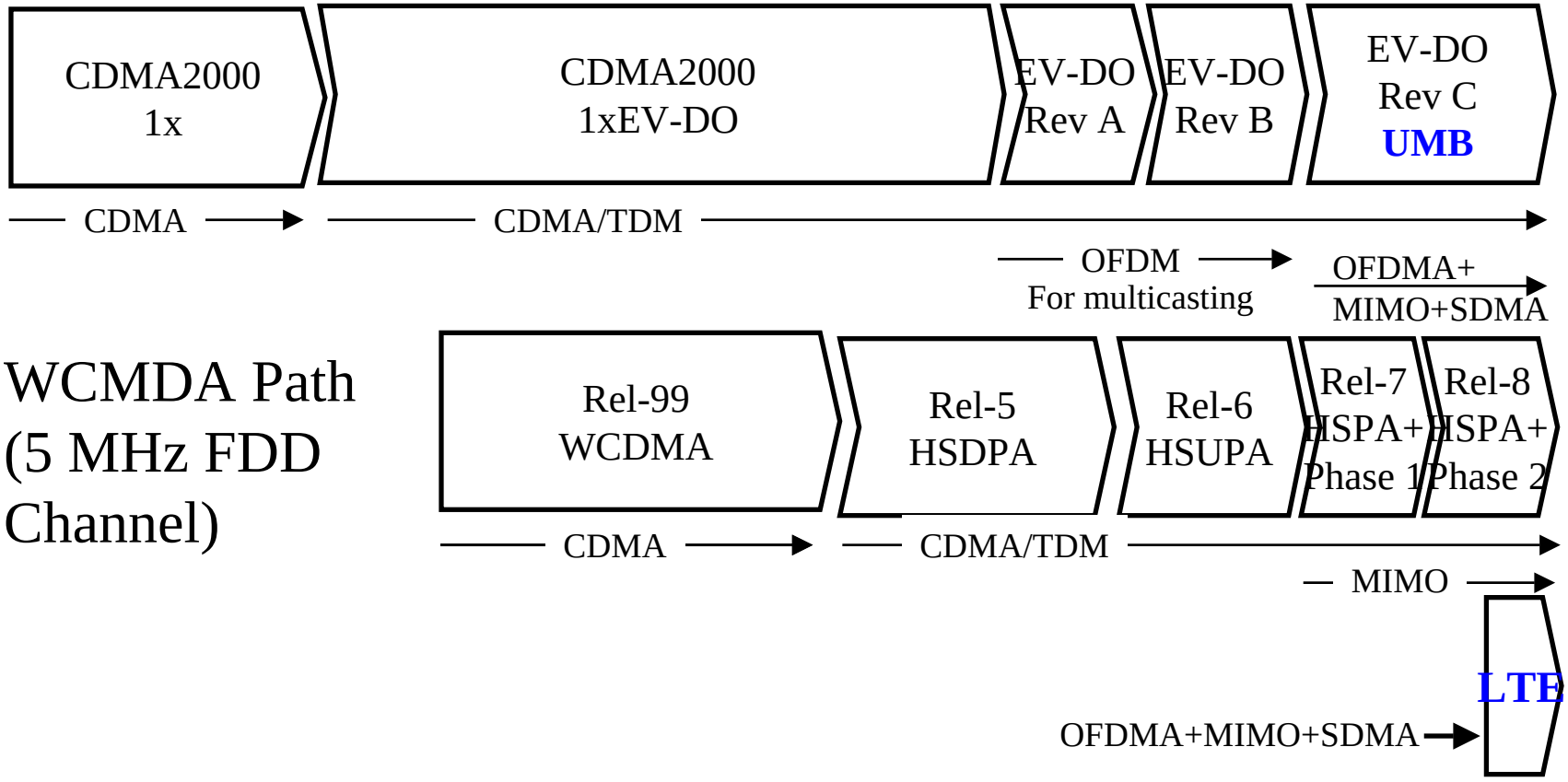


Note: WiMAX is also a 3G Technology now.

Source: www.cdg.org

3G Technologies: PHY

CDMA2000 Path (1.25 MH FDD Channel)



Source: www.cdg.org

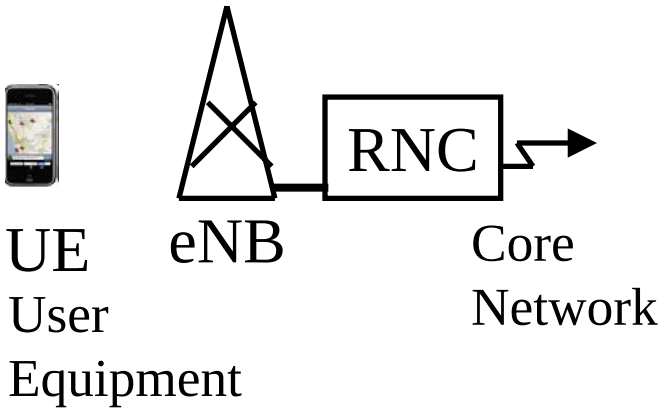
3G Technologies (Cont)

- All data rates are for FDD
  $\Rightarrow$ 20MHz = 2×20 MHz
- On the downlink, LTE uses a modified version of OFDMA called DFT-Spread OFDMA, also known as single-carrier FDMA.
- UMB may utilize a combination of OFDMA and CDMA or OFDM and CDMA (inactive?)
- Data rates depend upon level of mobility

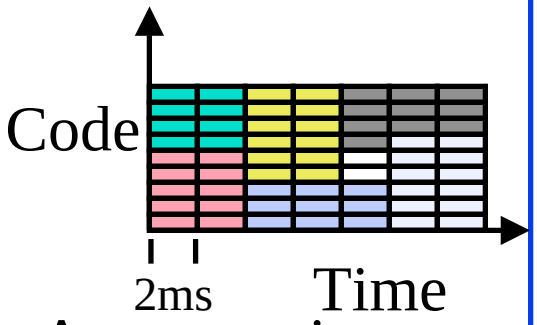
Evolution of UMTS

- UMTS = Universal Mobile Telephone System
  =3GPP standard for W-CDMA
- =UTRA (UMTS Access Network)
  + UTRAN (UMTS Terrestrial Radio Access Network)
- Evolution of UMTS Standards:

Release	Date	Features
Rel-99	3/2000	WCDMA
Rel-4	3/2001	TD-SCDMA
Rel-5	6/2002	HSDPA
Rel-6	3/2005	HSUPA
Rel-7	12/2007	HSPA+
Rel-8	12/2008	LTE, SAE



HSDPA



- High-Speed Downlink Packet Access for W-CDMA
- Improved spectral efficiency for downlink ⇒ Asymmetric
- Up to 10 Mbps in theory, 2Mbps+ in practice
- Adaptive modulation and coding (AMC)
  Channel dependent scheduling
- High-order modulations, e.g., 16QAM
- Multi-code (multiple CDMA channels) transmission
- 15 of 16 codes assigned for HSDPA
- Shared channel transmission (many users share the codes).
  Extension to WCDMA which uses dedicated user channels.
- 2ms Transmission time interval (TTI)

HSDPA (Cont)

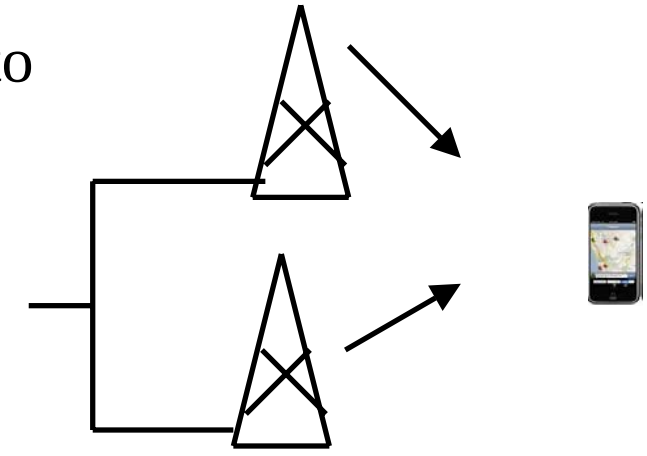
- Fast physical layer (L1) hybrid ARQ (H-ARQ)
- Packet scheduler moved from the radio network controller (RNC) to the Node-B (base station)
  $\Rightarrow$ advanced packet scheduling techniques
  $\Rightarrow$ user data rate can be adjusted to match the instantaneous radio channel conditions.

HSUPA

- Uplink difficult since multiple transmitters
- Fast power control essential
- Scheduler in NodeB but data in UE ⇒ Need to send requests
- A single user cannot utilize all codes ⇒ Parallel transmissions in each TTI
- Fast HARQ

MBMS

- Multimedia Broadcast Multicast Services
- Mobile TV
- All NodeB in an "MBMS service area" transmit the broadcast. Cells are time synchronized.
- Any user can receive "Broadcast" Users are not tracked
- For multicast, users need to subscribe to multicast group
- NodeB tracks the users and directs signal accordingly
  $\Rightarrow$ Could be unicast if one user



HSPA

- HSDPA+HSUPA
- Up to 64QAM in downlink and 16QAM in uplink in Rel 7
- 64QAM and MIMO in downlink in Rel 8
- Smaller Transmission time interval (TTI) of 2ms
- Fast UL datarate control in the NodeB
- Improved PHY performance through H-ARQ
- Dedicated resource allocation for latency sensitive applications
- Multiplexing of logical channels at MAC layer (instead of PHY layer) $\Rightarrow$ Sharing
- Fast mechanisms to request UL resources

Long Term Evolution (LTE)

- Evolution of UMTS: E-UTRA + E-UTRAN
- E-UTRA = LTE
- E-UTRAN = Evolved packet core (EPC)
- E-UTRA+E-UTRA = Evolved packet system (EPS)
- EPC =All-IP packet core=System Architecture Evolution (SAE)
  $\Rightarrow$ Voice also packet switched (VOIP)
- Designed for trial and deployments in 2010

1. Frequency domain equalization: OFDMA
2. MIMO
3. Channel dependent scheduling
4. Dynamic Channel Allocation

LTE Goals

- Downlink rates of 100 Mbps using 64QAM SISO on 2x20 MHz. 326.4 Mbps using 4x4 MIMO
- Uplink rates of 50-86.4 Mbps using SISO
- Scalable channel bandwidths of 1.4, 3.0, 5, 10, 20 MHz X2
- Multiple frequency bands: 700 MHz, 900 MHz, 1800…
- Sub 5ms latency for IP packets
- 0-15 km/hr optimized, 15-120 km/hr high performance, 120-350 km/hr supported
- Compatibility with other cellular standards (using multimode devices)

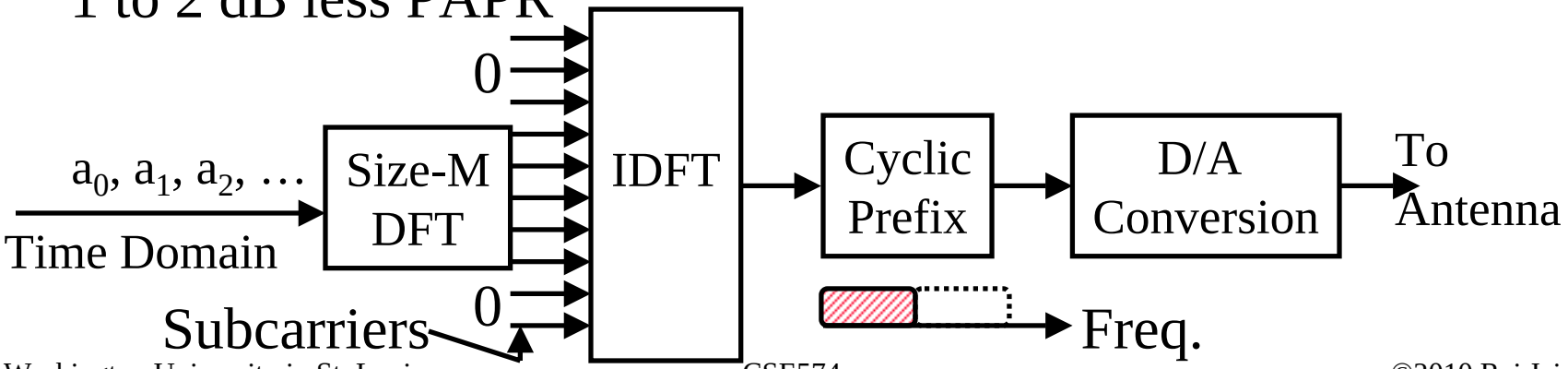
CDMA vs. OFDMA

- LTE uses OFDMA in the downlink

Feature	CDMA	OFDMA
Frequency Selective	No	Yes
Symbol period	Short	Long
Equalization	Easy up to 5 MHz	Easy for any bandwidth
Resistance to Multipath	Difficult above 5 MHz	East with proper cyclic prefix
MIMO	Difficult	Easy
Frequency Distortion	Averaged	Inter-carrier interference
User Multiplexing	Orthogonal codes	Frequency and Time

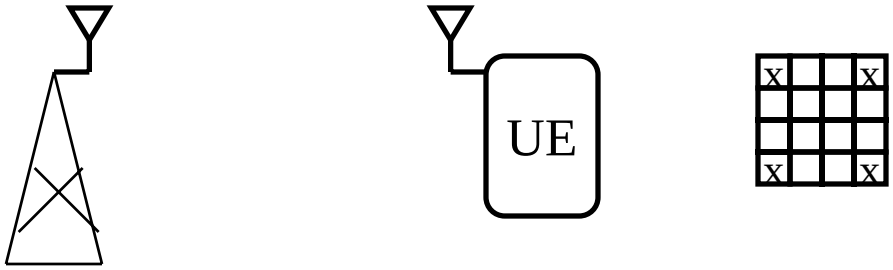
Single-Carrier FDMA

- OFDM
  - ⇒ Each carrier modulated according to specific channel condition
  - ⇒ High variation of power levels
  - ⇒ Higher Peak-to-Average Power Ratio (PAPR)
  - ⇒ Higher cost of amplifiers
- **DFT-Precoded OFDM**:
  MxM DFT is used before NxN IDFT, where M<N
  - ⇒ Results in a waveform that is similar to single carrier
  - 1 to 2 dB less PAPR



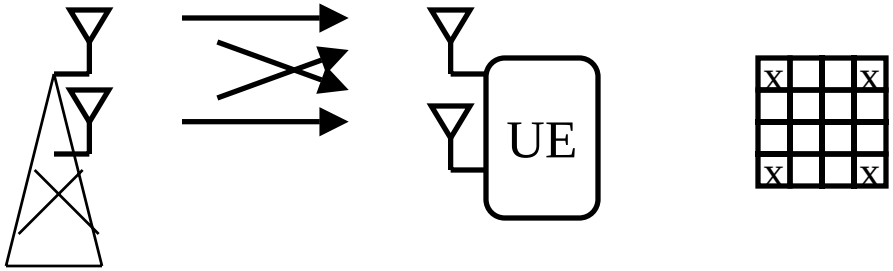
MIMO

- SISO



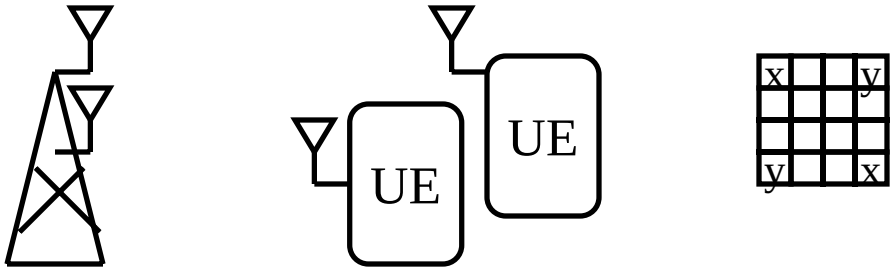
x=Pilot

- Single User MIMO



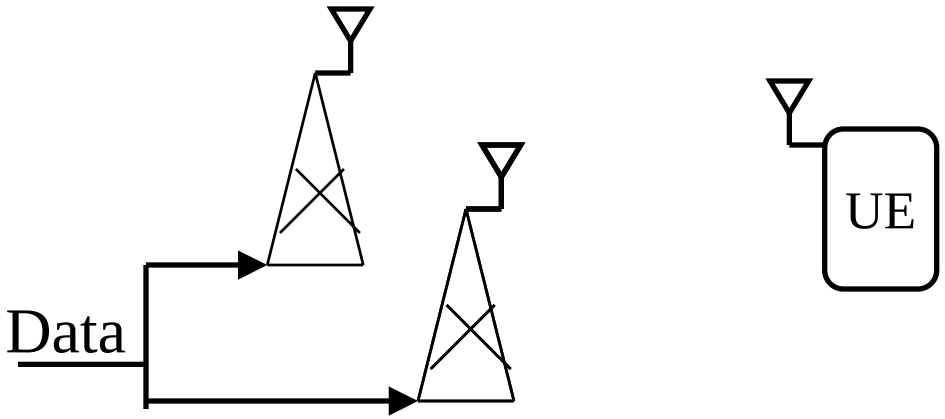
Pilots are used for channel estimation

- Multi-User MIMO

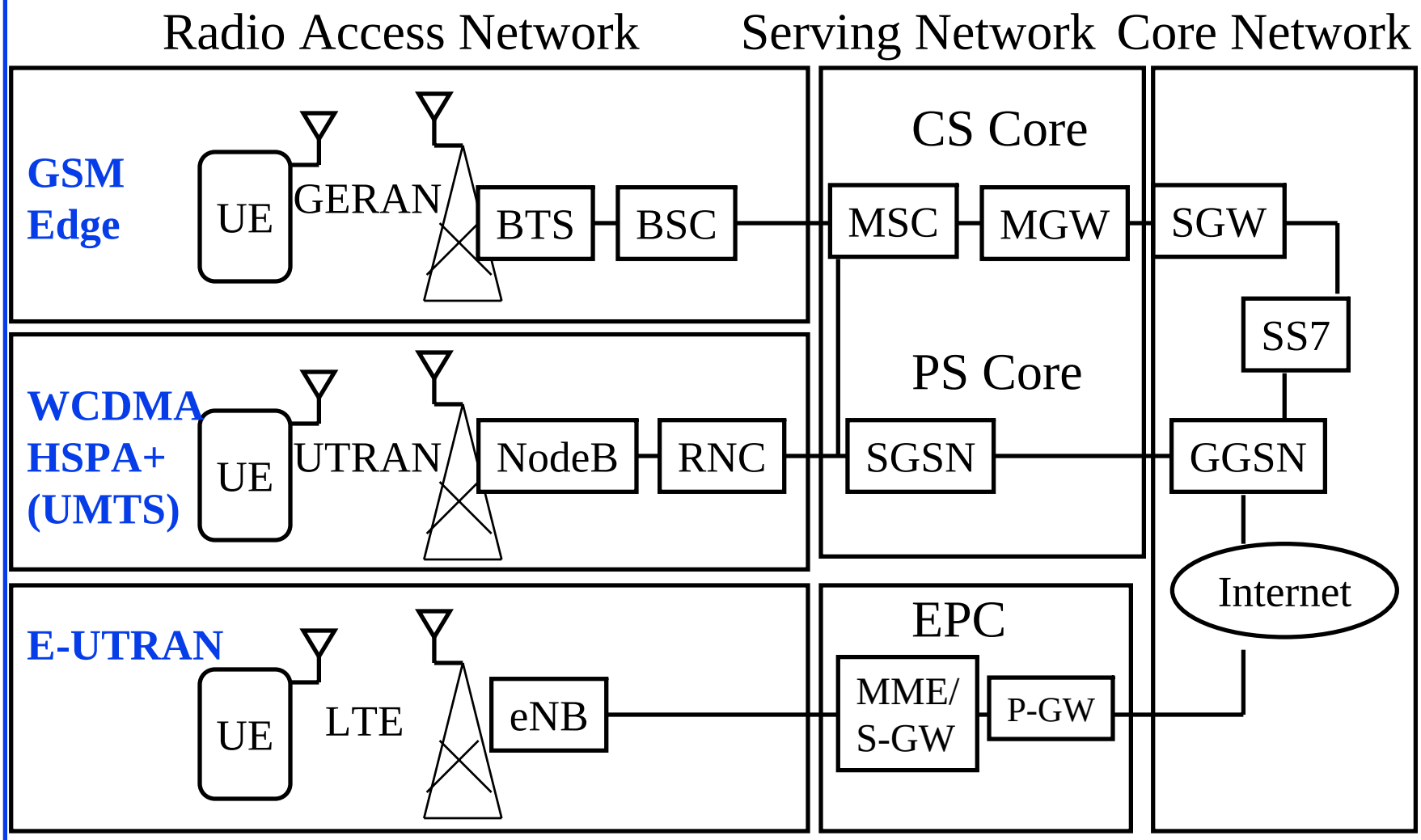


MIMO (Cont)

- **Cooperative MIMO**: Multiple towers coordinate the transmission of the data



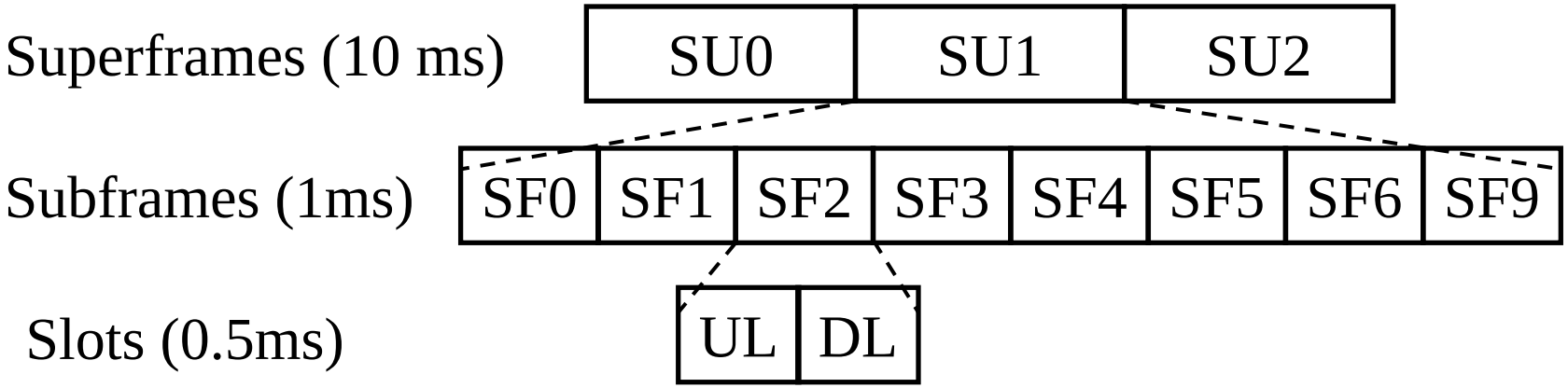
Evolved Packet System (EPS)



Evolved Packet System (Cont)

- CS = Circuit Switched
- EPC = Evolved Packet Core
- EPS = Evolved Packet System
- GERAN = GSM Enhanced Radio Access Network
- GGSN = Gateway GPRS Support Node
- LTE = Long Term Evolution
- MME = Mobility Management Utility
- MSC = Mobile Switching Center
- P-GW = Packet Gateway
- PS = Packet Switched
- RNC = Radio Network Control
- S-GW = Serving Gateway
- SGSN = Service GPRS Support Node
- SS7 = System 7
- eNB = Evolved NodeB

LTE Frame Structure



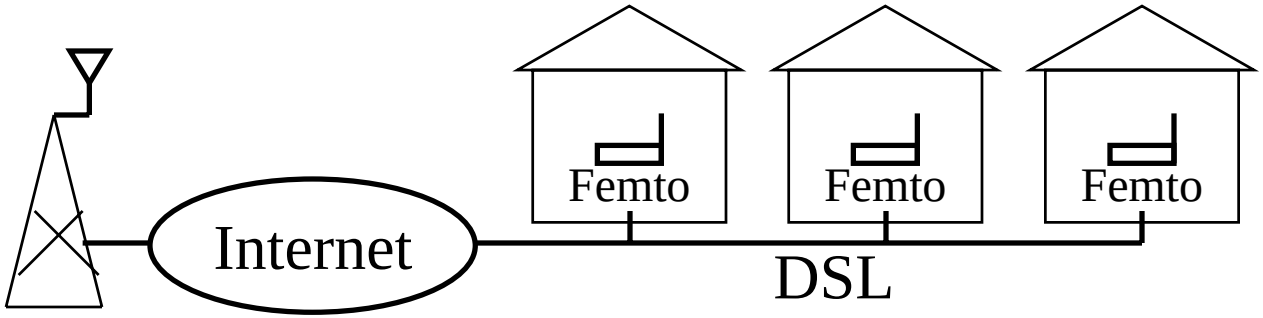
- Intercarrier spacing=15 kHz (Normal), 7.5 kHz(Multicell MBMS)

Cyclic Prefix	Subcarrier Spacing	Subcarriers /RB	Symbols /RB	Cyclic Prefix Time
Normal	15 kHz	12	7	5.2us for 1st symb 4.7 us for others
Extended	15 kHz	12	6	16.7 us
Extended	7.5 kHz	24	3	33.3 us

Ref: Rohde and Schwarz, "UMTS Long Term Evolution (LTE) Technology Introduction," http://www2.rohde-schwarz.com/file/1MA111_2E.pdf

Types of Cells

- **Cell** (**MacroCell**): Cover a few miles. Public Access. Open Area.
- **MicroCell** (10^{-6}): Less than a mile wide. Public Access. Malls, Hotels, Train Stations
- **PicoCell** (10^{-12}): in-Building with public access
- **FemtoCell** (10^{-15}): In-Building with restricted access
- **AttoCell** (10^{-18}): In-room
- **ZeptoCell** (10^{-21}): On-Desk
- No milli, nano cells.



FemtoCells: Key Features

- 50-100 m cell radius
- Indoor
- Residential, Small office/home office (SOHO)
- Backhaul over DSL
- Plug and Play: Self-Organizing, Self optimizing
- Omni-directional antenna. No sectorization
- 10-50 users, 10-40 Mbps, Low cost
- Defined User group
- Continuation of Macro network: Handover of calls
- Regular mobile equipment work in femtocells
- Multiple FemtoCells should coexist
- New Applications: HD video streaming, LAN services

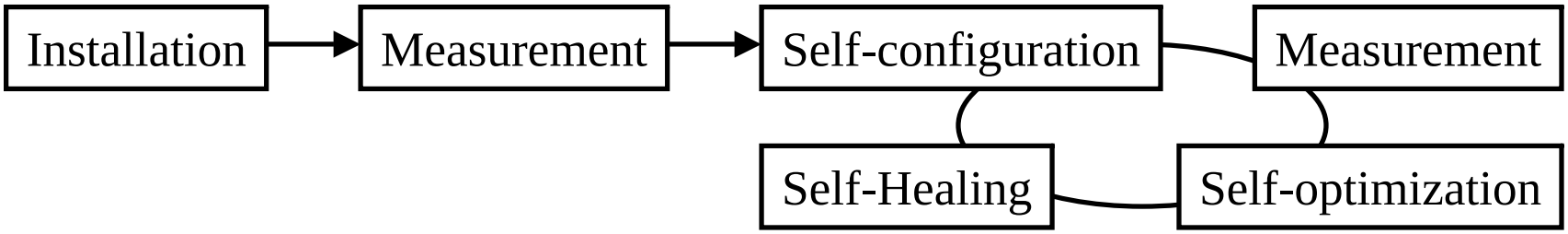
Deployment Configuration

1. **Closed, Dedicated Channel, Fixed Power Deployment**:
   RF different from macro.
   5 dBm power suggested by 3GPP.
   One channel may be shared by all femtocells.
2. **Closed, Dedicated Channel, Adaptive Power Deployment**:
   Power adjusted to minimize interference.
3. **Closed, Co-Channel Deployment**:
   Same RF as Macro. Macro attenuated inside walls.
   Femto power adjusted to minimize interference.
4. **Closed, Partial Co-Channel Deployment**:
   Femto RF selected from a set of available channels.
5. **Open Deployment**: Like a picocell.

Synchronization

- All Home NodeB (HNB) should broadcast preamble at the same time.
- Time aligned to 1us.
- Transmit frequency within ± 2 ppm
- Use Global Positioning System (GPS) or Network Time Protocol (NTP) or IEEE 1588 Precision Time Protocol (PTP)
- Can synchronize to macrocell

Self-Organizing Network (SON)



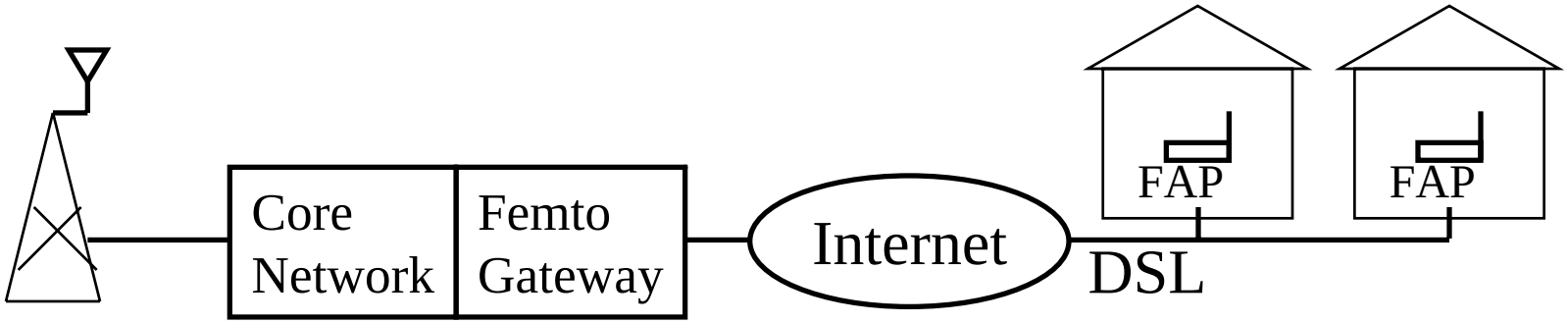
- User installable. 70M UMTS femtocells expected in 2012
- Not-physically accessible to the carrier
- Operator provides femtocell ID. Customer registers location
- Self-Configures:
  - Transmission Frequencies
  - Transmission Power
  - Preamble: Identifies the segment (IDcell). Some IDs for reserved for femtocells. Helps differentiate from macrocell.
  - Neighbor Cell list: Helps in handover
- Turned on/off by the consumer $\Rightarrow$ Dynamic topology

Management and Configuration

- Self-Configuration
- Remote configuration by service provider
- Femtocell senses the channel to detect neighboring cells
- May broadcast messages for neighbors
- Cognitive Radios: Should not interfere with the primary users of spectrum

Femtocell Security

- Network and Service Availability:
  Denial of service by overload
- Fraud and Service Theft: Hacker poses as a user
- Privacy and Confidentiality: Internet security
- IPSec is used between FAP and Femtocell gateway
- Extensible Authentication Protocol (EAP) can be used for user authentication with femto gateway



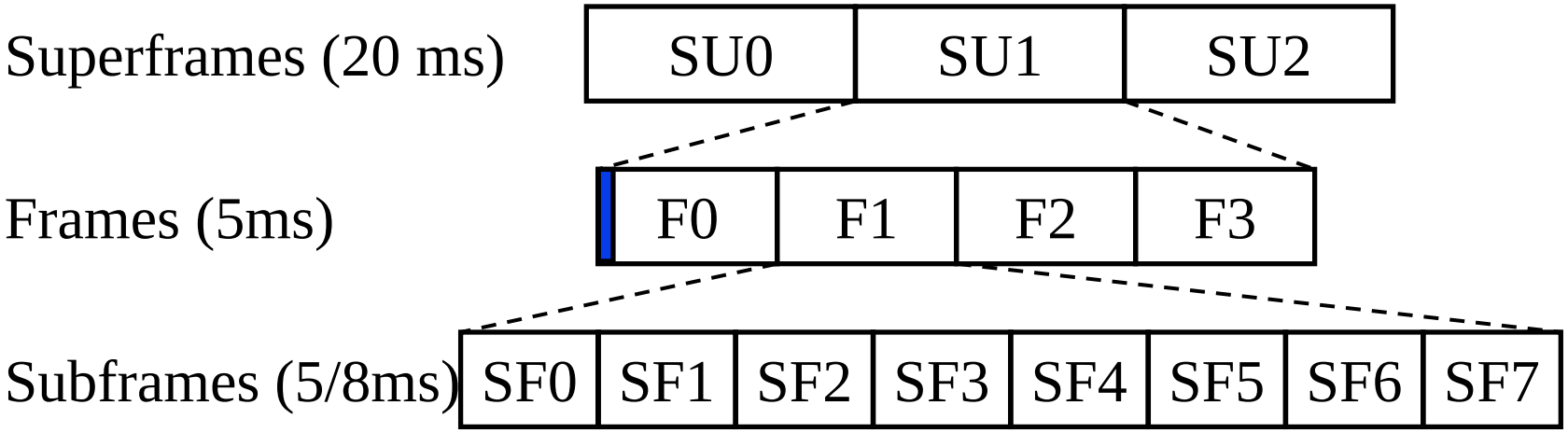
IMT Advanced

- ITU-R M.2072 requirements for **4G**
- 1.0 Gbps peak rate for fixed services with 100 MHz
- 100 Mbps for mobile services. High mobility to 500 km/hr
- Additional reqs on packet and handover latency, VOIP efficiency
- Deadline: Submit proposals by October 2009
  ⇒IEEE 802.16m started April 2007

Feature	Cell	Cell Edge	Peak
DL Spectral Efficiency (bps/Hz)	2.2	0.06	15
UL Spectral Efficiency (bps/Hz)	1.4	0.03	6.75
DL datarate w 40 MHz (Mbps)	88	2.4	600
UL datarate w 40 MHz (Mbps)	56	1.2	270

Ref: ITU-R M.1645, "Framework and overall objectives of the future development of IMT-2000 and systems beyond IMT-2000" (2003)

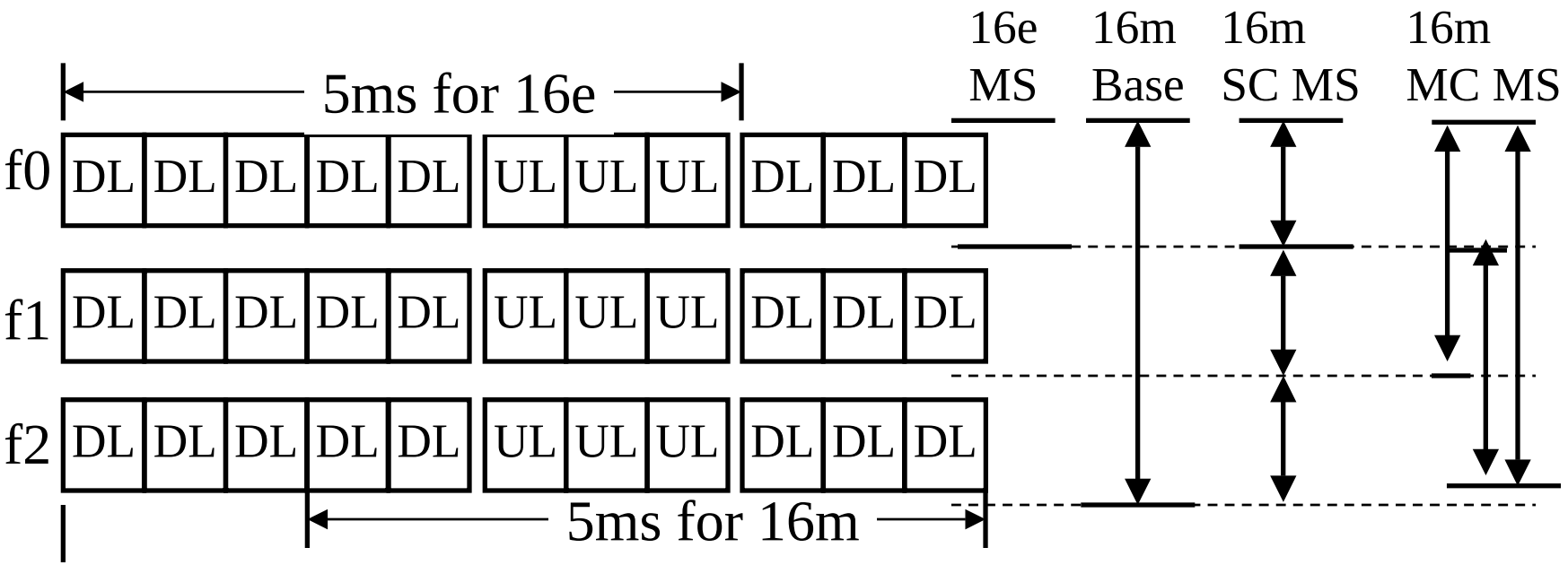
802.16m Frame Structure



- Superframes: Less control information. Common header in F0
- Frames: Compatible with 802.16e
- Subframes: Reduced latency (Request–Grant–Upload-Ack)
- Group and persistent allocations (VOIP) for recurring transmissions

Ref: A. Maeder, "IEEE 802.16m for IMT-Advanced: The Next Step in WirelessMAN Evolution," http://www3.informatik.uni-wuerzburg.de/euroview/2009/data/slides/Session1-Maeder-slides-handout.pdf

802.16m Multi-Carrier Operation



- Virtual Carrier with Multi-Carrier operation
- Lzone for Legacy and Mzone for 16m devices
  Brownfield and greenfield deployments
- Femtocell support: Self-organizing network with neighbor discovery, interference mitigation

LTE vs WiMAX vs WiMAX2

Feature	LTE R8	WiMAX R1 (16e)	WiMAX R2 (16m)
Interface	DL: OFDMA UL:SC-FDMA	OFDMA	OFDMA
Duplexing	FDD, TDD	TDD	FDD, TDD
Mobility	350 km/hr	60-120 km/hr	350 km/hr
Channel Bandwidth (MHz)	1.25, 1.6, 2.5, 5, 10, 15, 20	3.5, 5, 7, 8.75, 10	5, 10, 20, 40
Peak Datarate (Mbps)	DL: 302 (4x4) UL: 75 (2x4) 2x20 MHz (FDD)	DL: 46 (2x2) UL: 4 (1x2) 10 MHz TDD 3:1	DL> 350 (4x4) UL> 200 (2x4) 2x20 MHz FDD
Spectral Efficiency (bps/Hz)	DL: 1.91 (2x2) UL: 0.72 (1x2)	DL: 1.91 (2x2) UL: 0.84 (1x2)	DL > 2.6 (4x2) UL > 1.3 (2x4)
Latency (ms)	L2 < 5 Handover < 50	Link = 20 Handover 35-50	Link <10 Handover< 30

Ref: Ehud Reshef, "LTE & WiMAX Evolution to 4G," 29 oct 2008, http://www.comsysmobile.com/pdf/LTE_&_WiMAX_Evolution_to_4G.pdf

LTE-Advanced

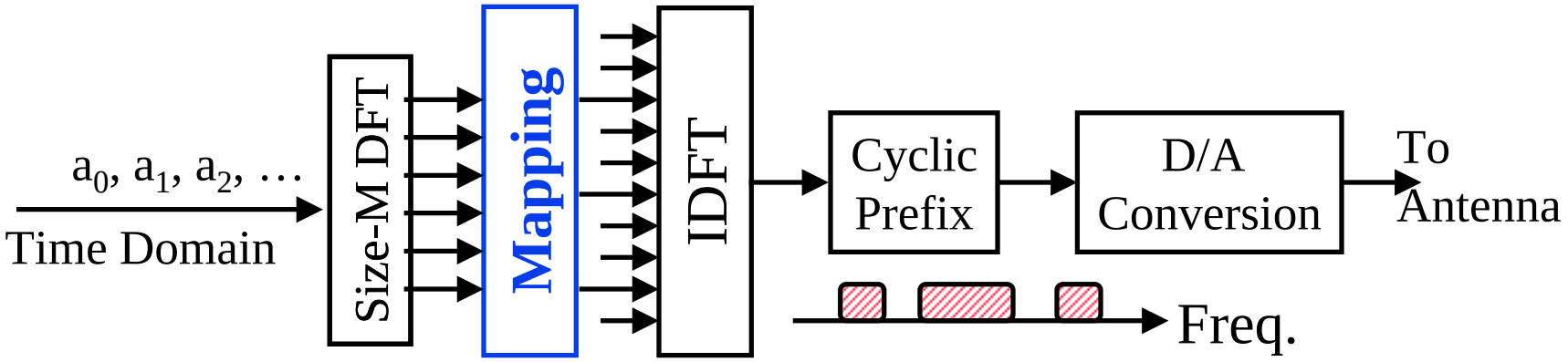
- UMTS Rel 10, 2011H1

1. Bandwidth aggregation = Multi-channel transmissions
2. Clustered SC-FDMA
3. Higher order MIMO (8x8 DL, 4x4 UL)
4. Coordinated MIMO

- Goal: to meet and exceed IMT-advanced requirements
- Requirements in 36.913, Solution proposals in 36.914, ITU-R submission, September 2009, TR 36.912

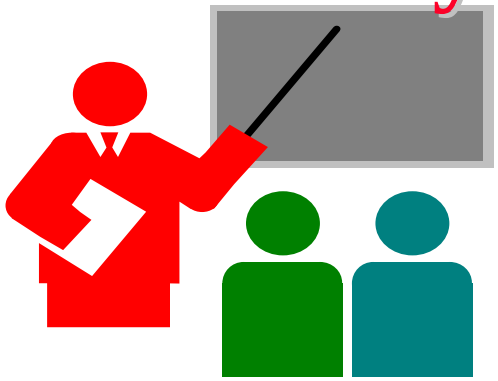
Ref: Study Item, RP-080599, ftp://ftp.3gpp.org/tsg_ran/TSG_RAN/TSGR_41/Docs/RP-080599.zip
Requirements, TR 36.913 v8.0.1 (03/2009), ftp://ftp.3gpp.org/Specs/html-info/36913.htm
Study Technical Report, TR 36.912 v2.2.0, ftp://ftp.3gpp.org/Specs/html-info/36912.htm
Latest Status Report, RP-090729, ftp://ftp.3gpp.org/tsg_ran/TSG_RAN/TSGR_45/Documents/RP-090729.zip
Physical Layer Aspects, TR 36.814 v1.3.0, ftp://ftp.3gpp.org/Specs/html-info/36814.htm

Clustered SC-FDMA



- Enables uplink frequency selective scheduling within a component carrier

Summary



1. HSDPA and HSUPA provide higher data rates beyond 3G in W-CDMA networks
2. LTE uses OFDMA in downlink and SC-FDMA in uplink
3. SC-FDMA is DFT-Precoded OFDM and provides 2 dB lower PAPR
4. Femtocells provide cellular access inside homes and are self-organizing
5. 16m and LTE-advanced are designed for 4G = IMT-advanced
6. 16m/LTE-A use bandwidth aggregation, higher-order MIMO., Coordinated MIMO

Related Wikipedia Pages

- http://en.wikipedia.org/wiki/History_of_mobile_phones
- http://en.wikipedia.org/wiki/Mobile_telephony
- http://en.wikipedia.org/wiki/Universal_Mobile_Telecommunications_System
- http://en.wikipedia.org/wiki/UMTS_Forum
- http://en.wikipedia.org/wiki/2G
- http://en.wikipedia.org/wiki/3G
- http://en.wikipedia.org/wiki/3GPP
- http://en.wikipedia.org/wiki/3GPP_Long_Term_Evolution
- http://en.wikipedia.org/wiki/LTE
- http://en.wikipedia.org/wiki/Single-carrier_FDMA
- http://en.wikipedia.org/wiki/Orthogonal_frequency-division_multiple_access

Related Wikipedia Pages (Cont)

- http://en.wikipedia.org/wiki/Orthogonal_frequency-division_multiplexing
- http://en.wikipedia.org/wiki/WiMAX
- http://en.wikipedia.org/wiki/3G_MIMO
- http://en.wikipedia.org/wiki/MIMO
- http://en.wikipedia.org/wiki/Multi-user_MIMO
- http://en.wikipedia.org/wiki/Ultra_Mobile_Broadband
- http://en.wikipedia.org/wiki/4G
- http://en.wikipedia.org/wiki/LTE_Advanced
- http://en.wikipedia.org/wiki/GSM
- http://en.wikipedia.org/wiki/Enhanced_Data_Rates_for_GSM_Evolution
- http://en.wikipedia.org/wiki/E-UTRA

Related Wikipedia Pages (Cont)

- http://en.wikipedia.org/wiki/EPS
- http://en.wikipedia.org/wiki/Generic_Access_Network
- http://en.wikipedia.org/wiki/High-Speed_Downlink_Packet_Access
- http://en.wikipedia.org/wiki/High-Speed_Uplink_Packet_Access
- http://en.wikipedia.org/wiki/High_Speed_Packet_Access
- http://en.wikipedia.org/wiki/DC-HSUPA
- http://en.wikipedia.org/wiki/Dual-Cell_HSDPA
- http://en.wikipedia.org/wiki/Evolved_HSPA
- http://en.wikipedia.org/wiki/Multimedia_Broadcast_Multicast_Service

Related Wikipedia Pages (Cont)

- http://en.wikipedia.org/wiki/Femtocell
- http://en.wikipedia.org/wiki/Home_Node_B
- http://en.wikipedia.org/wiki/Self-Optimizing_Networks
- http://en.wikipedia.org/wiki/4G
- http://en.wikipedia.org/wiki/Advanced_Mobile_Telephone_System

References

- Agilent Technologies, "LTE and the Evolution to 4G Wireless," Wiley, 2009, ISBN:0470682616
- J. Zhang and G Roche, "Femtocells: Technologies and Deployment," Wiley, 2010, ISBN:0470742983
- E. Dahlman, et al, "3G Evolution:HSPA and LTE for Mobile Broadband," 2nd Edition, Academic Press, 2008, ISBN:0123745385

Femtocell Standards

- 3GPP Rel 8 specifies HNB (Home Node B) and HeNB
- Rel 9 includes an IMS (IP Multimedia Subsystem) capable HNB
- TS22.220: Service Requirements for HNB and HeNB
- TR23.830: Architecture aspects of HNB and H3NB
- TR23.832: IMS aspects of architecture for HNB
- TS25.467: Mobility procedures for HNB
- TS25.469: UTRAN Iuh Interface HNB application part signaling
- TR25.820: 3G HNB study item
- TR25.967: FDD HNB RF Requirements

Femtocell Standards (Cont)

- TS32.581: HNB OAM&P (Operation, Administration, Management and Provisioning) concepts and requirements for Type 1 interface HNT to HNT Management system
- TS32.582: HNB OAM&P information model for Type 1 interface HNT to HNT Management system
- TS32.583: HNB OAM&P procedure flows for Type 1 interface HNT to HNT Management system
- TR32.821: Study of self-organizing networks related OAM interfaces for HNB
- TR33.820: Security of HNB/HeNB
- TS25468: UTRAN Iuh Interface RANAP (Radio Access Network Application Part) User adaptation signaling
- Broadband Forum TR-069 management protocol has been adopted to include femtocells.

References: Standards

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List of Abbreviation

- 3GPP 3rd Generation Partnership Project
- AMC Adaptive modulation and coding
- ARQ Automatic Repeat reQuest
- BS Base Station
- CDMA Code Division Multiple Access
- CS Circuit Switched
- DFT Discrete Fourier Transform
- EPS Evolved Packet System
- FDD Frequency division duplexing
- FDMA Frequency division multiple access
- GGSN Gateway GPRS Support Node
- GPS Global Positioning System
- GW Gateway
- HARQ Hybrid ARQ
- HD High Definition

List of Abbreviation (Cont)

- HNB Home NodeB
- HSDPA High-Speed Downlink Packet Access
- HSPA High-Speed Packet Access
- HSUPA High-Speed Uplink Packet Access
- ID Identifier
- IMT International Mobile Telephony
- IP Internet Protocol
- IPSec Secure IP
- ITU International Telecommunication Union
- LTE Long-Term Evolution
- MHz MegaHertz
- MIMO Multiple Input Multiple Output
- MME Mobility Management Utility
- P-GW Packet Gateway
- PAPR Peak-to-Average Power Ratio

List of Abbreviation (Cont)

- PHY Physical Layer
- QAM Quadrature Amplitude Modulation
- RF Radio Frequency
- RNC Radio Network Control
- S-GW Service Gateway
- SC-FDMA Single-Carrier Frequency Division Multiple Access
- SGSN Service GPRS Support Node
- SOHO Residential, Small office/home office
- SON Self-Organizing Network
- TV Television
- UE User Equipment
- UMTS Universal Mobile Telephony System
- UTRA UMTS Terrestrial Radio Access
- UTRAN UMTS Terrestrial Radio Access Network
- VOIP Voice over IP
- W-CDMA Wideband CDMA