Introduction to LTE

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Audio/Video recordings of this class lecture are available at:

http://www.cse.wustl.edu/~jain/cse574-24/

Student Questions

Q on 4b

1. LTE: Key Features
2. OFDMA and SC-FDMA
3. Evolved Packet Core (EPC)
4. LTE Frame Structure
5. Resource Allocation

Note: This is the 2nd lecture in a series of lectures on 1G to 5G.
4G, 4.5G, and 5G are covered in subsequent modules.

Student Questions

LTE: Key Features

Long-Term Evolution. 3GPP Release 8, 2009.

1. **3.9G** (Pre-4G) cellular technology
   Sold as 4G by some providers.
   4G=International Mobile Telecommunication (IMT) Advanced Requirements in ITU M.2134-2008
2. **Many different bands**: 700/1500/1700/**2100**/2600 MHz
3. **Flexible Bandwidth**: 1.4/3/5/10/15/20 MHz
4. Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD)
   ⇒ Both *paired* and *unpaired* spectrum
5. 4x4 MIMO, Multi-user collaborative MIMO
6. Beamforming in the downlink

Ref: A. Ghosh, J. Zhang, J. G. Andrews, R. Muhamed, "Fundamentals of LTE," Prentice Hall, 2010, ISBN: 0137033117, 464 pp. Safari book.

Student Questions

- ❑ Can you explain downlink versus uplink?

Uplink: Mobile to the tower
Downlink: Tower to Mobile

- ❑ You mentioned in the lecture that the 2100 MHz band was added later but what was the reason for that?

More demand and LTE was coming along well so they asked for new spectrum rather than recycling 3G spectrum.

- ❑ Are there any intermediate technologies that 5G uses significantly but cannot be classified as 5G, 4.9G?

Yes. 4.5G. There are many releases from 3GPP during the decade. Each release is not given a G-number.

LTE: Key Features

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Student Questions

- Why is 3GPP gone from the United States?

The US is a member. However, it was started during the 3G era to follow the European version of 3G, and so it is headquartered there.

- Why does it need so many different bands?

As the telecommunications business expanded, more bands were needed and added. Also, some bands may be specific to some countries.

LTE: Key Features (Cont)

8. Data Rate: 326 Mbps/down 86 Mbps up (4x4 MIMO 20 MHz)
9. Modulation: OFDM with QPSK, 16 QAM, 64 QAM
10. **OFDMA** downlinks,
    Single Carrier Frequency Division Multiple Access (**SC-FDMA**) uplinks
11. **Hybrid ARQ** Transmission
12. Short **Frame Sizes** of 10ms and 1ms ⇒ faster feedback and better efficiency at high speed
13. **Persistent scheduling** to reduce control channel overhead for low-bit rate voice transmission.
14. **IP-based** flat network architecture

Student Questions

- Why do we need Hybrid ARQ in LTE instead of regular ARQ?

It is better. It uses both Layer 1 and Layer 2. So the number of bits to be retransmitted is much smaller.

- What's the purpose of having different access methods for downlink and uplink?

Tower has much more power and can implement many more features than mobiles. In the uplink, the mobile is the transmitter.

LTE: Key Features (Cont)

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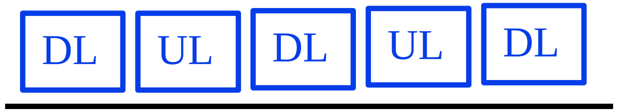
14. **IP-based** flat network architecture

Student Questions

- LTE: "Short Frame Sizes of 10ms and 1ms ⇒ faster feedback and better efficiency at high speed". How short can the frames be? What would be the trade-off?

DL and UL frames alternate. Short frames result in quicker opportunities to transmit.

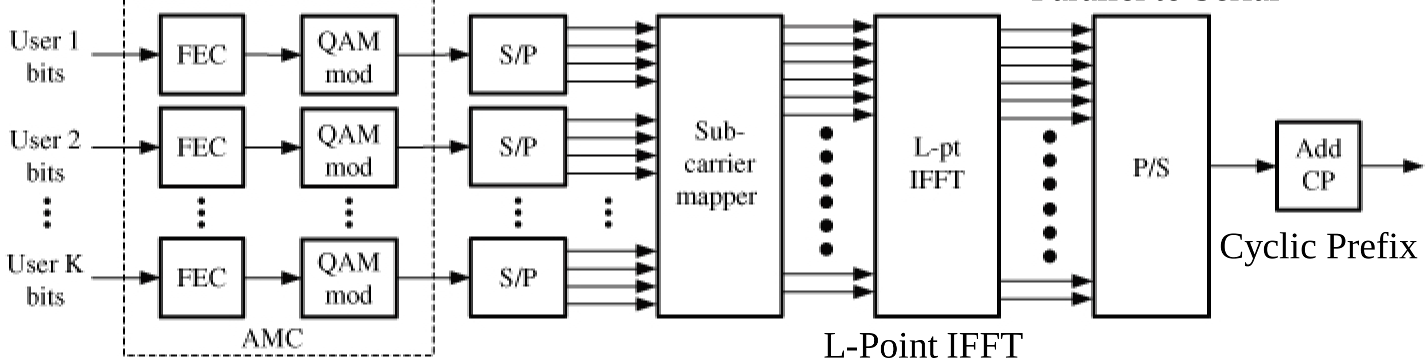


OFDMA Downlink

- Transmitter at Base Station: IFFT converts frequency to time

Serial to Parallel

Parallel to Serial

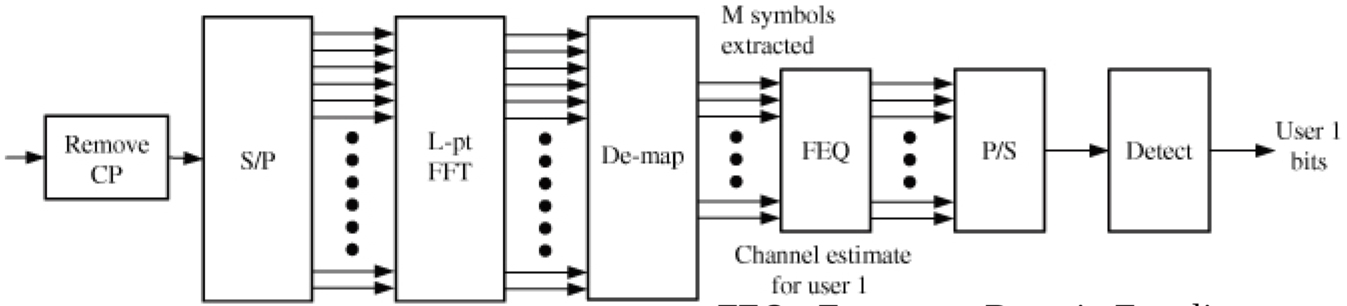


Cyclic Prefix

L-Point IFFT

Adaptive modulation and coding

- Receiver at User Terminal: FFT converts time to frequency



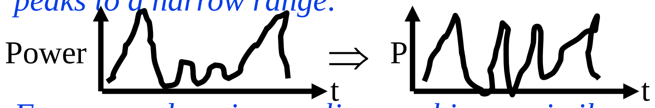
FEQ= Frequency Domain Equalizer

Ref: A. Ghosh, J. Zhang, J. G. Andrews, R. Muhamed, "Fundamentals of LTE," Prentice Hall, 2010, ISBN: 0137033117, 464 pp. Safari book.

Student Questions

- Could you explain why we need the FEQ?

Time domain equalizers equalize the power peaks to a narrow range:



Frequency domain equalizers achieve a similar effect in the frequency domain and reduce round-off errors.

- What is AMC in the first diagram?

Adaptive modulation and coding

- Why is S/P after the QAM mod rather than before the QAM mod?

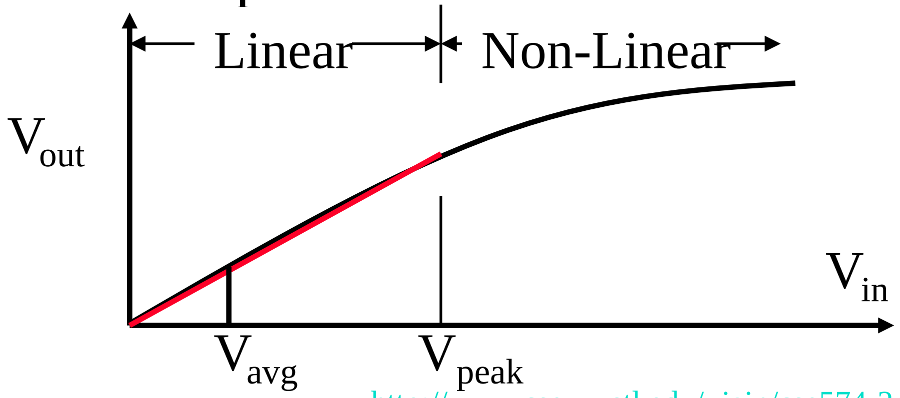
QAM produces a series of complex numbers.

- What is L-pt? Cp?

L-Point, Cyclic prefix

Peak-to-Average Power Ratio (PAPR)

- OFDM
  - ⇒ Each carrier is modulated according to the specific channel condition.
  - ⇒ High variation of power levels
  - ⇒ Higher Peak-to-Average Power Ratio (PAPR)
  - ⇒ Higher cost of amplifiers
- Amplifiers are linear only over a restricted region
  - ⇒ Costly amplifier or reduce average signal power significantly
  - ⇒ Can afford such amplifiers in Base stations but not in mobiles.



Student Questions

- In what sense are the amplifiers cheap? (Cost, Size, Thermal Efficiency, Power Usage...)

Cost. Cost for the same efficiency and other features.

- Is it better for the amplifier to be linear compared to non-linear even though the slope of Vout becomes less at higher Vin?

We want to produce Vin in the linear range and avoid the non-linear part.

- PAPR = V_{peak}/V_{avg}?

Yes.

- What is the effect of PAPR on OFDM?

Negligible

- What are the practical implications for mobile devices with PAPR?

This is more of a marketing than a real advantage. The practical effect was that this was the main differentiator from WiMAX for Qualcomm to gain back control.

SC-FDMA

- Single-Carrier Frequency Division Multiple Access
- Each user gets a contiguous part of the channel

- Uses single carrier modulation and adds a cyclic prefix
- Single carrier ⇒ Not much variation in amplitude
  ⇒ Lower PAPR
- Better for uplink because slight miss-synchronization among users does not affect the decoding significantly
- With OFDMA, each user's subcarriers are spread all over the band and may affect other users' subcarriers all over the band

Ref: A. Ghosh, J. Zhang, J. G. Andrews, R. Muhamed, "Fundamentals of LTE," Prentice Hall, 2010, ISBN: 0137033117, 464 pp.

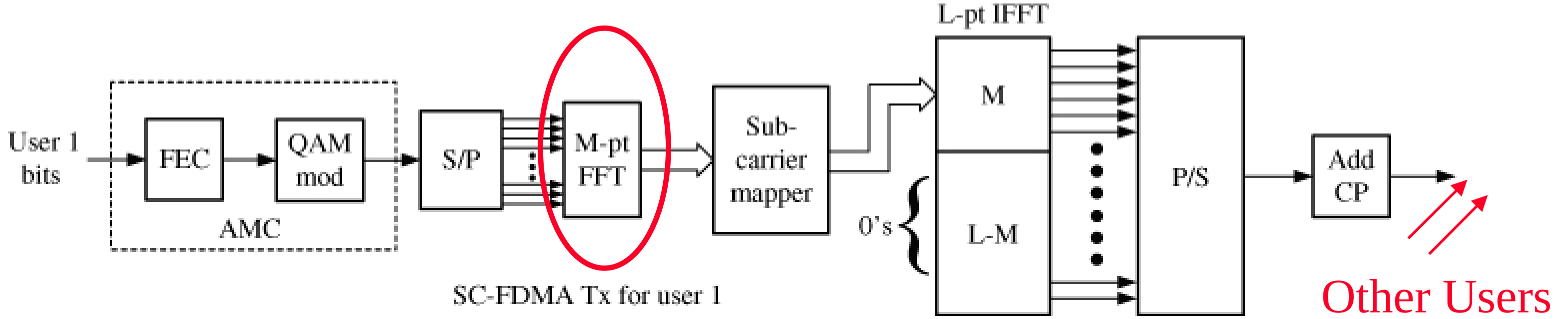
Student Questions

- Could you run out of frequency for users in a particularly dense area? Or can you just add more base stations to counteract this?

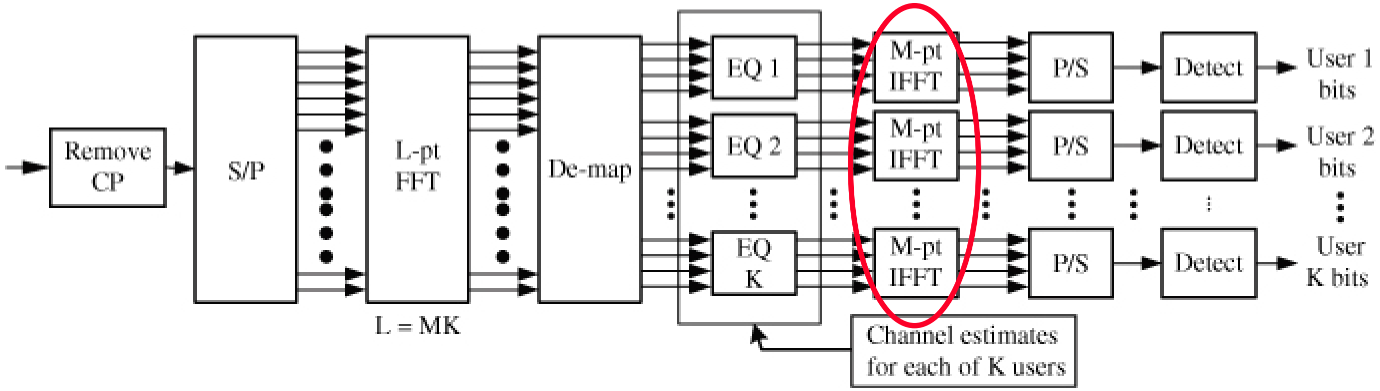
You can add more base station, update frequency reuse plan, and adjust power on existing base stations accordingly.

SC-FDMA (Cont)

- In practice, SC-FDMA is implemented as if the user is allocated a contiguous subset of subcarriers
- Transmitter at the User Terminal:



- Receiver at the Base Station:



- SC-FDMA = Discrete Fourier Transform *Pre-coded* OFDMA

Ref: A. Ghosh, J. Zhang, J. G. Andrews, R. Muhamed, "Fundamentals of LTE," Prentice Hall, 2010, ISBN: 0137033117, 464 pp.

Student Questions

- Can you explain where the multiple user bits are aggregated in the diagram?

After the right end of the upper diagram (i.e., in the air). The combined signal reaches the left end of the lower diagram.

- I don't understand why the base station is doing FFT and then IFFT in the later steps. Why is that?

FFT converts the signal from time domain to frequency domain. Some things are easier to do in time domain and others in frequency domain.

- What is M-pt? L-M?

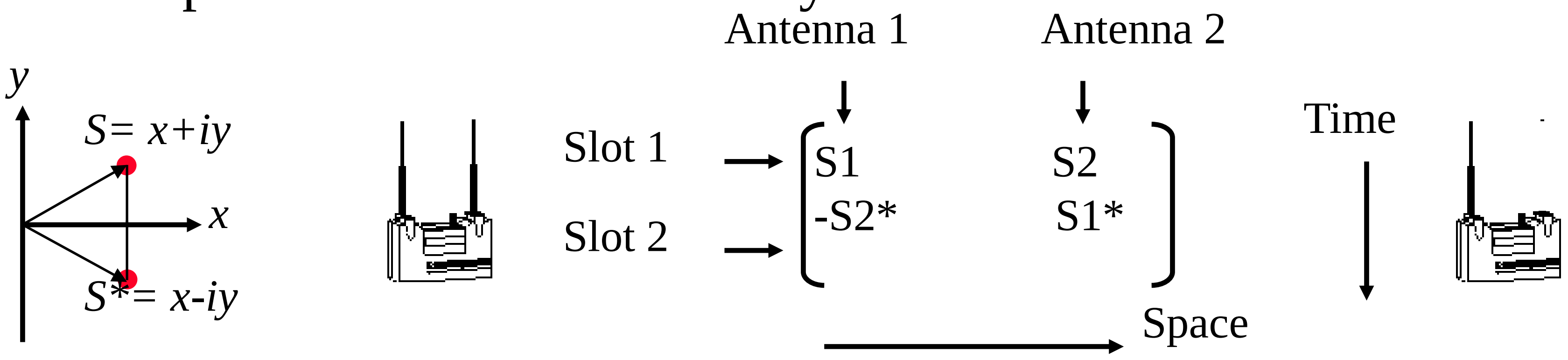
M-point, L minus M.

- Can you explain again why SC-FDMA is pre-coded OFDMA?

They both use FFT.

Space Time Block Codes (STBC)

- Invented in 1998 by Vahid Tarokh.
- Transmit multiple redundant copies from multiple antennas
- Precisely coordinate the distribution of symbols in space and time.
- Receiver combines multiple versions of the received signals optimally to overcome multipath.
- Example: Two antennas: Two symbols in two slots ⇒ Rate 1



S1* is complex conjugate of S1 ⇒ columns are orthogonal

Student Questions

- Does the efficacy come from fewer symbols being sent, and there is much less interference, reducing the retransmission of duplicate symbols?

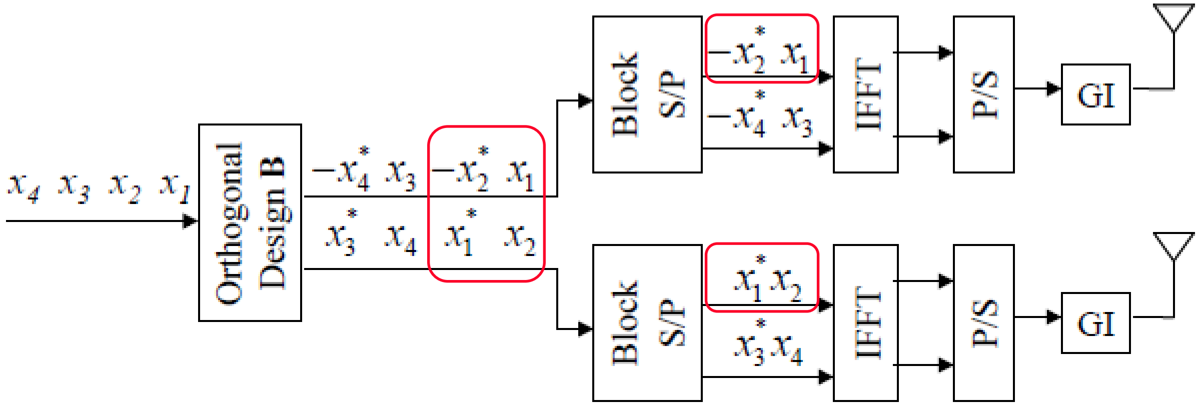
Yes. Less decoding errors.

- The quiz showed that STBC requires transmitting multiple related signals that are not the same. But the slide shows that "transmit multiple copies." Do the copies mean the same signals?

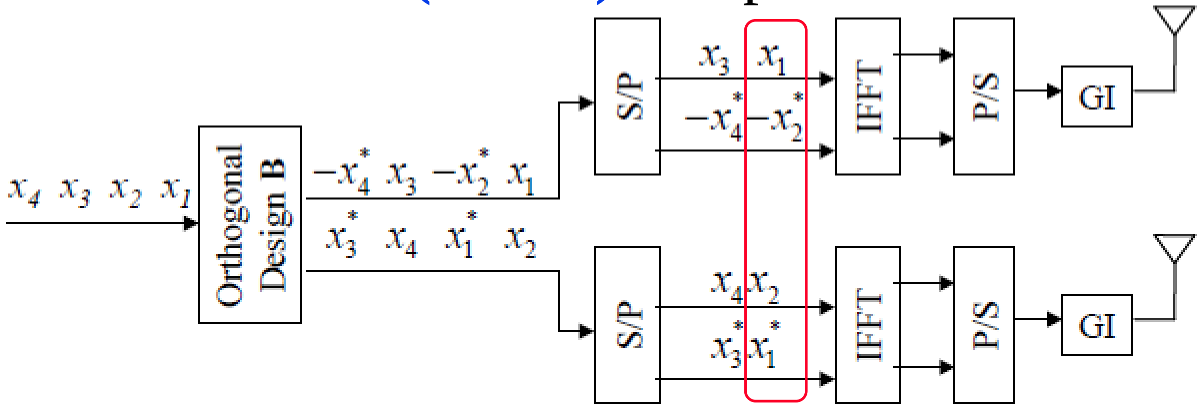
Multiple versions. They are related but not identical.

Space-Frequency Block Codes

- STBC on OFDM (Multi-carrier): Two alternatives
- **STBC on each subcarrier**:



- **STBC on across subcarriers (SFBC)**: Helps if channel changes fast



Ref: G. Bauch, "Space-Time Block Codes Versus Space-Frequency Block Codes," IEEE VTC, Apr 2003, https://pdfs.semanticscholar.org/105a/06314ba6718f3d698a7620b2e891d20c00de.pdf

Student Questions

- Would you please explain STBC and SFBC?

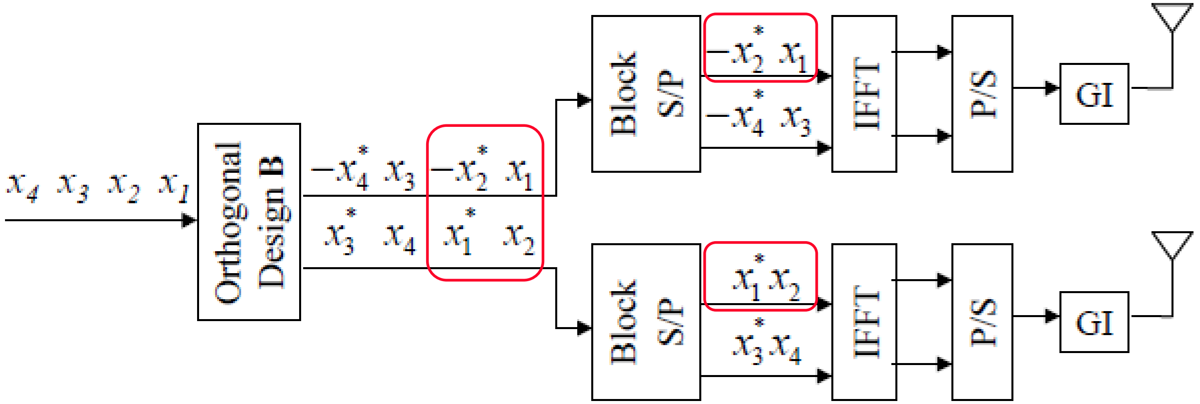
The previous slide was entirely on STBC. SFBC is its analog in the frequency domain.

- Assuming the top parallel-to-serial block outputs (x1, x3, -x2*, -x4*) in the top diagram, how does the receiver know that it's getting this as opposed to (x1, -x2*, x3, -x4*) from the top parallel-to-serial block from the bottom diagram?.

Standard allows two alternatives. One is selected at the time of implementation.

Space-Frequency Block Codes

- STBC on OFDM (Multi-carrier): Two alternatives
- **STBC on each subcarrier**:



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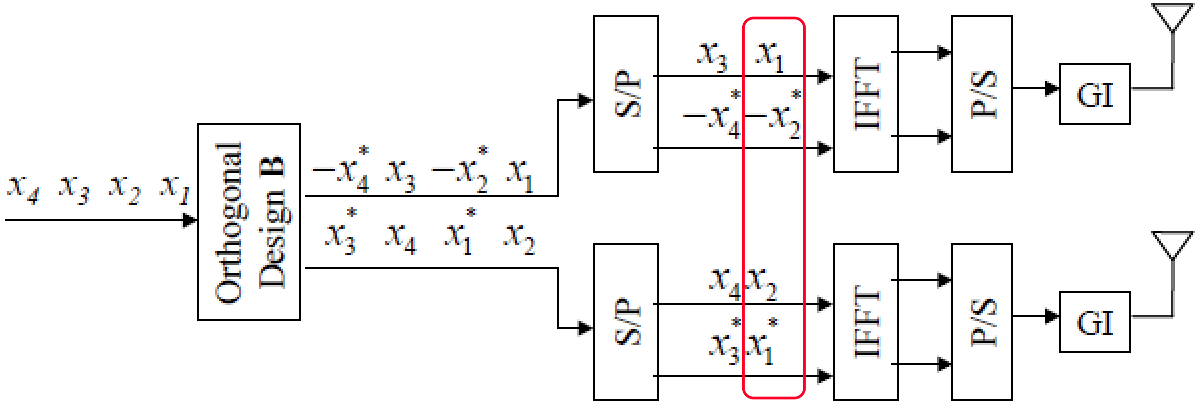

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Student Questions

- What happens if one of those subcarriers isn't received, is the STBC/SFBC still parsed or does it need to receive all symbols?

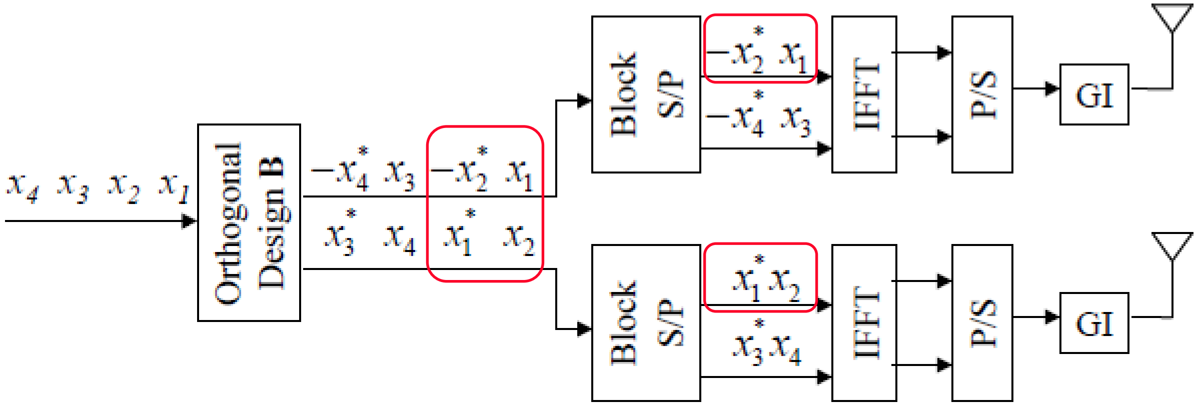
There is plenty of redundancy at each level – subcarriers, symbols, frames, etc.

- Can you give an example of how a channel changing would be helped by using SFBC? What changes about the channel?

If channel characteristics change fast, SFBC helps recover by having the redundant information on the other subcarriers.

Space-Frequency Block Codes

- STBC on OFDM (Multi-carrier): Two alternatives
- **STBC on each subcarrier**:



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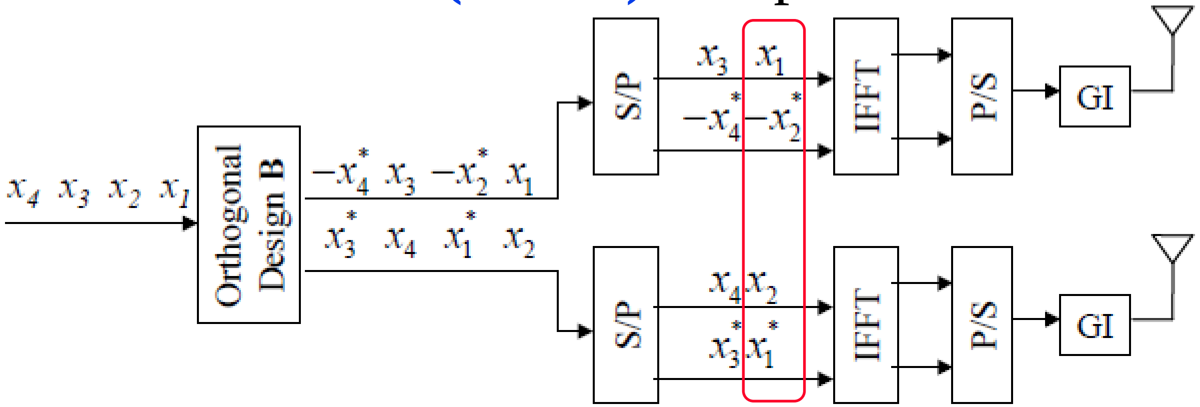

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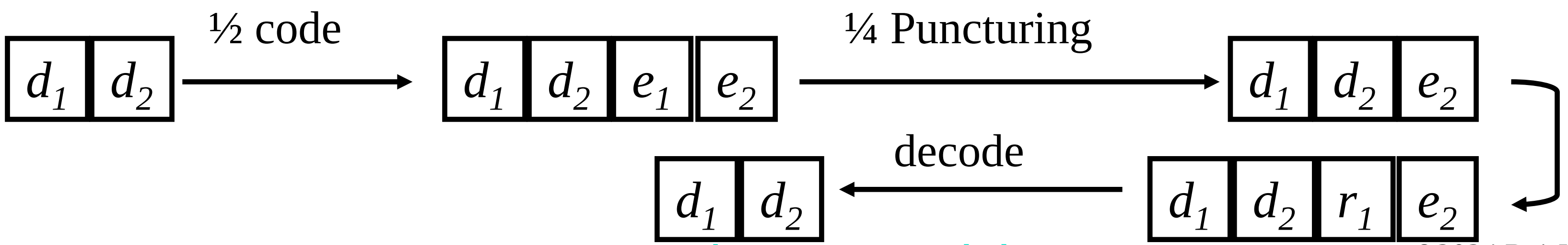
Student Questions

- Why there are two streams coming from the 'Orthogonal Design B' block and two streams coming from each S/P block? From the previous diagram I assumed only at the S/P block would there be a split, since after that is where subcarriers are mapped.

Streams are not subcarriers. All x_i's are symbols, not subcarriers. IFFT converts them to subcarriers (time domain to frequency domain transformation).

Puncturing

- Use a large number of error-correcting code (ECC) bits but send only some of them
- Example: 1/2 code = 1 ECC bit/Original bit
- Or 4 bits for each 2-bit symbol
- ¼ puncturing ⇒ Drop every 4th bit
  ⇒ send 3 bits for each 2-bit symbol = 2/3 code.
- Receiver puts random bits in the punctured positions and decodes ⇒ high probability of correct decoding, particularly if the SINR is high
- ½ code with 1/4th puncture is not as good as 2/3 code in general but puncturing helps in some situations, such as HARQ



Student Questions

- Should the 2nd bullet be 2 ECC bit/original bit or 1?

1 ECC bit + 1 Original bit = 2 Total bits ⇒ ½ code.

- Why is it called puncturing?

Puncture = Cut-out

- Why do we need puncturing rather than designing a new ECC algorithm with shorter bits? In this way, it would avoid randomness.

Puncturing was shown to be better than shorter ECC.

Puncturing

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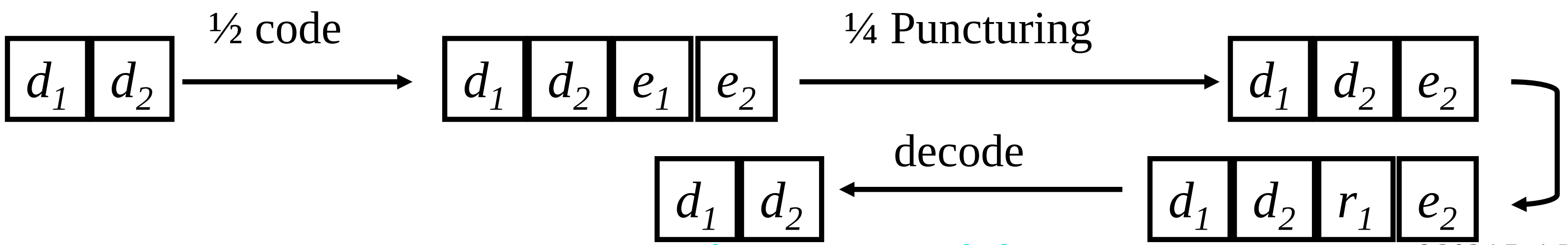


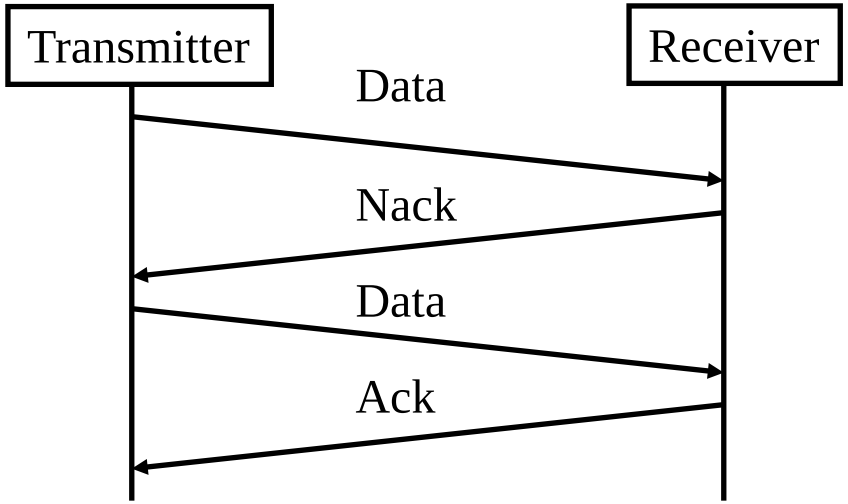
Student Questions

- How does the receiver know which puncture method is being used? Is there a negotiation process involved beforehand? The figure below mentions 1/4 puncturing and indicates that every 4th bit is dropped. Then why is e1 dropped? According to the figure, it is the 3rd bit.

All the details of the transmission are negotiated or announced at the time of connection.

ARQ

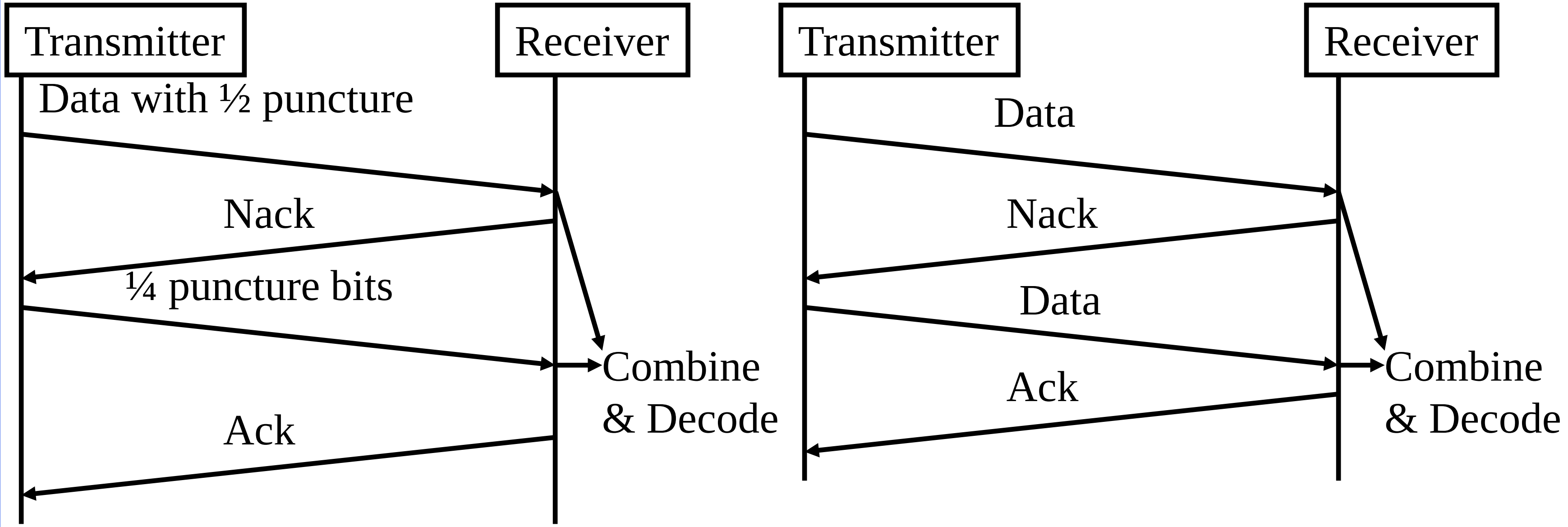
- **A**utomatic **R**epeat re**Q**uest (ARQ)
- Retransmit a packet if it is received in error
- Previous (bad) bits are discarded.



Student Questions

Hybrid ARQ

- PHY and MAC layers work together ⇒ Hybrid
- PHY layer sends some bits first (uses puncturing)
  - Sends other bits only if necessary.
  - Additional bits are sent until the decoding is successful. (**Incremental Redundancy** or **Type II** HARQ)
  - Another alternative is to combine the good bits of multiple transmissions (**Chase Combining** or **Type I** HARQ)



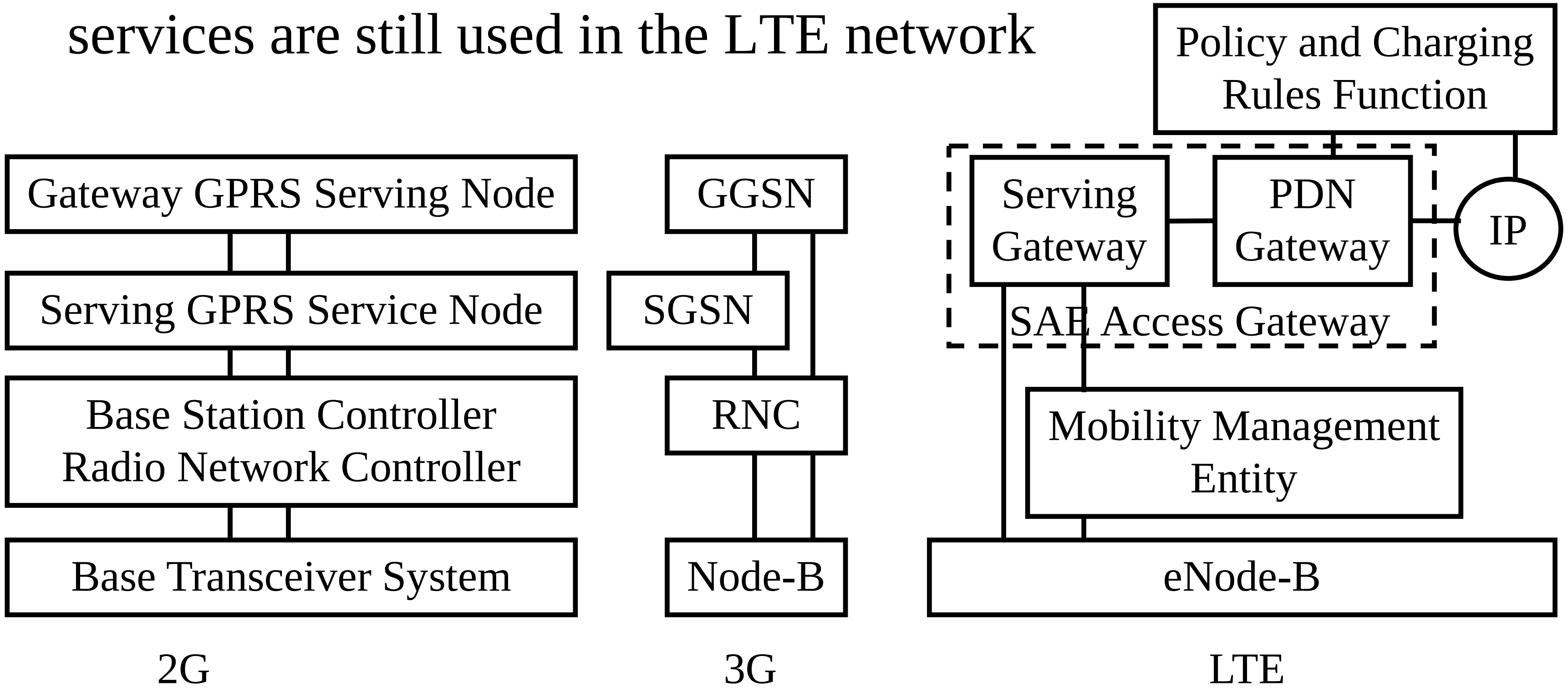
Student Questions

- Isn't this inefficient, because you need to keep sending the headers with each transmission, so you'll have a high overhead/data ratio?

This is an alternative to retransmitting the entire packet and so it is more efficient than the alternative.

IP-Based Flat Network Architecture

- Flat ⇒ Less hierarchical and fewer nodes
- All services (Voice/multimedia) over IP
- For backward compatibility, some non-IP protocols and services are still used in the LTE network



Student Questions

- What does nodes refer to in the first bullet?

Nodes = Functions = Equipment

- It seems like the flat IP-based architecture centralizes a lot of functionality. Does this create problems with scalability?

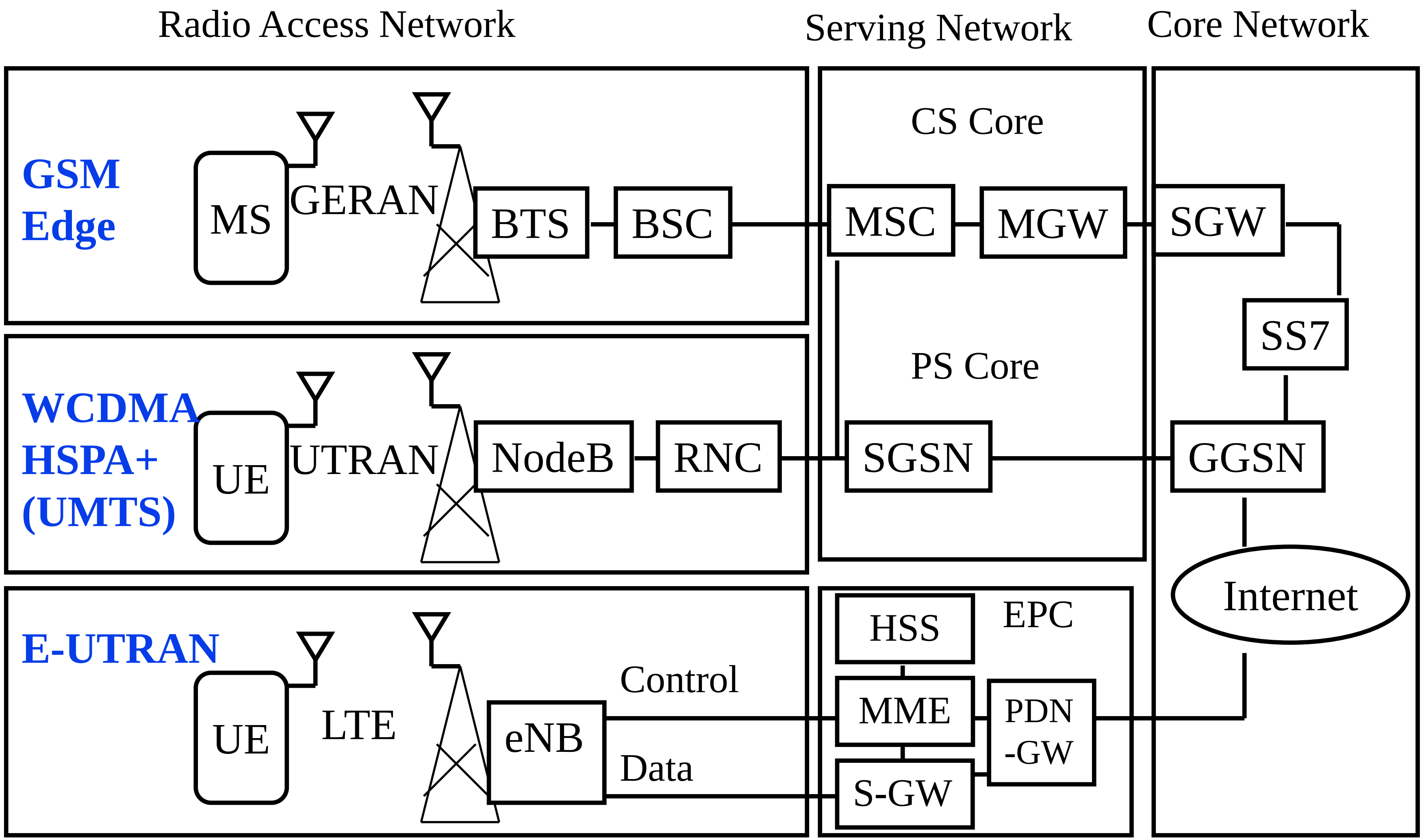
Telecommunications systems are, in general, more centralized than enterprise systems.

Evolved Packet Core (EPC)

- Four new elements:
  1. **Serving Gateway**: Demarcation point between RAN and Core. Serves as mobility anchor when terminals move
  2. **Packet Data Network Gateway (PGW)**: Termination of EPC towards Internet or IMS network. IP services, address allocation, deep packet inspection, policy enforcement
  3. **Mobility Management Entity (MME)**: Location tracking, paging, roaming, and handovers. All control plane functions related to subscriber and session management.
  4. **Policy and Charging Rules Function (PCRF)**: Manages QoS using info from Home Subscriber Server (HSS)

Student Questions

Evolved Packet System (EPS)



Student Questions

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
- HSS = Home Subscriber Server (similar to Home Location Register)
- LTE = Long-Term Evolution
- MME = Mobility Management Utility
- MSC = Mobile Switching Center
- PDN-GW = Public Data Network Gateway
- PS = Packet Switched
- RNC = Radio Network Control
- S-GW = Serving Gateway
- SGSN = Service GPRS Support Node
- SS7 = System 7
- eNB = Evolved NodeB

Student Questions

Evolved Packet Core (EPC)

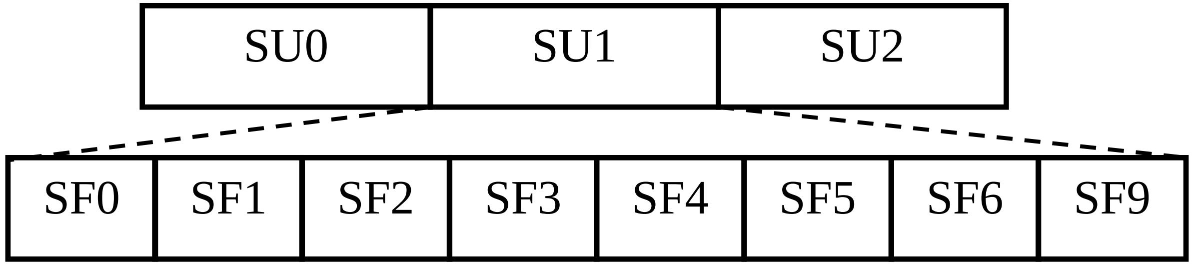
- **Mobility Management Entity (MME):**
  - Handles all control between base stations and core
  - Only non-access spectrum (NAS) signaling, i.e., not involving air interface matters
  - Authentication, Handovers, SMS, and voice
- **Serving Gateway (S-GW):**
  - Separates S1 tunnel to eNB from S5 tunnel to Internet
  - The two tunnels are independently changed as the user moves
- **PDN Gateway (PDN-GW):** Router to the Internet.
  - Assigns IP addresses to mobile devices
- **Home Subscriber Server (HSS):** Like HLR in 3G
  - Uses IP-based DIAMETER protocol
  - Maintains Users International Mobile Subscriber Identity (IMSI), authentication information, telephone number, etc.

Student Questions

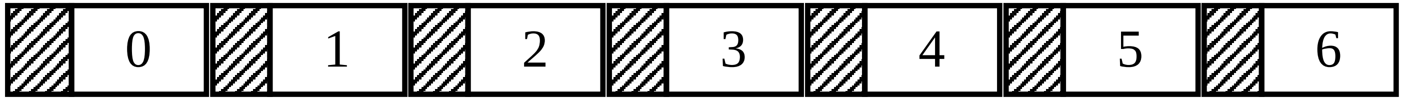
LTE Frame Structure

Superframes (10 ms)

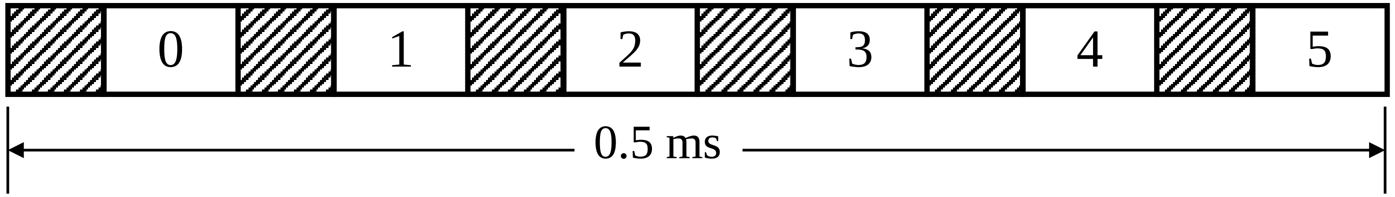
Subframes (1ms)



- Subframe = 2 slots of 0.5 ms each
- Slot = 6 or 7 symbols of 0.0667 ms each
- Normal Cyclic Prefix:5.2 us for 1st symbol, 4.7 us for others



- Extended Cyclic Prefix: for larger networks. 16.7 us



Ref: Rhode and Schwarz, "UMTS Long Term Evolution (LTE) Technology Introduction," http://www.rohde-schwarz.de/file/1MA111_4E_LTE_technology_introduction.pdf

Student Questions

- If there are six symbols in a slot, how could a symbol take longer time than a slot? (0.667 ms vs. 0.5 ms)

Corrected.
The slot size is 0.0667 ms.

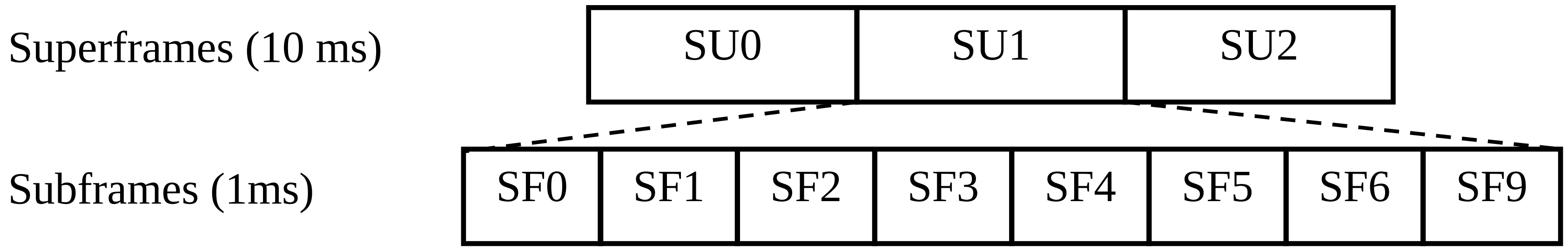
- Do we increase cyclic prefixes to ensure that the symbols don't overrun each other in a long-distance transmission? Example: give TX1 time to travel before sending TX2, so TX2 is not received before TX1.

Extended prefix gives more space for the symbols to expand. TX2 is not received before TX1 ends.

- How could we detect the cyclic prefix's end and the symbol's start? We need an exact timer because there is no guard between them.

There could be an inter-symbol gap. Anyway, bit coding provides synchronization.

LTE Frame Structure



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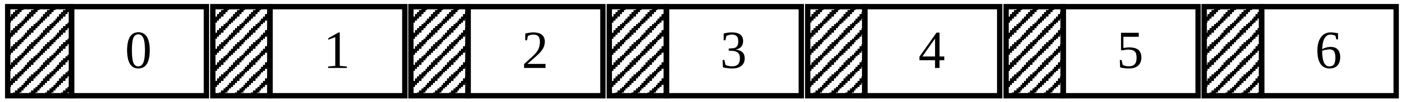

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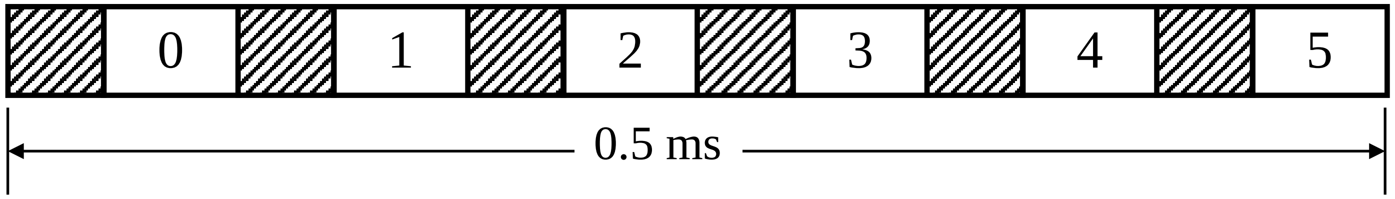

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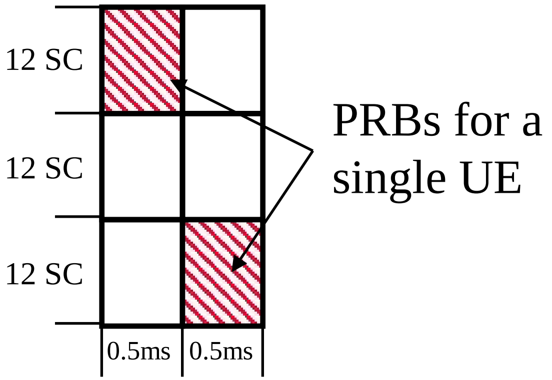
Student Questions

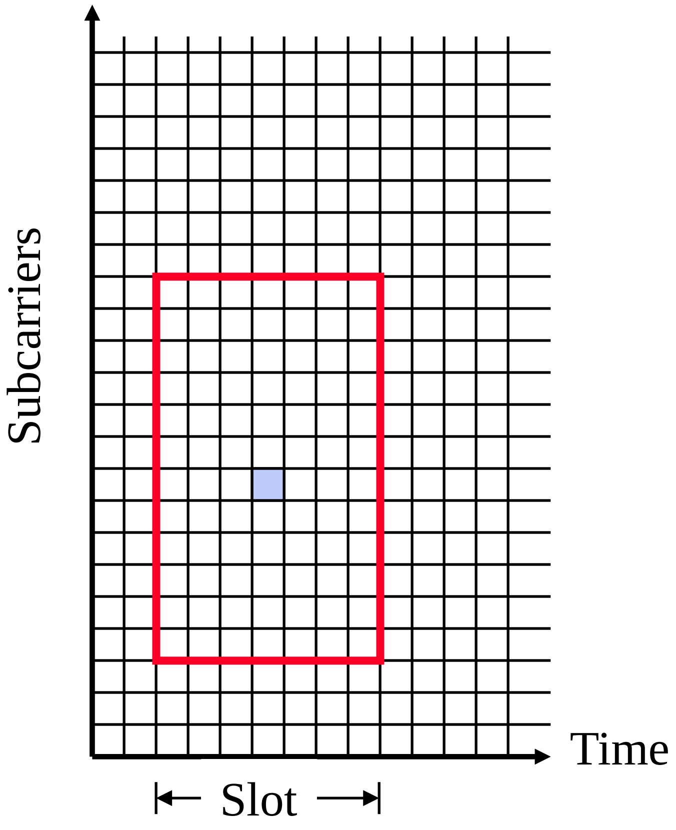
- In a Normal Cyclic Prefix situation, why does the 1st symbol have a larger prefix?

The first symbol has a higher chance of being overrun.

Resource Allocation

- **Time slot:** 0.5 ms
  6 or 7 OFDM symbols
- **Subcarriers:** 15 kHz
- **Physical Resource Block:**
  12 subcarriers (180 kHz)
  over 1 time slot
- **Minimum Allocation**: 2 PRBs
  per subframe





Ref: A. Ghosh, J. Zhang, J. G. Andrews, R. Muhamed, "Fundamentals of LTE," Prentice Hall, 2010, ISBN: 0137033117, 464 pp.

Student Questions

- Is the red colored rectangle the PRB?

Yes.

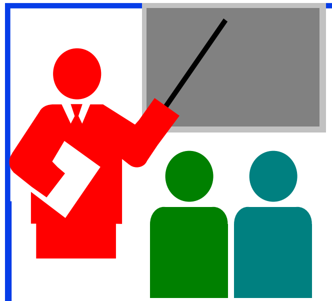
WiMAX vs. LTE

- Similar with minor differences
- Net Head vs. Bell Head
- Enterprise Networking vs. Carrier Networking
- Academic vs. Telecom
- Intel/Google vs. Ericsson/QUALCOMM
- Both use OFDMA.
  Both are incompatible with 2G and 3G (CDMA) radios.
- Quad-band ⇒ Penta-band

Student Questions

- Could you explain the difference between Net head and Bell head again?

Sure.



Summary

1. WiMAX and LTE are pre-4G technologies.
2. WiMAX and LTE have numerous **common features**: Many bands, flexible bandwidth, and FDD/TDD. MIMO/Beamforming HARQ, IP-Based, OFDMA. The key differentiator is SC-FDMA for uplink in LTE to reduce **PAPR**.
3. STBC requires transmitting redundant symbols from multiple antennae. **SFBC** requires that these redundant symbols be sent on different subcarriers.
4. **Puncturing** allows some ECC bits to be not transmitting. This is used in **HARQ** to send extra bits only if necessary.
5. LTE uses a **super-frame** of 10 subframes of 1 ms each. Each **subframe** has one **slot** for uplink and downlink each.

Student Questions

- Slides 17-15 (EPC), 17-22 (DASH), and 17-23 (VoLTE) are not covered by the video.

17-22 and 17-23 are misplaced. DASH is covered in CSE473, not here. VoLTE is covered in Module 18. EPC is explained in Slides 17-16 (EPS) and 17-17 (EPS Cont).

Reading List

- A. Ghosh, J. Zhang, J. G. Andrews, R. Muhamed, "Fundamentals of LTE," Prentice Hall, 2010, ISBN: 0137033117, 464 pp., Safari Book.
- Rhode and Schwarz, "UMTS Long Term Evolution (LTE) Technology Introduction," http://www.rohde-schwarz.de/file/1MA111_4E_LTE_technology_introduction.pdf

Student Questions

Wikipedia Links

- https://en.wikipedia.org/wiki/IMT-Advanced
- https://en.wikipedia.org/wiki/4G
- https://en.wikipedia.org/wiki/Radio_Resource_Control
- https://en.wikipedia.org/wiki/Radio_resource_management
- https://en.wikipedia.org/wiki/Single-carrier_FDMA
- https://en.wikipedia.org/wiki/Space%E2%80%93time_block_code
- https://en.wikipedia.org/wiki/Space-time_block_coding_based_transmit_diversity
- https://en.wikipedia.org/wiki/Space%E2%80%93time_code
- https://en.wikipedia.org/wiki/Spatial_multiplexing
- https://en.wikipedia.org/wiki/Multi-user_MIMO
- https://en.wikipedia.org/wiki/Transmit_diversity
- https://en.wikipedia.org/wiki/Mobility_management
- https://en.wikipedia.org/wiki/MIMO
- https://en.wikipedia.org/wiki/Multi-user_MIMO
- https://en.wikipedia.org/wiki/Precoding

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Wikipedia Links (Cont)

- https://en.wikipedia.org/wiki/Antenna_diversity
- https://en.wikipedia.org/wiki/Many_antennas
- https://en.wikipedia.org/wiki/Multi-user_MIMO
- https://en.wikipedia.org/wiki/Smart_antenna
- https://en.wikipedia.org/wiki/Beamforming
- https://en.wikipedia.org/wiki/Precoding
- https://en.wikipedia.org/wiki/Radio_Network_Controller
- https://en.wikipedia.org/wiki/Crest_factor
- https://en.wikipedia.org/wiki/PDCP
- https://en.wikipedia.org/wiki/Crest_factor
- https://en.wikipedia.org/wiki/E-UTRA
- https://en.wikipedia.org/wiki/Policy_and_charging_rules_function
- https://en.wikipedia.org/wiki/Puncturing
- https://en.wikipedia.org/wiki/Fading
- https://en.wikipedia.org/wiki/Single-frequency_network
- https://en.wikipedia.org/wiki/Evolved_Packet_System

Student Questions

Wikipedia Links (Cont)

- https://en.wikipedia.org/wiki/Channel_allocation_schemes
- https://en.wikipedia.org/wiki/Hybrid_automatic_repeat_request
- https://en.wikipedia.org/wiki/LTE_timeline
- https://en.wikipedia.org/wiki/Flat_IP
- https://en.wikipedia.org/wiki/E-UTRA
- https://en.wikipedia.org/wiki/Mobility_Management_Entity
- https://en.wikipedia.org/wiki/System_Architecture_Evolution
- https://en.wikipedia.org/wiki/EnodeB
- https://en.wikipedia.org/wiki/Signaling_gateway
- https://en.wikipedia.org/wiki/Packet_data_serving_node
- https://en.wikipedia.org/wiki/Automatic_repeat_request
- https://en.wikipedia.org/wiki/Hybrid_automatic_repeat_request
- https://en.wikipedia.org/wiki/Beamforming
- https://en.wikipedia.org/wiki/Multimedia_Broadcast_Multicast_Service
- https://en.wikipedia.org/wiki/Broadcast/Multicast_Control
- https://en.wikipedia.org/wiki/Multicast-broadcast_single-frequency_network

Student Questions

Wikipedia Links (Cont)

- https://en.wikipedia.org/wiki/Orthogonal_frequency-division_multiple_access
- https://en.wikipedia.org/wiki/Single-carrier_FDMA
- https://en.wikipedia.org/wiki/4G
- https://en.wikipedia.org/wiki/Orthogonal_frequency-division_multiplexing
- https://en.wikipedia.org/wiki/Orthogonal_frequency-division_multiple_access
- https://en.wikipedia.org/wiki/E-UTRA
- https://en.wikipedia.org/wiki/Cooperative_MIMO
- https://en.wikipedia.org/wiki/Cyclic_prefix

Student Questions

LTE References

- Agilent Technologies, “LTE and the Evolution to 4G Wireless,” Wiley, 2009, ISBN:0470682616
- E. Dahlman, et al, “3G Evolution:HSPA and LTE for Mobile Broadband,” 2nd Edition, Academic Press, 2008, ISBN:0123745385
- 3GPP TS 36.104, “Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) radio transmission and reception (Release 8) ”
- 3GPP TR 25.913., “Requirements for Evolved UTRA (E-UTRA) and Evolved UTRAN (E-UTRAN),” v8.0.0, December 2008.
- ITU-R Report M.2134, “Requirements Related to Technical Performance for IMT-Advanced Radio Interface(s),” November 2008.
- 3GPP TR 36.913, “Requirements for Further Advancements for E-UTRA,” v8.0.1, March 2009.
- S. Sesia, I. Toufik, "LTE – The UMTS Long Term Evolution From Theory to Practice, Second Edition," Wiley , 2011, ISBN: 9780470660256, 792 pp. Safari book.

Student Questions

Acronyms

- 3GPP 3rd Generation Partnership Project
- ARQ Automatic Repeat Request
- BPSK Binary Phase Shift Keying
- BSC Base Station Controller
- BTS Base Transceiver Station
- CDMA Code Division Multiple Access
- CS Circuit Switched
- ECC Error Correcting Code
- eNB Enhanced Node B
- eNode-B Enchanced Node B
- EPC Evolved Packet Core
- EPS Evolved Packet System
- FDD Frequency Division Duplexing
- FDMA Frequency Division Multiple Access
- FEQ Frequency Domain Equalizer
- FFT Fast Fourier Transform

Student Questions

Acronyms (Cont)

- FSTD Frequency-Shift Transmit Diversity
- GERAN GSM/EDGE Radio Access Network
- GGSN Gateway GPRS Support
- GPRS General Packet Radio Service
- GSM Global System for Mobile Communications
- GW Gateway
- HSPA High-Speed Packet Access
- IEEE Institution of Electrical and Electronic Engineers
- IMS Internet Multimedia System
- IMT-Advanced International Mobile Telecommunications Advanced
- IP Internet Protocol
- ITU International Telecommunications Union
- kHz Kilo Hertz
- LTE Long Term Evolution
- MAC Message Authentication Code
- MBMS Multicast-Broadcast Mobile Services

Student Questions

Acronyms (Cont)

- MGW Media Gateway
- MHz Mega Hertz
- MIMO Multiple Input Multiple Output
- MME Mobility Management Entity
- MS Mobile Station
- MSC Mobile Switching Center
- OFDM Orthogonal Frequency Division Modulation
- OFDMA Orthogonal Frequency Division Multiple Access
- PAPR Peak-to-Average Power Ratio
- PCRF Policy and Charging Rules Function
- PDFICH Physical Control Format Indicator Channel
- PDN Packet Data Network
- PGW Packet Data network Gateway
- PHY Physical Layer
- PS Packet Switched
- QAM Quadrature Amplitude Modulation

Student Questions

Acronyms (Cont)

QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RAN	Radio Access Network
RNC	Radio Network Control
SAE	Service Access Gateway
SC-FDMA	Single Carrier Frequency Division Multiple Access
SC	Single Carrier
SF	Subframe
SFBC	Space Frequency Block Code
SGSN	Service GPRS Support
SGW	Serving Gateay
SINR	Signal to Interference and Noise Ratio
SN	Sequence Number
SNR	Signal-to-noise ratio
SOstart	Begining of Segment

Student Questions

Acronyms (Cont)

- STBC — Space Time Block Code
- SU — Superframe
- TD-SCDMA — Time Division Synchronous Code Division Multiple Access
- TDD — Time Division Duplexing
- TDMA — Time Division Multiple Access
- UE — User Element
- UMTS — Universal Mobile Telecommunications System
- UTRAN — UMTS Terrestrial Radio Access Network
- VTC — Vehicular Technology Conference
- WCDMA — Wideband Code Division Multiple Access
- WiMAX — Worldwide Interoperability for Microwave Access

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http://rajjain.com

http://www.cse.wustl.edu/~jain/cse574-24/j_17lte.htm

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Related Modules

CSE567M: Computer Systems Analysis (Spring 2013),
https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n_1X0bWWNyZcof

CSE473S: Introduction to Computer Networks (Fall 2011),
https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8Azcgy5e_10TiDw

Recent Advances in Networking (Spring 2013),
https://www.youtube.com/playlist?list=PLjGG94etKypLHyBN8mOgwJLHD2FFIMGq5

CSE571S: Network Security (Fall 2011),
https://www.youtube.com/playlist?list=PLjGG94etKypKvzfVtutHcPFJXumyyg93u

Video Podcasts of Prof. Raj Jain's Lectures,
https://www.youtube.com/channel/UCN4-5wzNP9-ruOzQMs-8NUw

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