Lec29

Tuesday, March 6, 2018 10:07 AM

Resource Grid

Tuesday, March 24, 2020 5:18 PM

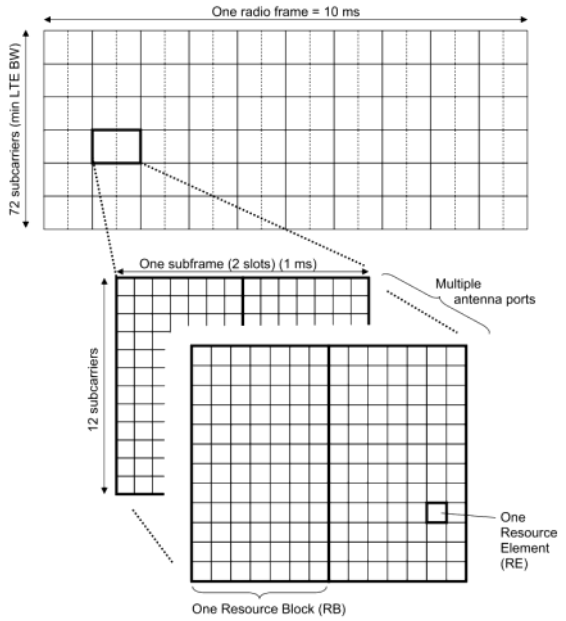


Figure 6.1: Basic time-frequency resource structure of LTE (normal cyclic prefix case).

- Each RE is one symbol over one subcarrier.
  - 2-6 bits depending on modulation
- Each RB spans 12 subcarriers & 0.5 ms (slot)
  - unit for scheduling
- LTE allows different total BW from 1.4 MHz to 20 MHz

Total bandwidth	Number of resource blocks	Number of sub-carriers	Occupied bandwidth	Usual guard bands
1.4 MHz	6	72	1.08 MHz	2×0.16 MHz
3 MHz	15	180	2.7 MHz	2×0.15 MHz
5 MHz	25	300	4.5 MHz	2×0.25 MHz
10 MHz	50	600	9 MHz	2×0.5 MHz
15 MHz	75	900	13.5 MHz	2×0.75 MHz
20 MHz	100	1200	18 MHz	2×1 MHz

≈ 2G CDMA
≈ WCDMA

↑

20 MHz	100	1200	18 MHz	2 × 1 MHz

Table 6.7 Cell bandwidths supported by LTE

note the different # of RBs

An example of the downlink/uplink mapping of the resource grid.

– FDD, 5MHz, normal cyclic prefix.

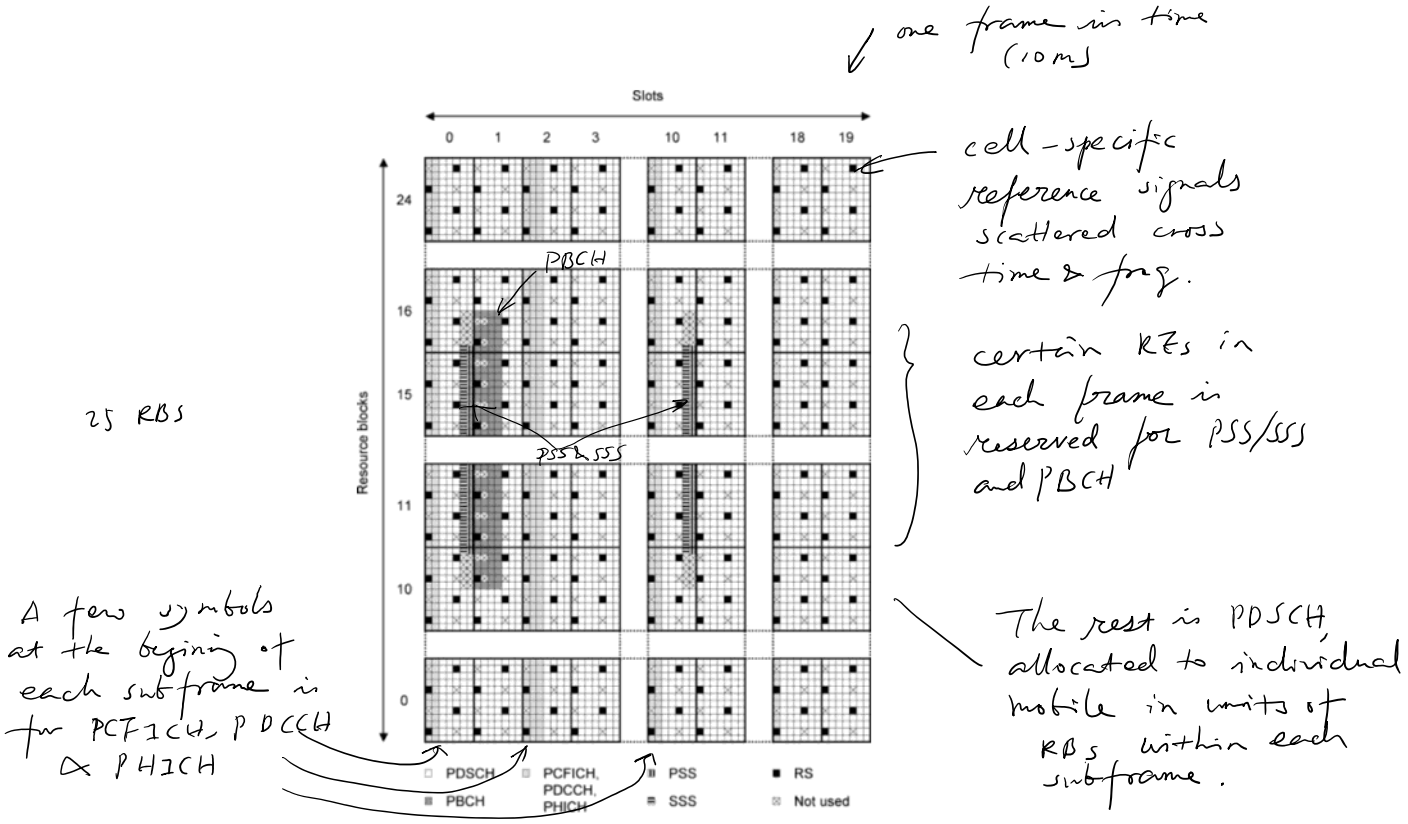
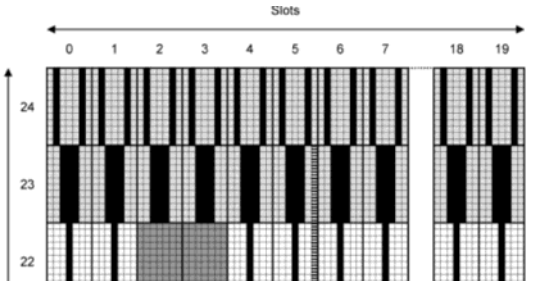
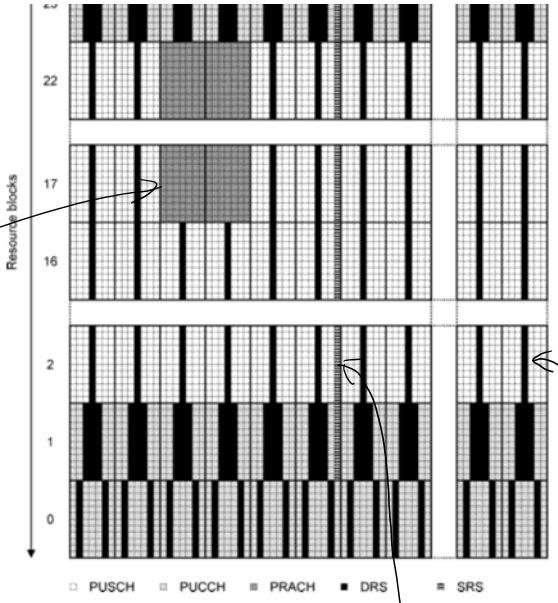


Figure 6.10 Example mapping of physical channels to resource elements in the downlink, using FDD mode, a normal cyclic prefix, a 5MHz bandwidth, the first antenna port of two and a physical cell ID of 1





Certain RBs reserved by the BS for PRACH (6 RBs, 1 to 3 subframes)

The rest is PUSCH, allocated to individual mobiles in units of RBs within each subframe.

DM-RS: reference signal associated with data. 1 symbol per slot

The last symbol for some subframe is used for SRS, shared by all UEs via freq or code-division multiplexing.

Figure 6.11 shows the corresponding situation on the uplink. The figure assumes the use of FDD mode, the normal cyclic prefix and a bandwidth of 5MHz.

Reference:

Chapter 6.2, S. Sesia, I. Toufik, and M. Baker, "LTE-the UMTS long term evolution: from theory to practice," John Wiley & Sons, 2011. (available online from Purdue library.)

Reference signals in the DL

Sunday, February 25, 2018 8:38 PM

- To enable channel-dependent scheduling, the UE needs to measure the channel condition continuously
- In the DL, BS broadcast reference signals at designated REs

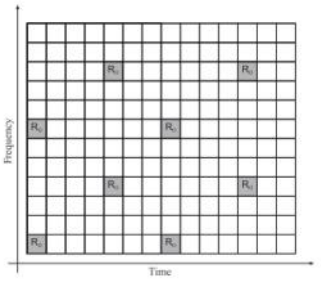
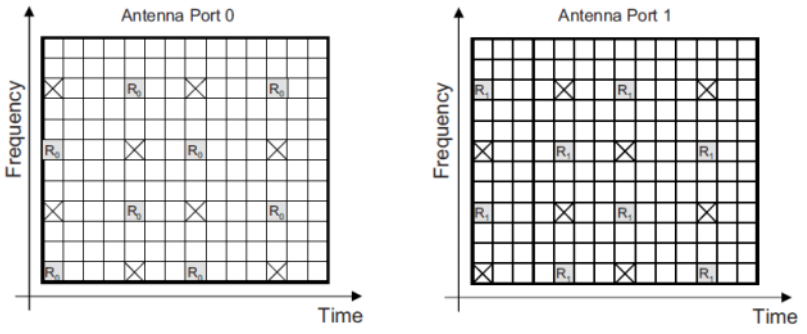


Figure 8.2: Cell-specific reference symbol arrangement in the case of normal CP length for one antenna port. Reproduced by permission of © 3GPP.

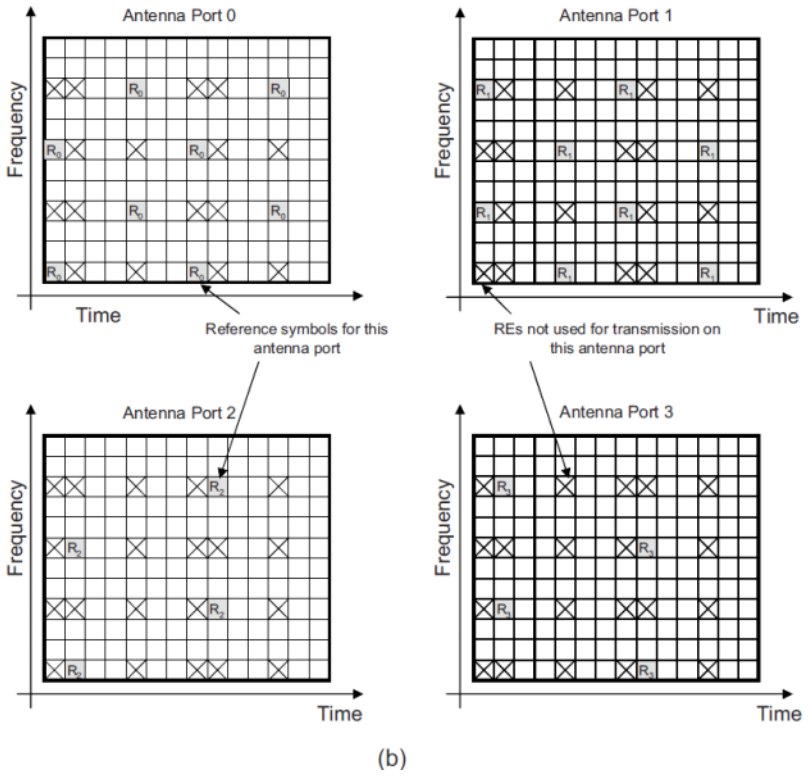
- see above for single antenna



(a)

two antenna

2/25/2018 8:41 PM - Screen Clipping



(b)

2/25/2018 8:41 PM - Screen Clipping

- UL needs control channel to feedback the channel measurement.
- UE measurement is reported to the BS using PUCCH (Physical uplink control channel)

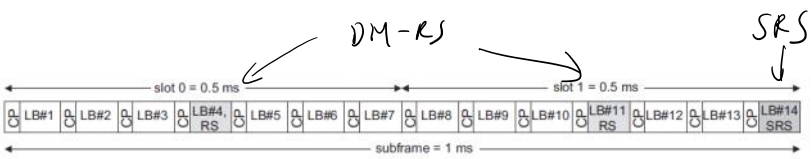
Reference:
Chapter 8.2, S. Sesia, I. Toufik, and M. Baker, "LTE-the UMTS long term evolution: from theory to practice," John Wiley & Sons, 2011. (available online from Purdue library.)

Uplink reference signals

Monday, February 26, 2018 11:32 AM

- Uplink reference signal is divided into two types
  - Those associated with data or control channel traffic
    - Demodulation RS (DM-RS)
    - mainly for channel estimation for coherent demodulation
  - Those not associated with data or control traffic.
    - Sounding RS (SRS)
    - channel quality determination to enable UL scheduling.

- The design of SRS is trickier in the UL
  - In the DL, the BS is the only transmitter. One set of RS is sufficient
  - In the UL, multiple transmitters all need to provide RS.
  - SRS need to be over the entire band for scheduling purpose
  - Need some way of multiplexing.
- In LTE, SRSs are transmitted on the last SC-FDMA symbol in a subframe.
  - UEs transmitting SRS in the same subframe are multiplexed via either freq or code division multiplexing
- DM-RS is sent on one or two symbol per slot.



LB = 1 symbol

Figure 15.8: Uplink subframe configuration with SRS symbol.

3/1/2018 2:41 PM - Screen Clipping

- The # of subframes that SRS are transmitted can be adjusted. (or completely shut off).
- Each UE is assigned a subset of freq & time to send SRS
  - Otherwise, the UE may not have sufficient power, or the # of simultaneous UE is small.
- Multiple UEs on the same subframe can use different orthogonal code.
  - No interference within cell, but there will be interference from other cell
  - pilot contamination.

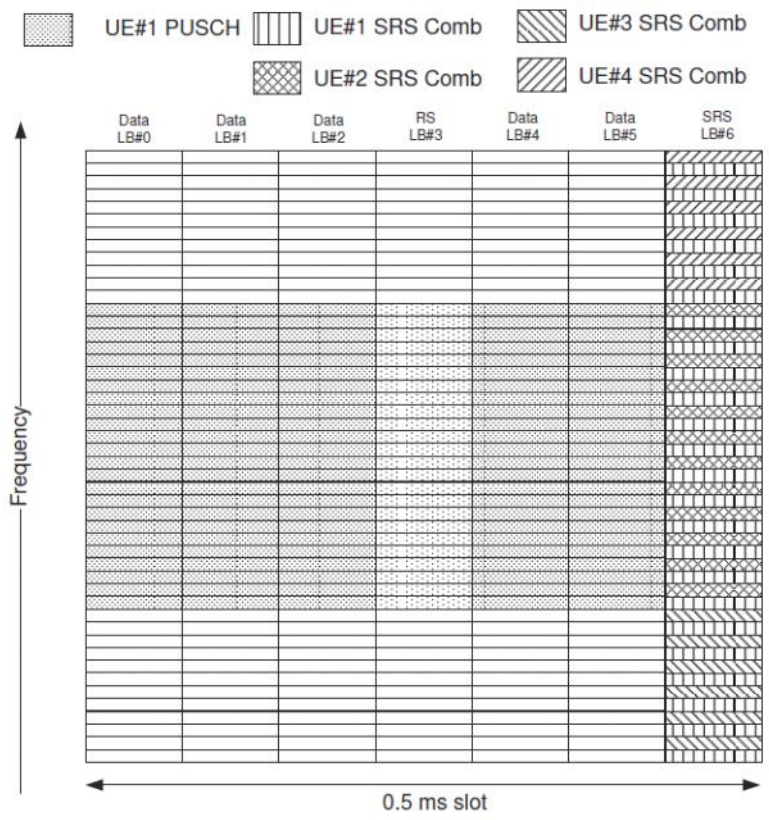


Figure 15.9: SRS symbol structure with RPF = 2.

3/1/2018 2:51 PM - Screen Clipping

— DS means SRS

— For PUCCH, DR-MS & SRS locations are different. (Chapter 16.3.3 & 16.3.5)

Reference:
Chapter 15.1, 15.5, 15.6, S. Sesia, I. Toufik, and M. Baker, "LTE-the UMTS long term evolution: from theory to practice," John Wiley & Sons, 2011. (available online from Purdue library.)

Resource allocation decisions - 10min

Sunday, February 25, 2018 8:47 PM

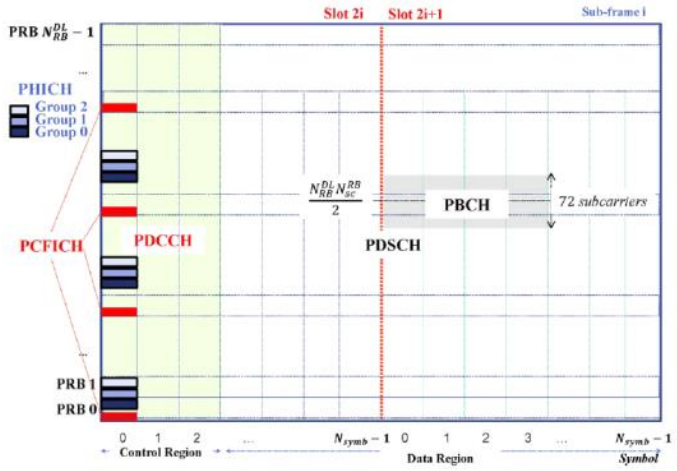


Fig. 10. DL control information: PCFICH, PHICH, PBCH, PDCCH, PDSCH.

- Once the BS acquires UL & DL CQI, it can schedule both UL & DL transmissions
- Such decision is conveyed to the UEs using the PDCCH (Physical downlink control channel)
- PDCCH occupies the first 1, 2, or 3 symbols in a subframe
- Variable length

TABLE V
PDCCH FORMAT

PDCCH Format	Number of CCEs	Number of Resource Element Groups	# PDCCH bits
0	1	9	72
1	2	18	144
2	4	36	288
3	8	72	576

- each REG contains 4 symbols
- 9 REGs form a CCE (control channel element)
- Each PDCCH is sent using one or more CCEs (variable length)

2/25/2018 8:30 PM - Screen Clipping

- In order for the UE to know which PDCCH

message is intended for the UE
- instead of using an ID field
- use a UE specified scrambling code on the CRC → intended UE will see correct CRC

- The length is indicated by the PCFICH.
  - known as CFI (control format indicator)

How to encode scheduling decisions?

- Have to strike a balance between flexibility & overhead.
- One extreme is that the UE can be assigned an arbitrary set of freq in each sub-frame
  ⇒ bit-map of RBs assigned
  - When the BW is large (eg. 20MHz ⇒ ≥ 100RB), the bit-map can incur significant overhead.
  - Particularly problematic for small packets (e.g. voice)
- One way to reduce overhead is to group RBs into groups of 2, 3, or 4 RBs, and use bit-map to indicate each RBG.
  - This helps to control the DCI payload to be around 20~50 bits for all BWs

TABLE X
DL RESOURCE ALLOCATION TYPE 0 WITH DCI FORMAT 1

Bits	DCI Format 1
0 or 3	**Carrier Indicator (Rel. 10-11)**
1	**Resource Allocation Header**: Set to **0**

TABLE X
DL RESOURCE ALLOCATION TYPE 0 WITH DCI FORMAT 1

Bits	DCI Format 1
0 or 3	**Carrier Indicator (Rel. 10-11)**
1	**Resource Allocation Header**: Set to **0**
$\left\lceil \frac{N_{RB}^{DL}}{P} \right\rceil$	**Resource Allocation Type 0** $\left\lceil \frac{N_{RB}^{DL}}{P} \right\rceil$: *Resource Assignment*
5	***MCS***
3 or 4	**HARQ Process number** : 3 for FDD, 4 for TDD
1	**New Data Indicator**
2	**Redundancy Version**
2	**TPC command for PUCCH**
2	**Downlink Assignment Index** : TDD
2	**HARQ ACK resource offset for EPDCCH (Rel. 11)**

Type 0, format 1

3/2/2018 7:34 AM - Screen Clipping

— The other extreme is to restrict to a contiguous range of RBs
— only need to specify the starting RB & length
— restrict the flexibility in assignments
— natural for uplink
— # of bits as low as 2 4.

TABLE XIV
DL RESOURCE ALLOCATION TYPE 2 WITH DCI FORMAT 1A

Bits	DCI Format 1A
0 or 3	**Carrier Indicator in Rel. 10-11**
1	Format Flag **: Set to 1**
-	**Random Access Initiated** - 1 bit : set to **0** (Localized VRB) - $\left\lceil \log_2\left(\frac{N_{RB}^{DL}(N_{RB}^{DL}+1)}{2}\right) \right\rceil$ bits : Resource Assignment : **all bits set to 1** **Setting** : 6 bits (Preamble Index), 4 bits (PRACH Mask Index) **Otherwise** - 1 bit : **0** (Localized VRB) or **1** (Distributed VRB) - $\left\lceil \log_2\left(\frac{N_{RB}^{DL}(N_{RB}^{DL}+1)}{2}\right) \right\rceil$ bits : Resource block assignment -- For distributed VRB and $N_{RB}^{DL} \geq 50$ and not associated with RA/P/SI-RNTI* **1** bit for gap indicator + $\left\lceil \log_2\left(\frac{N_{RB}^{DL}(N_{RB}^{DL}+1)}{2}\right) \right\rceil - 1$ bits - 5 bits : ***MCS*** - 3 or 4 bits : **HARQ process number** : 3 bits (FDD) , 4 bits (TDD) - 1 bit : **New data indicator** - 2 bits : **Redundancy version** - 2 bits : **UL Power Control** (PUCCH) - 2 bits **: Downlink Assignment Index** (TDD, not FDD) - **0 or 1 bit** : SRS Request in Rel. 10-11 - **2 bits** : HARQ ACK resource offset for EPDCCH in Rel. 11

*RNTI (Radio Network Temporary Identifier)
P-RNTI (for Paging), RA-RNTI (for Random Access), SI-RNTI (for System Information)

— type 2 format 1A
— contiguous VRB is then mapped to RBs via a predefined permutation.

— Further, UEs can be constrained to search only a subset of PDCCH resources to conserve energy

Finally, for short, voice packets, LTE allows "distributed scheduling"

The mapping of data to physical RBs can be carried out in one of two ways: *localized mapping* and *distributed mapping*.[5]

Localized resource mapping entails allocating all the available REs in a pair of RBs to the same UE. This is suitable for most scenarios, including the use of dynamic channel-dependent scheduling according to frequency-specific channel quality information reported by the UE (see Sections 10.2.1 and 12.4).

Distributed resource mapping entails separating in frequency the two physical RBs comprising each pair, with a frequency-hop occurring at the slot boundary in the middle of the subframe, as shown in Figure 9.3. This is a useful means of obtaining frequency diversity for small amounts of data which would otherwise be constrained to a narrow part of the downlink bandwidth and would therefore be more susceptible to narrow-band fading. An example of a typical use for this transmission mode could be a Voice-over-IP (VoIP) service, where, in order to minimize overhead, certain frequency resources may be 'semi-persistently scheduled' (see Section 4.4.2.1) – in other words, certain RBs in the frequency domain are allocated on a periodic basis to a specific UE by Radio Resource Control (RRC) signalling rather than by dynamic PDCCH signalling. This means that the transmissions are not able to benefit from dynamic channel-dependent scheduling, and therefore the frequency diversity which is achieved through distributed mapping is a useful tool to improve performance. Moreover, as the amount of data to be transmitted per UE for a VoIP service is small (typically sufficient to occupy only one or two pairs of RBs in a given subframe), the degree of frequency diversity obtainable via localized scheduling is very limited.

3/2/2018 8:21 AM - Screen Clipping

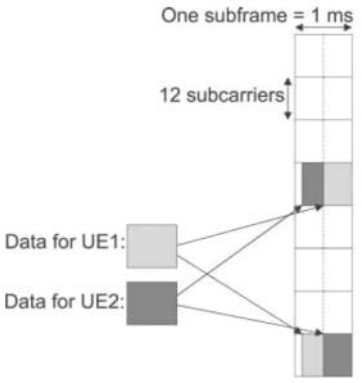


Figure 9.3: Frequency-distributed data mapping in LTE downlink.

3/2/2018 8:21 AM - Screen Clipping

Reference:

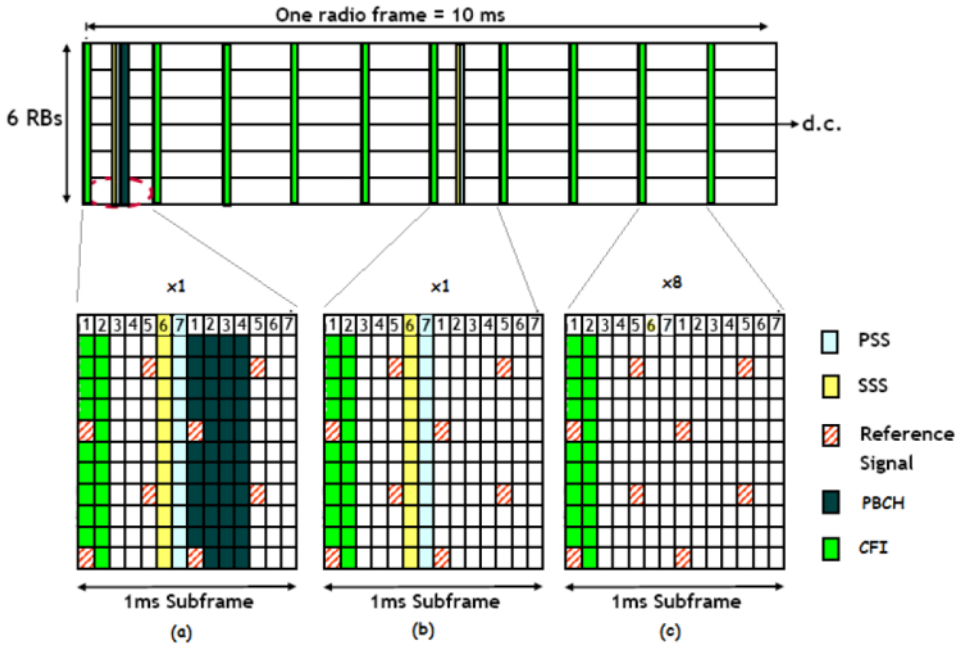
Section V.A, G. Ku and J. M. Walsh, "Resource Allocation and Link Adaptation in LTE and LTE Advanced: A Tutorial," *IEEE Communication Surveys & Tutorials*, vol. 17, no. 3, 2015.

Chapter 9.3.5, S. Sesia, I. Toufik, and M. Baker, "LTE-the UMTS long term evolution: from theory to practice," John Wiley & Sons, 2011. (available online

from Purdue library.)

Downlink control channels - 10min

Sunday, February 25, 2018 8:00 PM



Four types of control channels in the DL

- PBCH: physical broadcast channel
  - essential system info of the cell
- PDCCH: physical downlink control channel
  - UL/DL scheduling decisions
  - link adaptation
- PHICH: physical hybrid-ARQ indicator channel
  - Ack of UL transmissions
- PCFICH: physical control format indicator channel
  - size of the control block

- They are mapped to the resource grid in a non-overlapping manner in the following order

PCFICH → PHICH → PDCCH → PBCH → PDSCH (→ traffic channel)

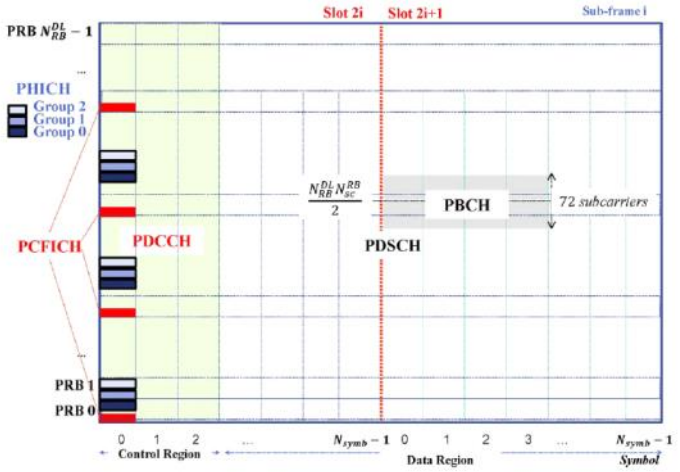


Fig. 10. DL control information: PCFICH, PHICH, PBCH, PDCCH, PDSCH.

2/25/2018 8:06 PM - Screen Clipping

PCFICH

- every DL subframe (1ms) contains a portion of the control information
- They can occupy the first 1, 2, or 3 symbols in time.
- The length is indicated by the PCFICH.
  - known as CFI (control format indicator)
- PCFICH contains 16 REs, in group of 4 (called RE Group), and is at the first OFDM symbol of

every DL subframe at 4 given freq locations

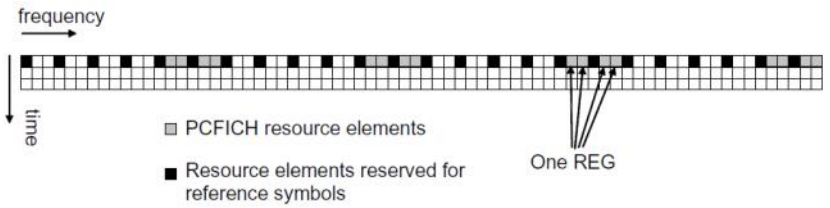


Figure 9.6: PCFICH mapping to Resource Element Groups (REGs).

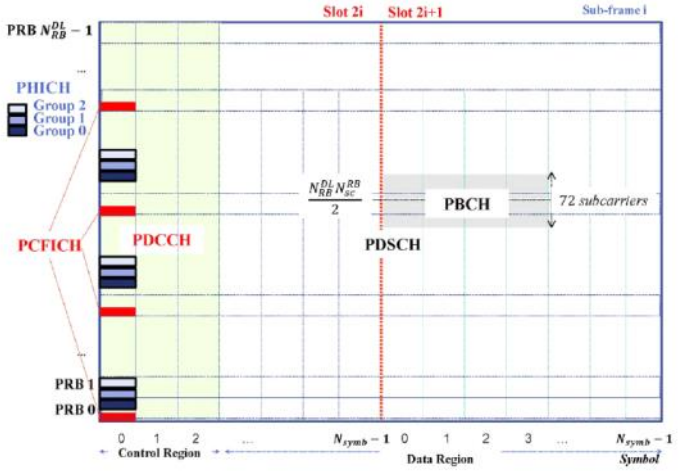
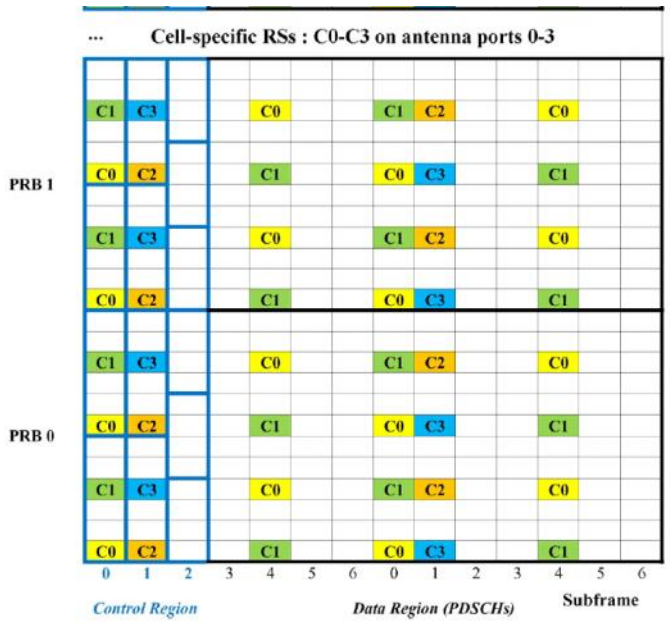


Fig. 10. DL control information: PCFICH, PHICH, PBCH, PDCCH, PDSCH.

- In this way, the amount of control overhead can be tuned based on the total BW etc.
- Depending on the value of CFI, RBs are organized in REGs



Note that some REs are already taken out for RS.

how to specify which UE?

PHICH:

- ACK or NACK for UL transmission
- LTE uses a group-wise HARQ process
  - each group consists of 4 or 8 UEs
  - separated by orthogonal Walsh codes
  - each group is mapped to 3 freq. locations

PDCCH

- time/freq scheduling information
- Variable length

TABLE V
PDCCH FORMAT

PDCCH Format	Number of CCEs	Number of Resource Element Groups	# PDCCH bits
0	1	9	72
1	2	18	144
2	4	36	288
3	8	72	576

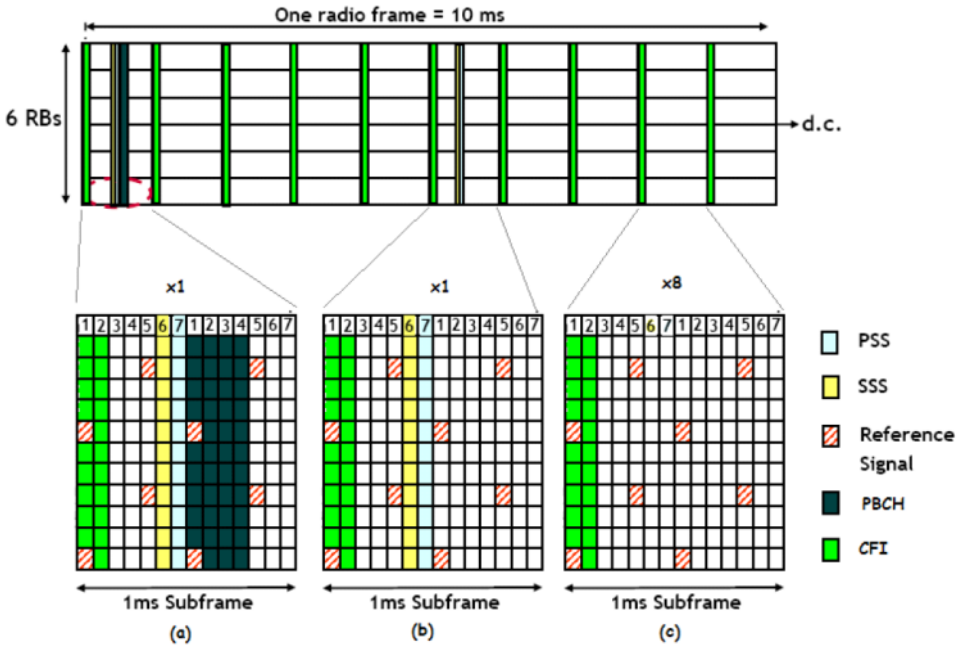
- In order for the UE to know which PDCCH message is intended for the UE
  - instead of using an ID field
  - use a UE specified scrambling code along with CRC checking.

PBCH

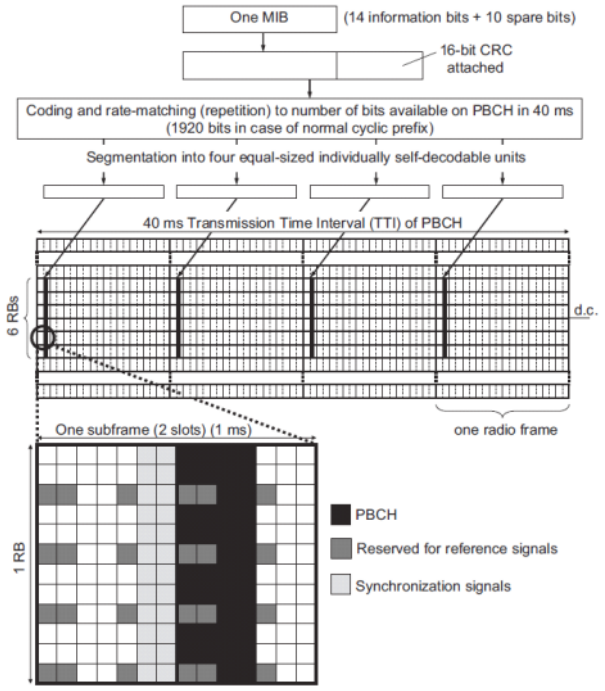
- essential system information before normal data transmission (MIB)
  - # of PRBs
  - FDD/TDD

  } master information block (MIB)

- every 40 ms (4 frame)
  - 4 symbols in the first subframe of each frame
  - over the center 6 PRB (72 subcarrier).



2/25/2018 8:35 PM - Screen Clipping



2/25/2018 8:36 PM - Screen Clipping

Reference:

Section IV.A, G. Ku and J. M. Walsh, "Resource Allocation and Link Adaptation in LTE and LTE Advanced: A Tutorial," *IEEE Communication Surveys & Tutorials*, vol. 17, no. 3, 2015.

Chapter 9, S. Sesia, I. Toufik, and M. Baker, "LTE-the UMTS long term evolution: from theory to practice," John Wiley & Sons, 2011. (available online from Purdue library.)

Synchronization signals

Sunday, February 25, 2018 8:42 PM

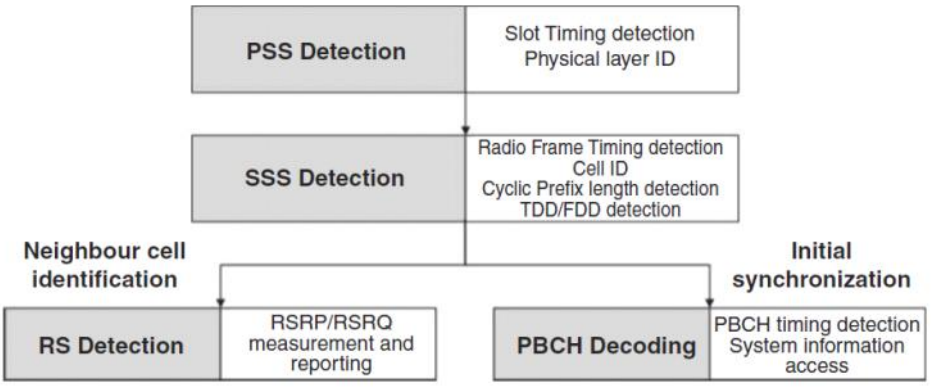


Figure 7.1: Information acquired at each step of the cell search procedure.

3/2/2018 8:05 AM - Screen Clipping

- Synchronization signals allow UEs to perform cell search
  - Acquire cell id, CP length, FDD/TDD
  - frame synchronization (of the 10ms frame)
- Both PSS and SSS are at the central 6 RBs. Allow UEs to work with any BW.
-

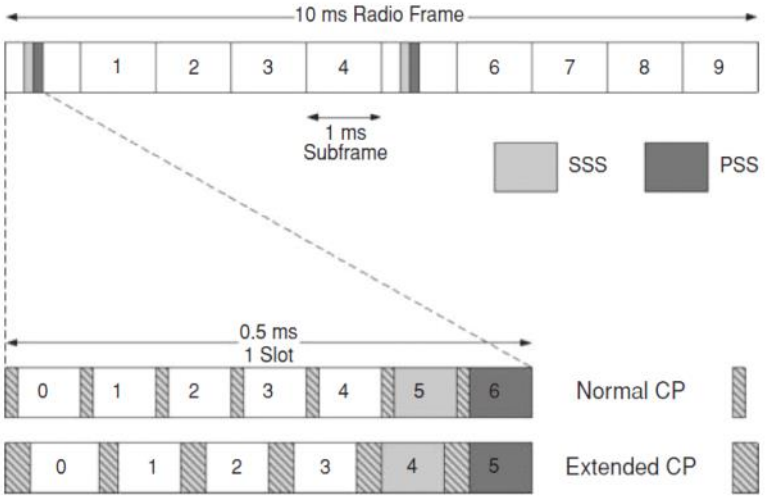


Figure 7.2: PSS and SSS frame and slot structure in time domain in the FDD case.

3/2/2018 8:08 AM - Screen Clipping

- PSS is always at the last symbol of the 1st and 11th slot
  - position independent of the CP
- SSS is right before it.
  - The two SSS use different spreading codes, enable UEs to detect frame synchronization
  - UE checks the two CPs + detect SSS.

Reference:

Chapter 7.1, 7.2, S. Sesia, I. Toufik, and M. Baker, "LTE-the UMTS long term evolution: from theory to practice," John Wiley & Sons, 2011. (available online from Purdue library.)