UMTS Long Term Evolution (LTE)

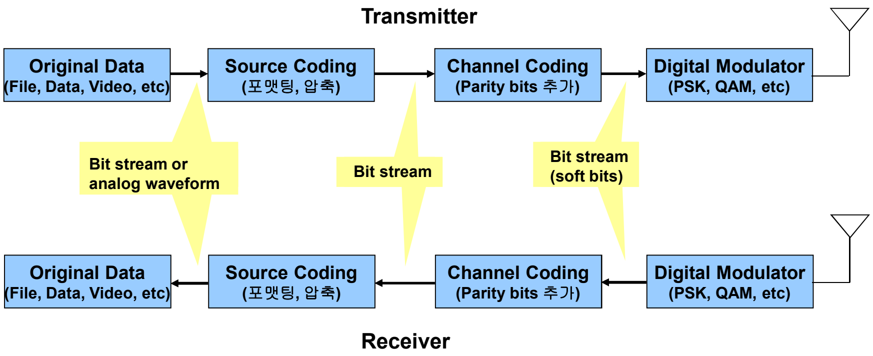
안 수 현
suhyun.an@rohde-schwarz.com

Rohde & Schwarz, Korea

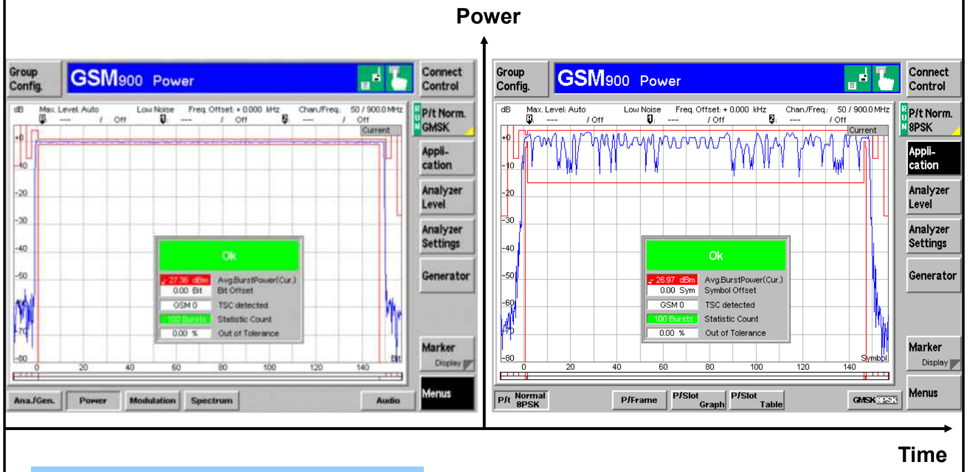
ROHDE&SCHWARZ

Standard Overview

Data 처리 Processing



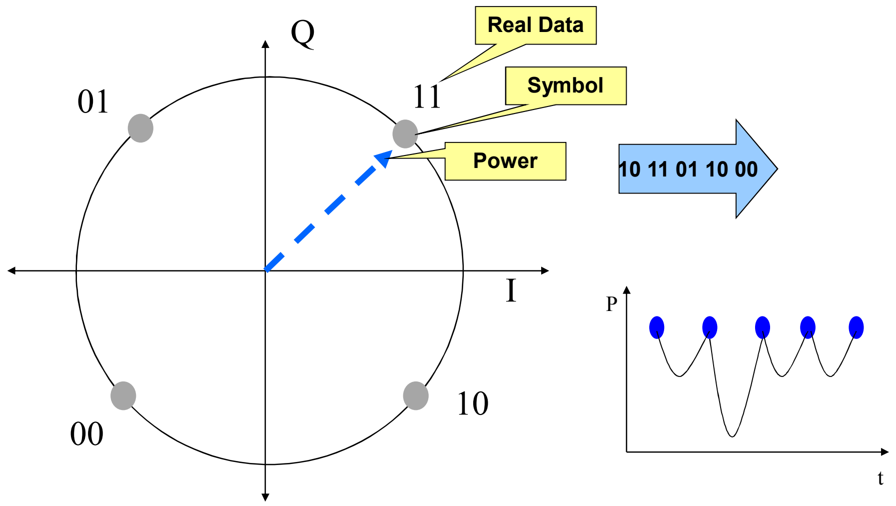
GSM vs EGPRS



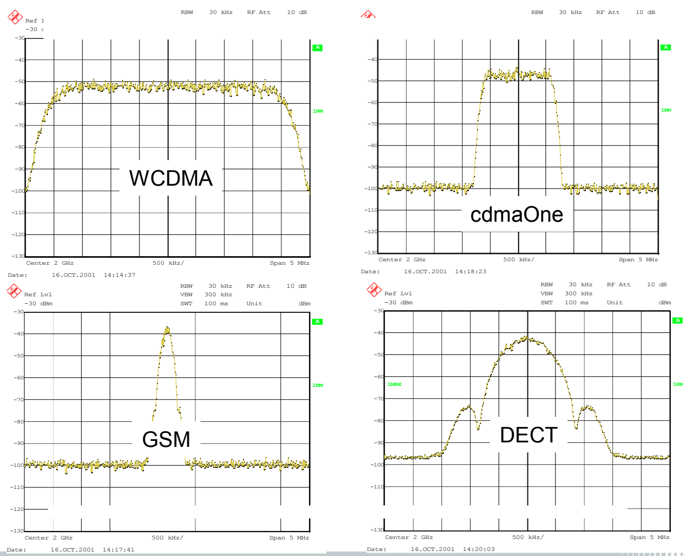
Time Domain 상에 전송되는 Data ???

해당 **Data**가 가지는 **Power**는???

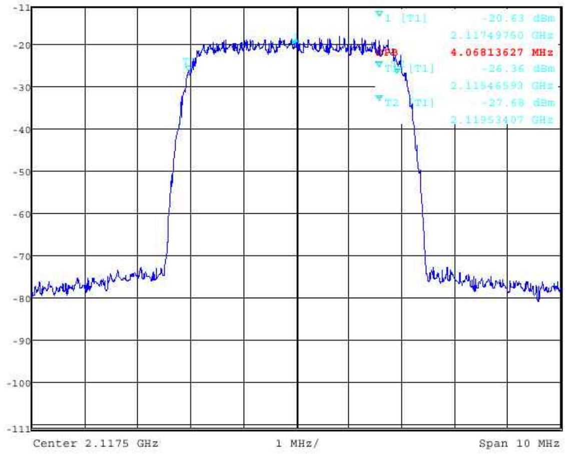
Digital Modulation



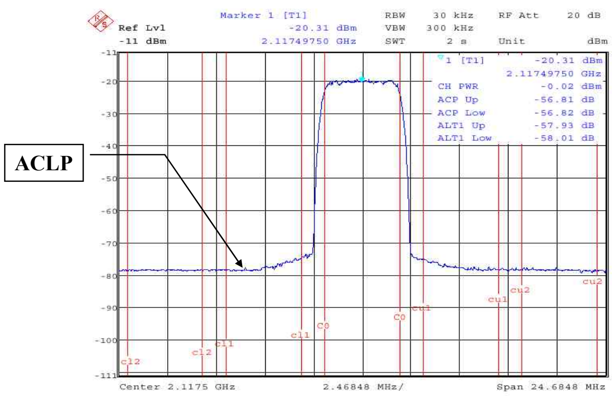
3GPP RTT Spectra



Occupied Bandwidth



ACLR Measurement

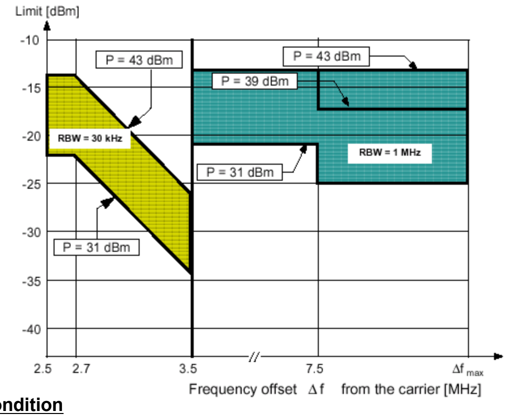


Condition

Max. TX Power

At ±5MHz/ ± 10MHz, RMS or Average Pwr

Spectrum Emission Mask Limits



Condition

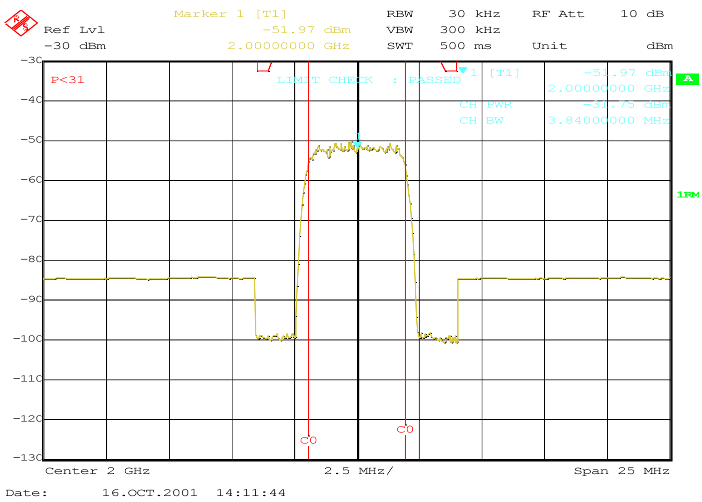
Max. TX Power

Reference : 3.84 RRC Filter

At 2.5MHz~12.5MHz, RMS or Average Pwr

30KHz(±2.5MHz~ ± 3.84MHz)/1MHz(4MHz~12MHz) Gaussian Filter

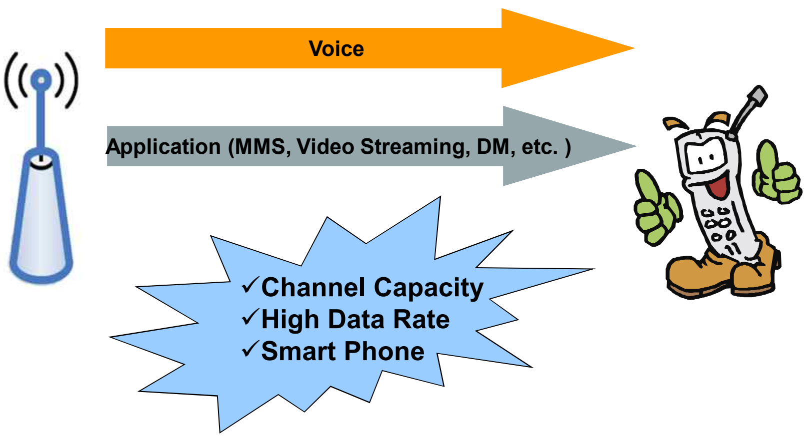
Spectrum Emission Mask



Overview

- 1991 : GSM
- 1995~8 : GPRS/EGPRS
- 1997~9 : WCDMA
- 2005 : HSDPA
- 2004~5 : WiMAX
- 2006 : HSUPA
- 2007 : HSPA+
- 2008 : LTE
- 4G : ???

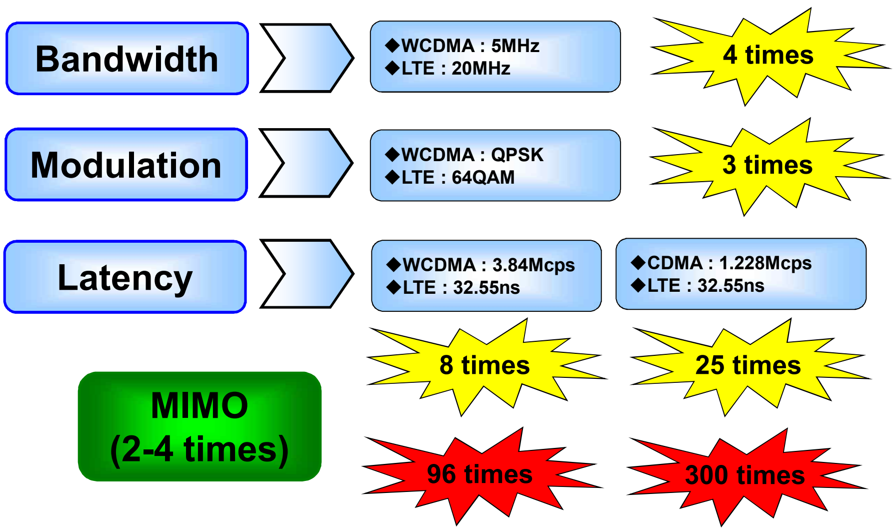
Why we need new technology ?



How to increase the data rate?

1. **Bandwidth**
2. **Modulation Scheme**
3. **MIMO**
4. **Occupied time**
5. **Packet Switched**
6. **Processing time ➔ Reduced Structure**

How?



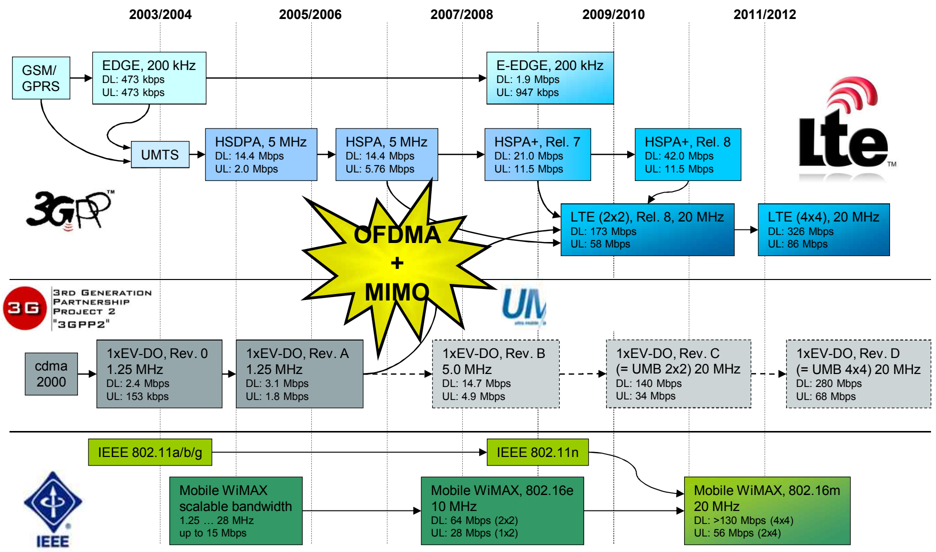
How to Increase the data rate?

1991 : GSM	14.4 Kbps	Circuit Switched 1 time slot per channel(200KHz) GMSK Modulation
1995~8 : GPRS/EGPRS	171.2 / 473.6 Kbps	Packet Switched / ~ 8 time slots / Coding Scheme Modulation(8PSK)
1997~9 : WCDMA	384 Kbps ~ 2Mbps	3.84M BW, QPSK / Dual-BPSK CDMA 방식 + 단일 Code Circuit & Packet Switched
2005 : HSDPA	14.4 Mbps (D/L only)	Packet Switched only Multi-code Modulation(16QAM)
2004~5 : WiMAX	70/35Mbps(D.L/U.L)	Packet Switched only / 10M BW OFMDA+MIMO Modulation(64QAM)
2006 : HSUPA	5.76 Mbps (U/L only)	Packet Switched Multi-code Dual-BPSK
2007 : HSPA+	28/11Mbps(D.L/U.L)	MIMO Modulation(64QAM/16QAM)
2008 : LTE	100/50Mbps(D.L/U.L)	Packet Switched only / 20M BW OFMDA+MIMO Modulation(64QAM)
4G : ???	1/0.5Gbps(D.L/U.L)	OFMDA+MIMO base Modulation ??BW

Why???

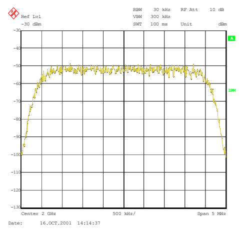
Overview:
Market Trend

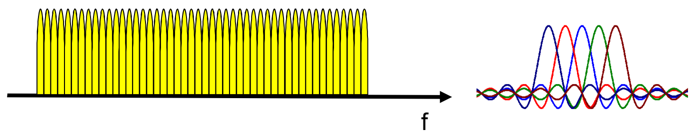
Today's technology evolution path

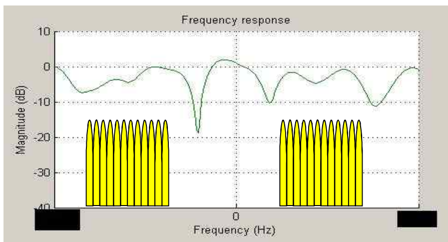


ROHDE&SCHWARZ Date | Title of presentation | 17

OFDM





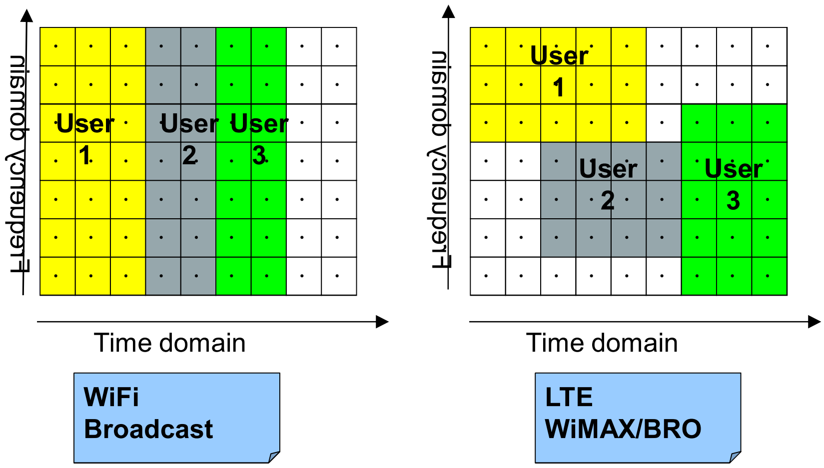


✓Frequency Selectivity!!

✓Better than 1 carrier based system!!

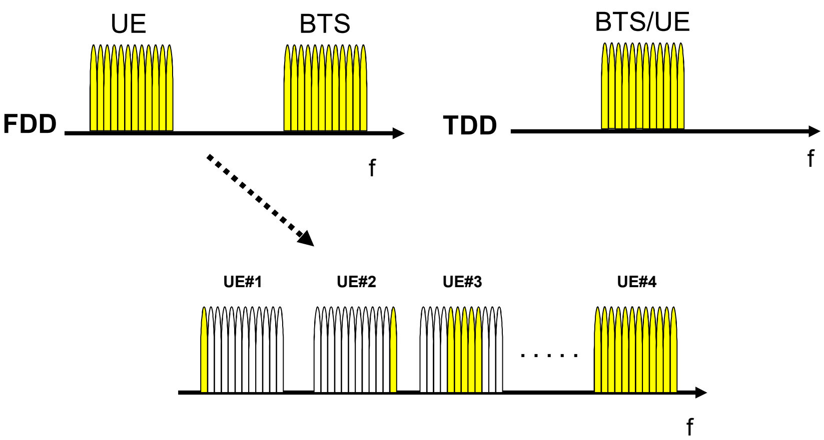
ROHDE&SCHWARZ Date | Title of presentation | 18

OFDM vs OFDMA



ROHDE&SCHWARZ Date | Title of presentation | 19

FDD vs TDD



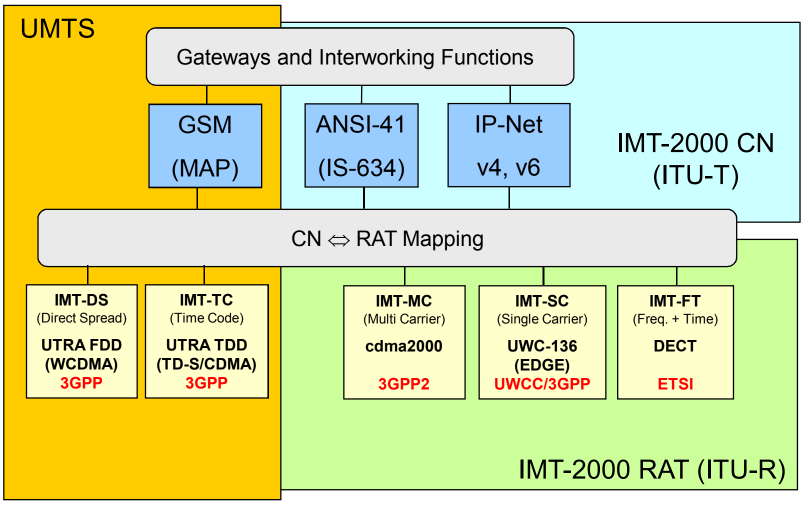
ROHDE&SCHWARZ Date | Title of presentation | 20

UMTS Long Term Evolution (LTE) Ambitious targets

- Significantly increased **peak data rate** e.g. 150 Mbps (downlink) and 75 Mbps (uplink)
- Significantly improved **spectrum efficiency** (e.g. 2-4 x Release 6)
- Improved **latency**:
  - Possibility for a radio access network latency (user plane UE – RNC - UE) below 10 ms
  - Significantly reduced control plane latency
- Scaleable **bandwidth**
  - 5, 10, 15, 20 MHz
  - Smaller bandwidths to allow flexibility in narrow spectral allocations
- Support for **inter-working** with existing 3G systems and non-3GPP specified systems (CDMA2000/WiMAX/etc.)
- Reduced **CAPEX and OPEX** including backhaul
- Cost effective **migration** from release 6 UTRA radio interface and architecture
- Efficient support of the various types of services, especially from the **PS domain**
- System should be optimized for **low mobile speed** but also support high mobile speed
- Operation in **paired and unpaired** spectrum should not be precluded (FDD and TDD modes)
- Enhanced Multimedia Broadcast Multicast Services (**E-MBMS**)

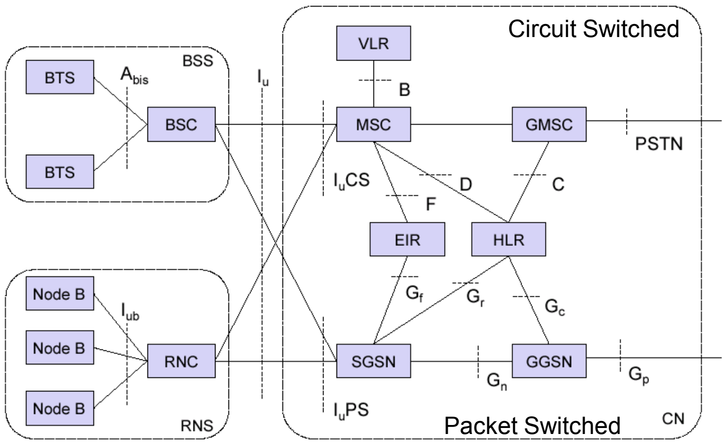
Network Structure

Network Architecture



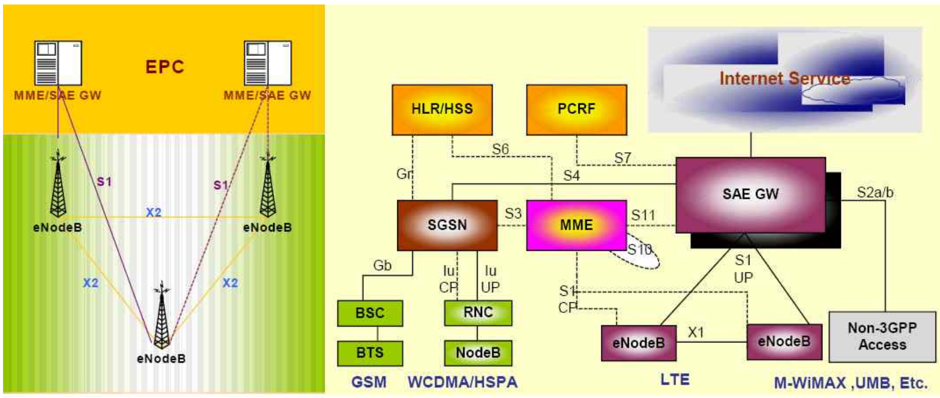
ROHDE&SCHWARZ Date | Title of presentation | 23

Network Architecture – 3GPP



ROHDE&SCHWARZ Date | Title of presentation | 24

Network Architecture – 3GPP+LTE



EPC:Evolved Packet Core, MME:Mobility Management Entity

LTE Protocol Architecture
New network elements and functional split

eNB functions:

- RRM, Radio Bearer Control, Radio Admission Control, Connection Mobility Control, Scheduling for uplink and downlink
- IP header compression and encryption of user data stream
- Selection of an MME at UE attachment
- Routing of user plane data towards SAE Gateway
- Scheduling and transmissino of paging messages originated from MME
- Scheduling and transmission of broadcast informationoriginated from MME or O&M
- Measurement and measurement reporting configuration

MME functions:

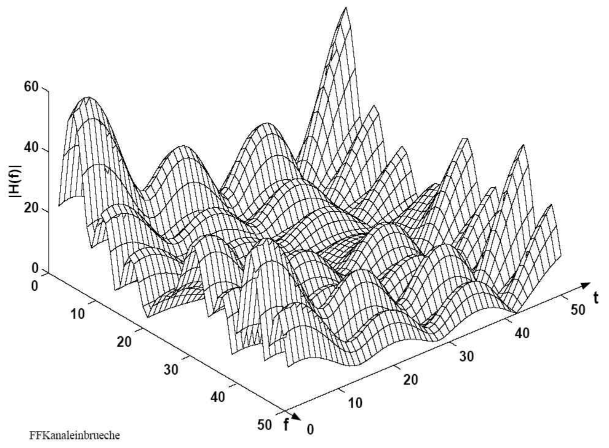
- Distribution of paging messages to eNBs
  - Security Control
- Idle state mobility control
- SAE bearer ccontrol
- Ciphering and integrity protection of NAS Signalling

SAE Gateway:

- Termination of user plane packets for paging reasons
- Switching of user plane for support of UE mobility

OFDMA

Wideband Signal



Non-Linear System

Fading

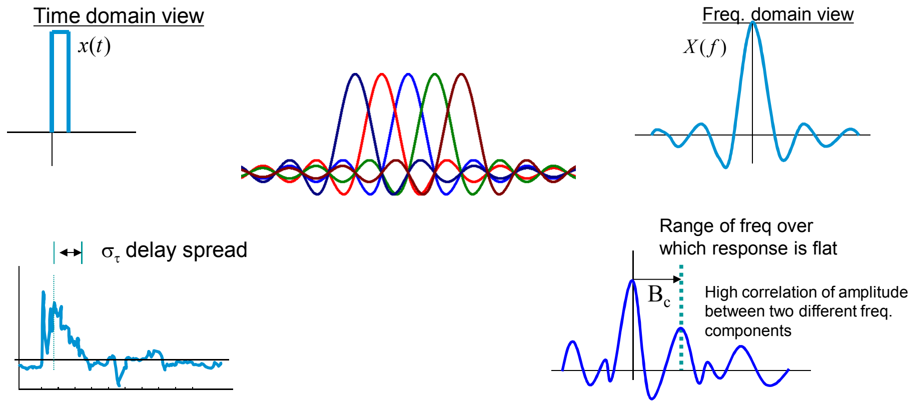
SINR

Amp. Design

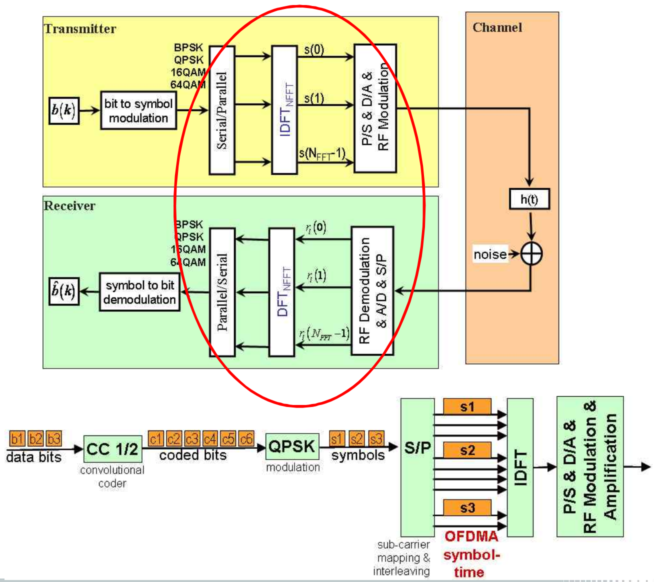
Scalable BW

Coherence Bandwidth

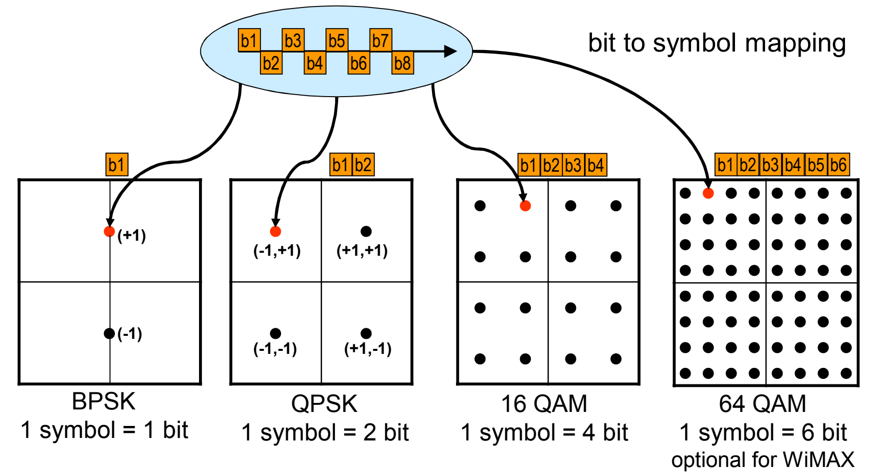
Coherence BW
- Max Frequency for "Flat" with 1 signal
- Max Frequency for "Comparison" with 2 signal



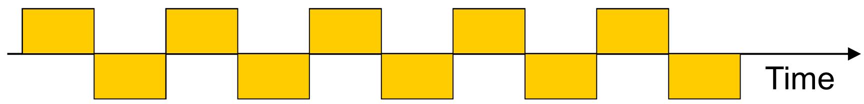
Block Diagram Transmitter Receiver



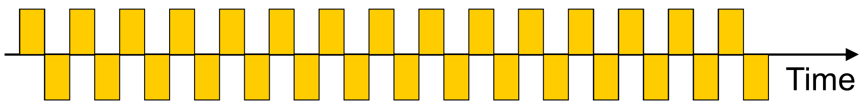
How to Increase Data Rates: Modulation

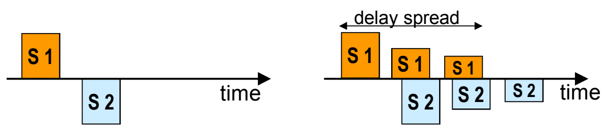


How to reach higher data rates?



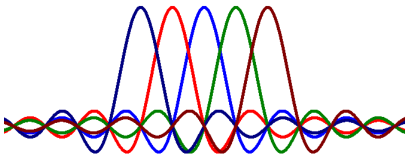
1. Possibility: Reduce Symbol Time



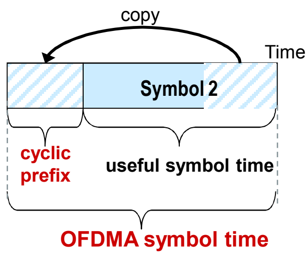


Weak Points & Solution

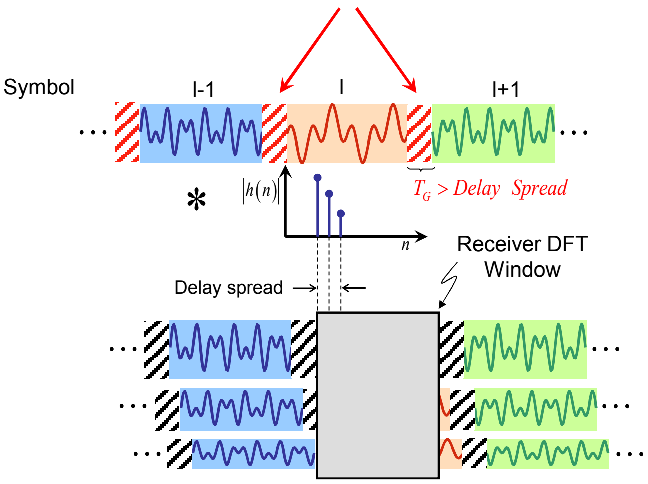
ICI (Inter-Carrier Interference)



ISI (Inter-Symbol Interference)

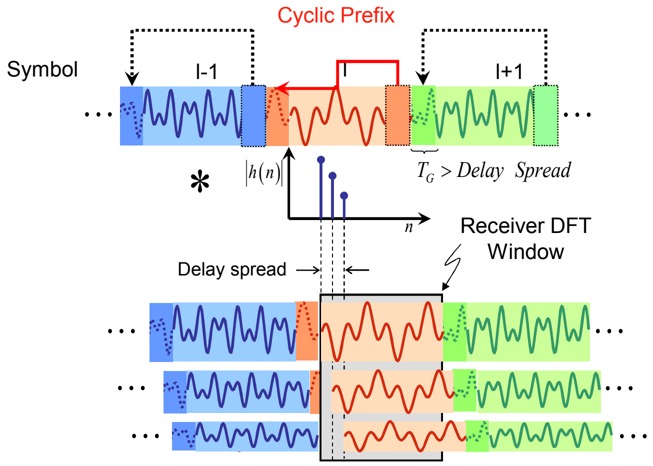


ISI and ICI: Guard Intervall



Guard Interval guarantees the suppression of ISI!
But, there is some week point in the “Amplifier”

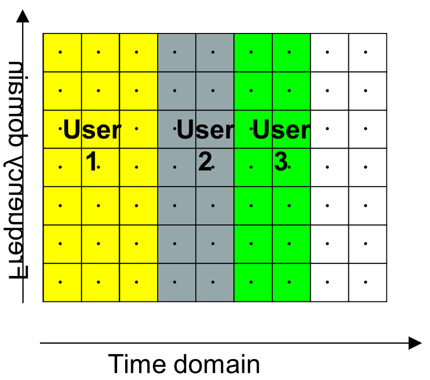
Guard Intervall as Cyclic Prefix

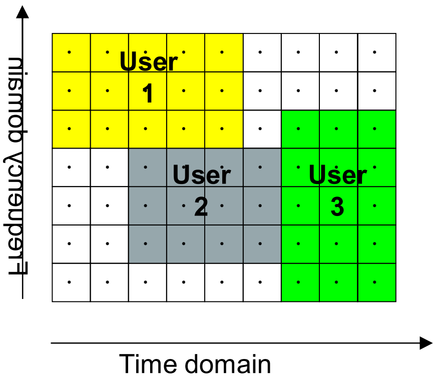


Cyclic Prefix guarantees the suppression of ISI and ICI!

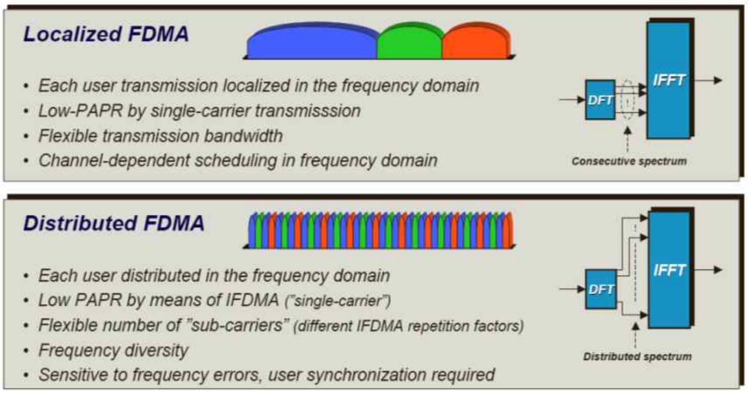
Difference between OFDM and OFDMA

- **OFDM allocates users in time domain only**
- **OFDMA allocates users in time <u>and</u> frequency domain**





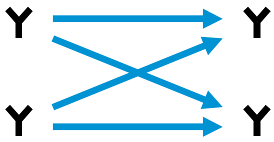
Localized versus Distributed FDMA

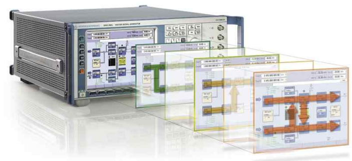


MIMO

MIMO (Multiple In Multiple Out)

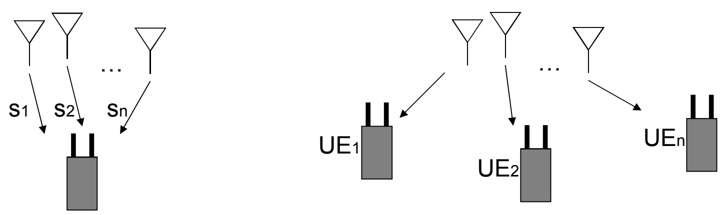
- **Technical Overview for**
  - EDGE Evolution
  - WiMAX
  - HSPA+
  - LTE
  - IEEE 802.11n
  - 1xEVDO Rev C (UMB)





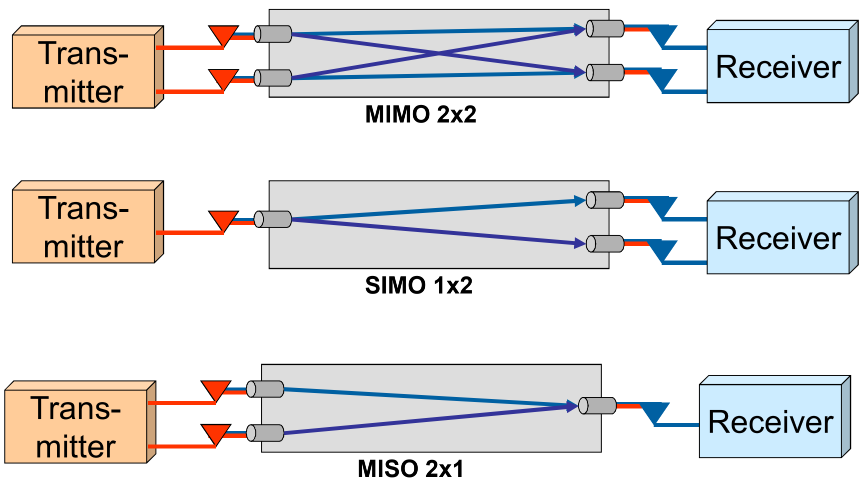
UMB = Universal Mobile Broadband

SU-MIMO versus MU-MIMO

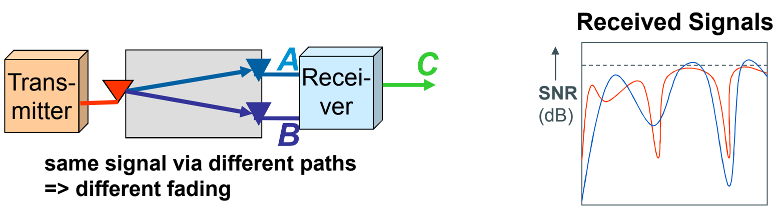


- **SU (Single User)-MIMO**
  - Goal: to increase user data rate
  - Simultaneous transmission of different data streams to 1 user
  - Efficient when the user experiences good channel conditions
- **MU (Multiple User)-MIMO**
  - Goal: to increase sector capacity
  - Selection of the users experiencing good channel conditions
  - Efficient when a large number of users have an active data transmission simultaneously

MIMO & SIMO & MISO



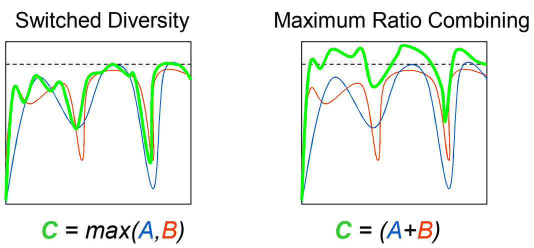
RX Diversity = SIMO



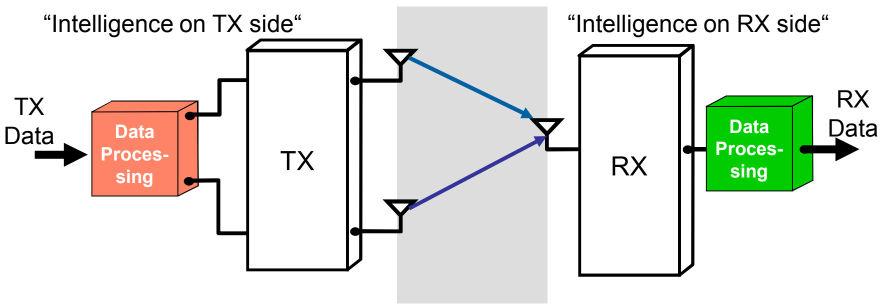
Aim:

increase of S/N ratio

➔ increase of throughput

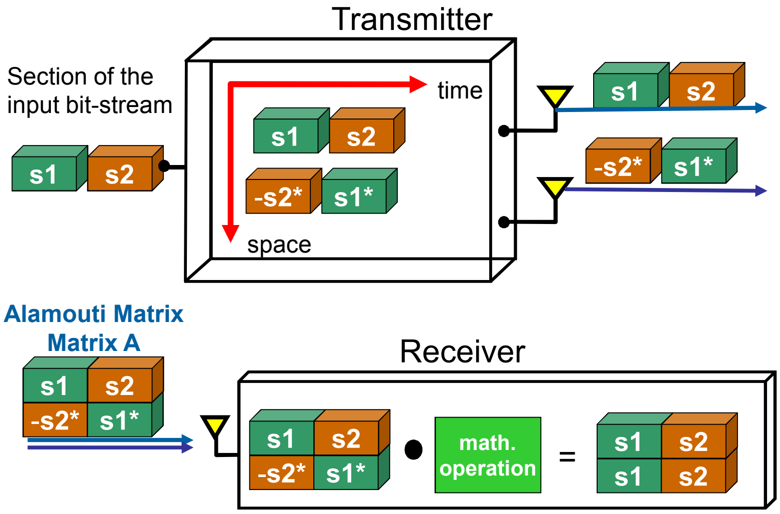


TX Diversity = MISO

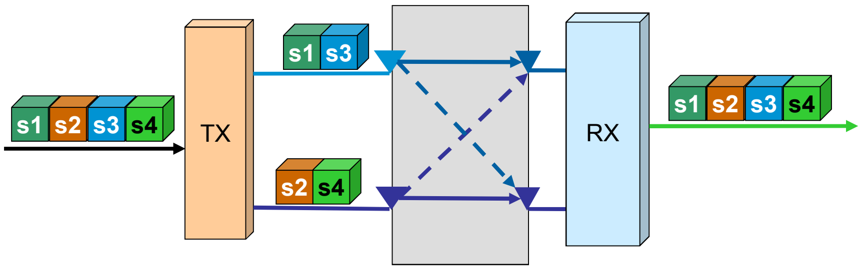


Motivation for Alamouti Space-Time-Coding:
- increase of range,
- improvement of BER,
- improvement of antenna diversity,
- **improvement of signal quality**

Space Time Coding



Spatial Multiplexing (MIMO 2x2)



Motivation for Space-Time-Coding with Matrix B:
- increase of data rate by multiplexing (theory by factor 2)

The MIMO promise

❖ **Channel capacity grows linearly with antennas ☺**

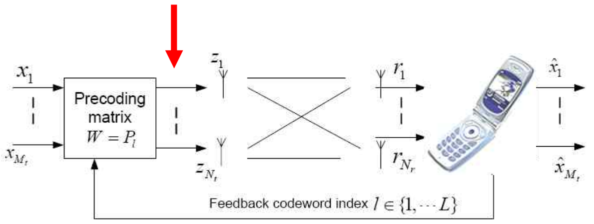
Max Capacity ~ min(N_{TX}, N_{RX})

❖ **Assumptions ☹**
- Perfect channel knowledge
- Spatially uncorrelated fading

❖ **Reality ☺**
- Imperfect channel knowledge
- Correlation ≠ 0 and rather unknown

Downlink spatial multiplexing - precoding

- The signal is “pre-coded” at Node B side before transmission



- Optimum precoding matrix is selected from predefined “codebook” known at Node B and UE side
- UE estimates the channel, selects the best precoding matrix at the moment and sends back its index

MIMO channel

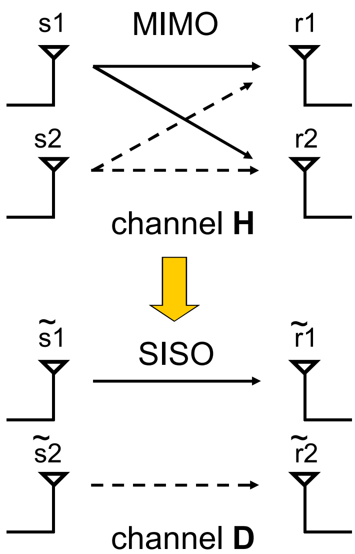
know

$\underline{r} = \mathbf{H}\,\underline{s} + \underline{n}$

Singular Value Decomposition

wanted

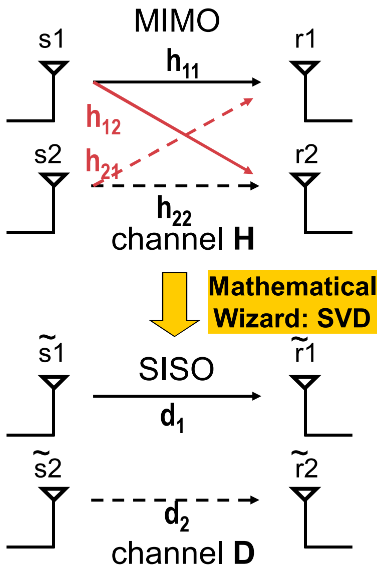
$\underline{\tilde{r}} = \mathbf{D}\,\underline{\tilde{s}} + \underline{\tilde{n}}$



MIMO channel

$$H = \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{pmatrix}$$

This is the reality ☹



$$D = \begin{pmatrix} d_1 & 0 \\ 0 & d_2 \end{pmatrix}$$

What we like to have ☺

Singular Value Decomposition (SVD)

$$\underline{r} = \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{pmatrix} \underline{s} + \underline{n}$$

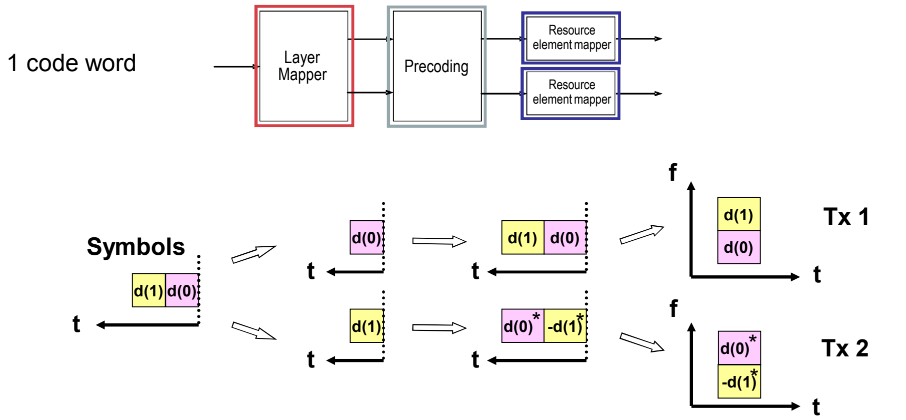
$$\underline{r} = U \begin{pmatrix} d_1 & 0 \\ 0 & d_2 \end{pmatrix} (V^*)^T \underline{s} + \underline{n}$$

$$(U^*)^T \underline{r} = (U^*)^T U \begin{pmatrix} d_1 & 0 \\ 0 & d_2 \end{pmatrix} (V^*)^T \underline{s} + (U^*)^T \underline{n}$$

$$\tilde{\underline{r}} = \begin{pmatrix} d_1 & 0 \\ 0 & d_2 \end{pmatrix} \tilde{\underline{s}} + \tilde{\underline{n}}$$

MIMO Precoding in LTE (DL)

Tx diversity (2 antennas)



Space Frequency Coding (SFC)

MIMO Precoding in LTE (DL)

Spatial multiplexing – Code book for precoding

Code book for 2 Tx:

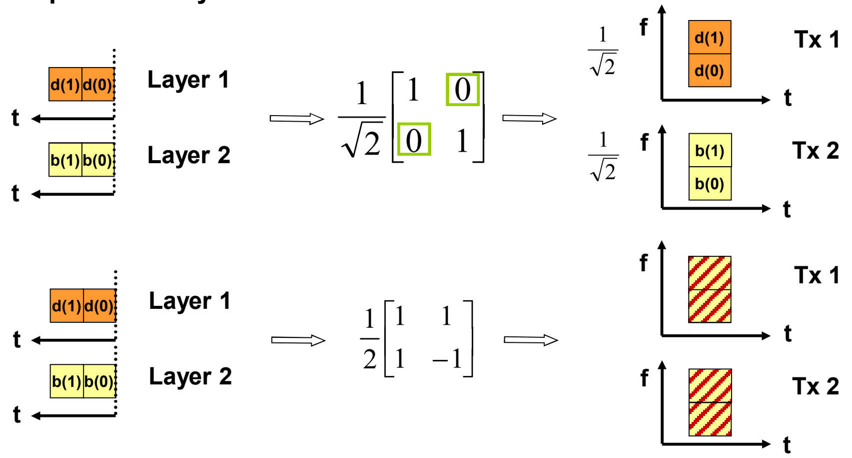
Codebook index	Number of layers υ	
	1	2
0	$\begin{bmatrix} 1 \\ 0 \end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$
1	$\begin{bmatrix} 0 \\ 1 \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$
2	$\frac{1}{\sqrt{2}}\begin{bmatrix} 1 \\ 1 \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 & 1 \\ j & -j \end{bmatrix}$
3	$\frac{1}{\sqrt{2}}\begin{bmatrix} 1 \\ -1 \end{bmatrix}$	-
4	$\frac{1}{\sqrt{2}}\begin{bmatrix} 1 \\ j \end{bmatrix}$	-
5	$\frac{1}{\sqrt{2}}\begin{bmatrix} 1 \\ -j \end{bmatrix}$	-

Additional multiplication of the layer symbols with codebook entry

MIMO Precoding in LTE (DL)

Spatial multiplexing – Code book for precoding

2 examples for 2 layers and 2 Tx antennas



Some technical details of LTE / EUTRA

UMTS Long Term Evolution (LTE)
All new again, here's what is most important:

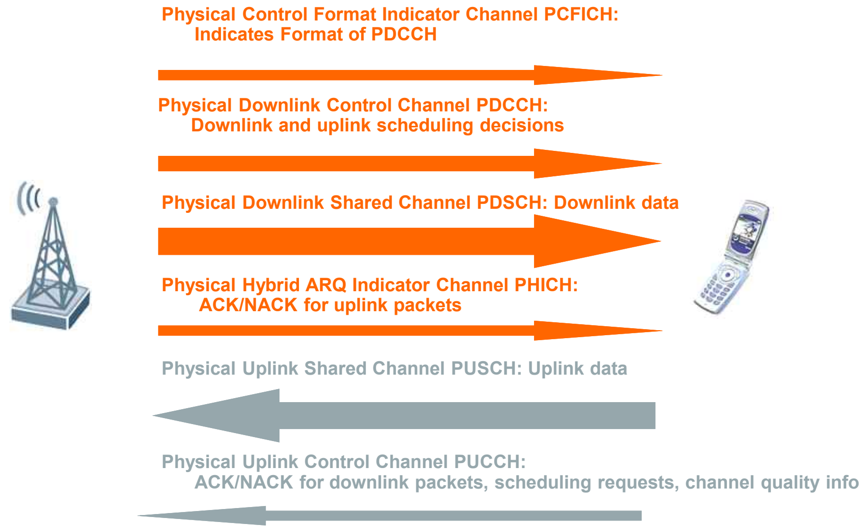
- **New radio transmission schemes**
  - **OFDMA** in downlink:
    Orthogonal Frequency Division Multiple Access
  - **SC-FDMA** in uplink:
    Single Carrier Frequency Division Multiple Access
  - **MIMO** Multiple antenna technology
- **New radio protocol architecture**
  - Complexity reduction
  - Focus on shared channel operation, no dedicated channels any more
- **New network architecture**
  - New functional split between radio network nodes
  - More functionality in the base station (eNodeB)
  - Focus on packet switched domain
  - System architecture evolution (SAE)
- **MBMS**
  - Support of Multimedia Broadcast, Multicast Service

LTE Physical Layer

LTE Downlink: Physical layer tasks

- Error detection on the transport channel and indication to higher layers
- FEC encoding/decoding of the transport channel
- Hybrid ARQ soft-combining
- Rate matching of the coded transport channel to physical channels
- Mapping of the coded transport channel onto physical channels
- Power weighting of physical channels
- Modulation and demodulation of physical channels
- Frequency and time synchronisation
- Radio characteristics measurements and indication to higher layers
- Multiple Input Multiple Output (MIMO) antenna processing
- Transmit Diversity (TX diversity)
- Beamforming
- RF processing(Note: RF processing aspects are specified in the TS 36.100 series)

LTE: new physical channels for data and control



LTE Downlink: Downlink Physical Channels

- Physical Downlink Shared Channel, PDSCH:
  - Used for data transfer, shared principle, variable modulation
  - Mapping between DL-SCH and PCH
  - MBMS information can be mapped
- Physical Downlink Control Channel, PDCCH
  - specific control information, shared principle, fixed modulation QPSK
  - Carries scheduling decision from eNodeB
  - Informs UE about resource allocation fo PCH and DL-SCH
  - HARQ information related to DL-SCH
  - UL scheduling grant
  - Mapped to 2-4 symbols in case of less than 10 RB
  - Mapped to 1-3 symbols in case of bigger than 10 RB
- Common Control Physical Channel, CCPCH
  - General control information, broadcast principle, fixed modulation QPSK
- Physical Multicast Channel, PMCH
  - Like PDSCH, but no transmit multiplexing

LTE Downlink: Downlink Physical Channels

- Physical control format indicator channel, PCFICH :
  - The physical control format indicator channel carries information about the number of OFDM symbols (1-3 or 2-4) used for transmission of PDCCHs in a subframe. Only QPSK.
  - Transferred in every sub-frame
- Physical HARQ Indicator Channel, PHICH
  - The PHICH carries the hybrid-ARQ ACK/NAK, fixed modulation QPSK
- Physical Broadcast Channel PBCH
  - General control information, broadcast principle, fixed modulation QP나
  - MIB (Master Information Block) Transmission
  - 4 subframes within a 40ms interval
  - 40 ms timing is blindly detected

LTE Uplink: Uplink Physical Channels

- Physical Uplink Shared Channel, PUSCH
  - For user data, shared scheduling principle, variable modulation scheme: QPSK, 16-QAM, 64-QAM. Timing similar to downlink
- Physical Uplink Control Channel, PUCCH
  - For uplink control information, never transmit simultaneous to PUSCH. Frequency and time multiplexed, fixed modulation scheme: QPSK.

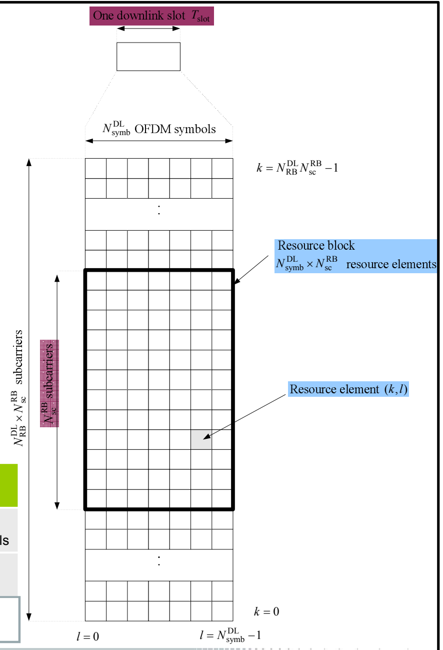
LTE Physical Layer: OFDMA in downlink

Resource Allocation

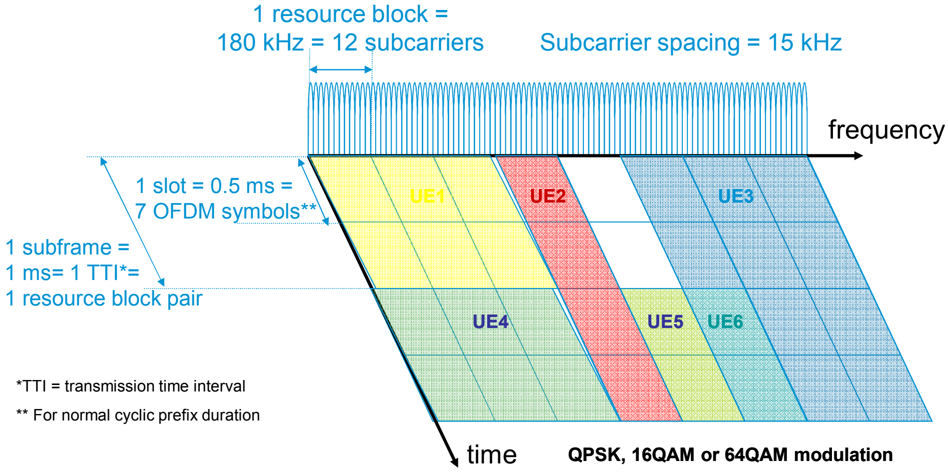
- Smallest resource unit is Resource Element, which is 1 symbol on 1 subcarrier,
- But minimum allocation for transmission is a Resource Block (RB),
- 1 RB spans 12 sub-carriers (12*15 kHz = 180 kHz) in the frequency domain and 1 Time Slot (= 0.5 ms) in the time domain,
  - 10 MHz = 50 RB ⇨ 50 RB*180 kHz = 9.0 MHz + 1 unused DC subcarrier (= $f_{Carrier}$) = 9.015 MHz
  - TTI is 1 subframe, which is 2 time slots,
  - With normal (extended) cyclic prefix (CP) we got 7 (6) OFDM symbols per time slot,

Configuration	OFDM Symbols	Sub-carrier	Cyclic Prefix Length in Samples	Cyclic Prefix Length in µs
Normal CP Δf = 15 kHz	7	12	160 for 1st symbol 144 for other symbols	5.2 for 1st symbol 4.7 for other symbols
Extended CP Δf = 15 kHz	6		512	16.7

MBMS Scenario



LTE Downlink
OFDMA time-frequency multiplexing



QPSK, 16QAM or 64QAM modulation

*TTI = transmission time interval

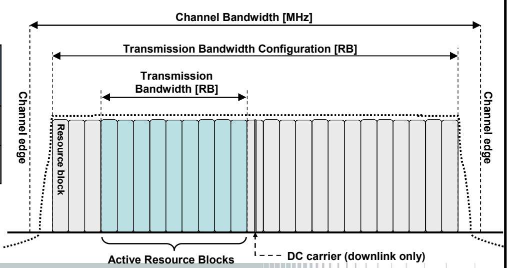
** For normal cyclic prefix duration

LTE – spectrum flexibility

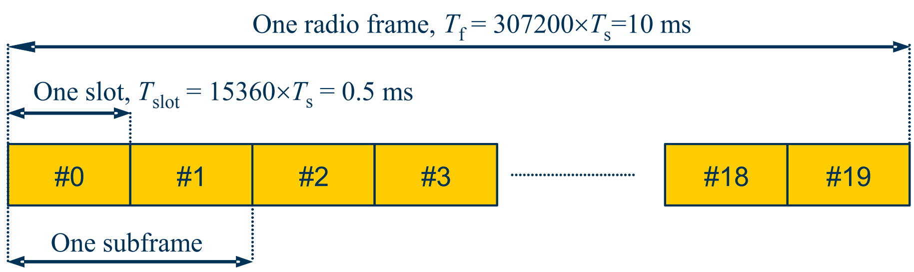
- LTE physical layer supports any bandwidth from 1.4 MHz to 20 MHz in steps of 180 kHz (resource block)
- Current LTE specification supports only a subset of 8 different system bandwidths
- All UEs must support the maximum bandwidth of 20 MHz

Channel bandwidth $BW_{Channel}$ [MHz]	1.4	1.6	3	3.2	5	10	15	20
FDD mode	6	n/a	15	n/a	25	50	75	100
TDD mode	[TBD]	[7]	[TBD]	[16]	25	50	75	100

number of resource blocks



LTE Downlink:
Downlink slot and (sub)frame structure

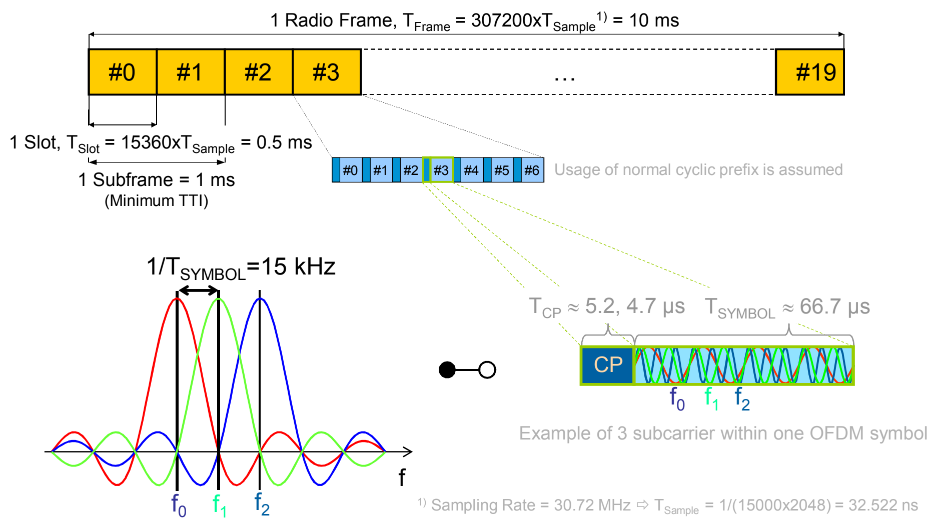


We talk about 1 slot, but the minimum resource is 1 subframe = 2 slots !!!!!

$$T_s = 1/(15000 \times 2048)$$

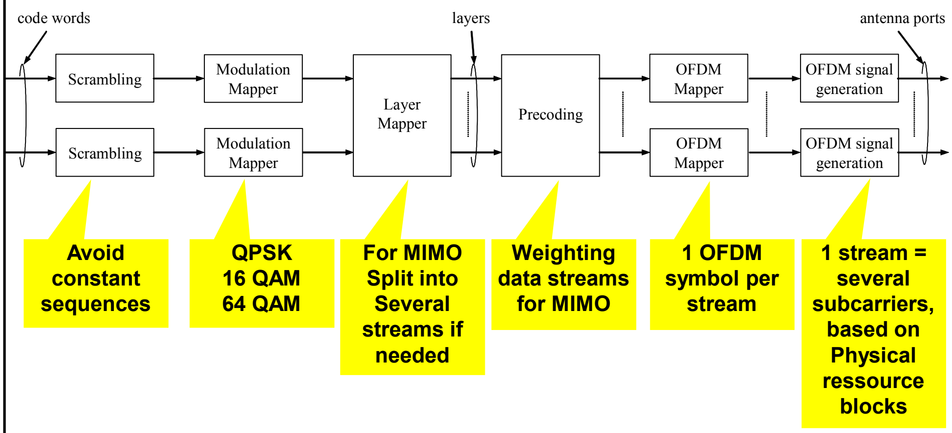
Ts = 32.522 ns

Downlink frame structure type I (FDD)



[1] Sampling Rate = 30.72 MHz ⇨ T_{Sample} = 1/(15000x2048) = 32.522 ns

LTE Downlink: baseband signal generation



Modulation

Physical channel	Modulation schemes
PDSCH	QPSK, 16QAM, 64QAM
PMCH	QPSK, 16QAM, 64QAM

Physical channel	Modulation schemes
PBCH	QPSK

Physical channel	Modulation schemes
PCFICH	QPSK

Physical channel	Modulation schemes
PDCCH	QPSK

Physical channel	Modulation schemes
PHICH	BPSK

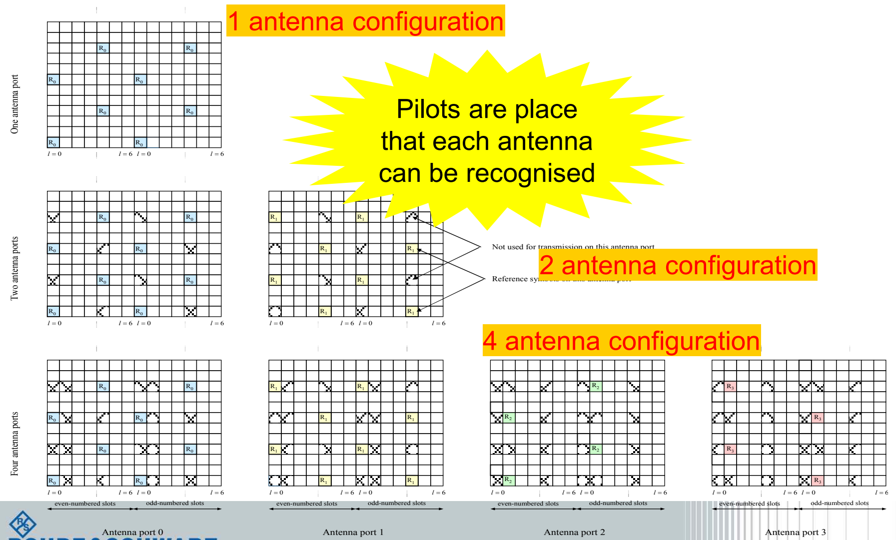
LTE Downlink: Downlink Reference Signals

Of course, there will be reference signals

- Cell-specific reference signals, associated with non-MBSFN transmission
- MBSFN reference signals, associated with MBSFN transmission
- UE-specific reference signals (supported in frame structure type 2 only)

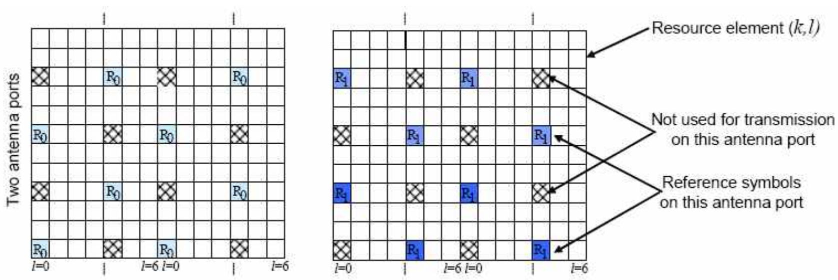
- Downlink reference signal(s) can be used for
  - Downlink-channel-quality measurements
  - Downlink channel estimation for coherent demodulation/detection at the UE
  - Cell search and initial acquisition (carries cell ID)

LTE Downlink, Common Control physical channel: Downlink Reference Signals - mapping

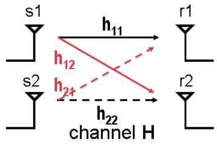


MIMO in LTE (DL)

Reference Symbols / Pilots



Antenna 1 Antenna 2



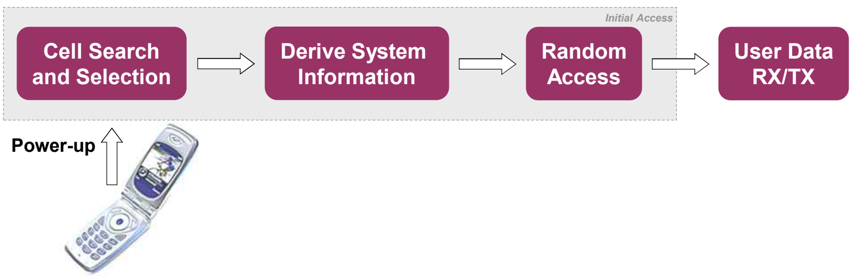
$r_1 = h_{11}*s_1 + h_{21}*s_2$

$r_2 = h_{12}*s_1 + h_{22}*s_2$

$* h_{12}=h_{21}=0$

LTE Physical Layer Concepts
Initial Access, Part I

LTE Initial Access



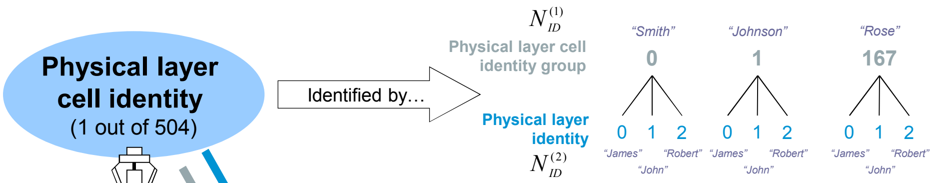
Downlink physical channels and signals

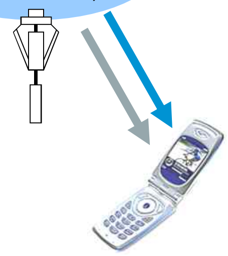
LTE Downlink Physical Signals	
Primary and Secondary Synchronization Signal	Provide acquisition of cell timing and identity during cell search
Downlink Reference Signal	Cell search, initial acquisition, coherent demod., channel estimation

LTE Downlink Physical Channels	
Physical Broadcast Channel (PBCH)	Provides essential system information e.g. system bandwidth

not required for cell search and cell selection

Cell search in LTE



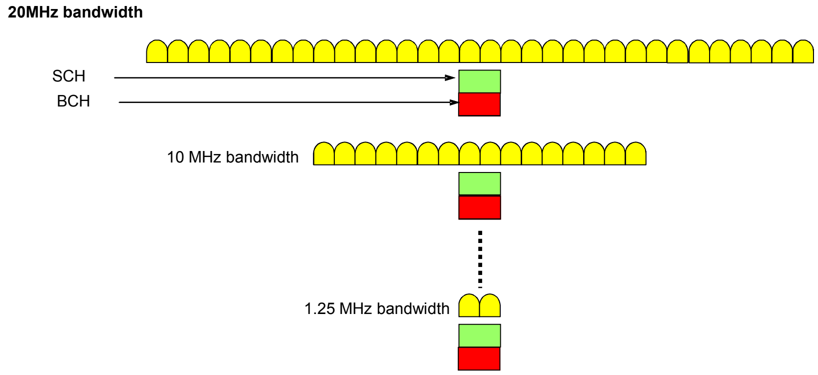


1. Primary synchronization signal (PSS)
   - 3 possible sequences to identify the cell's physical layer identity (0, 1, 2),
2. Secondary synchronization signal (SSS)
   - 168 different sequences to identity physical layer cell identity group,
3. Physical broadcast channel (PBCH)
   - Carrying broadcast channel with predefined information : System BW, No. of transmit antennas, Ref. signal transmit power…

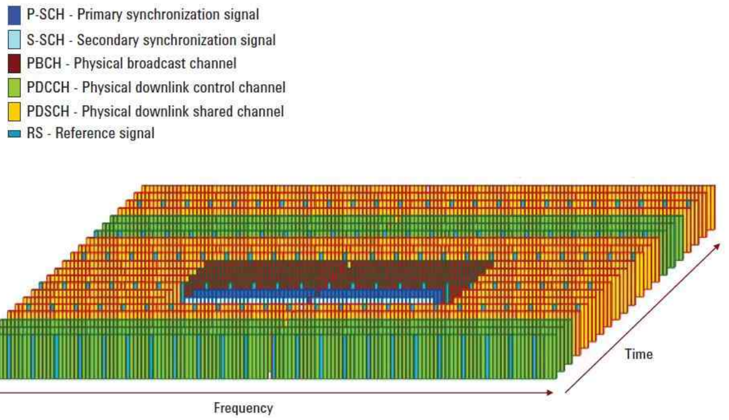
- Hierarchical cell search as in 3G; providing PSS and SSS for assistance,
  - PSS is carrying physical layer identity $N_{ID}^{(2)}$,
  - SSS is carrying physical layer cell identity group $N_{ID}^{(1)}$,
  - Cell Identity is computed as $N_{ID}^{cell} = 3N_{ID}^{(1)} + N_{ID}^{(2)}$, where $N_{ID}^{(1)} = 0,1,\ldots,167$ and $N_{ID}^{(2)} = 0, 1, 2$

Initial synchronization

BCH and SCH always located at the center



LTE Downlink
Configuration of physical broadcast channel



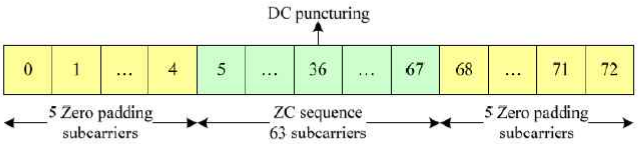
Initial synchronization : PSS

■ The sequence for the PSS is generated from a freq.-domain Zadoff-Chu sequence (Length-62)

$$d_u(n) = \begin{cases} e^{-j\frac{\pi u n(n+1)}{63}} & n = 0,1,\ldots,30 \\ e^{-j\frac{\pi u (n+1)(n+2)}{63}} & n = 31,32,\ldots,61 \end{cases}$$

$N_{ID}^{(2)}$	Root index u
0	25
1	29
2	34

<TS 36.211 / Table 6.11.1.1-1>



$c_0(n) = \tilde{c}((n + N_{ID}^{(2)}) \bmod 31)$

$c_1(n) = \tilde{c}((n + N_{ID}^{(2)} + 3) \bmod 31)$

$N_{ID}^{(2)} \in \{0,1,2\}$

$\tilde{c}(i) = 1 - 2x(i) \quad 0 \le i \le 30$

$x(\bar{i} + 5) = (x(\bar{i} + 3) + x(\bar{i})) \bmod 2, \quad 0 \le \bar{i} \le 25$

■ Background of Zadoff-Chu Sequence

$$a_{k,l} = d(n), \quad k = n - 31 + \frac{N_{RB}^{DL} N_{sc}^{RB}}{2} \quad n = 0,\ldots,61$$

- Appeared in IEEE Trans. I in 1972
- Poly-phase sequence
- Cyclic autocorrelations are zero for all non-zero lags Non-zero cross-correlations
- PAPR이 낮아 (신호의 Amplitude 일정) 전력 소모적 측면에서 유리
- CAZAC (Constant Amplitude Zero Auto Correlation) Sequence의 일종

Initial synchronization : SSS

■ The sequence for the PSS is an interleaved concatenation of two m-sequence (length 31)

■ The concatenated sequence is scrambled with a scrambling sequence given by PSS

■ 2 m-sequences are differ between subframe 0 and subframe 5

even RE

$$d(2n) = \begin{cases} s_0^{(m_0)}(n) c_0(n) & \text{in subframe } 0 \\ s_1^{(m_1)}(n) c_0(n) & \text{in subframe } 5 \end{cases}$$

$$d(2n+1) = \begin{cases} s_1^{(m_1)}(n) c_1(n) z_1^{(m_0)}(n) & \text{in subframe } 0 \\ s_0^{(m_0)}(n) c_1(n) z_1^{(m_1)}(n) & \text{in subframe } 5 \end{cases}$$

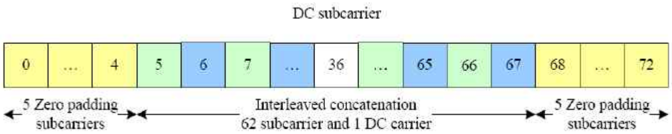
odd RE

$c_0(n) = \tilde{c}((n + N_{ID}^{(2)}) \bmod 31)$ $\quad s_0^{(m_0)}(n) = \tilde{s}((n + m_0) \bmod 31)$

$c_1(n) = \tilde{c}((n + N_{ID}^{(2)} + 3) \bmod 31)$ $\quad s_1^{(m_1)}(n) = \tilde{s}((n + m_1) \bmod 31)$

$z_1^{(m_0)}(n) = \tilde{z}((n + (m_0 \bmod 8)) \bmod 31)$

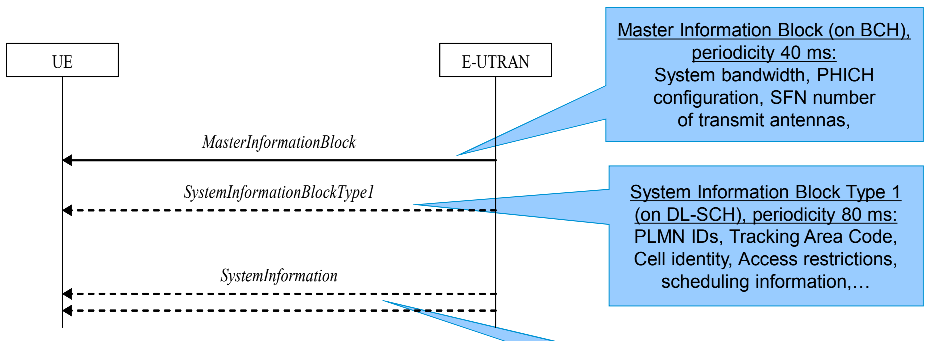
$z_1^{(m_1)}(n) = \tilde{z}((n + (m_1 \bmod 8)) \bmod 31)$



$N_{ID}^{(1)}$	m_0	m_1	$N_{ID}^{(1)}$	m_0	m_1	$N_{ID}^{(1)}$	m_0	m_1	$N_{ID}^{(1)}$	m_0	m_1	$N_{ID}^{(1)}$	m_0	m_1
0	0	1	34	4	6	68	9	12	102	15	19	136	22	27
1	1	2	35	5	7	69	10	13	103	16	20	137	23	28
2	2	3	36	6	8	70	11	14	104	17	21	138	24	29
3	3	4	37	7	9	71	12	15	105	18	22	139	25	30
4	4	5	38	8	10	72	13	16	106	19	23	140	0	6
5	5	6	39	9	11	73	14	17	107	20	24	141	1	7
6	6	7	40	10	12	74	15	18	108	21	25	142	2	8
7	7	8	41	11	13	75	16	19	109	22	26	143	3	9

<TS 36.211 / Table 6.11.2.1-1>

System information broadcast in LTE



SI-RNTI is used on **PDCCH** to address System Information Block Type 1 and SI messages

System information blocks with same scheduling requirements can be mapped to same SI message (DL-SCH)

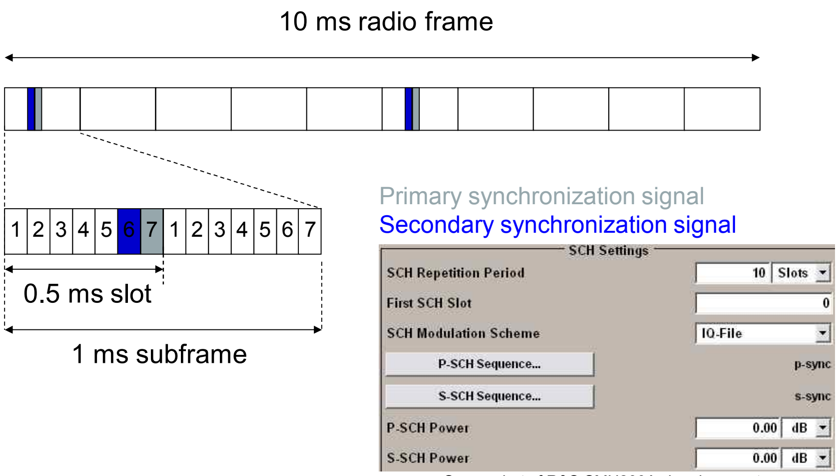
Organization of system information in LTE

MIB	SIB Type 1
Physical Layer Information	Access restrictions, SIB scheduling information

- SIB Type 1, carrying the scheduling information for all other SIB, is transmitted with a periodicity of 80 ms,
  - 1st time transmitted in subframe #5 of radio frames belonging to SFN mod 8 = 0,
- All other SIB are mapped to SI messages, where SIB with same periodicity can be mapped to same SI messages; there can be up to 32 SI messages,
  - SIB Type 2, carrying information about control and shared channels, is present in each SI message and is always listed as first entry in the related scheduling information,

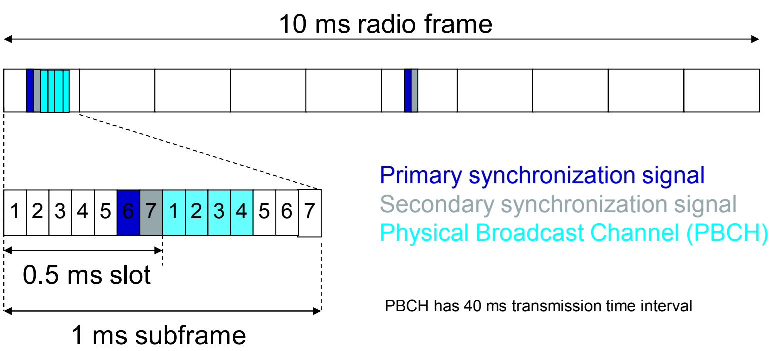
[1] ETWS = Earthquake and Tsunami Warning System

LTE Downlink
Configuration of synchronization signals



Screenshot of R&S SMU200A signal generator

LTE Downlink
Configuration of physical broadcast channel



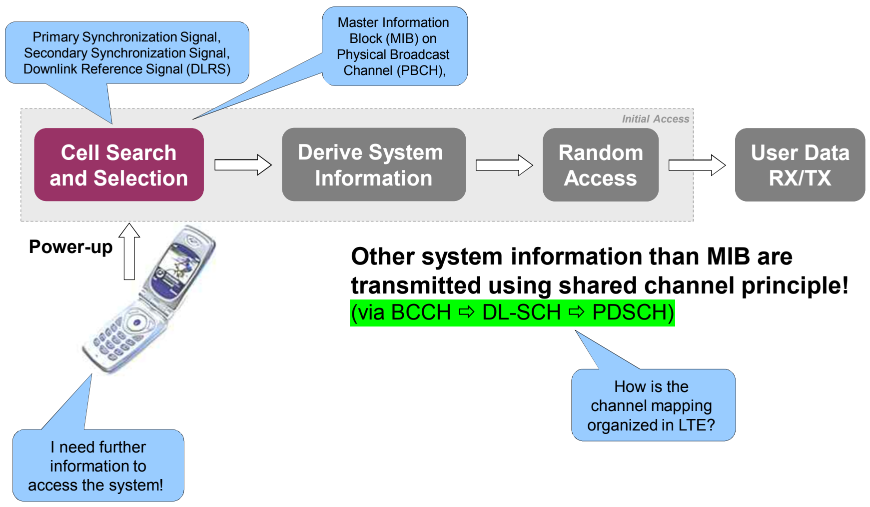
PBCH has 40 ms transmission time interval

CAZAC sequence – constellation diagram

Constant Amplitude Zero Auto Correlation

LTE Physical Layer Concepts
Initial Access, Part II

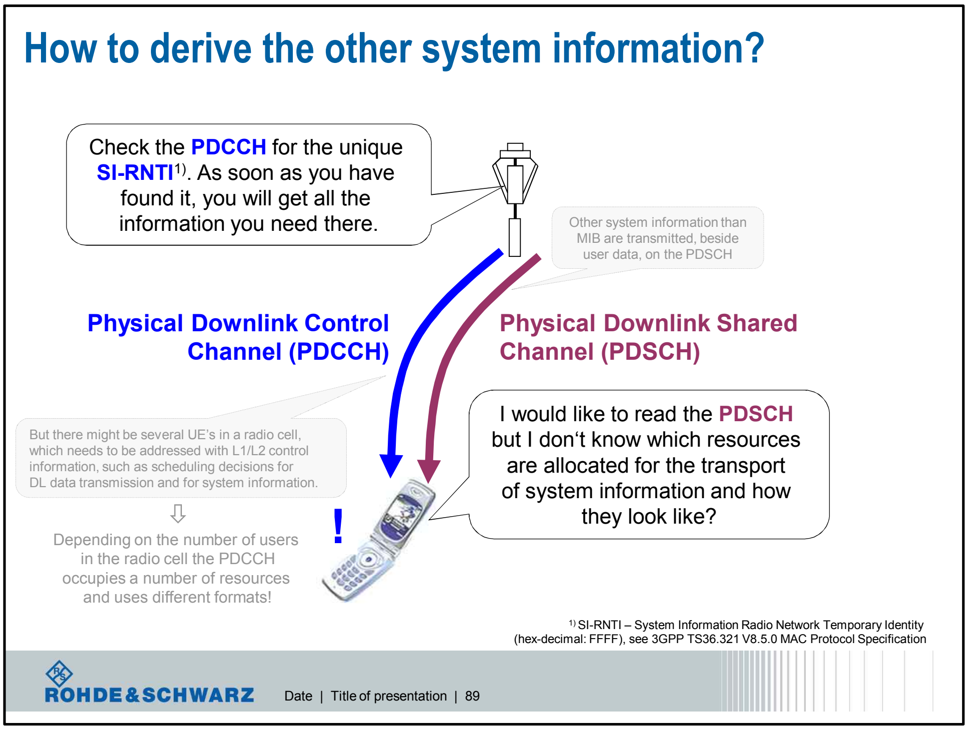
LTE Initial Access

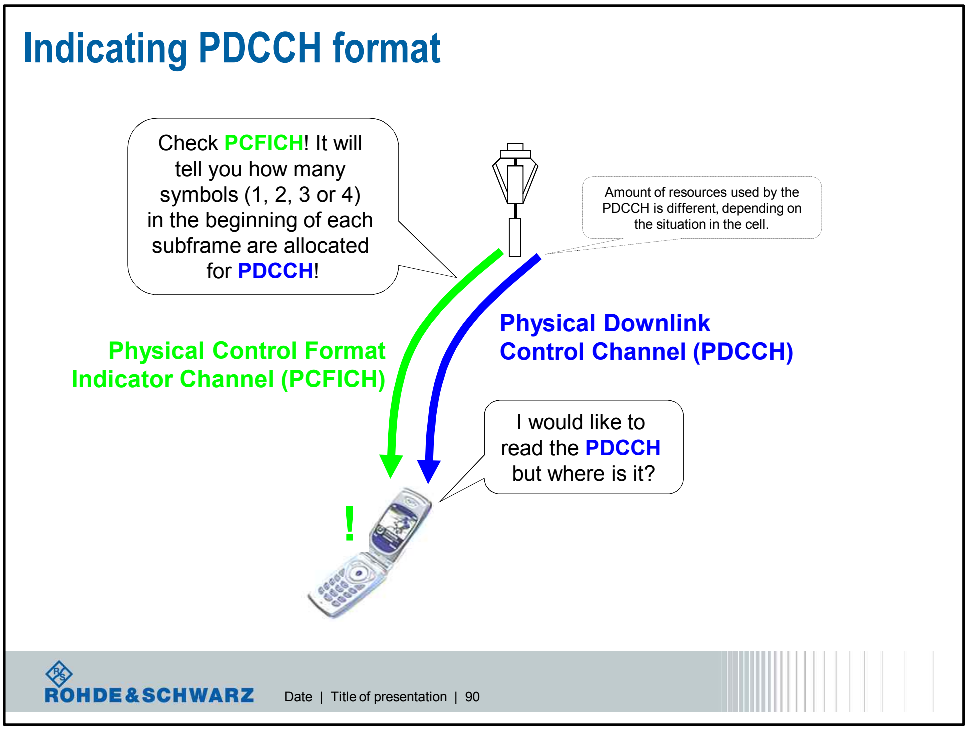


Downlink physical channels and signals

LTE Downlink Physical Channels	
***at this step*, these are the DL PHY channels…**	
Physical Control Format Indicator Channel (PCFICH)	Indicates format of PDCCH (CFI)
Physical Downlink Control Channel (PDCCH)	Carries control information (DCI = Downlink Control Information)
Physical Downlink Shared Channel (PDSCH)	Carries data (user data, system information,…)

…which are required to find Resource Blocks carrying system information!


How to derive the other system information?
Check the PDCCH for the unique SI-RNTI1). As soon as you have found it, you will get all the information you need there.
Other system information than MIB are transmitted, beside user data, on the PDSCH
Physical Downlink Control Channel (PDCCH)
Physical Downlink Shared Channel (PDSCH)
I would like to read the PDSCH but I don't know which resources are allocated for the transport of system information and how they look like?
But there might be several UE's in a radio cell, which needs to be addressed with L1/L2 control information, such as scheduling decisions for DL data transmission and for system information.
Depending on the number of users in the radio cell the PDCCH occupies a number of resources and uses different formats!
!
1) SI-RNTI – System Information Radio Network Temporary Identity (hex-decimal: FFFF), see 3GPP TS36.321 V8.5.0 MAC Protocol Specification
ROHDE&SCHWARZ
Date | Title of presentation | 89


Indicating PDCCH format
Check PCFICH! It will tell you how many symbols (1, 2, 3 or 4) in the beginning of each subframe are allocated for PDCCH!
Amount of resources used by the PDCCH is different, depending on the situation in the cell.
Physical Control Format Indicator Channel (PCFICH)
Physical Downlink Control Channel (PDCCH)
I would like to read the PDCCH but where is it?
!
ROHDE&SCHWARZ
Date | Title of presentation | 90

LTE Downlink: PCFICH

- The number of OFDM symbols used for control channel is variable
  - TTI마다 바뀔 수 있음
- CFI (Control Format Indication)

<10 RB : 2~4 OFDMA symbols
>10RB : 1~3 OFDMA symbols

  - Information about the number of OFDM symbols (1~4) used for transmission of PDCCHs in a subframe
- PCFICH carries CFI
  - Cell-specific scrambling prior to modulation
  - 2 info bits ➔ Coding rate of 1/16 ➔ Number ofo bits = 32bits
  - Modulation : QPSK
  - Mapping to resource elements : 4REG (16 RE excluding RS) in the 1st OFDM symbol
    - Spread over the whole system bandwidth
    - Same mapping for 1,2 and 4 antennas

CFI	CFI codeword < $b_0, b_1, \ldots, b_{31}$ >
1	<0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1>
2	<1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0>
3	<1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1>
4 (Reserved)	<0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0>

3GPP TS 36.212 / Table 5.3.4-1: CFI codewords

LTE Downlink: PDCCH

- First n OFDM symbols
  - <10 RB : 2~4 OFDMA symbols
  - >10RB : 1~3 OFDMA symbols
- Scheduling assignment
  - Transport format, resource allocation, HARQ info related to DL-SCH, PCH
  - Transport format, resource allocation, HARQ info related to UL-SCH
- DPCCH format based on # of CCE (Control Channel Element = 9 REGs) used

PDCCH format	Number of CCEs	Number of REGs	Number of PDCCH bits
0	1	9	72
1	2	18	144
2	4	36	288
3	8	72	576

3GPP TS 36.211 / Table 6.8.1-1: Supported PDCCH formats

- Cell-specific scrambling, QPSK with tail-biting Conv. Code
- TX diversity, the same antenna ports as PBCH
- Mapped to REG no assigned to PCFICH or PHICH

LTE Downlink: PDCCH

- DCI transports downlink or uplink scheduling information, or uplink power control commands

DCI Formats	Description
0	For the scheduling of PUSCH
1	For the scheduling of one PDSCH codeword (SIMO, TxD)
1A	For the compact scheduling of one PDSCH codeword (SIMO, TxD)
1B	For the compact scheduling of one PDSCH codeword with precoding information (closed-loop single-rank)
1C	For very compact scheduling of one PDSCH codeword (paging, RACH response and dynamic BCCH scheduling)
1D	For the compact scheduling of one PDSCH codeword with precoding and power offset information
2	For scheduling PDSCH to use configured in closed-loop SM
2A	For scheduling PDSCH to use configured in open-loop SM
3	For the transmission of TPC commands for PUCCH and PUSCH with 2-bit power adjustment
3A	For the transmission of TPC commands for PUCCH and PUSCH with single bit power adjustment

PDCCH layer 1/2 control channel contents
Uplink scheduling grant (DCI format 0)

- Hopping flag – 1 bit
- Resource block assignment and hopping resource allocation
- Modulation and coding scheme, redundancy version – 5 bits
- New data indicator – 1 bit
- TPC command for scheduled PUSCH – 2 bits
- Cyclic shift for demodulation reference signal – 3 bits
- Uplink index for TDD - 2 bits
- CQI request – 1 bit

PDCCH layer 1/2 control channel contents Uplink scheduling grant (DCI format 1)

- Resource block assignment – 1bit
- Modulation and coding scheme – 5 bits
- Redundancy version – 2bits
- HARQ Process number – 3bits (FDD), 4bits (TDD)
- New Data Indicator – 1bit
- TPC command for scheduled PUSCH – 2 bits
- Downlink Assignment Index – 2 bits

PDCCH layer 1/2 control channel contents Downlink scheduling assignment (DCI format 2)

- Resource allocation header (allocation type 0 or 1) – 1 bit
- Resource block assignment
- TPC command for PUCCH and persistent PUSCH – 2 bits
- Downlink assignment index for TDD – 2 bits
- Number of layers – 2 bits
- HARQ process number – 3 bits (FDD), 4 bits (TDD)
- Transport block to code word swap flag – 1 bit
- Precoding information and confirmation

For the first codeword:

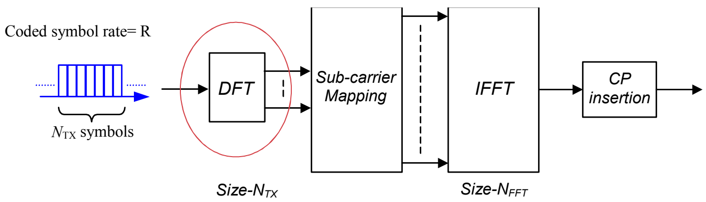
- Modulation and coding scheme – 5 bits
- New data indicator – 1 bit
- Redundancy version – 2 bits

For the second codeword:

- Modulation and coding scheme – 5 bits
- New data indicator – 1 bit
- Redundancy version – 2 bits

LTE Physical Layer:
SC-FDMA in uplink

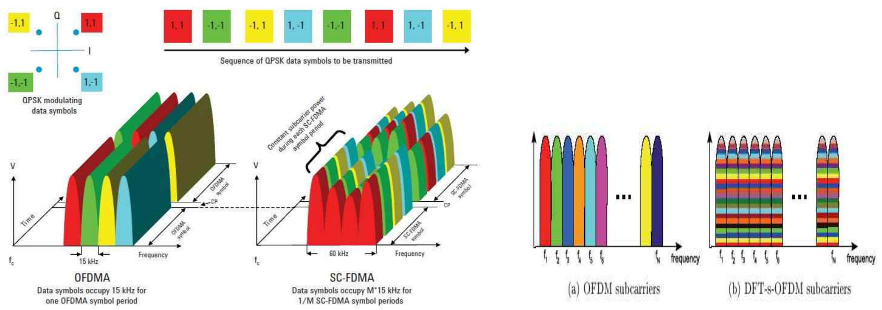
LTE Uplink:
How to generate an SC-FDMA signal in theory?



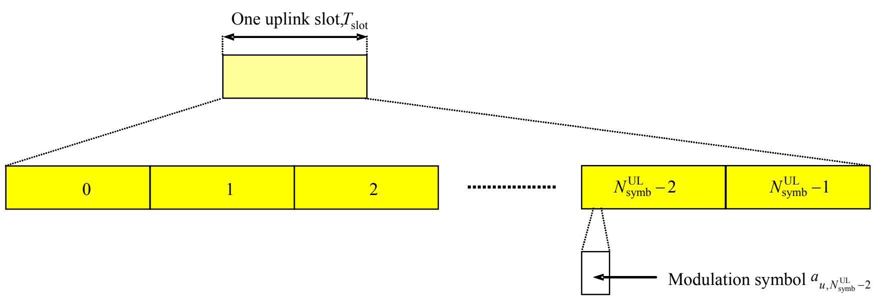
- LTE provides QPSK,16QAM, and 64QAM as uplink modulation schemes
- Each subcarrier carries a portion of superposed DFT spread data symbols
- CAZAC (Constant Amplitude Zero Autocorrelation) sequence 사용
  - Ref. signal 및 제어 정보 채널 전송 시 각 단말들의 신호를 구분하기 위해 CDM을 수행하는 경우, CAZAC sequence를 주로 사용
  - CAZAC sequence는 time/freq. domain에서 일정한 amplitude를 유지하는 특성을 가지므로 단말의 PAPR을 낮추어 커버리지를 증가시키기에 적합함
- MU-MIMO 지원

LTE Uplink:
How does the SC-FDMA signal look like?

- In principle similar to OFDMA, **BUT**:
  - In OFDMA, each sub-carrier only carries information related to **one specific symbol**
  - In SC-FDMA, each sub-carrier contains information of **ALL** transmitted symbols



LTE Uplink: SC-FDMA parametrization for PUSCH and PUCCH, slot format



Configuration	Number of symbols N_{symb}^{UL}	Cyclic Prefix length in samples	Cyclic Prefix length in µs
Normal cyclic prefix Δf=15 kHz	7	160 for first symbol 144 for other symbols	5.2 µs for first symbol 4.7 µs for other symbols
Extended cyclic prefix Δf=15 kHz	6	512	16.7 µs

LTE Uplink: Physical Channels in uplink

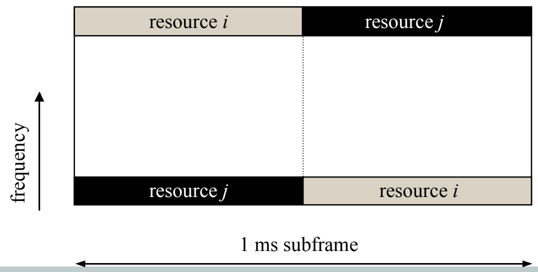
- **Physical Uplink Shared Channel, PUSCH**
  - Uplink data with localized transmission (with/without hopping)
  - Frequency hopping is available on both slot basis and subframe basis
- **Physical Uplink Control Channel, PUCCH**
  - Carries HARQ ACK/NACK in response to DL transmission
  - Carries Scheduling Request (SR), CQI, PMI and RI
  - PUCCH transmission
- **Physical Random Access Channel, PRACH**
  - Carries the random access preamble
- **UCI transmission with PUSCH**
  - CQI/PMI is multiplexed with PUSCH and mapped into PUSCH bands
  - ACK/NAK is multiplexed with PUSCH by punchuring the data
  - RS would be transmitted through RRC Signalling (RAN2)
- **UL Signal**
  - An uplink physical signal is used by the physical layer but does not carry information originating from higher layers
  - UL RS (Uplink Reference Signal) for PUSCH, PUCCH
  - UL Sounding RS not associated with PUSCH, PUCCH transmission

※ Can't send PUSCH/PUSCCH at same time

ROHDE&SCHWARZ Date | Title of presentation | 101

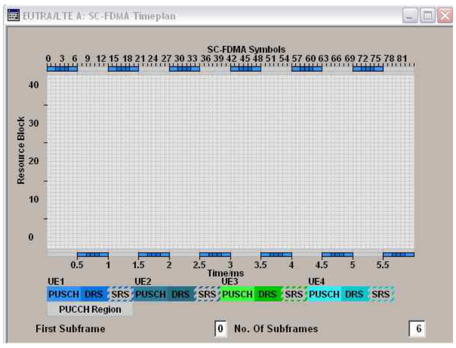
LTE Uplink : Physical Uplink Control Channel (PUCCH)

- PUCCH is never transmitted simultaneously with PUSCH from the same UE
- Only needed when there is no PUSCH available
- Carries Uplink Control Information (UCI) in PUCCH or PUSCH
- Carries ACK/NACK, CQI, PMI, RI and SR (Scheduling Request)
- Symbol mapping of BPSK or QPSK
- 2 consecutive PUCCH slots in Time-Frequency Hopping at the slot boundary

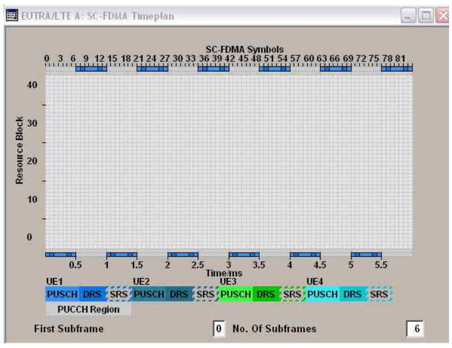


ROHDE&SCHWARZ Date | Title of presentation | 102

LTE Uplink
Physical Uplink Control Channel (PUCCH)

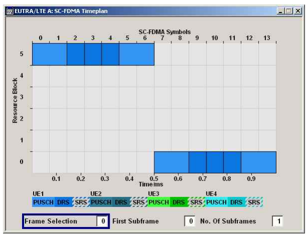


Format 1x

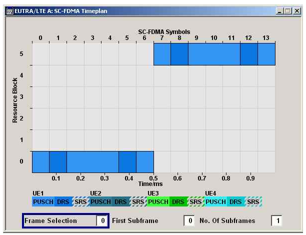


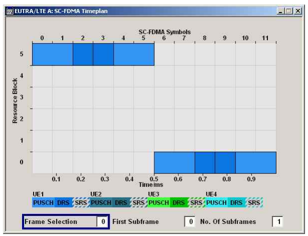
Format 2x

LTE Uplink
Physical Uplink Control Channel (PUCCH)

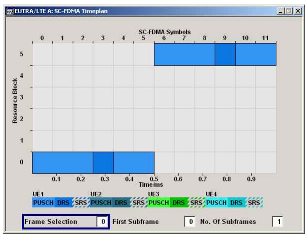


CP=normal





CP=extended



Format 1x

Format 2x

LTE Uplink
Physical Uplink Control Channel (PUCCH)

PUCCH format	Description	Physical Bits	Modulation Scheme	ODFM Symbols used for DRS (normal CP)	ODFM Symbols used for DRS (extended CP)
1	Scheduling Request	0	-	2, 3, 4	2, 3
1a	ACK/NACK	1	BPSK	2, 3, 4	2, 3
1b	ACK/NACK for MIMO	2	QPSK	2, 3, 4	2, 3
2	CQI	20	QPSK	1, 5	3
2a	CQI and ACK/NACK	21	QPSK+BPSK	1, 5	-
2b	CQI and ACK/NACK for MIMO	22	QPSK+QPSK	1, 5	-

3GPP 36.211 Table 5.4.-1 PUCCH format

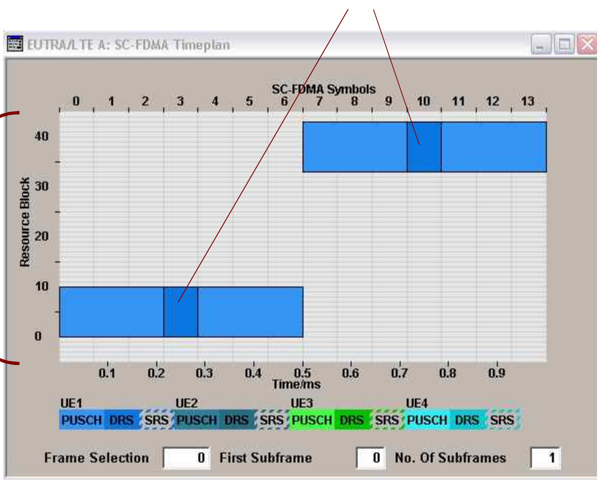
LTE Uplink
Physical Uplink Shared Channel (PUSCH)

Demodulation pilot signal

Inter/Intra Hopping

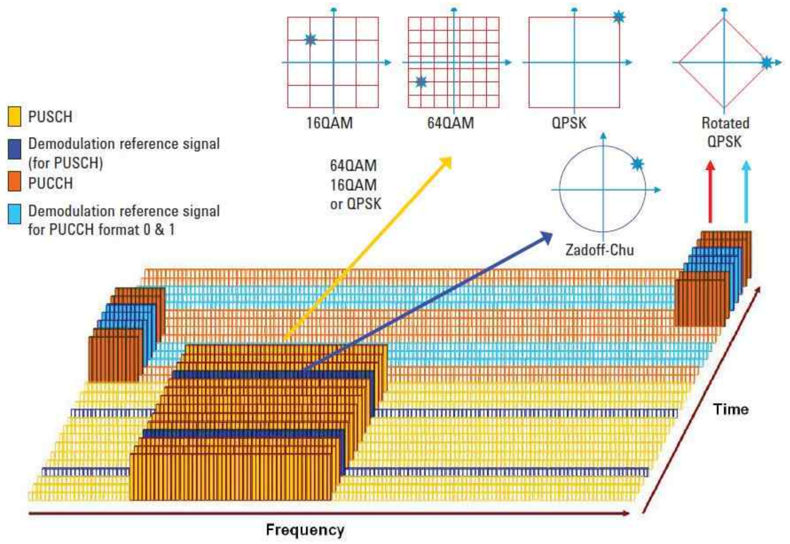
For PUSCH

50 resource blocks in 10 MHz



Screenshot of R&S SMU200A signal generator

LTE Uplink: Resource allocation

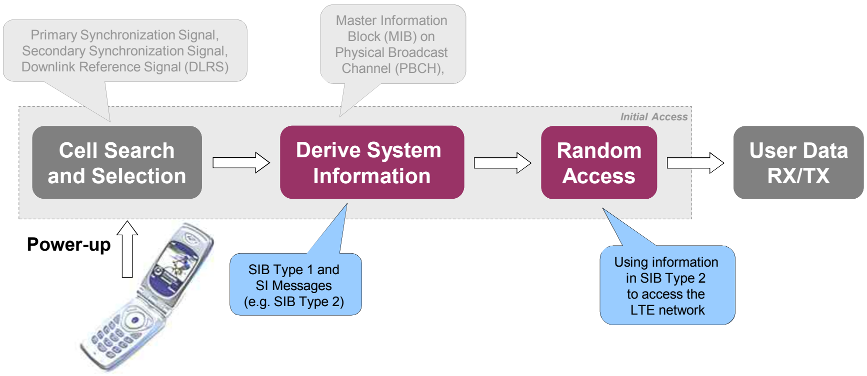


ROHDE&SCHWARZ Date | Title of presentation | 107

LTE Physical Layer Concepts
Initial Access, Part III

ROHDE&SCHWARZ Date | Title of presentation | 108

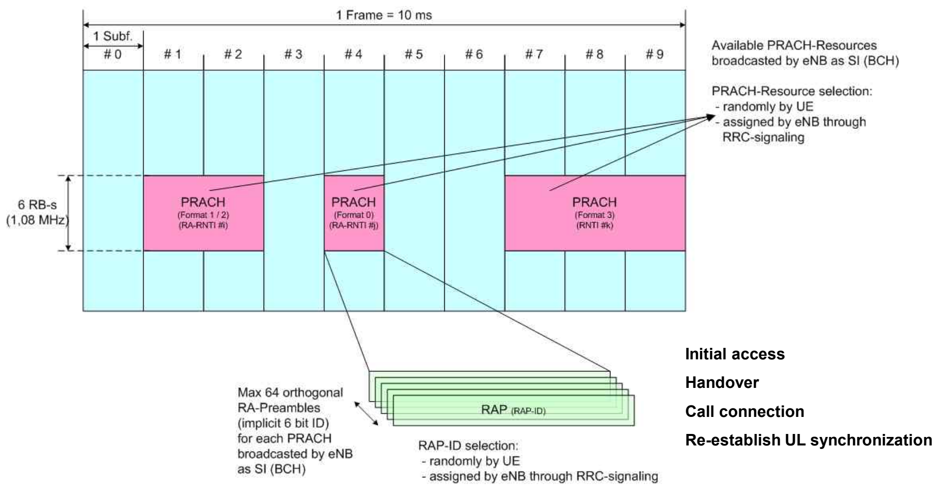
LTE Initial Access



ROHDE&SCHWARZ Date | Title of presentation | 109

LTE Uplink: Random Access Procedure

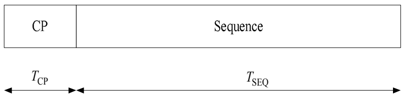
Higher layers indicate position of random access in frequency/time domain



ROHDE&SCHWARZ Date | Title of presentation | 110

LTE Uplink : Random access preamble

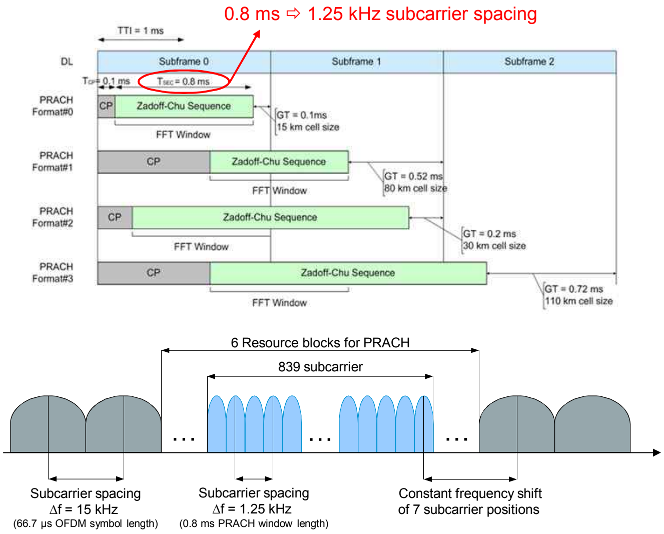
- PRACH 는 RA 과정에서 단말이 기지국으로 전송하는 Preamble
- 6RB를 차지하며 subcarrier는 1.25KHz (Format #4는 7.5KHz)
- Sequence 부분은 길이 839의 ZC sequence로 구성 (Format#4는 길이 139)
- 5 types of preamble formats (Higher layers control the preamble format/configuration)
  Preamble format X PRACH configuration의 조합으로 구성



PRACH configuration	System frame number	Subframe number
0	Even	1
1	Even	4
2	Even	7
3	Any	1
4	Any	4
5	Any	7
6	Any	1, 6
7	Any	2 ,7
8	Any	3, 8
9	Any	1, 4, 7
10	Any	2, 5, 8
11	Any	3, 6, 9
12	Any	0, 2, 4, 6, 8
13	Any	1, 3, 5, 7, 9
14	Any	0, 1, 2, 3, 4, 5, 6, 7, 8, 9
15	Even	9

Preamble format	T_{CP}	T_{SEQ}	
0	$3168 \cdot T_s$	$24576 \cdot T_s$	→ 넓은 반경의 셀 환경과 같이 시간 지연이 긴 경우
1	$21024 \cdot T_s$	$24576 \cdot T_s$	→ SINR이 낮은 상황을 고려하여 sequence repetition
2	$6240 \cdot T_s$	$2 \cdot 24576 \cdot T_s$	→ SINR이 낮은 상황을 고려하여 sequence repetition
3	$21024 \cdot T_s$	$2 \cdot 24576 \cdot T_s$	→ TDD 모드용
4 (frame structure type 2 only)	$448 \cdot T_s$	$4096 \cdot T_s$	

PRACH formats



Thank you for your Attention

ROHDE&SCHWARZ Date | Title of presentation | 113