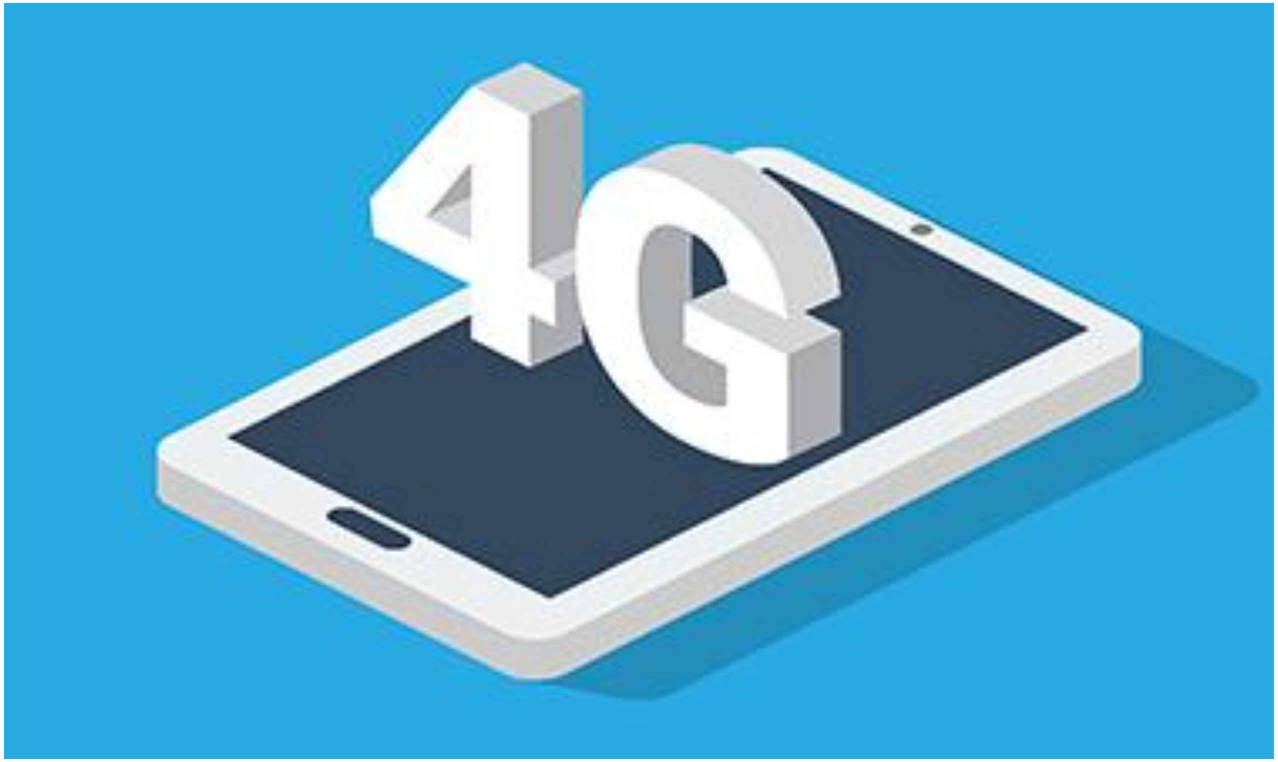
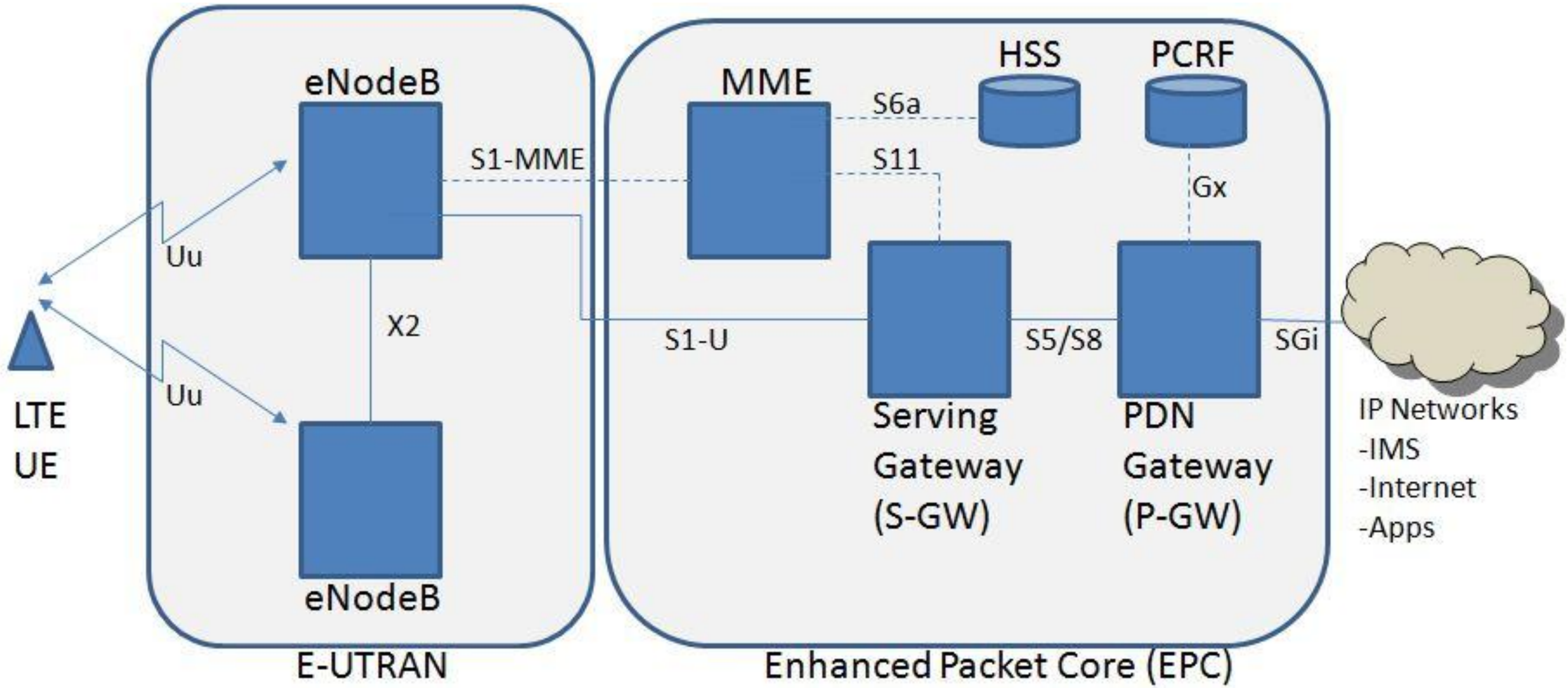



# Long Term Evolution (LTE)
# Long Term Evolution – Advanced (LTE-A)

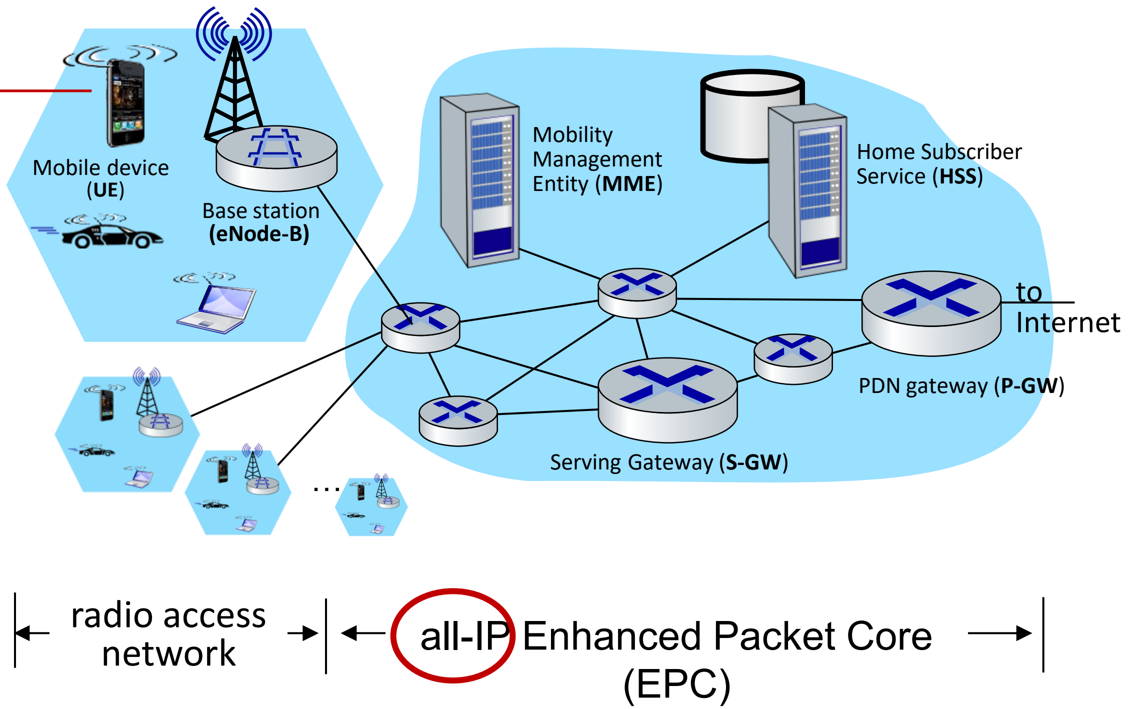
# LTE Architecture



# Elements of 4G LTE architecture

Mobile device:

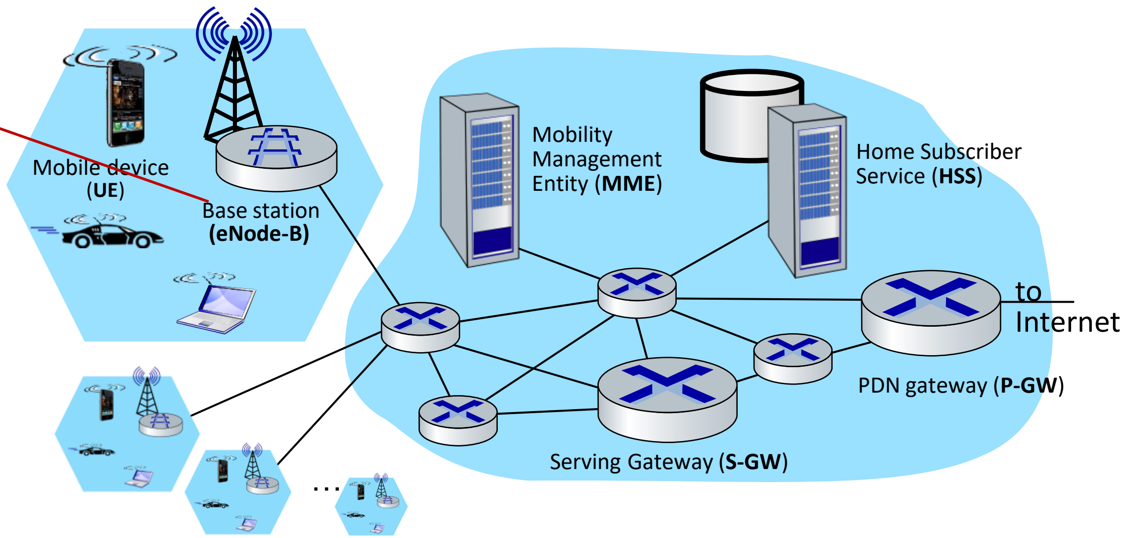
- smartphone, tablet, laptop, IoT, ... with 4G LTE radio
- 64-bit International Mobile Subscriber Identity (IMSI), stored on SIM (Subscriber Identity Module) card
- LTE jargon: User Equipment (UE)



# Elements of 4G LTE architecture

Base station:

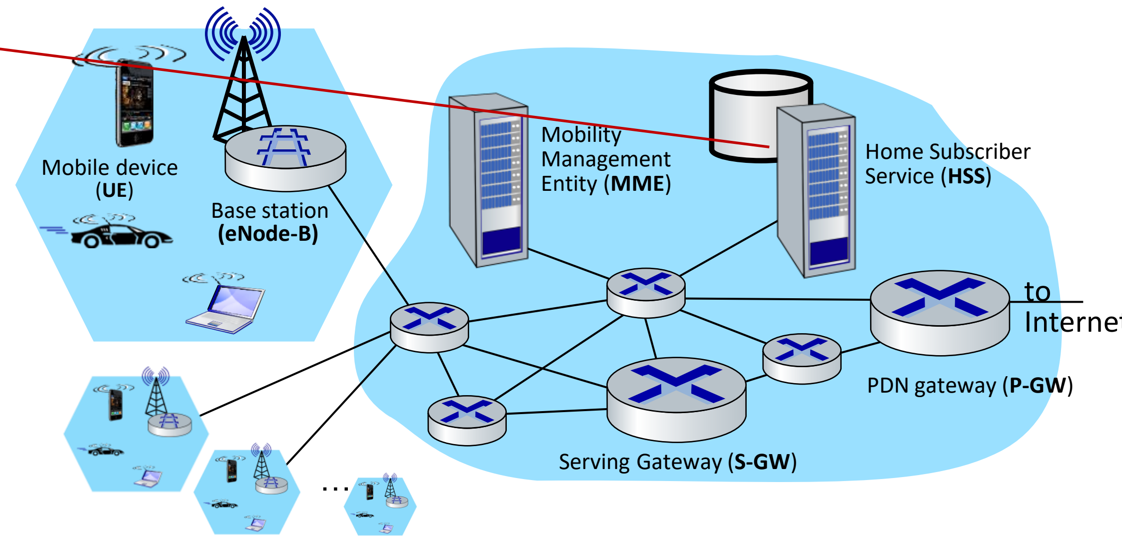
- at "edge" of carrier's network
- manages wireless radio resources, mobile devices in its coverage area ("cell")
- coordinates device authentication with other elements
- similar to WiFi AP but:
  - active role in user mobility
  - coordinates with nearly base stations to optimize radio use
- LTE jargon: eNode-B



# Elements of 4G LTE architecture

## Home Subscriber Service

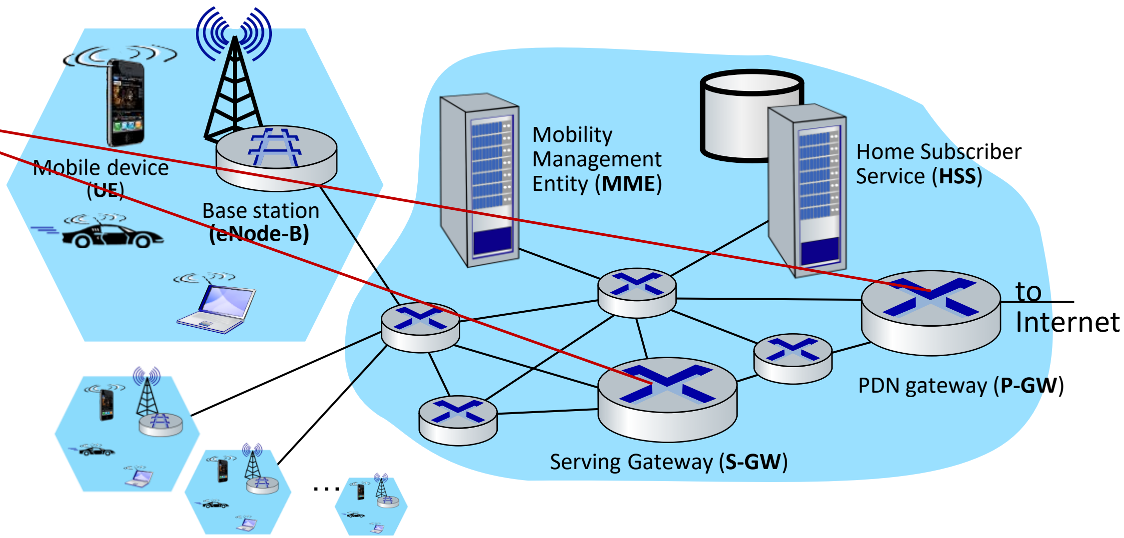
- stores info about mobile devices for which the HSS's network is their "home network"
- works with MME in device authentication



# Elements of 4G LTE architecture

Serving Gateway (S-GW), PDN Gateway (P-GW)

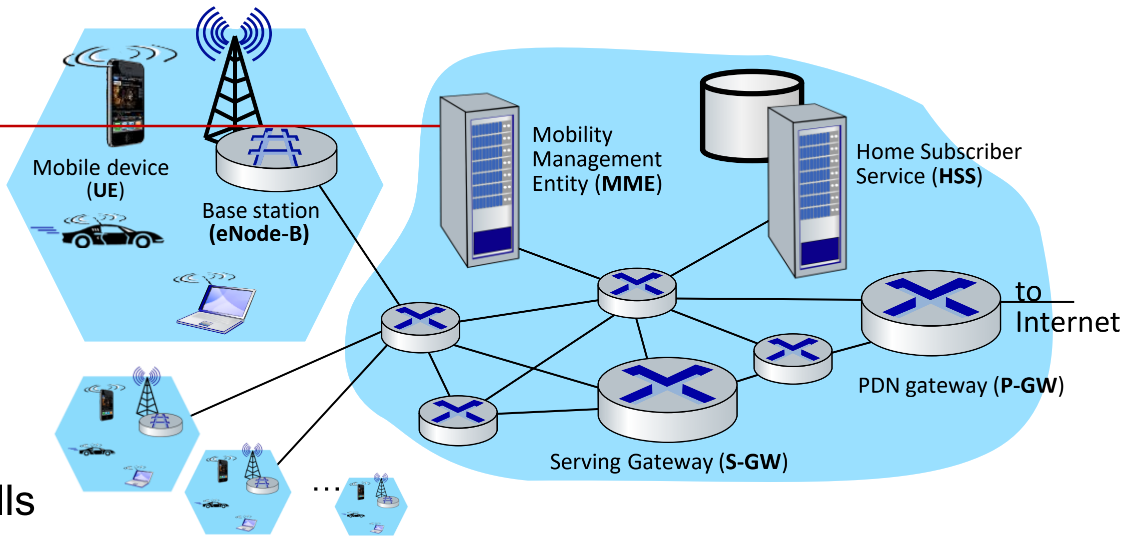
- lie on data path from mobile to/from Internet
- P-GW
  - gateway to mobile cellular network
  - Looks like any other internet gateway router
  - provides NAT services
- other routers:
  - extensive use of tunneling



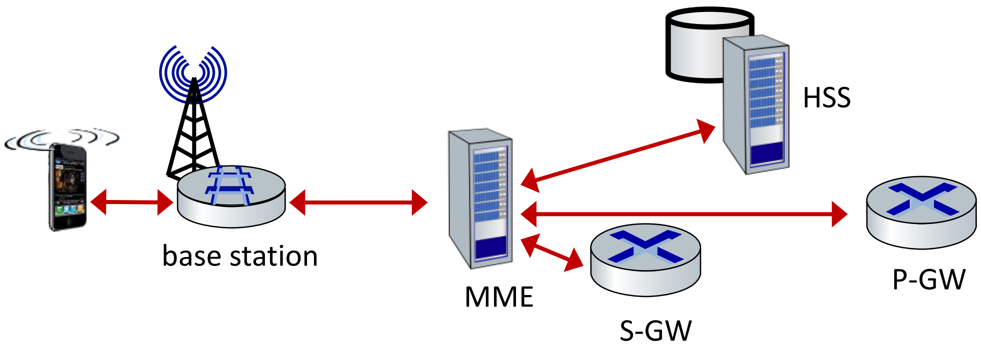
# Elements of 4G LTE architecture

Mobility Management Entity

- device authentication (device-to-network, network-to-device) coordinated with mobile home network HSS
- mobile device management:
  - device handover between cells
  - tracking/paging device location
- path (tunneling) setup from mobile device to P-GW

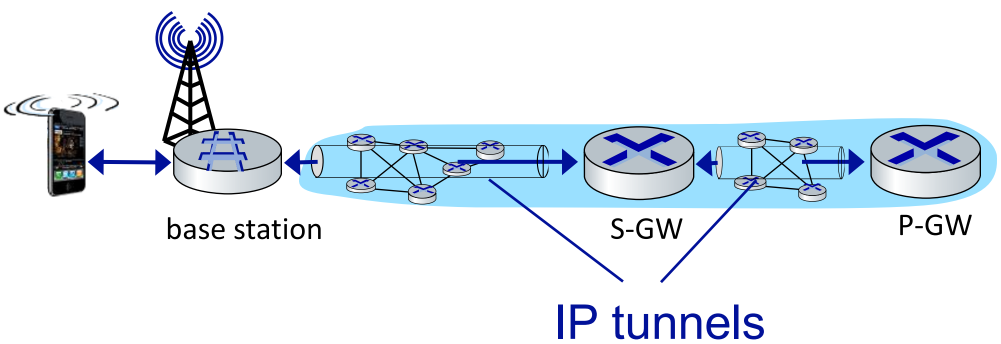


# LTE: data plane control plane separation




control plane

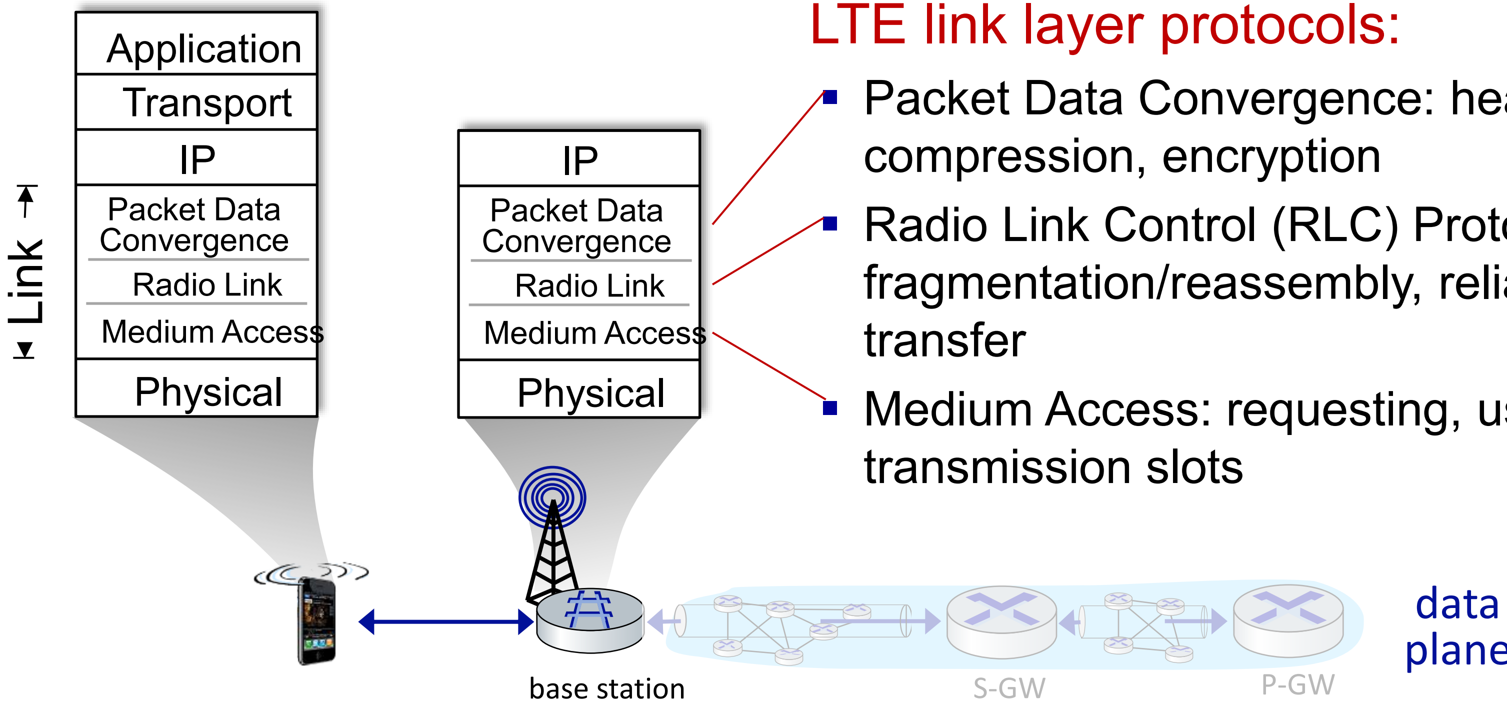
- new protocols for mobility management , security, authentication




data plane

- new protocols at link, physical layers
- extensive use of tunneling to facilitate mobility

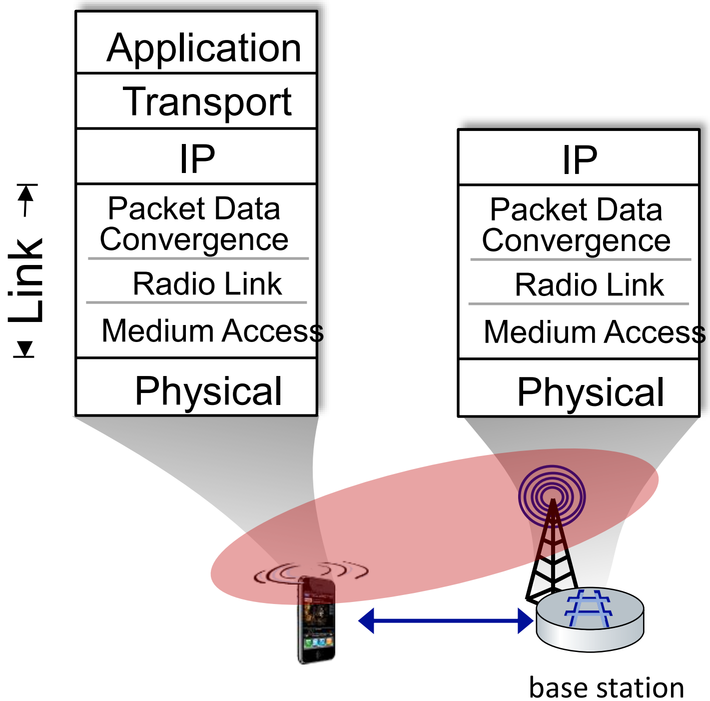
# LTE data plane protocol stack: first hop




## LTE link layer protocols:

- Packet Data Convergence: header compression, encryption
- Radio Link Control (RLC) Protocol: fragmentation/reassembly, reliable data transfer
- Medium Access: requesting, use of radio transmission slots

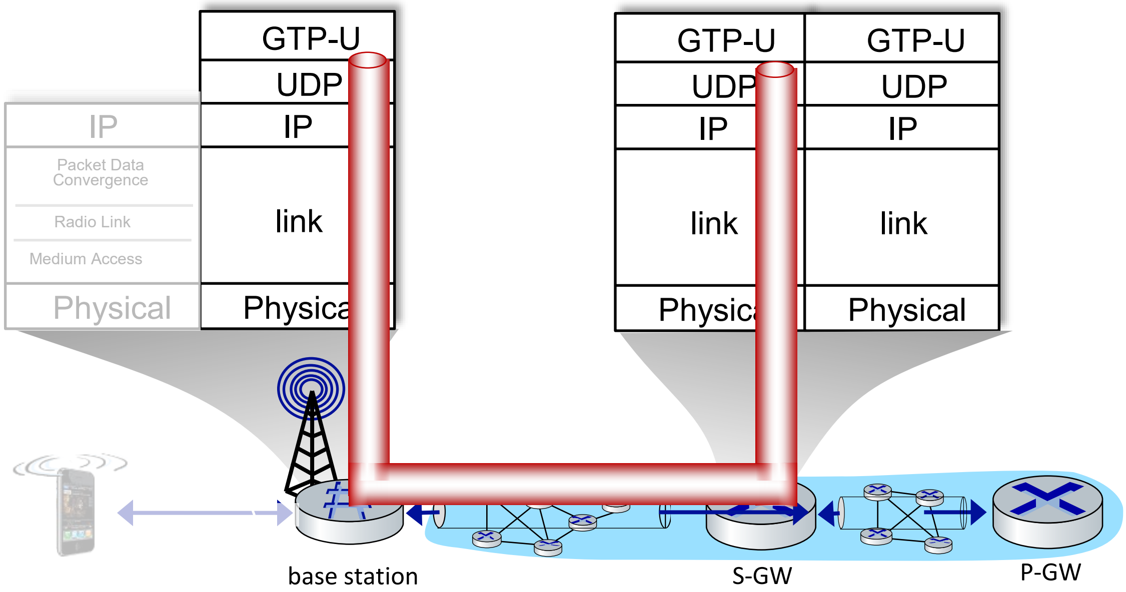
# LTE data plane protocol stack: first hop




LTE radio access network:

- downstream channel: FDM, TDM within frequency channel (OFDM - orthogonal frequency division multiplexing)
  - "orthogonal": minimal interference between channels
  - upstream: FDM, TDM similar to OFDM
- each active mobile device allocated two or more 0.5 ms time slots over 12 frequencies
  - scheduling algorithm not standardized – up to operator
  - 100's Mbps per device possible

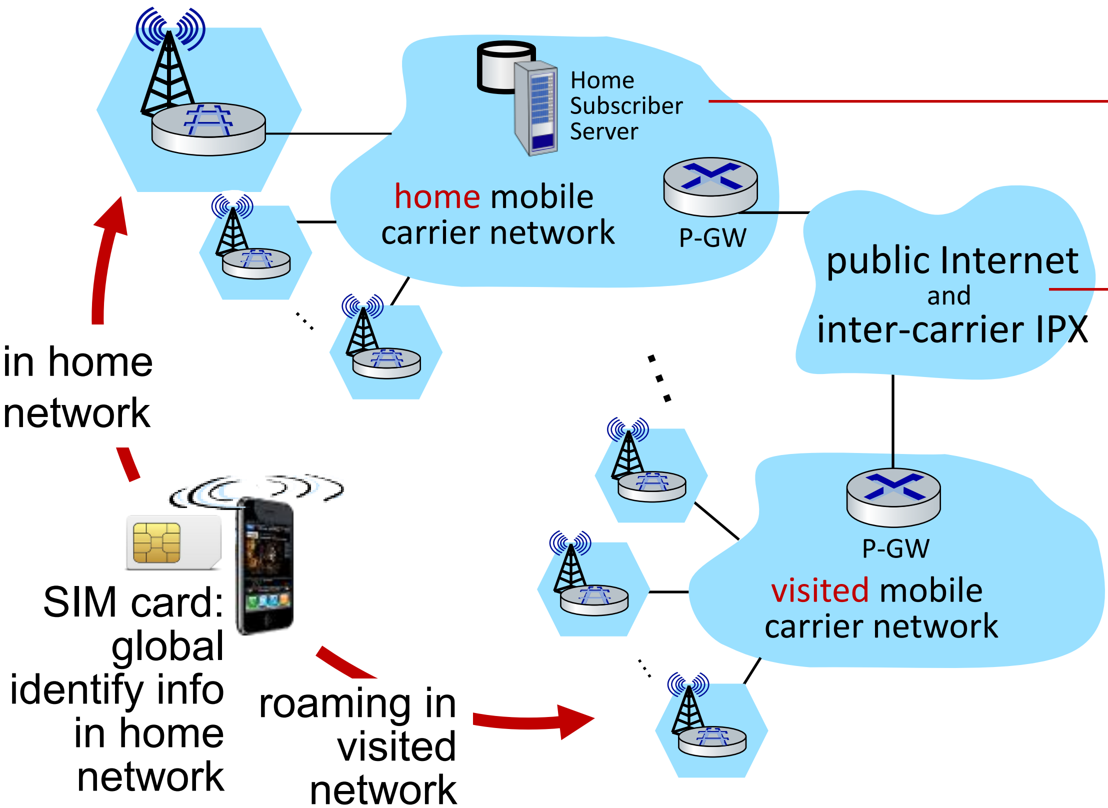
# LTE data plane protocol stack: packet core




tunneling:

- mobile datagram encapsulated using GPRS Tunneling Protocol (GTP), sent inside UDP datagram to S-GW
- S-GW re-tunnels datagrams to P-GW
- supporting mobility: only tunneling endpoints change when mobile user moves

# Global cellular network: a network of IP networks




home network HSS:

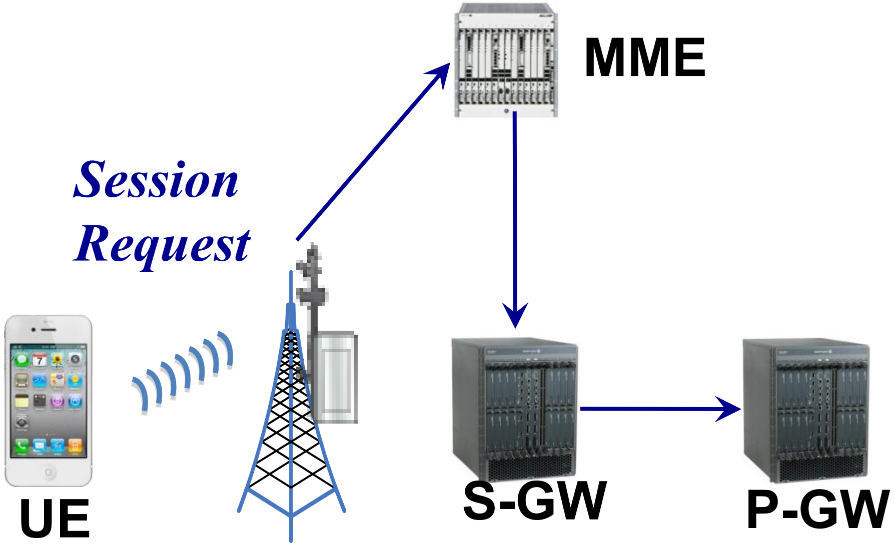
- identify & services info, while in home network and roaming

all IP:

- carriers interconnect with each other, and public internet at exchange points
- legacy 2G, 3G: not all IP, handled otherwise

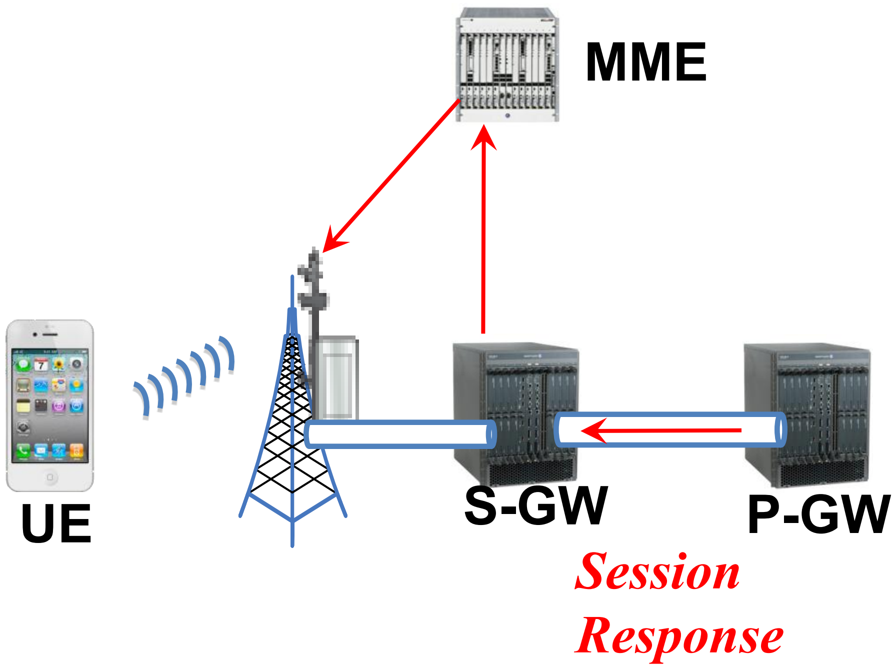
# Connection Setup

- Session Requests
  - UE to base station
  - Base station to MME
    - MME obtains subscriber info from HSS, selects S-GW and P-GW
  - S-GW sends to P-GW
    - P-GW obtains policy from PCRF



# Connection Setup (Cont'd)

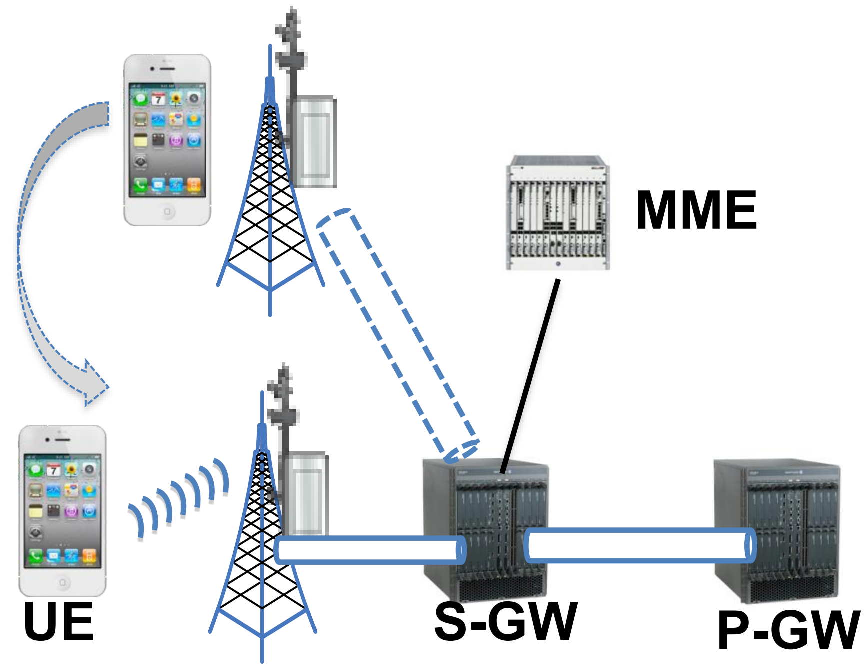
- Session Response
  - Establishes GPRS Tunnels (GTP) between S-GW and P-GW, between S-GW and UE
  - Base station allocates radio resources to UE



# Mobility Management

Handoff

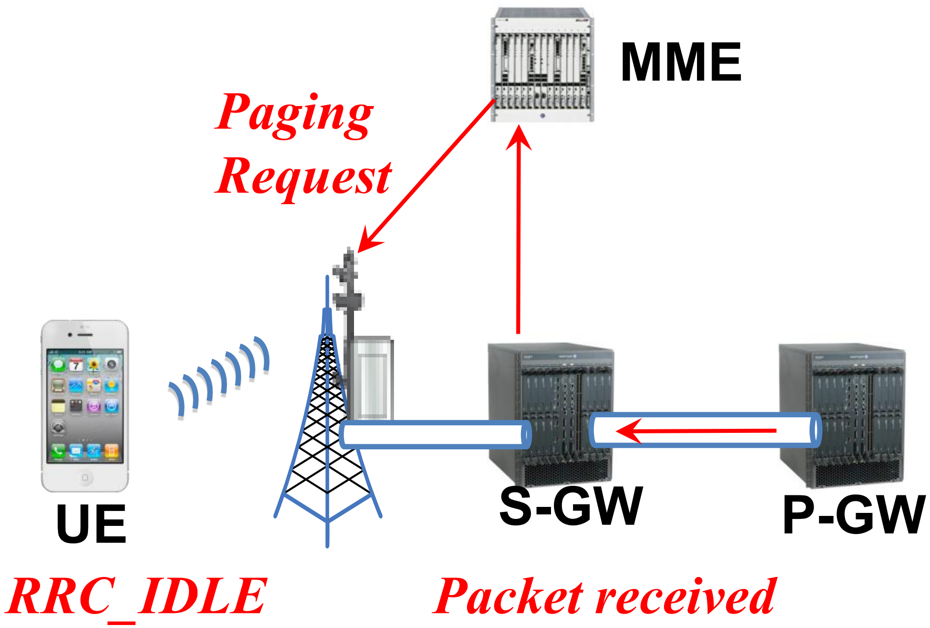
- Handoff without change of S-GW
  - No change at P-GW
- Handoff with change of S-GW or MME
- Inter-technology handoff (LTE to 3G)



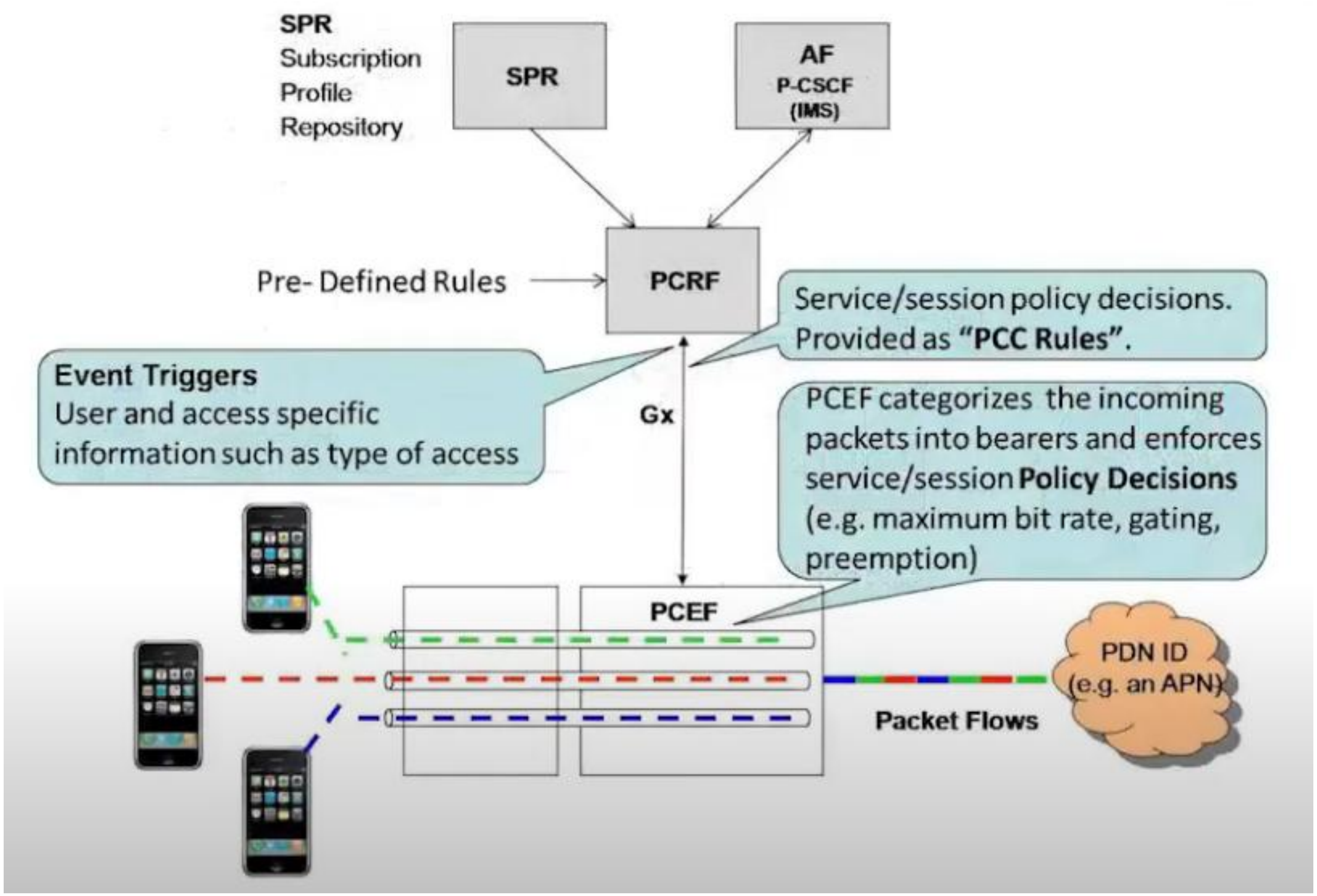
# Mobility Management (Cont'd)

Paging

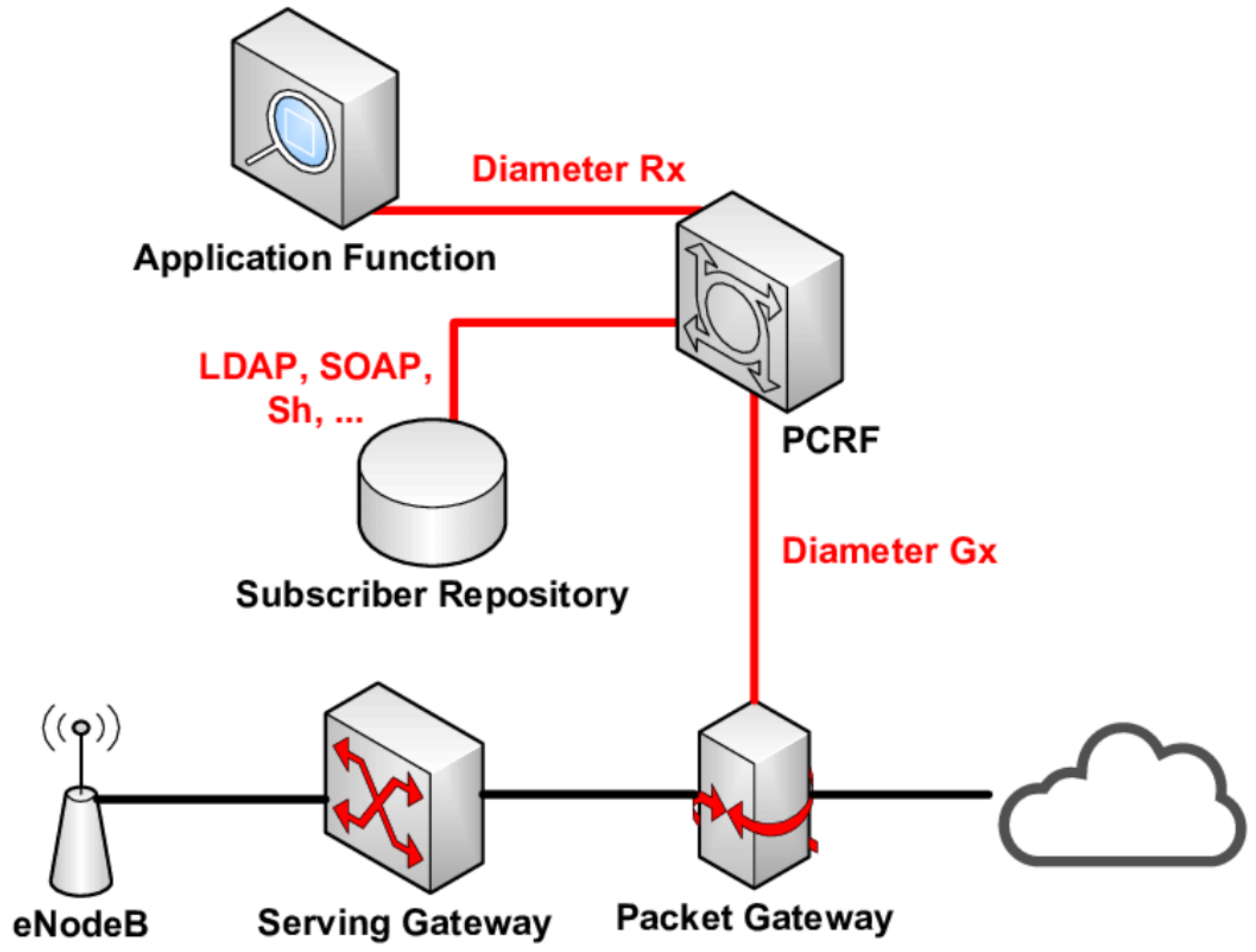
- If S-GW receives a packet to a UE in IDLE state, inform MME
- MME pages UE through base station



# Policy and Charging Rules Function (PCRF)

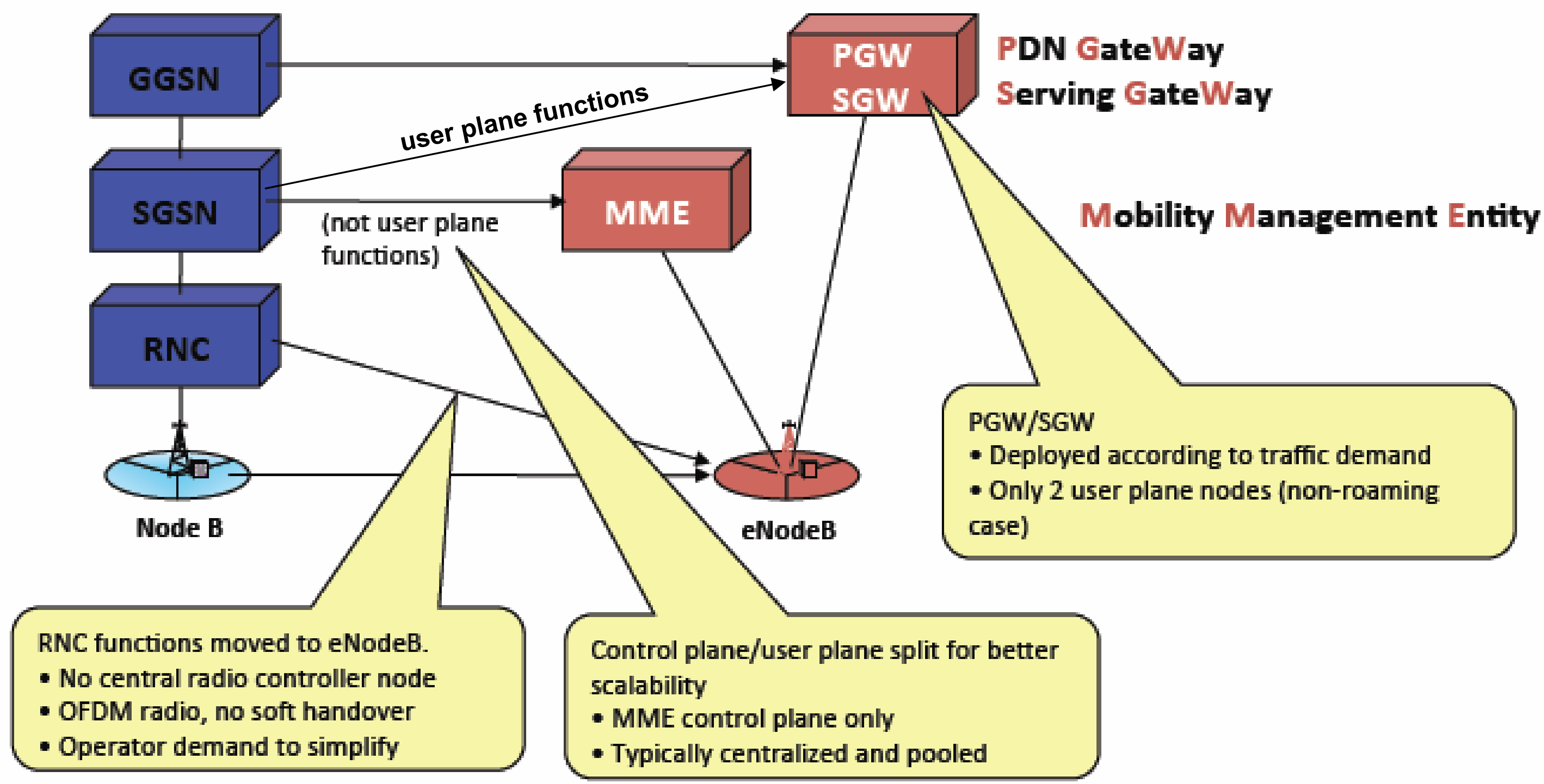


# Policy and Charging Rules Function (PCRF)

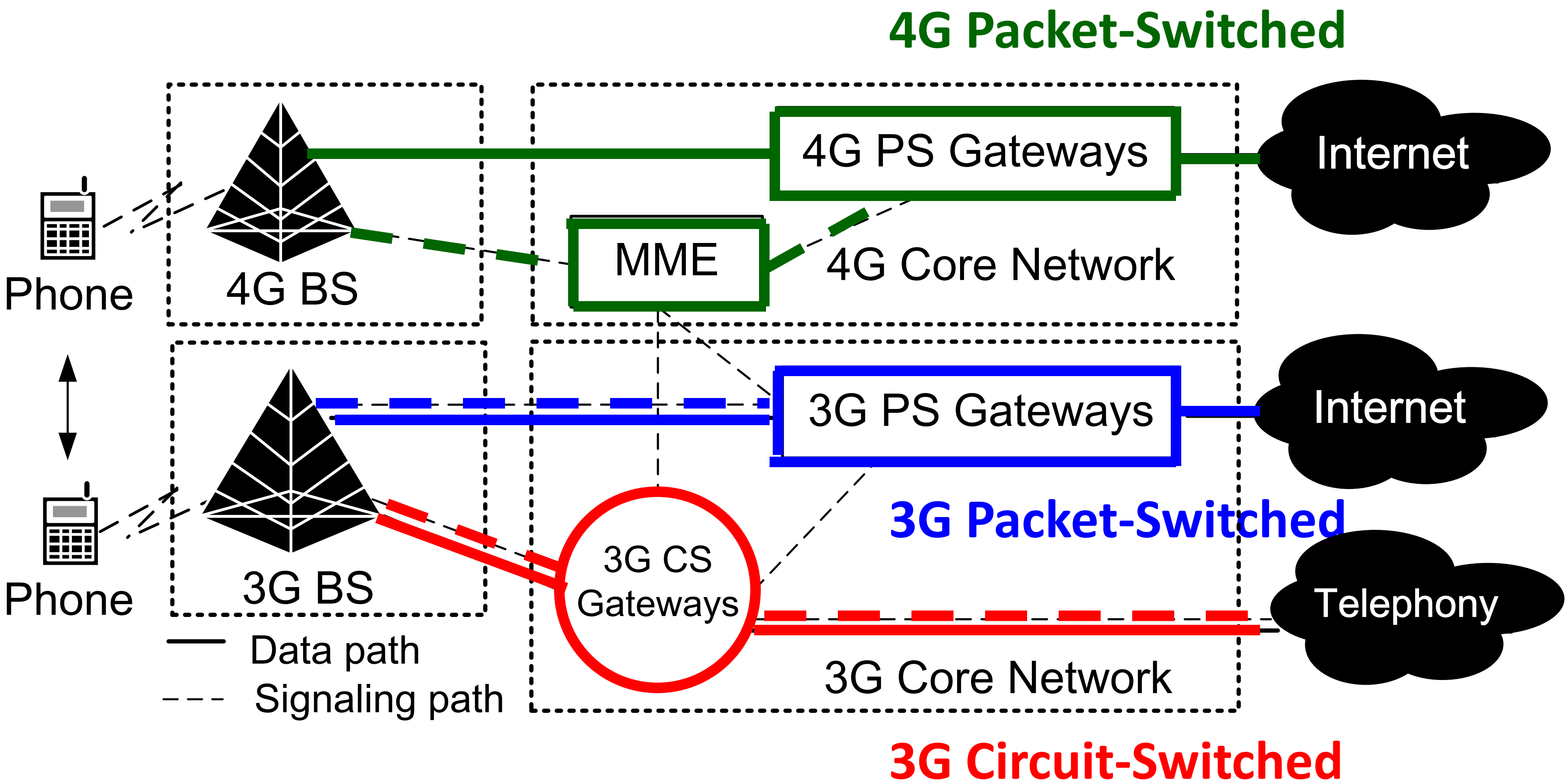


# LTE vs UMTS

- Functional changes compared to the UMTS architecture



# LTE vs UMTS

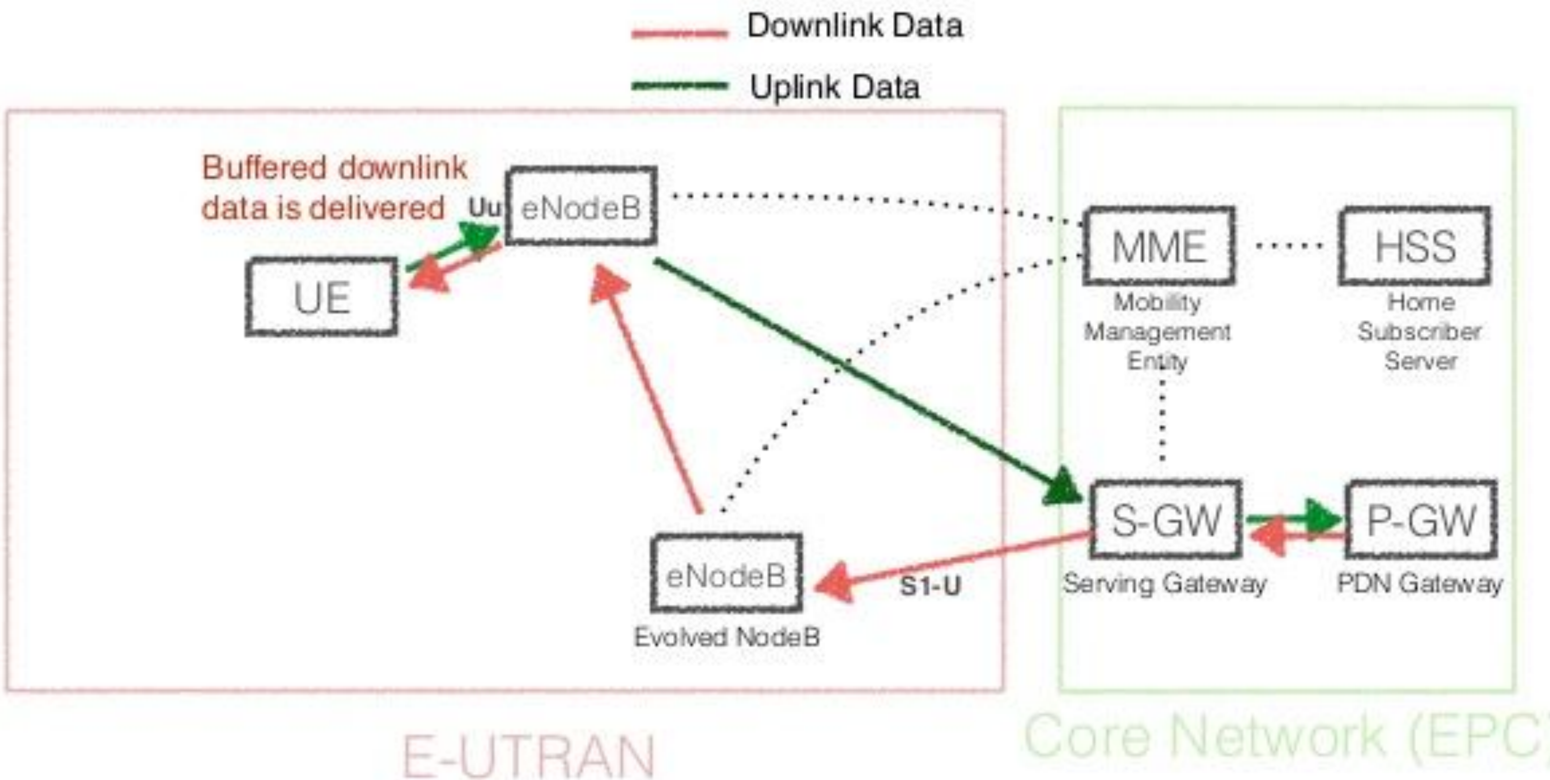


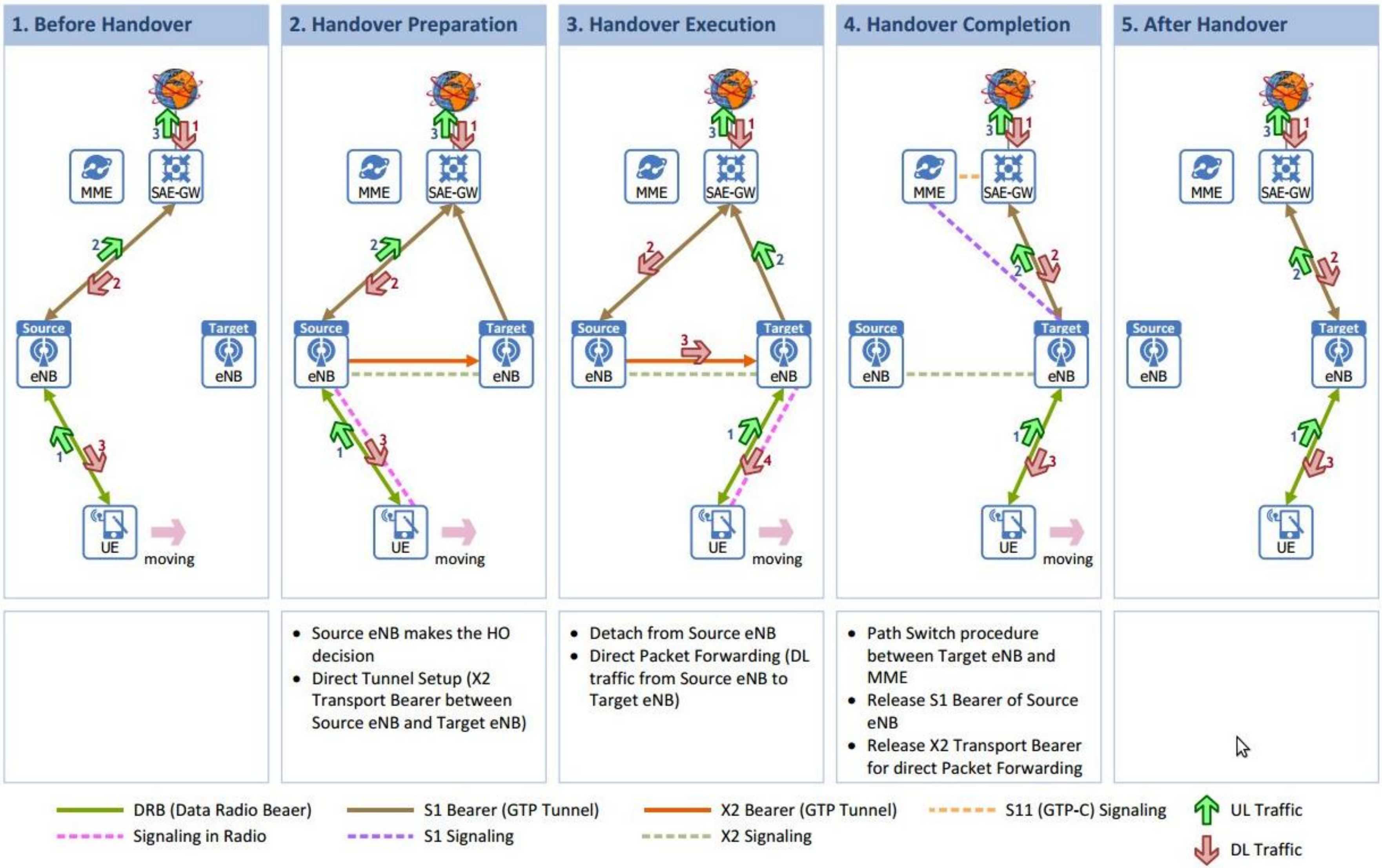
4G Packet-Switched
4G PS Gateways
Internet
MME
4G Core Network
Phone
4G BS
3G PS Gateways
Internet
3G Packet-Switched
3G CS
Gateways
Telephony
Phone
3G BS
Data path
Signaling path
3G Core Network
3G Circuit-Switched

Decision → Request → Preparation → Path Switch → Complete

# X2 Handover

**Data flow during handover execution (after ho preparation):**

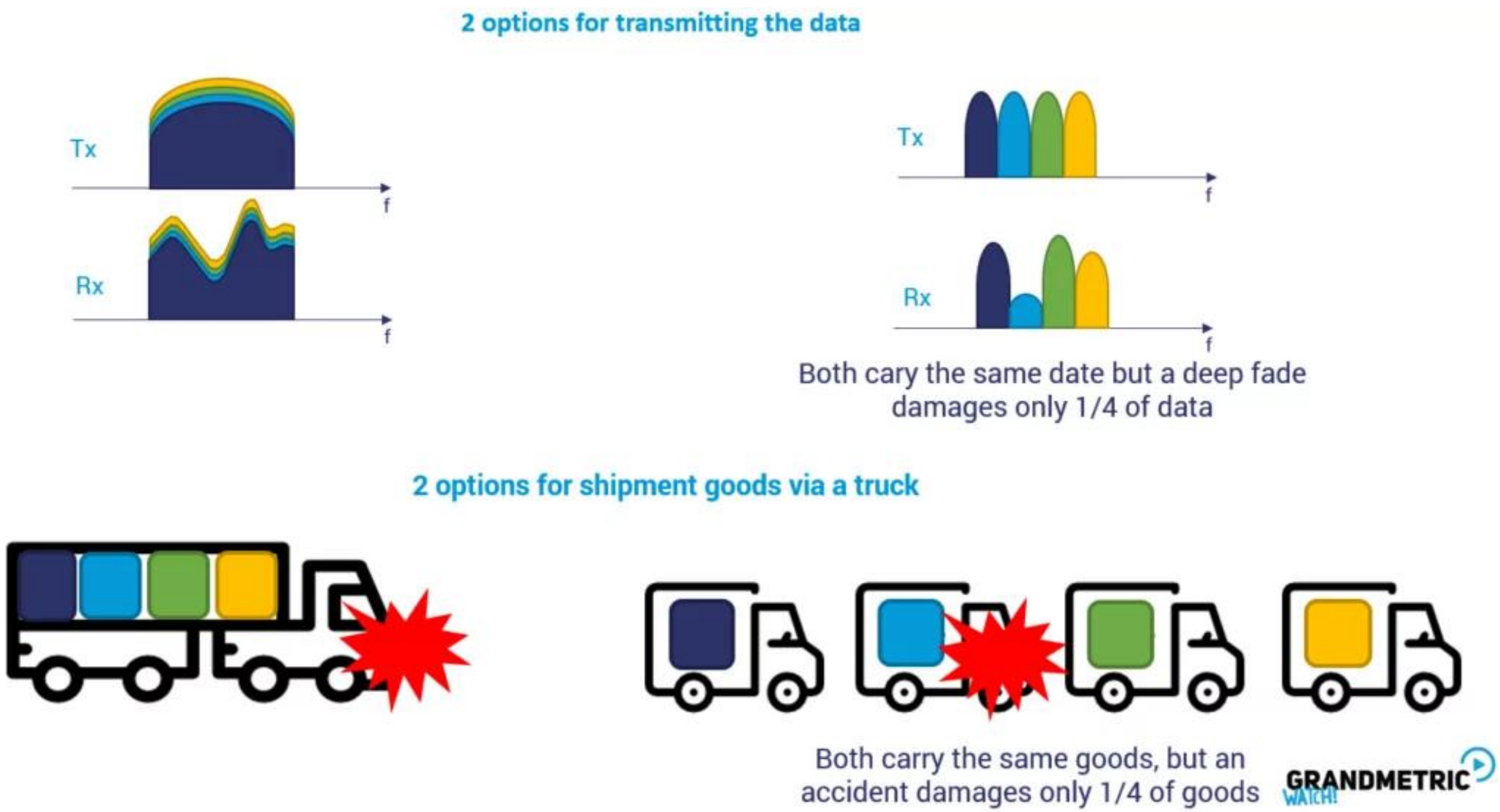



1. Before Handover
2. Handover Preparation
3. Handover Execution
4. Handover Completion
5. After Handover
MME
SAE-GW
Source
eNB
Target
eNB
UE
moving
• Source eNB makes the HO decision
• Direct Tunnel Setup (X2 Transport Bearer between Source eNB and Target eNB)
• Detach from Source eNB
• Direct Packet Forwarding (DL traffic from Source eNB to Target eNB)
• Path Switch procedure between Target eNB and MME
• Release S1 Bearer of Source eNB
• Release X2 Transport Bearer for direct Packet Forwarding
DRB (Data Radio Beaer)
Signaling in Radio
S1 Bearer (GTP Tunnel)
S1 Signaling
X2 Bearer (GTP Tunnel)
X2 Signaling
S11 (GTP-C) Signaling
UL Traffic
DL Traffic

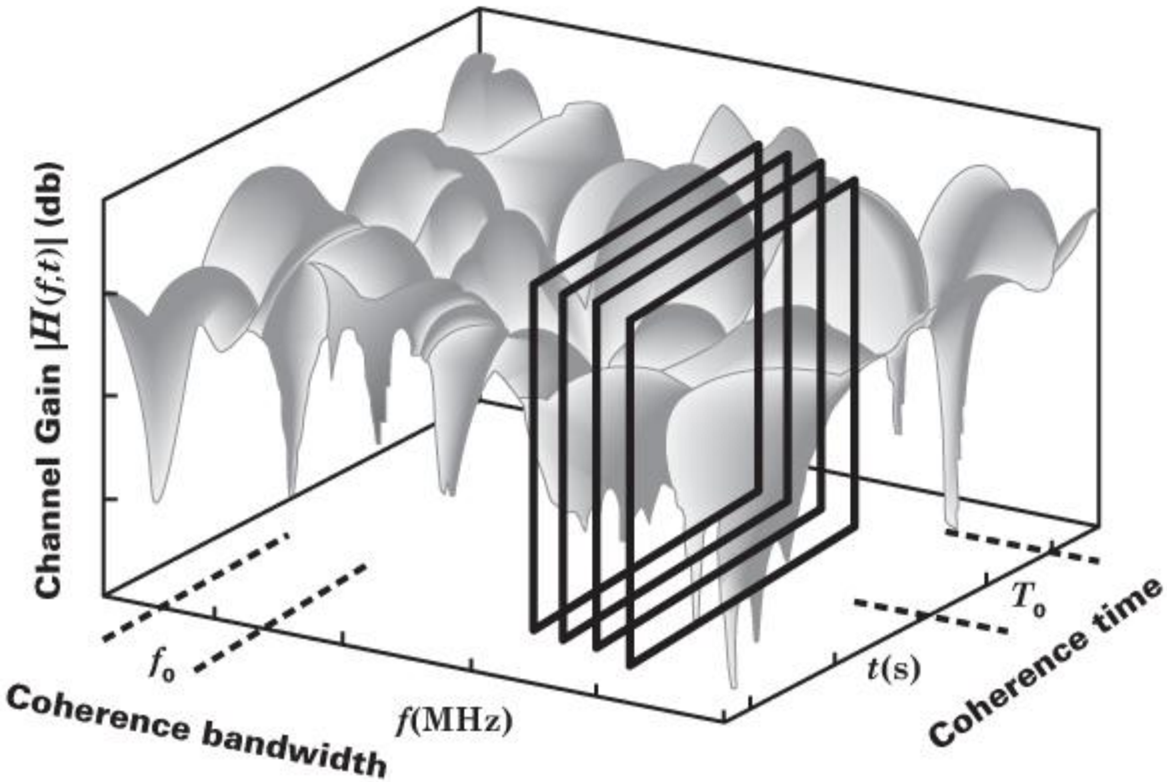
# LTE Transmission Techniques

- LTE employs Orthogonal Frequency Division Multiple Access (OFDMA) for downlink data transmission and Single Carrier FDMA (SC-FDMA) for uplink transmission

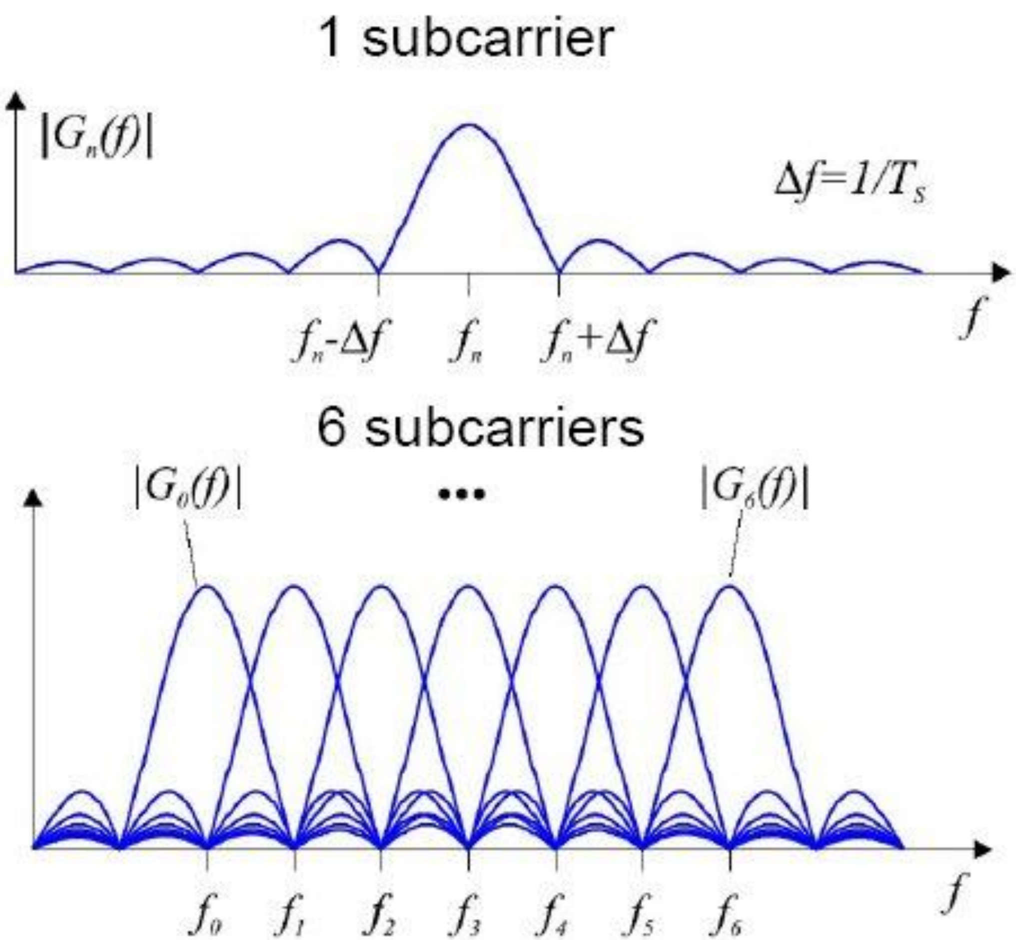
# LTE-Downlink (OFDM)



# LTE-Downlink (OFDM)



# LTE-Downlink (OFDM)



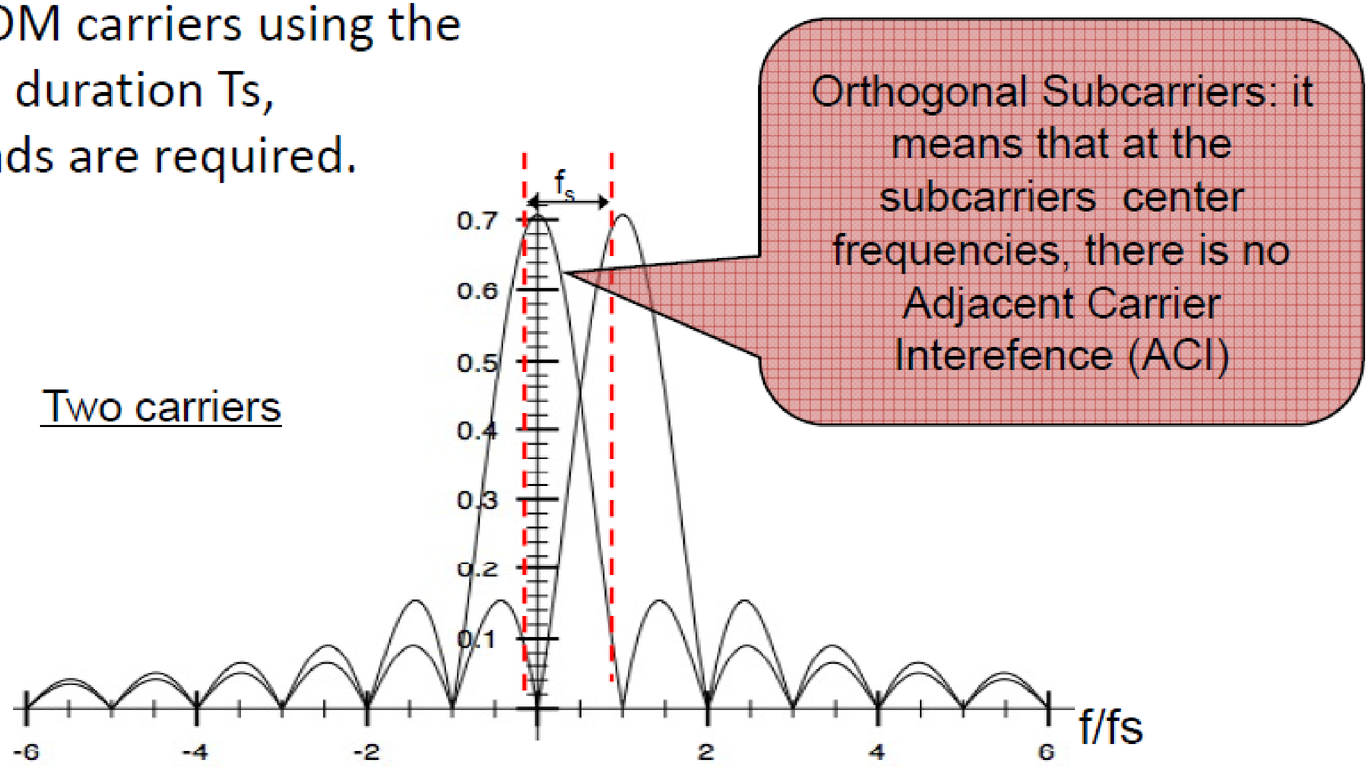

- Improved spectral efficiency
- Reduce ISI effect by multipath
- Against frequency selective fading

# OFDM: Orthogonal Frequency Division Multi-Carrier

Thus OFDM simply places the next carrier exactly in the first null point of the previous one.

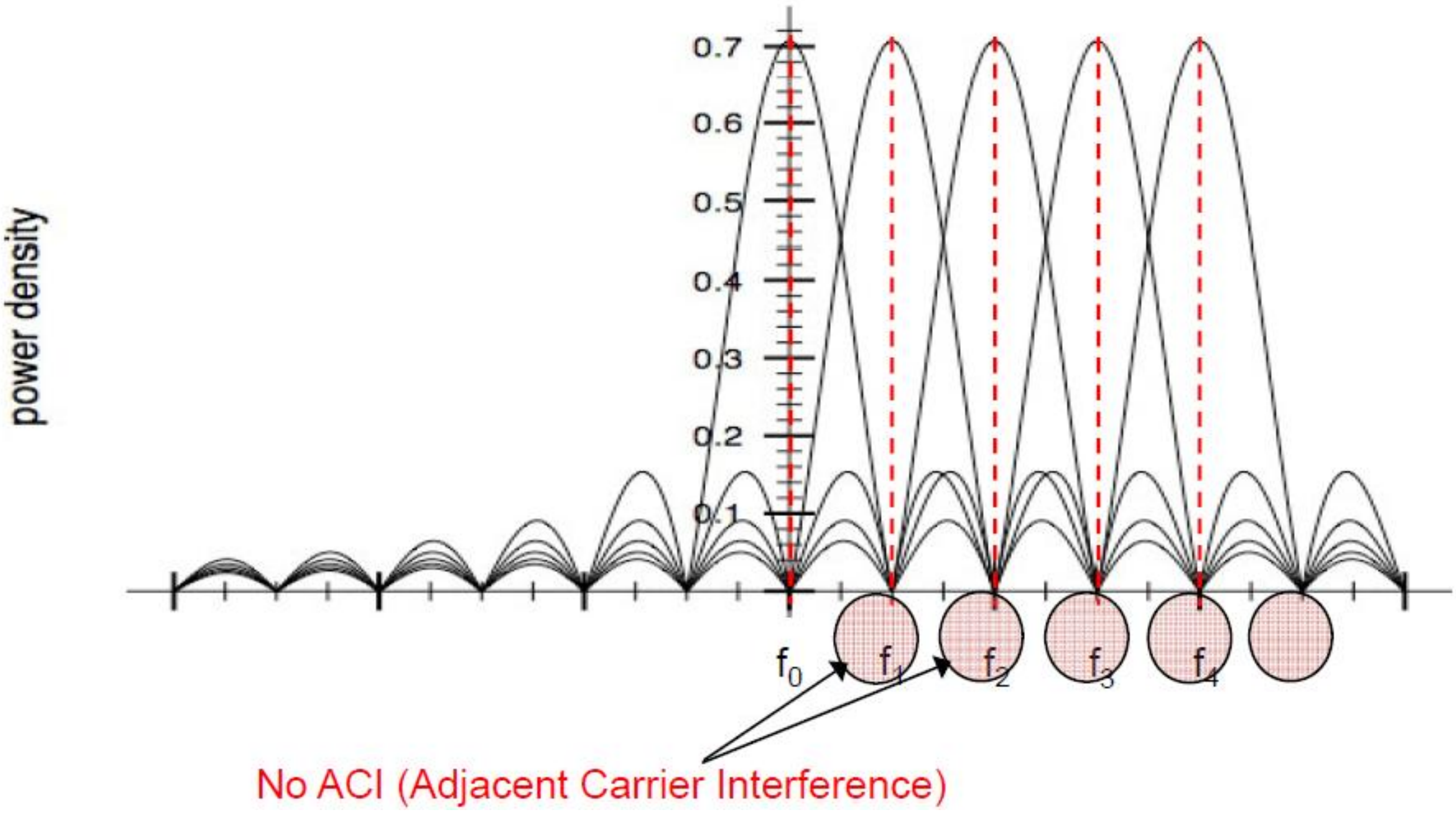
With this we don't need any pulse-shaping.

Between OFDM carriers using the same symbol duration Ts, no guard bands are required.



# Spectrum Overlapping of multiple OFDM carriers

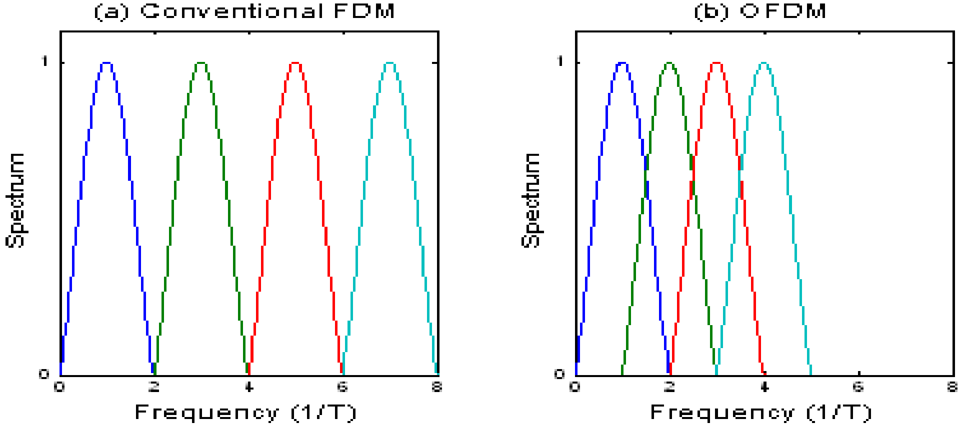
$$f_n = f_0 + nf_s = f_0 + n\frac{1}{T_s} \qquad n = \ldots -1, 0, 1, 2 \ldots$$



# OFDM pros and cons

Pros

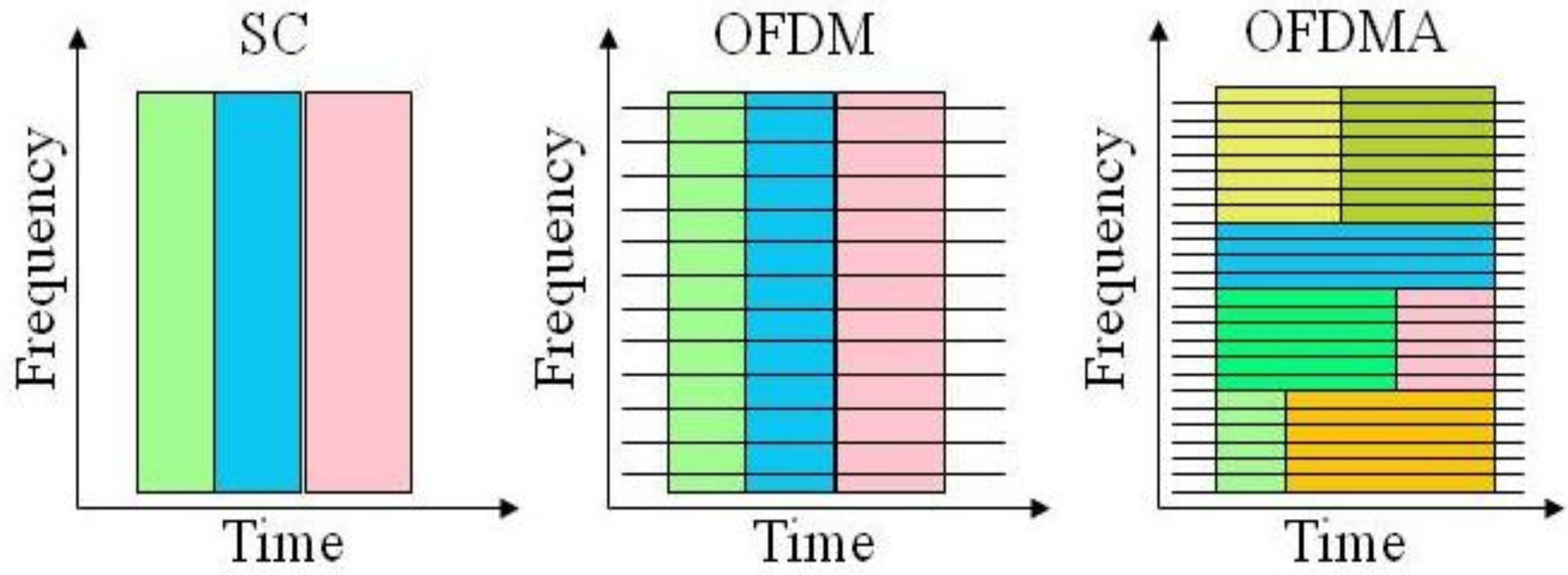
- Spectral efficiency
- Robust against narrow-band co-channel interference
- Higher throughput in the same frequency band (more subcarriers)




Cons

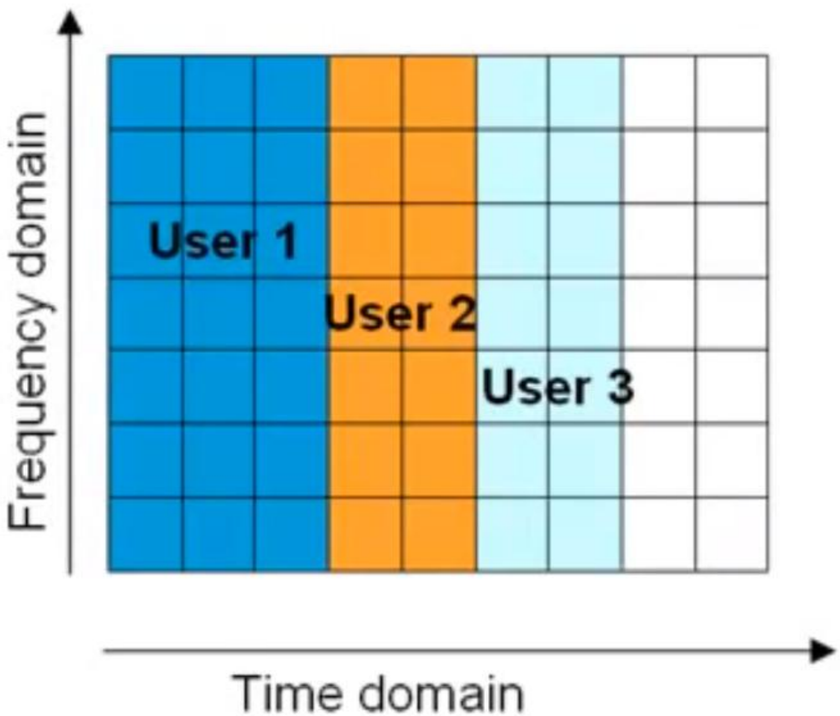
- It is more sensitive to carrier frequency offsets
- More energy requirements due to high peak-to-average power ratio (PAPR)

# SC/OFDM/OFDMA

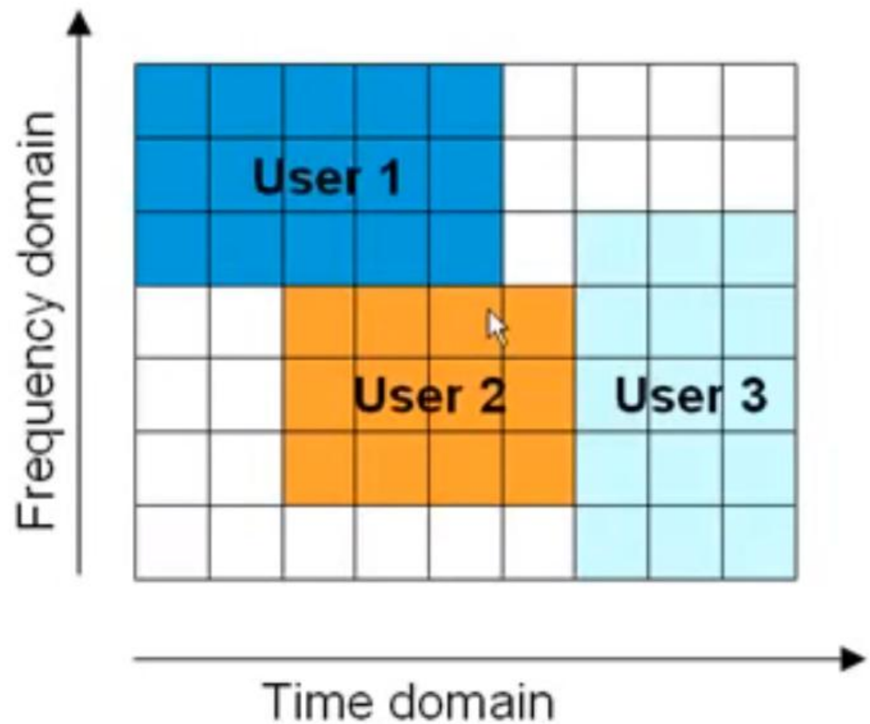


# OFDMA allocation

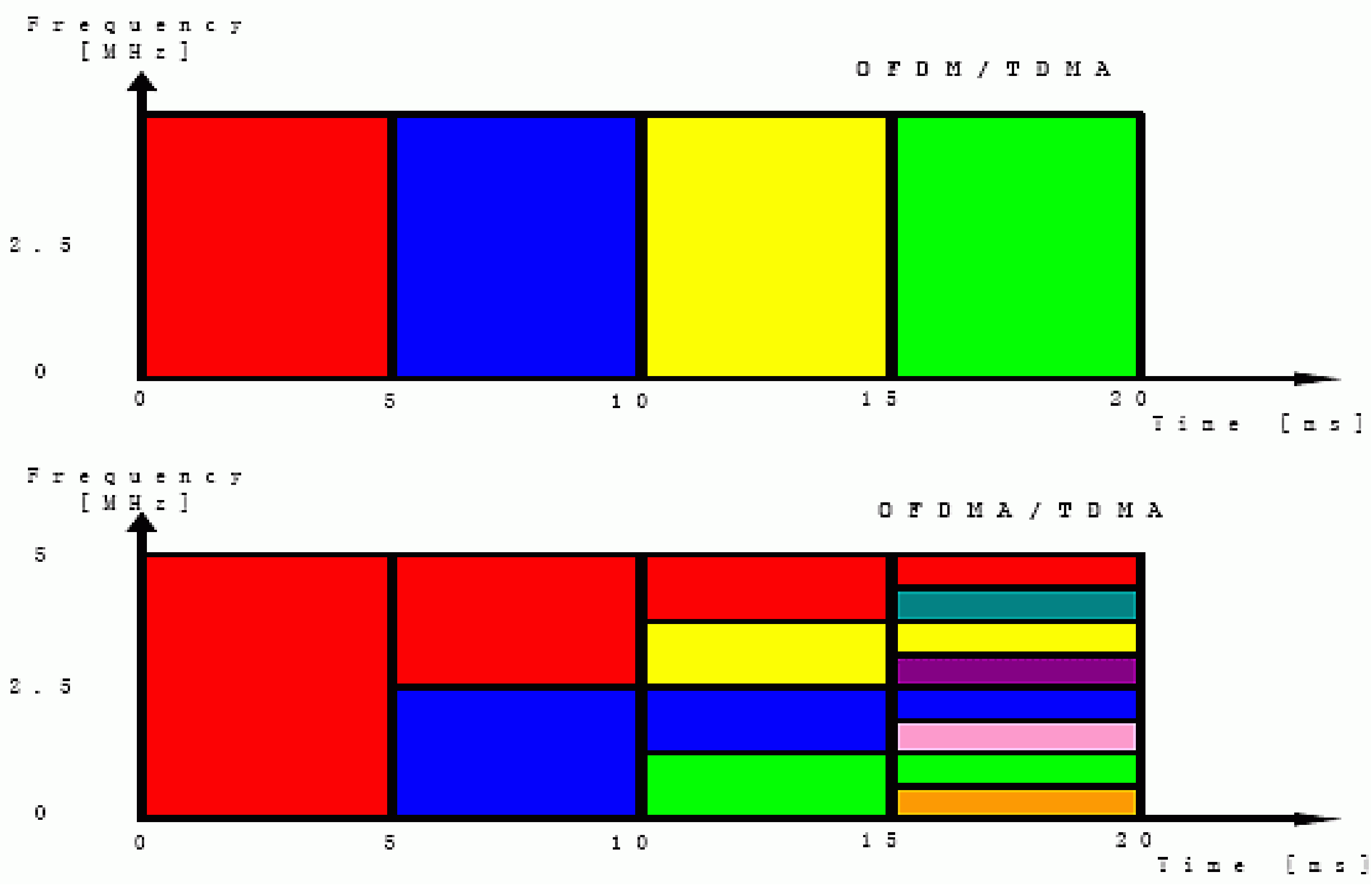
- OFDM allocates users in time domain only



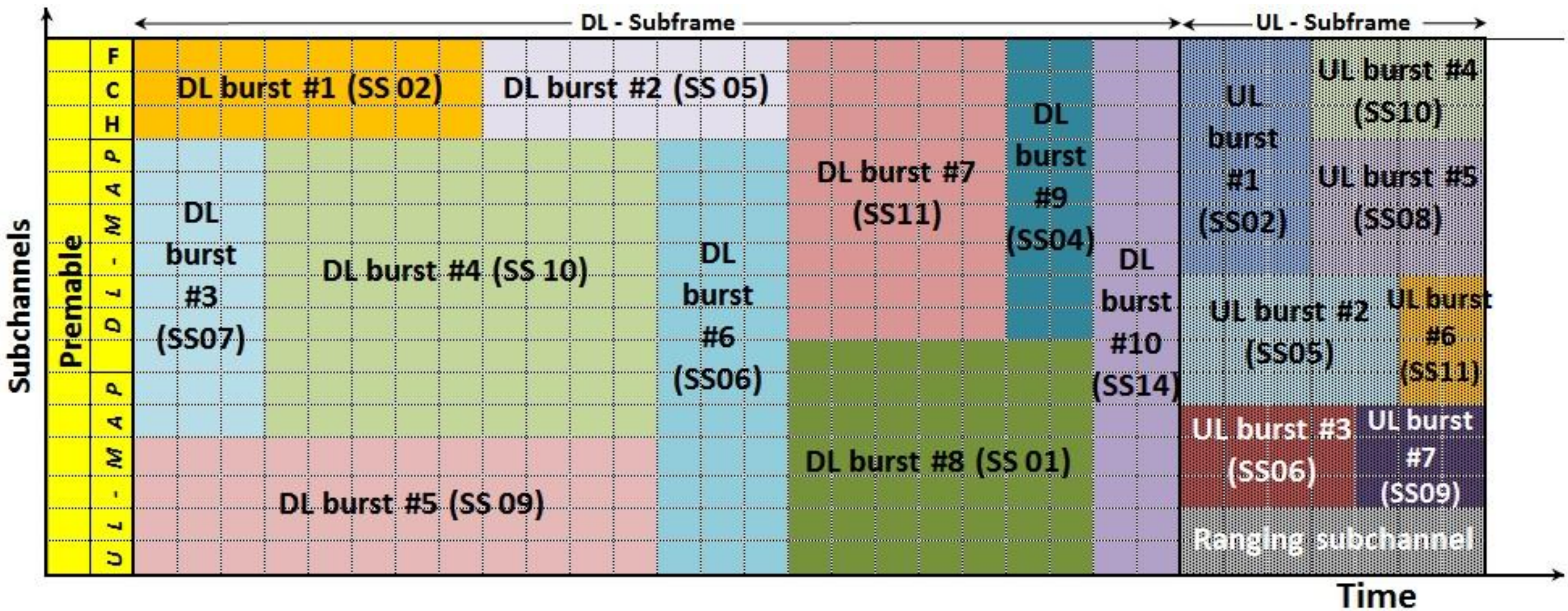

- OFDMA allocates users in time and frequency domain



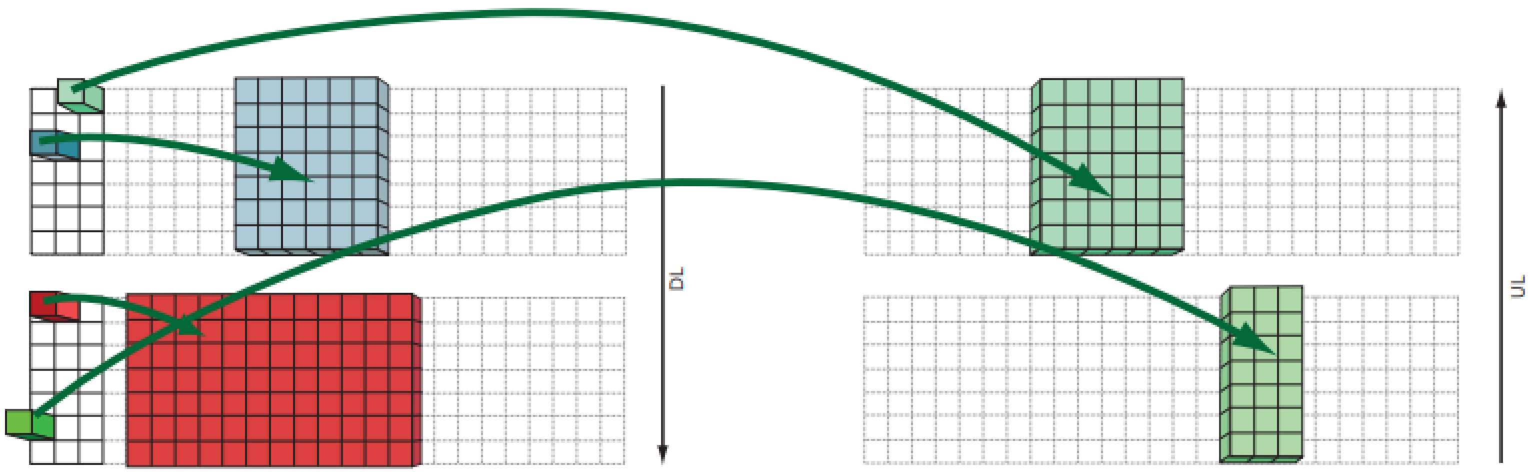
# OFDMA allocation



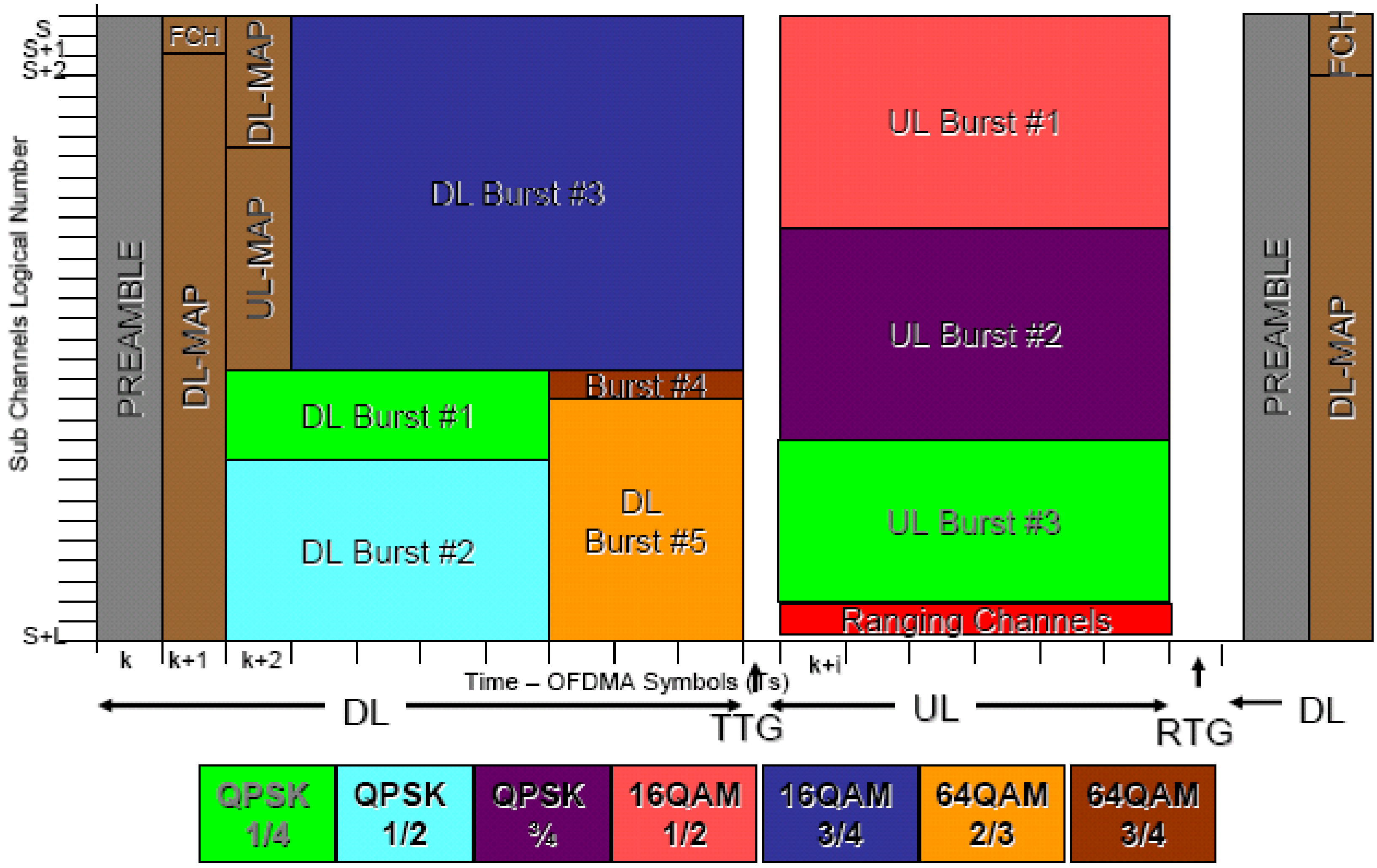
# OFDMA/TDD structure



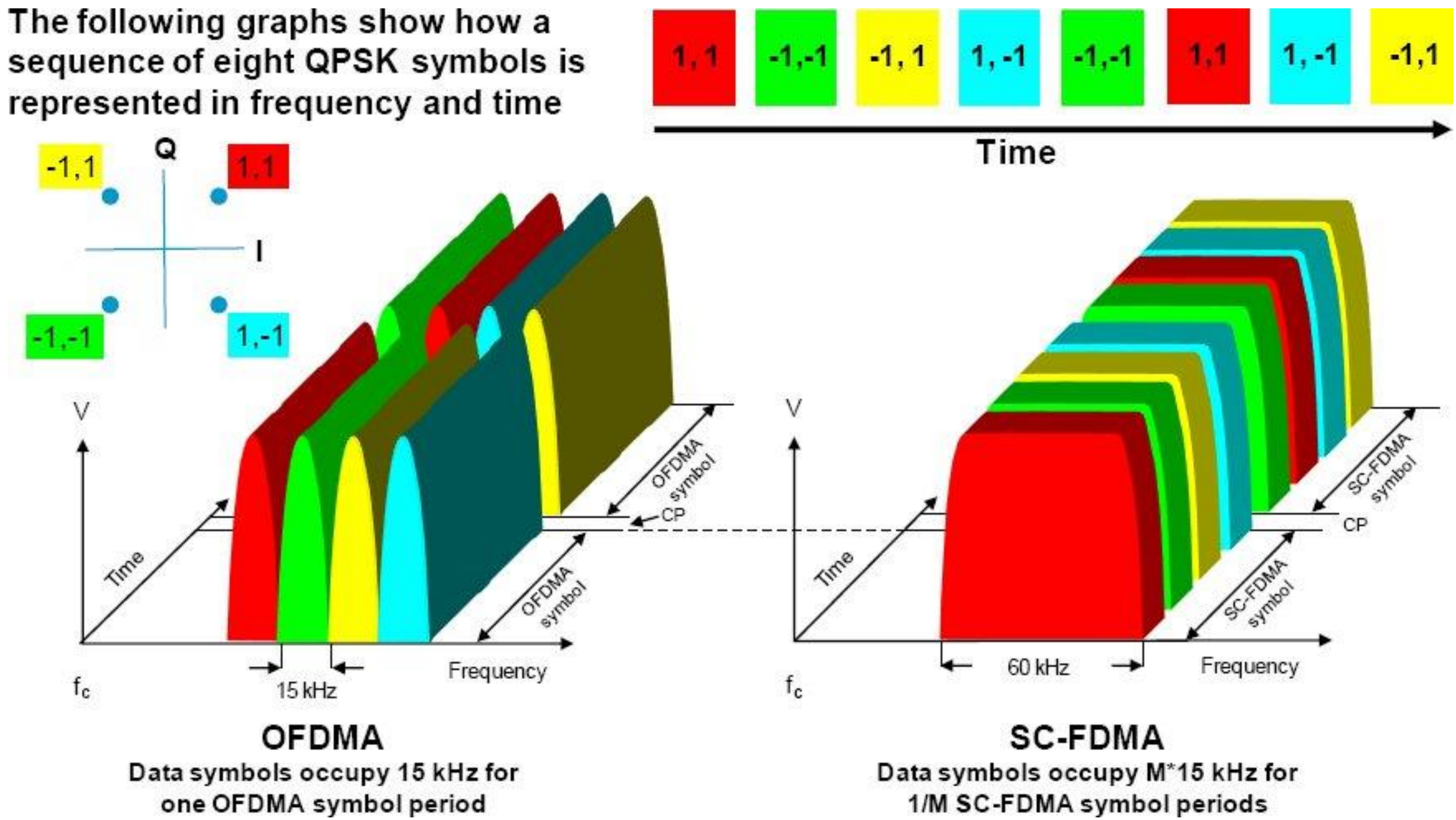
# OFDMA/TDD structure



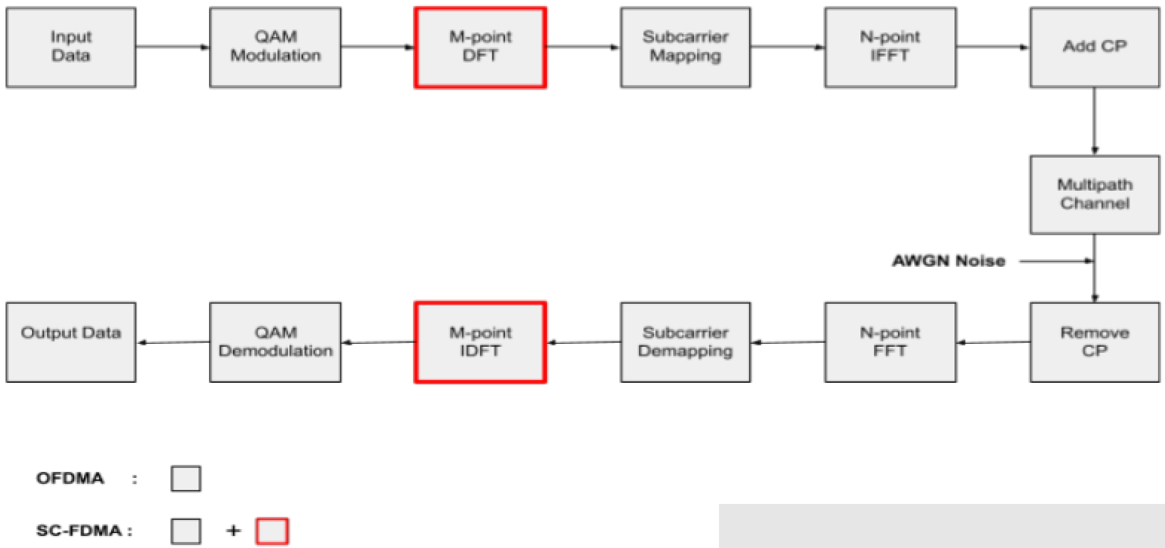
# OFDMA/TDD structure

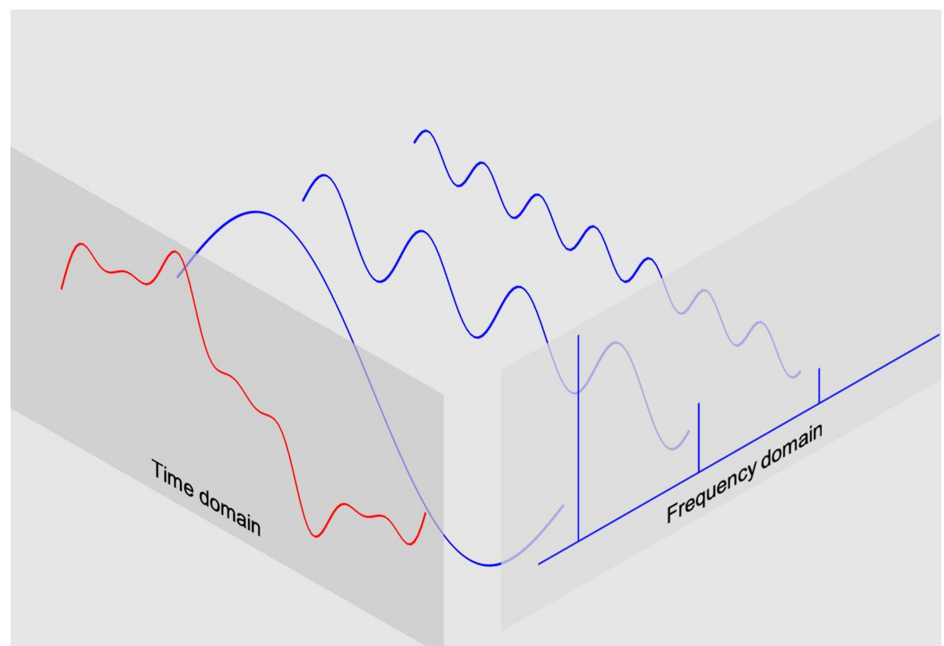


# OFDMA vs SC-FDMA

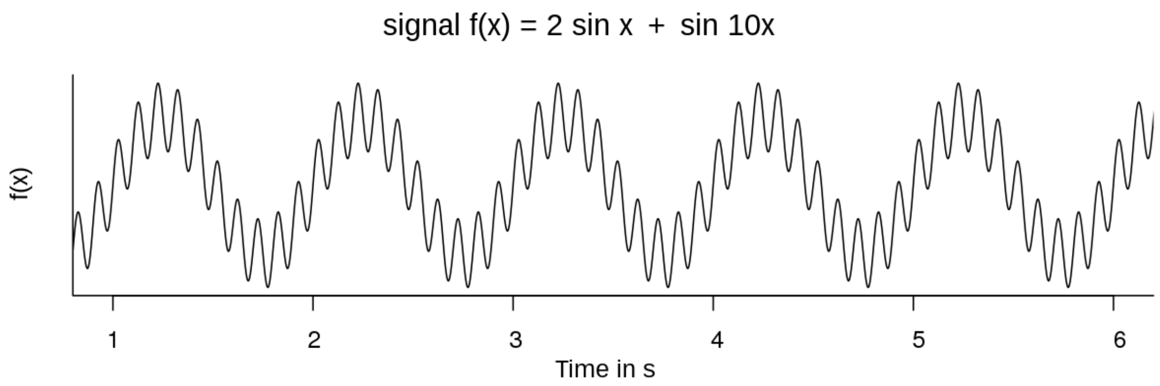


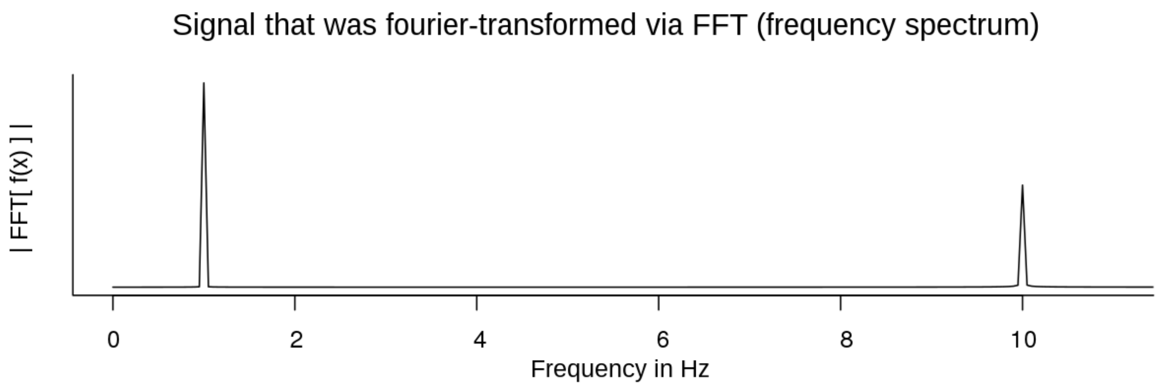
# OFDMA vs SC-FDMA



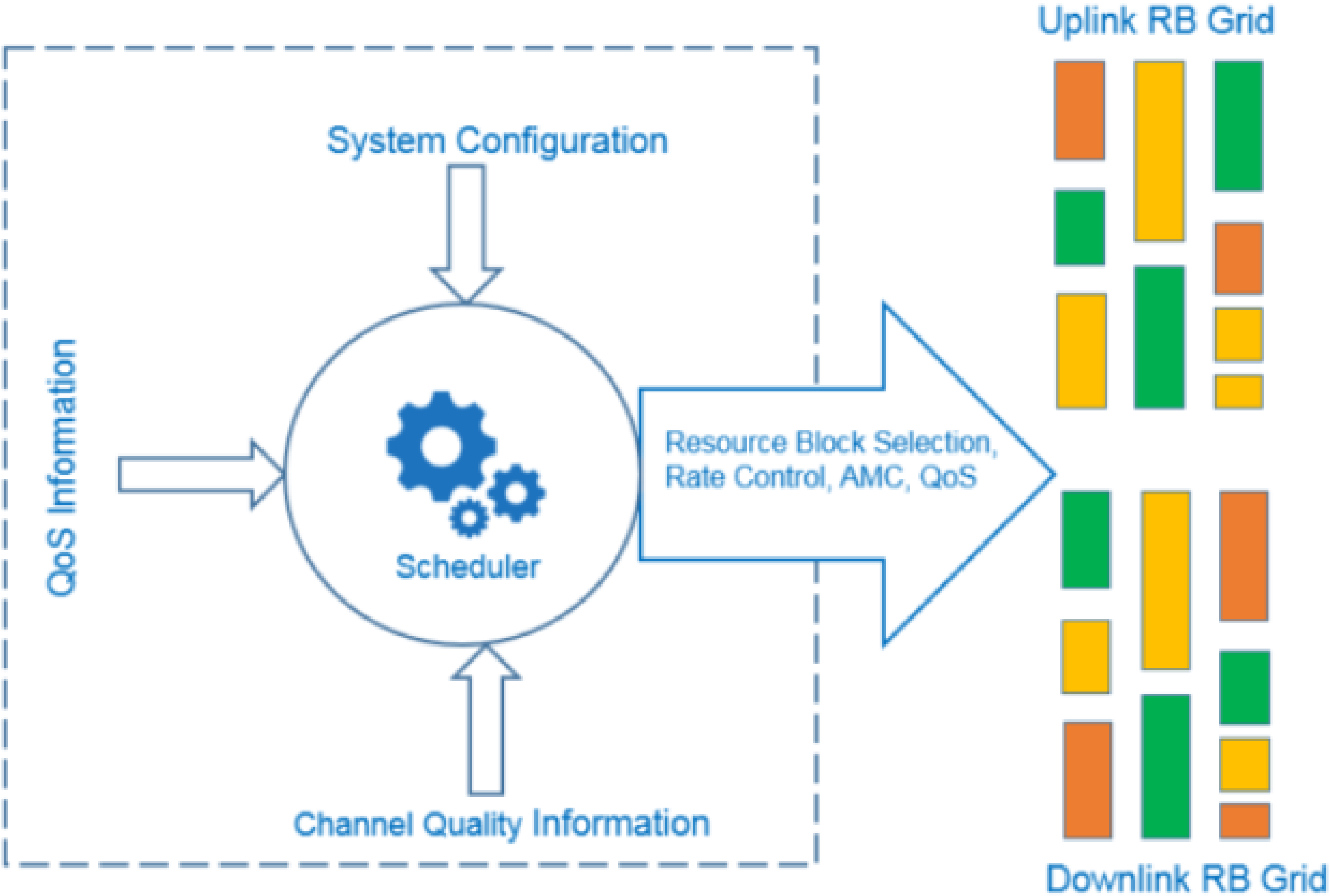



# Fast Fourier Transform

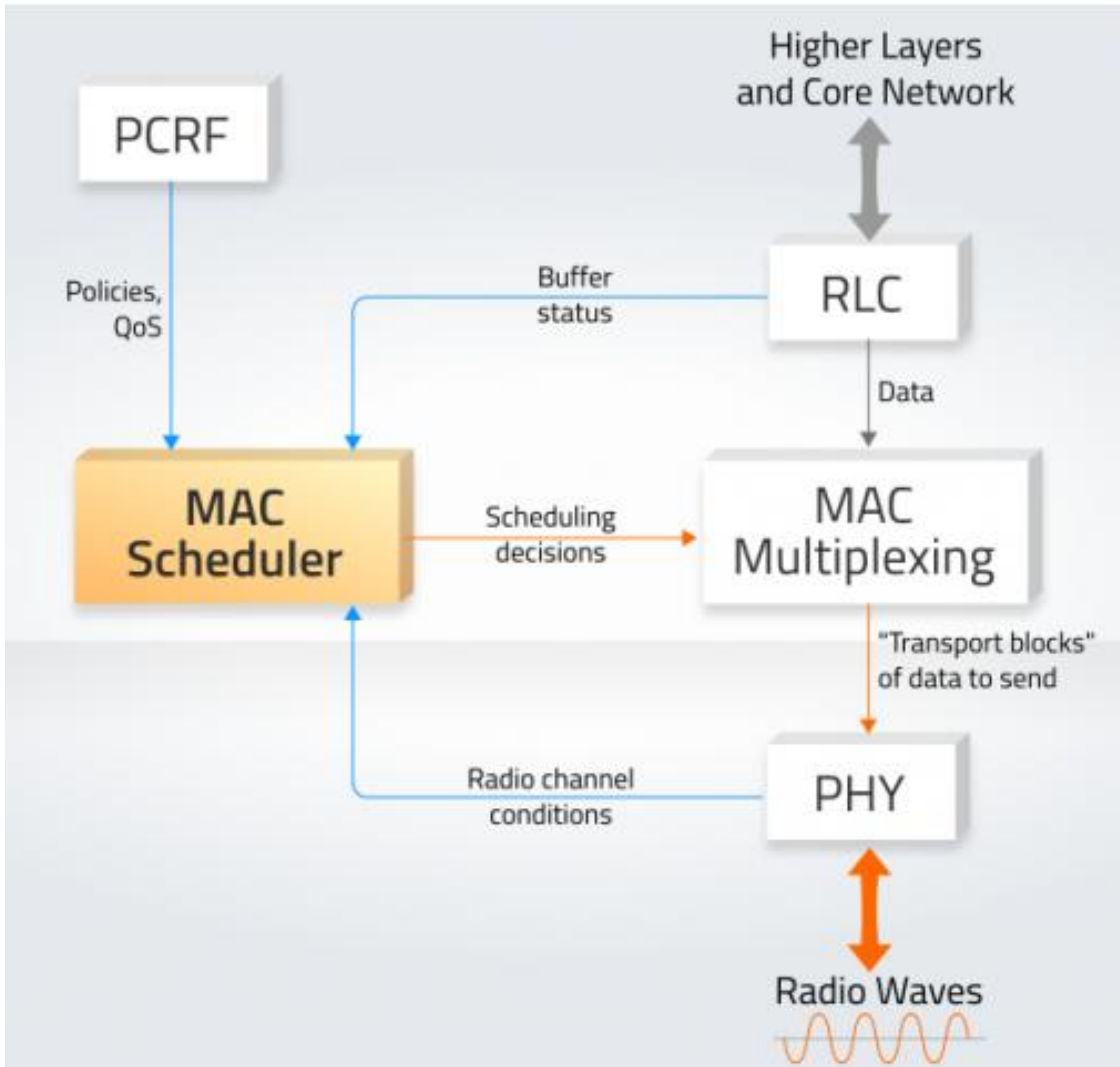


# Traffic Scheduling

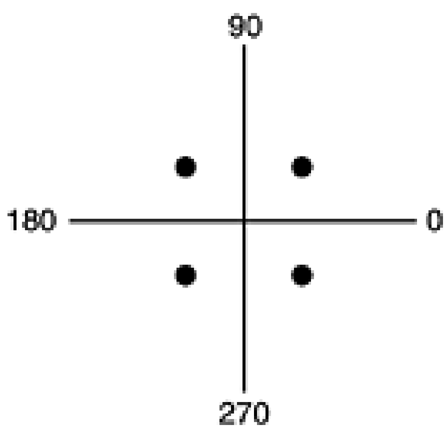


# Traffic Scheduling

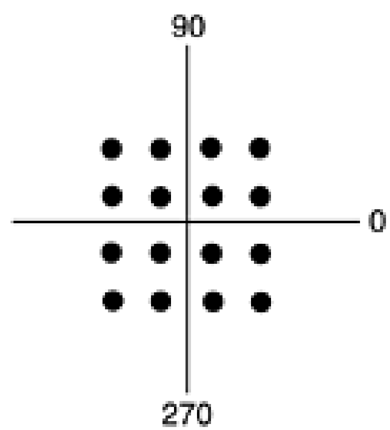


# Multiple Modulations

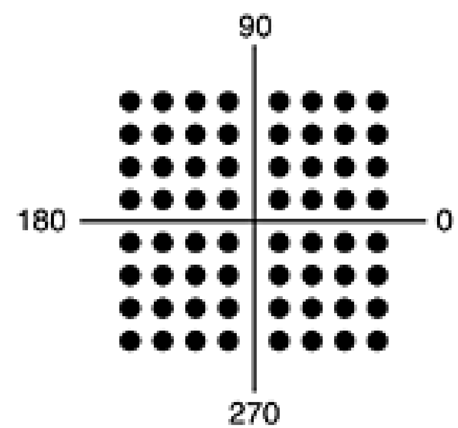
- QPSK (Quadrature Phase Shift Keying) = 4 phase shifts, 1 amplitude level, 2 bits/symbol
- QAM-16 = 4 phase shifts, 4 amplitude levels, 4 bits/symbol
- QAM-64 = 4 phase shifts, 16 amplitude levels, 6 bits/symbol



QPSK

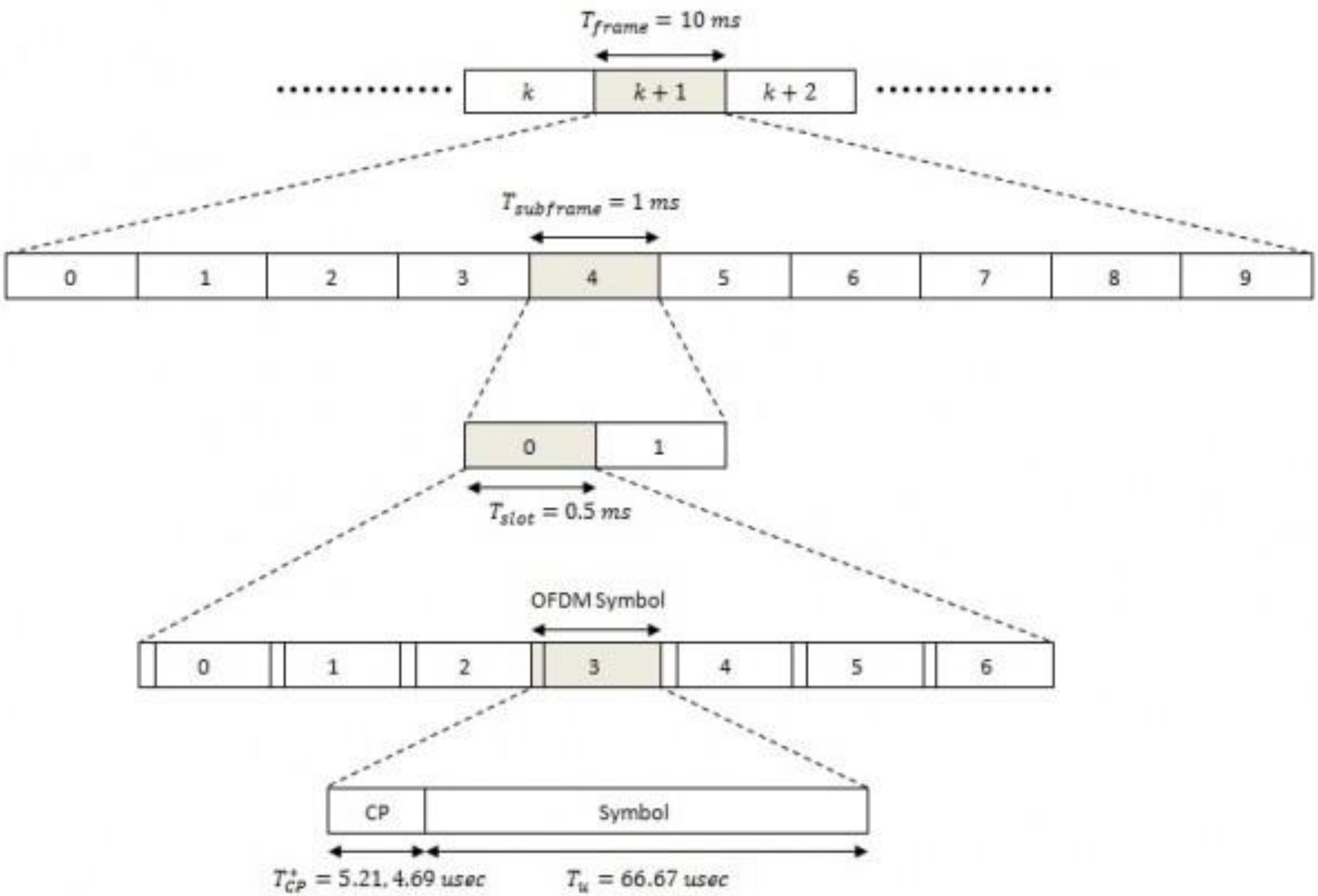


QAM-16

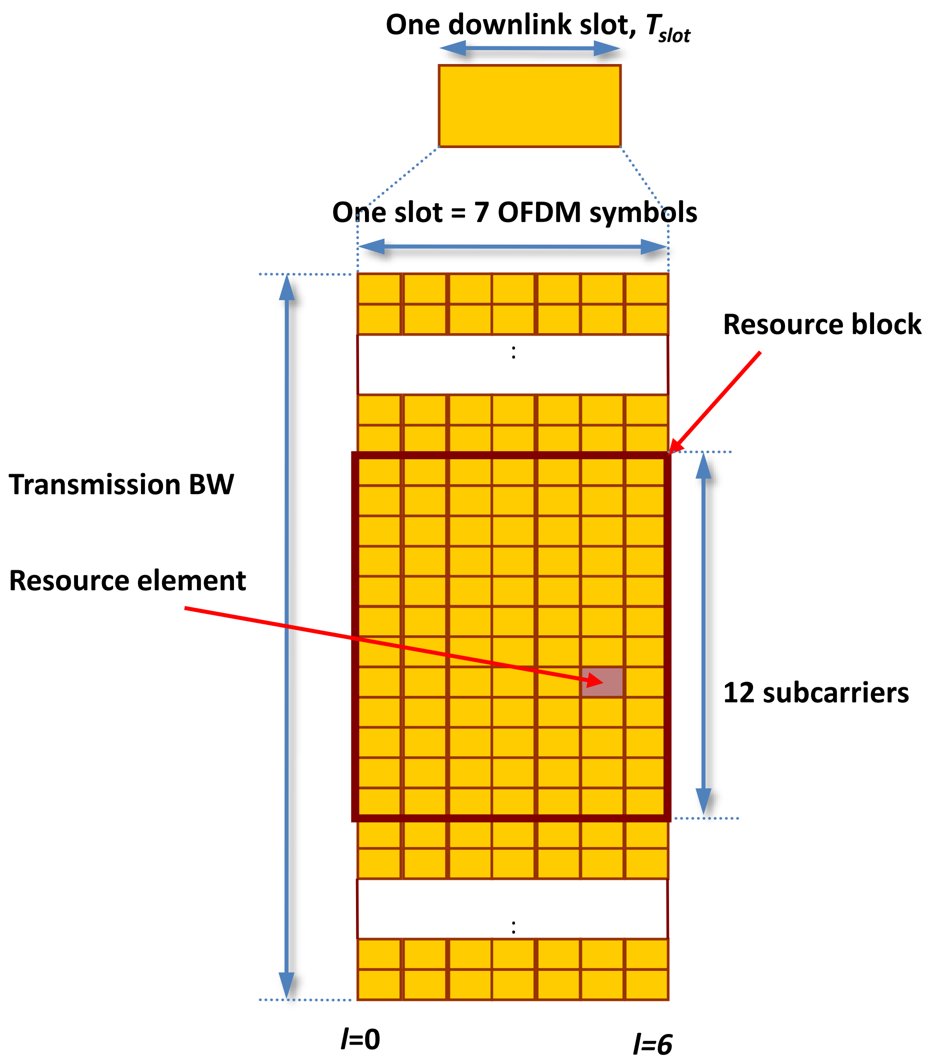


QAM-64

# Generic Frame Structure

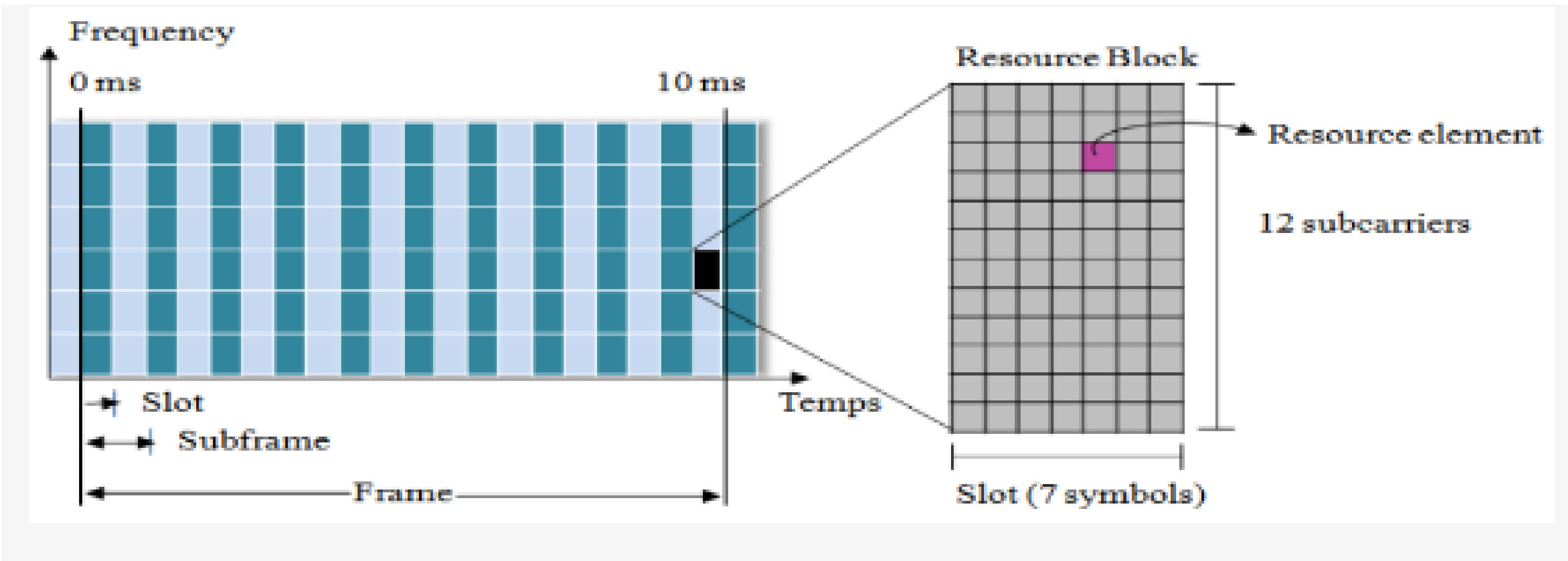


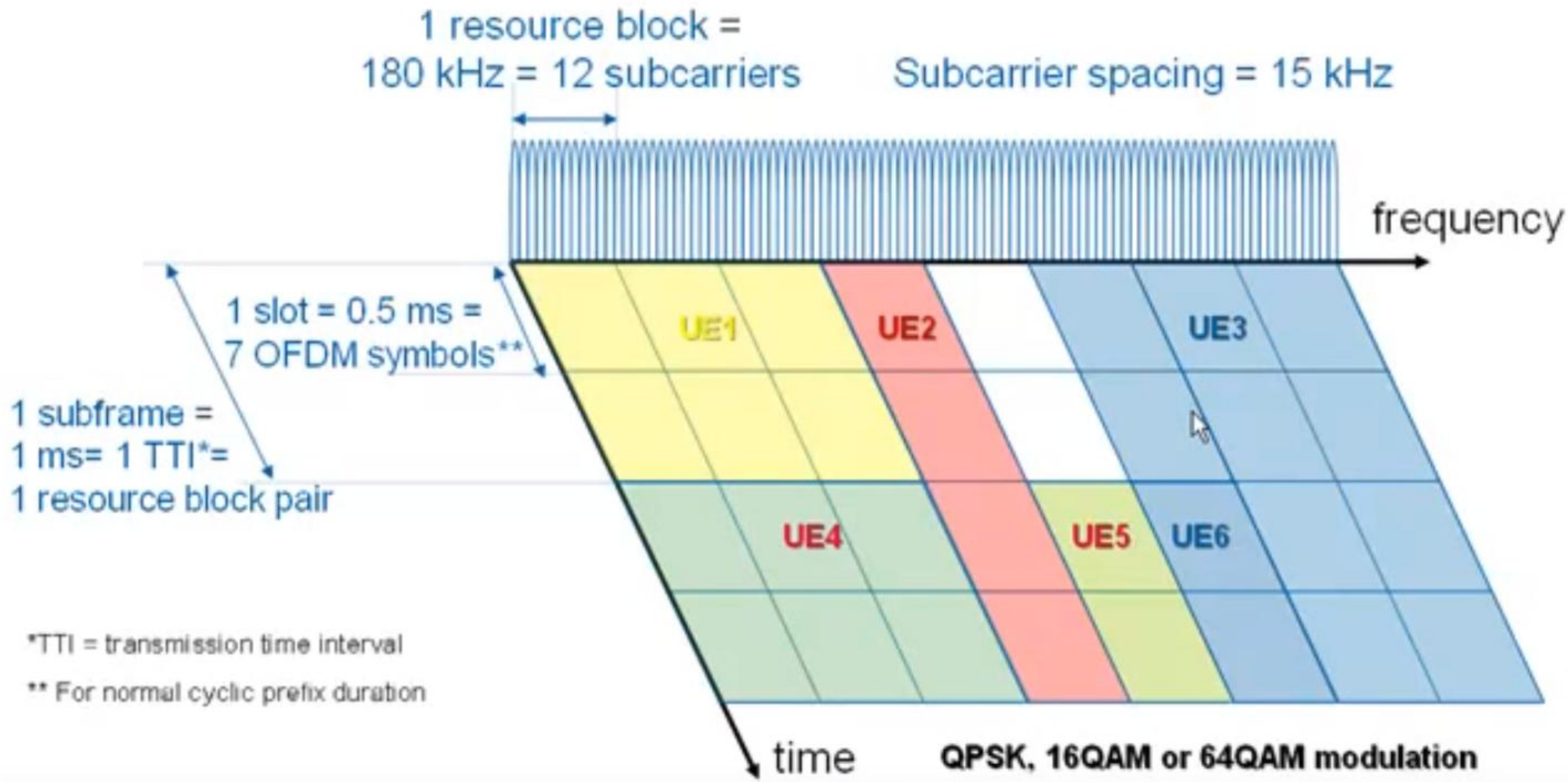
# Resource Grid



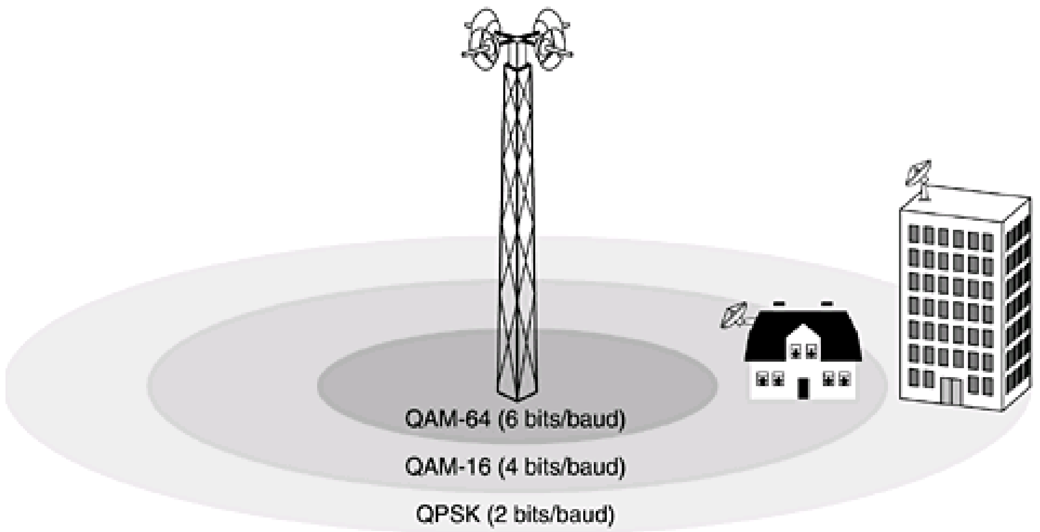

- 6 or 7 OFDM symbols in 1 slot
- Subcarrier spacing = 15 kHz
- Block of 12 SCs in 1 slot = 1 RB
  - *0.5 ms x 180 kHz*
  - Smallest unit of allocation

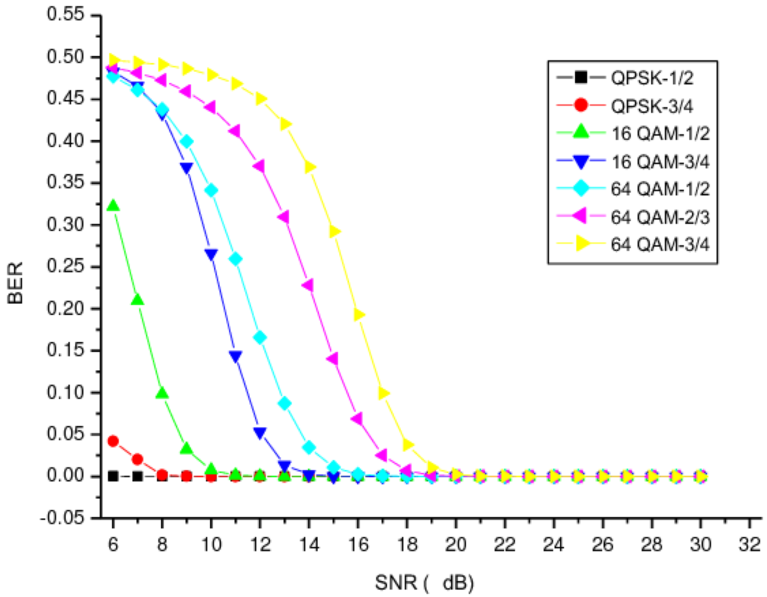
# Resource Grid

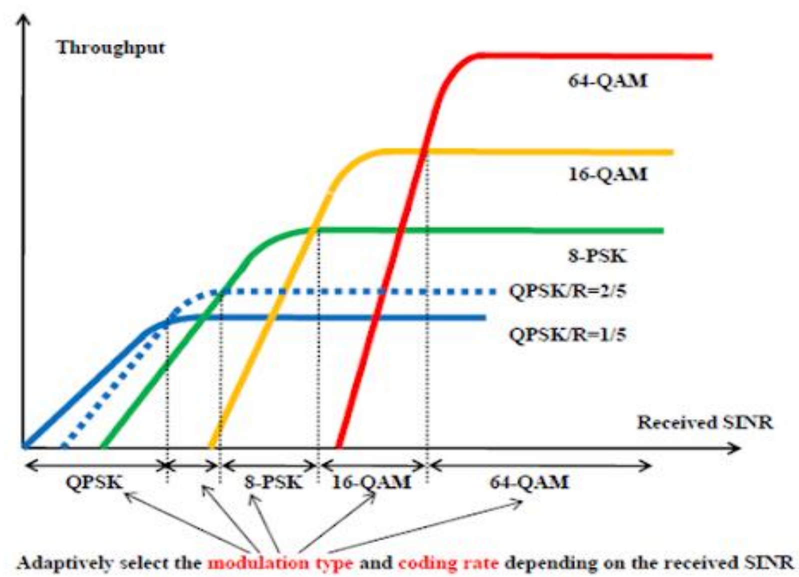



1 resource block =
180 kHz = 12 subcarriers
Subcarrier spacing = 15 kHz
frequency
1 slot = 0.5 ms =
7 OFDM symbols**
1 subframe =
1 ms= 1 TTI*=
1 resource block pair
UE1
UE2
UE3
UE4
UE5
UE6
*TTI = transmission time interval
** For normal cyclic prefix duration
time
QPSK, 16QAM or 64QAM modulation

# Adaptive modulation



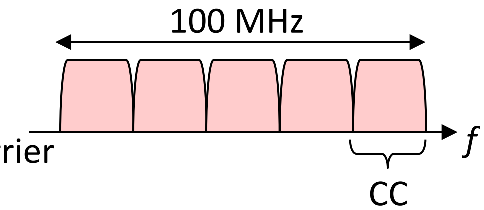



| | WCDMA (UMTS) | HSPA HSDPA / HSUPA | HSPA+ | LTE | LTE ADVANCED (IMT ADVANCED) |
|---|---|---|---|---|---|
| Max downlink speed (bps) | 384k | 14 M | 28 M | 100 M | 1 G |
| Max uplink speed (bps) | 128 k | 5.7 M | 11 M | 50 M | 500 M |
| Latency round trip time (approx.) | 150 ms | 100 ms | 50 ms (max) | ~10 ms | Less than 5 ms |
| 3GPP releases | Rel 99/4 | Rel 5/6 | Rel 7 | Rel 8/9 | Rel 10 |
| Approx years of initial roll out | 2003/4 | 2005/6 HSDPA<br>2007/8 HSUPA | 2008/9 | 2009/10 | |
| Access methodology | CDMA | CDMA | CDMA | OFDMA/SC-FDMA | OFDMA/SC-FDMA |

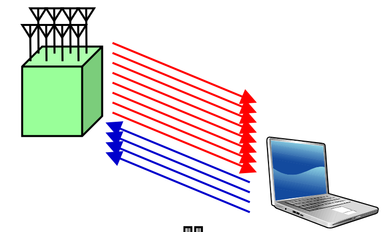
# LTE-A main features

## Support of Wider Bandwidth(Carrier Aggregation)



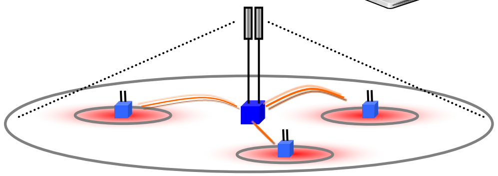

- Use of multiple component carriers(CC) to extend bandwidth up to 100 MHz
- Common physical layer parameters between component carrier and LTE Rel-8 carrier
- ➔ Improvement of peak data rate, backward compatibility with LTE Rel-8

## Advanced MIMO techniques



- Extension to up to 8-layer transmission in downlink
- Introduction of single-user MIMO up to 4-layer transmission in uplink
- Enhancements of multi-user MIMO
- ➔ Improvement of peak data rate and capacity

## Heterogeneous network and eICIC (enhanced Inter-Cell Interference Coordination)

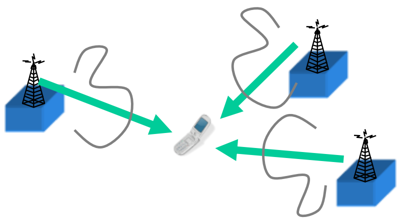


- Interference coordination for overlaid deployment of cells with different Tx power
- ➔ Improvement of cell-edge throughput and coverage

## Relay

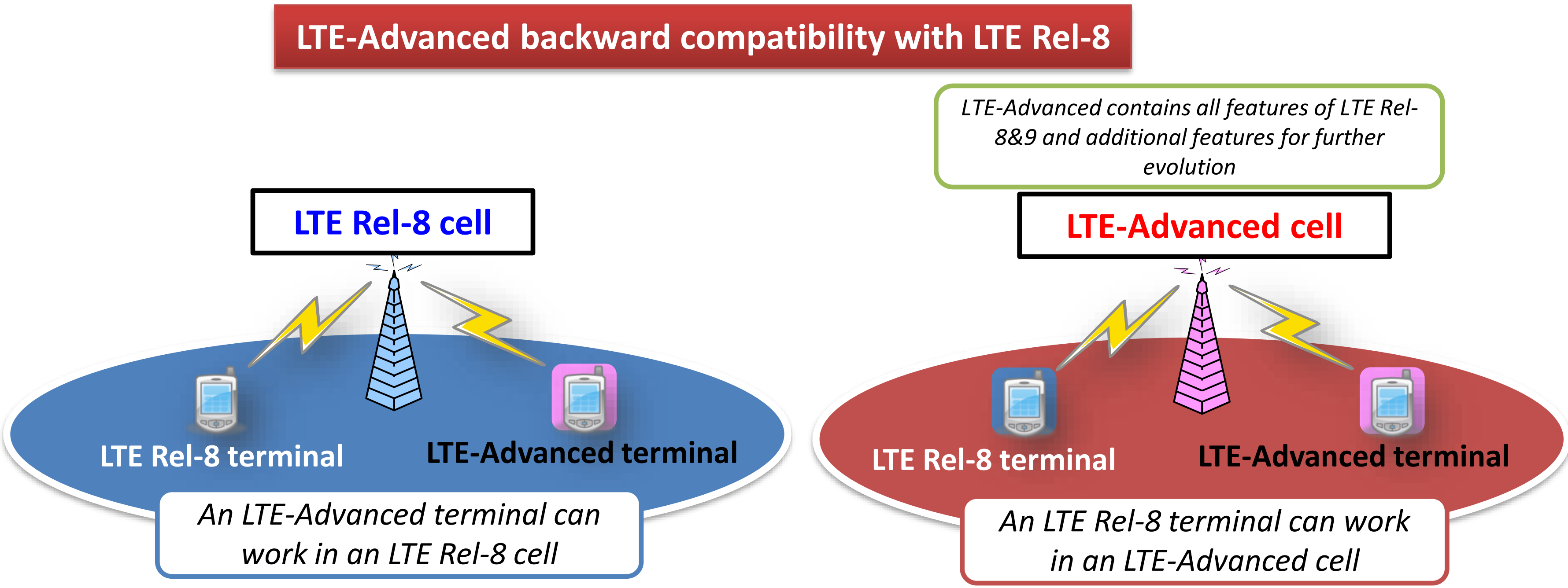
- Supports radio backhaul and creates a separate cell and appear as Rel. 8 LTE eNB to Rel. 8 LTE UEs
- ➔ Improvement of coverage and flexibility of service area extension

## Coordinated Multi-Point transmission and reception (CoMP)

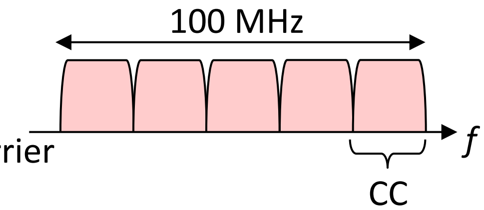


- Support of multi-cell transmission and reception
- ➔ Improvement of cell-edge throughput and coverage

# Backward compatibility



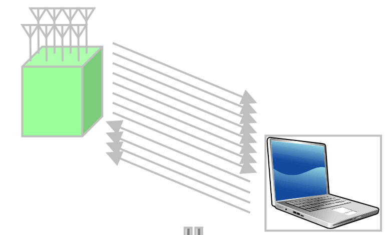
# LTE-A main features




## Support of Wider Bandwidth(Carrier Aggregation)

- Use of multiple component carriers(CC) to extend bandwidth up to 100 MHz
- Common physical layer parameters between component carrier and LTE Rel-8 carrier

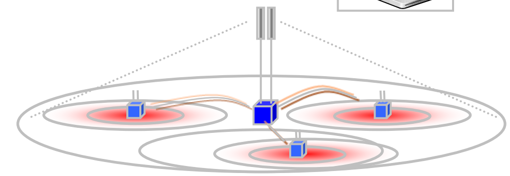
➔ Improvement of peak data rate, backward compatibility with LTE Rel-8



## Advanced MIMO techniques

- Extension to up to 8-layer transmission in downlink
- Introduction of single-user MIMO up to 4-layer transmission in uplink
- Enhancements of multi-user MIMO

➔ Improvement of peak data rate and capacity



## Heterogeneous network and eICIC (enhanced Inter-Cell Interference Coordination)

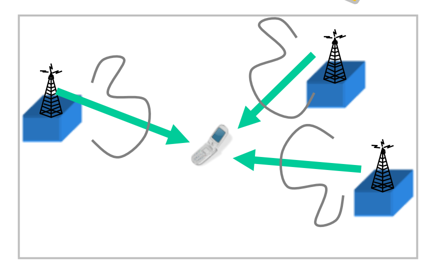
- Interference coordination for overlaid deployment of cells with different Tx power

➔ Improvement of cell-edge throughput and coverage

## Relay

- Supports radio backhaul and creates a separate cell and appear as Rel. 8 LTE eNB to Rel. 8 LTE UEs

➔ Improvement of coverage and flexibility of service area extension



## Coordinated Multi-Point transmission and reception (CoMP)

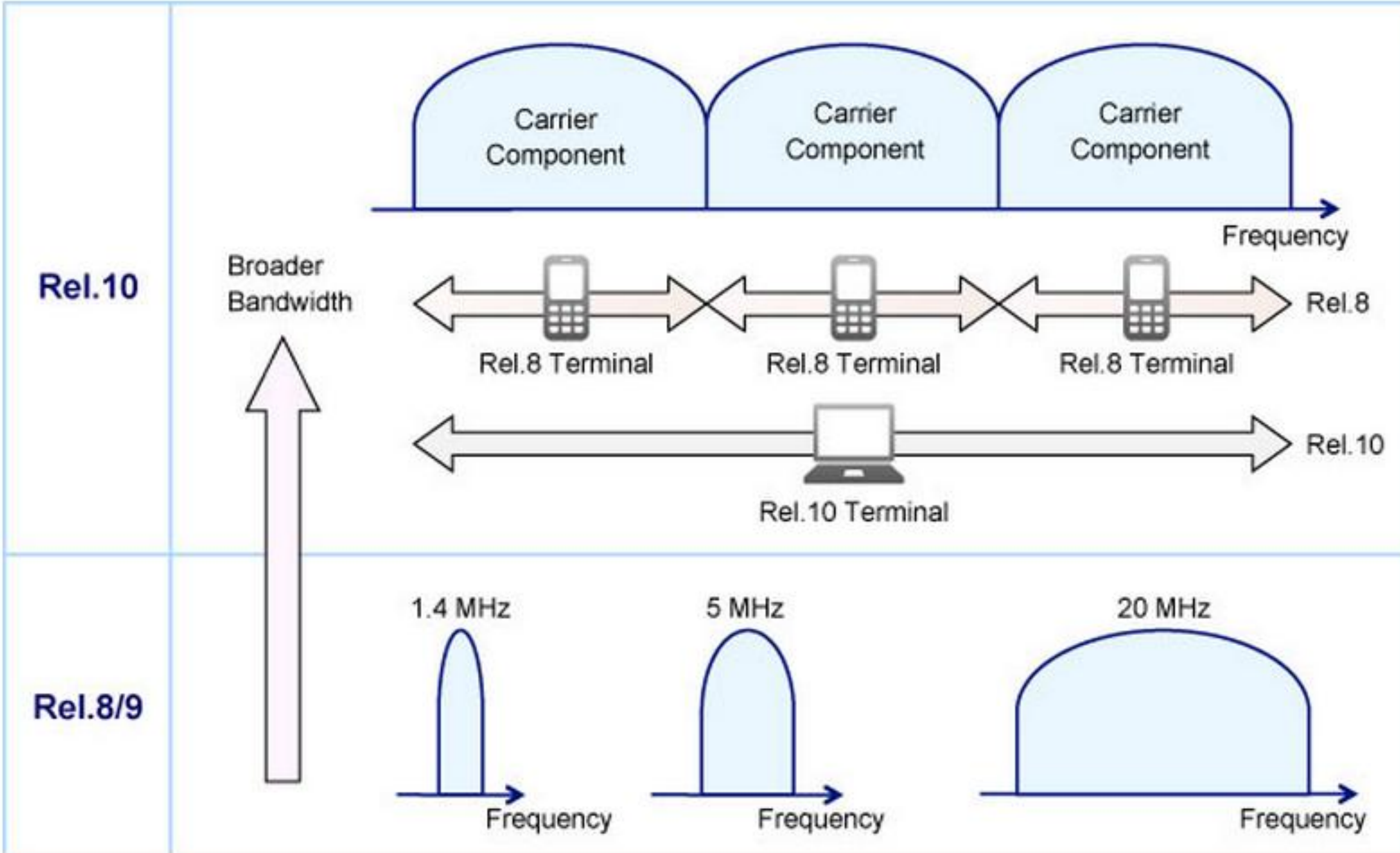
- Support of multi-cell transmission and reception

➔ Improvement of cell-edge throughput and coverage

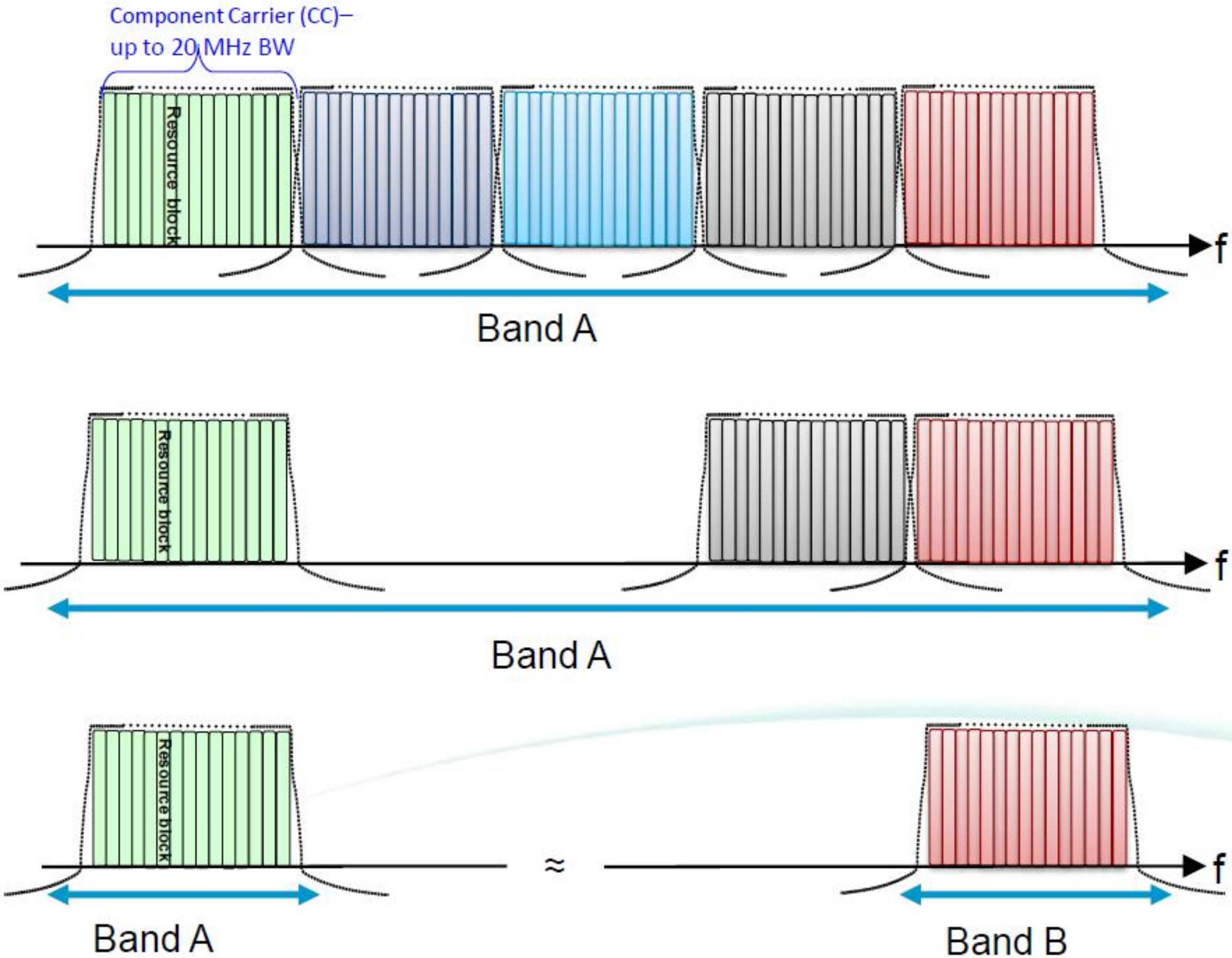
# Carrier aggregation

- Extends the maximum transmission bandwidth, up to 100MHz, by aggregating up to five LTE carriers – also known as component carriers (CCs)
- Lack of sufficient contiguous spectrum forces use of carrier aggregation to meet peak data rate targets:
  - 1 Gbps in the downlink and 500 Mbps in the uplink
- Motivation:
  - Achieve wide bandwidth transmissions
  - Facilitate efficient use of fragmented spectrum
  - Efficient interference management for control channels in heterogeneous networks

# Carrier aggregation



# Carrier aggregation modes

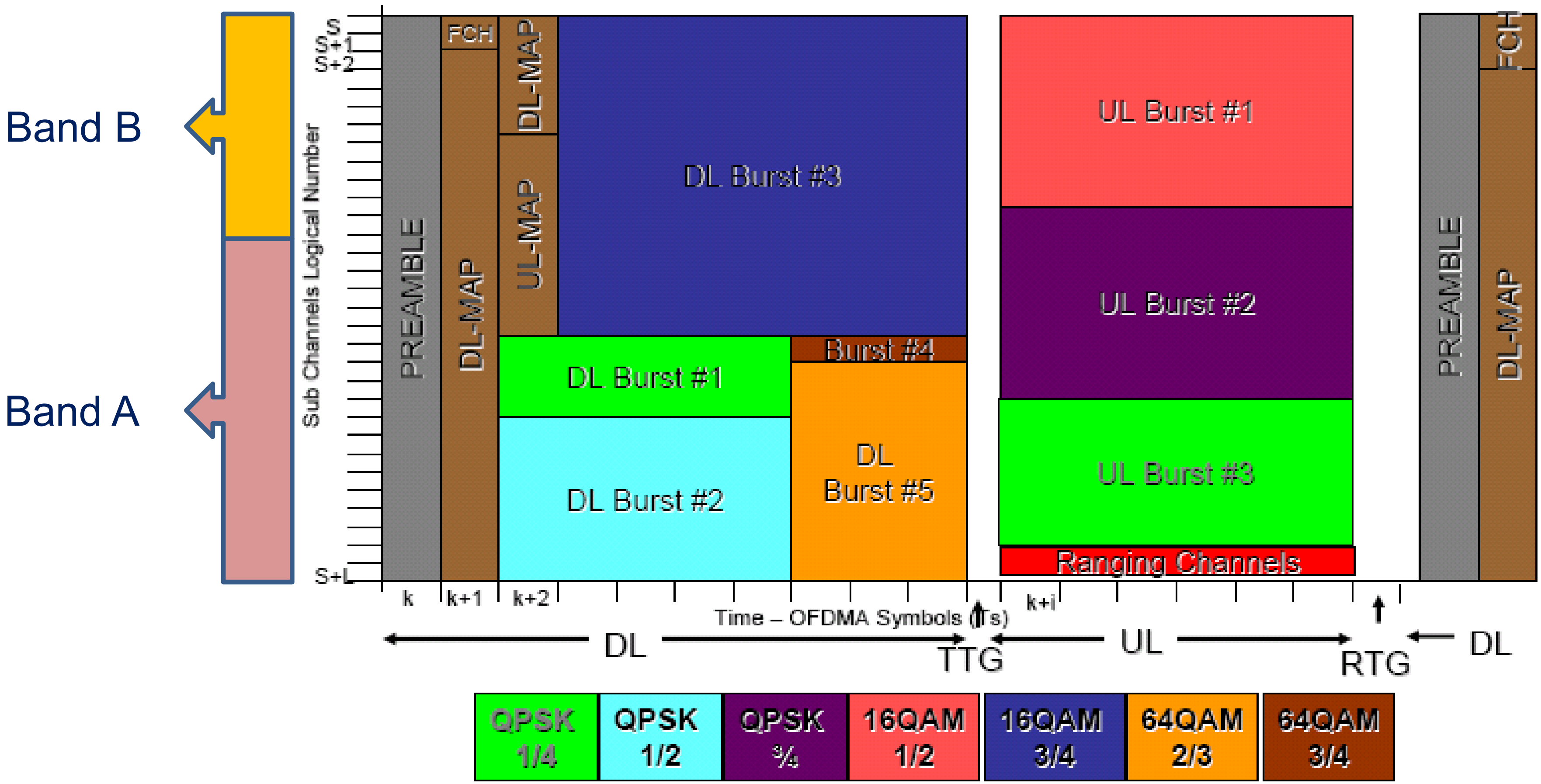



Intra -band contiguous allocation

Intra-band non-contiguous allocation

Inter-band non-contiguous allocation

# OFDMA/TDD structure

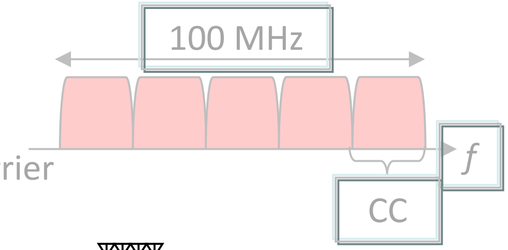


# LTE-A main features

## Support of Wider Bandwidth(Carrier Aggregation)

- Use of multiple component carriers(CC) to extend bandwidth up to 100 MHz
- Common physical layer parameters between component carrier and LTE Rel-8 carrier

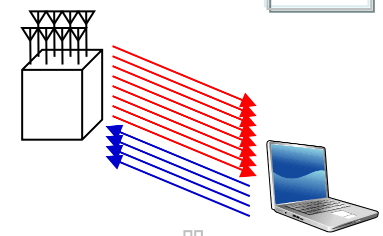
➔ Improvement of peak data rate, backward compatibility with LTE Rel-8




## Advanced MIMO techniques

- Extension to up to 8-layer transmission in downlink
- Introduction of single-user MIMO up to 4-layer transmission in uplink
- Enhancements of multi-user MIMO

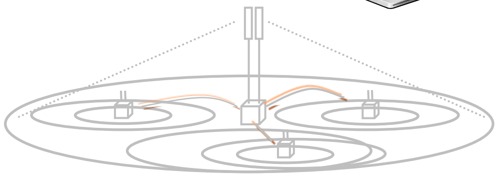
➔ Improvement of peak data rate and capacity



## Heterogeneous network and eICIC (enhanced Inter-Cell Interference Coordination)

- Interference coordination for overlaid deployment of cells with different Tx power

➔ Improvement of cell-edge throughput and coverage



## Relay

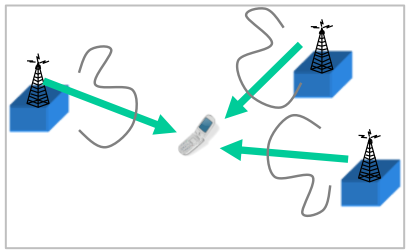
- Supports radio backhaul and creates a separate cell and appear as Rel. 8 LTE eNB to Rel. 8 LTE UEs

➔ Improvement of coverage and flexibility of service area extension

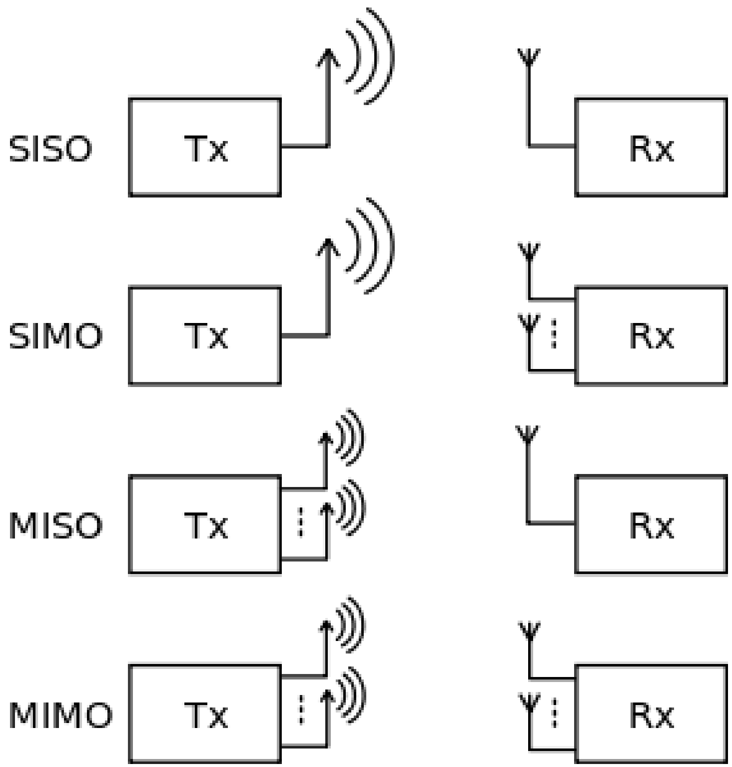
## Coordinated Multi-Point transmission and reception (CoMP)

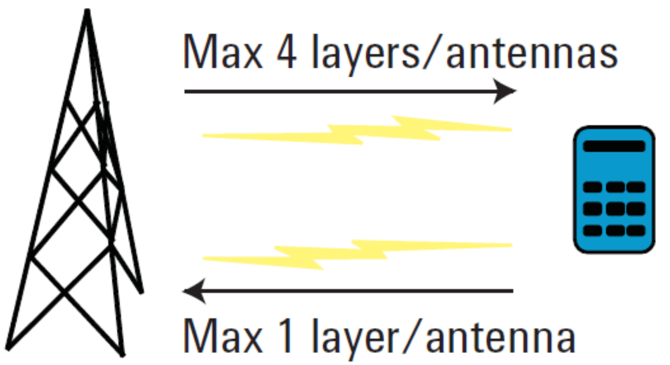
- Support of multi-cell transmission and reception

➔ Improvement of cell-edge throughput and coverage

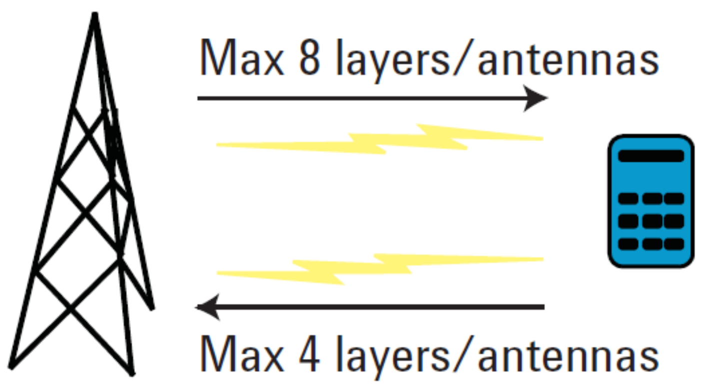


# MIMO capabilities



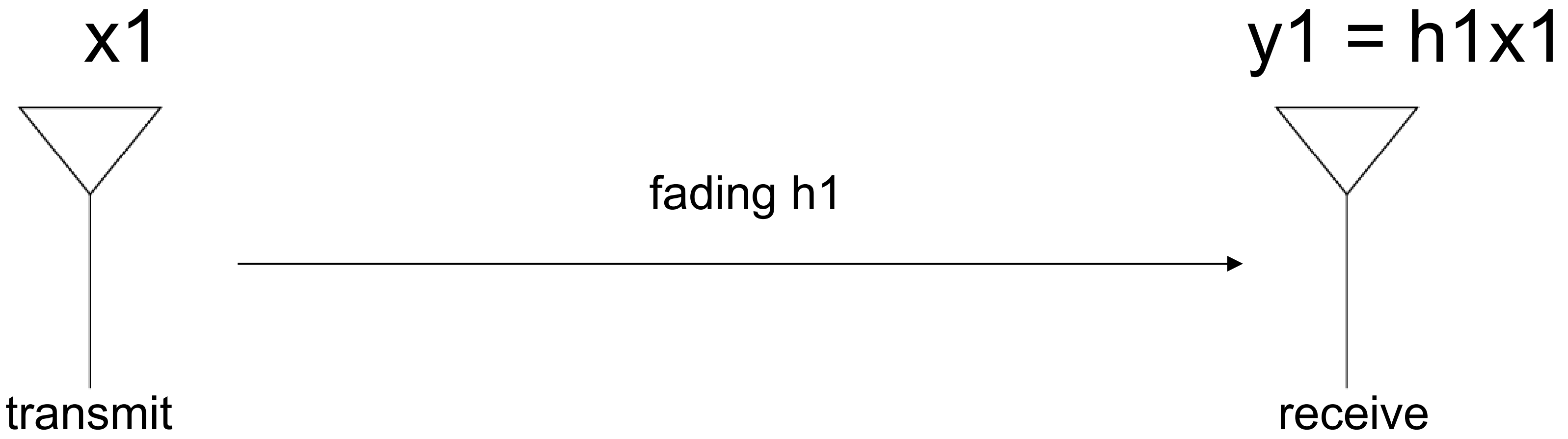




LTE

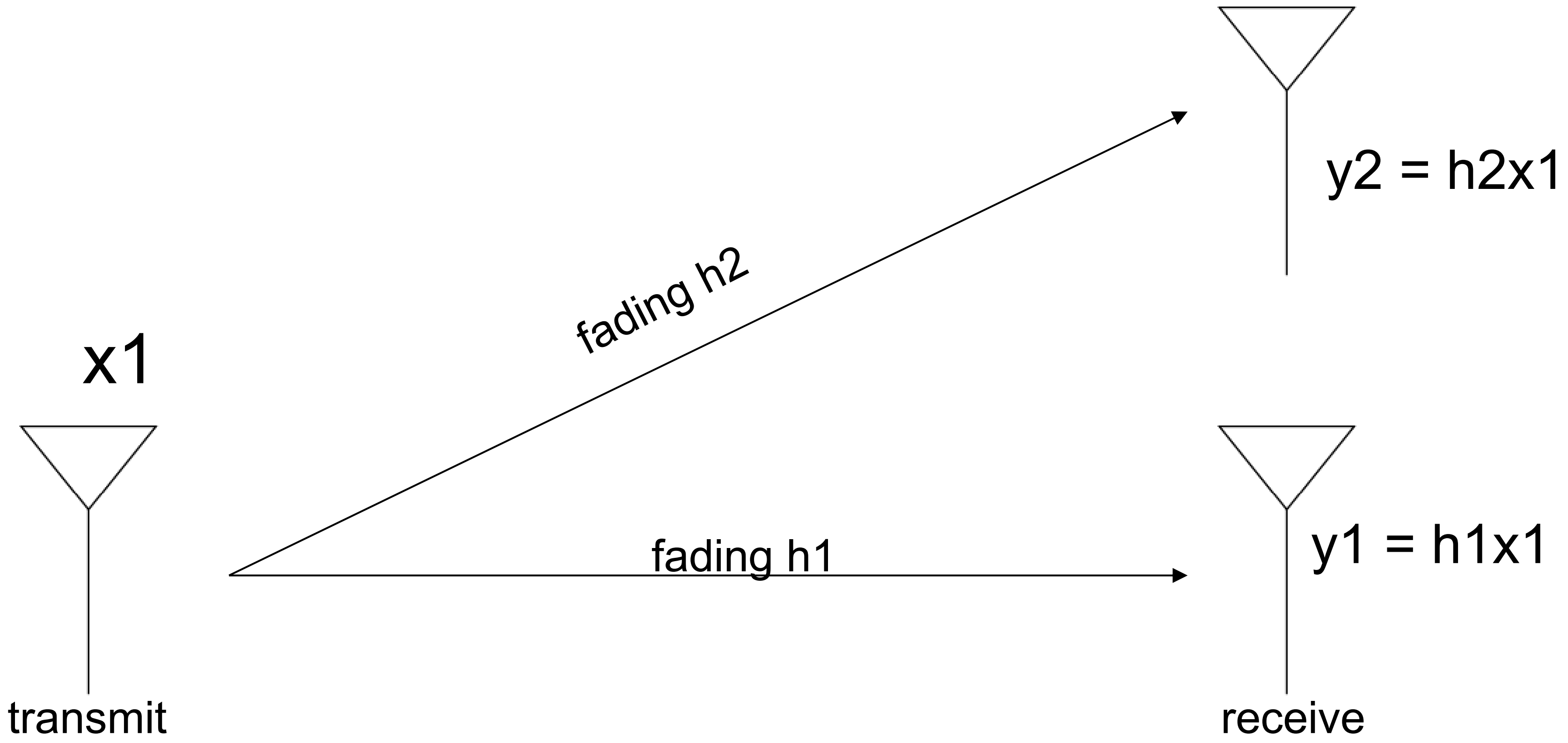



LTE-A

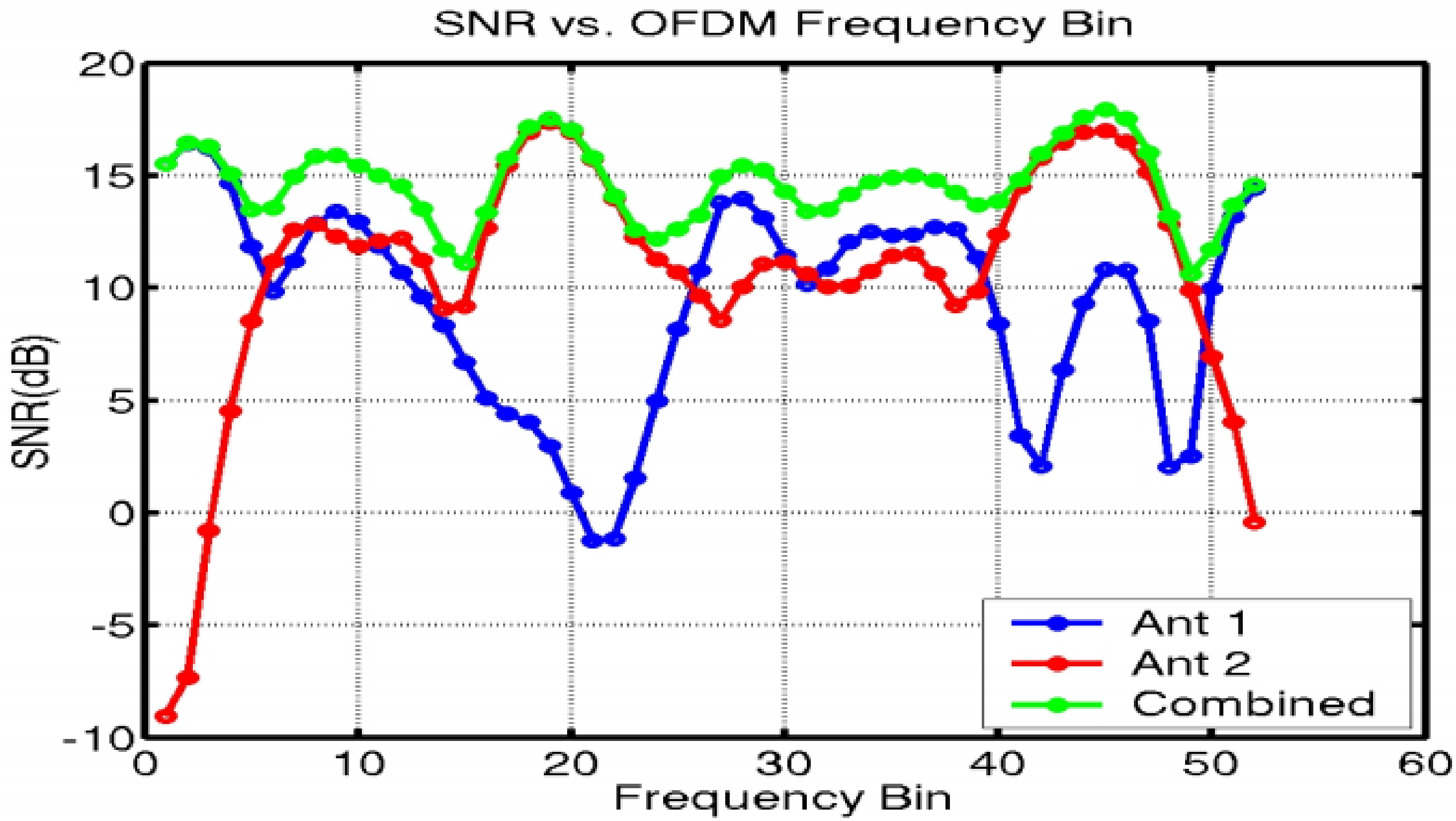
# SISO Single Input Single Output



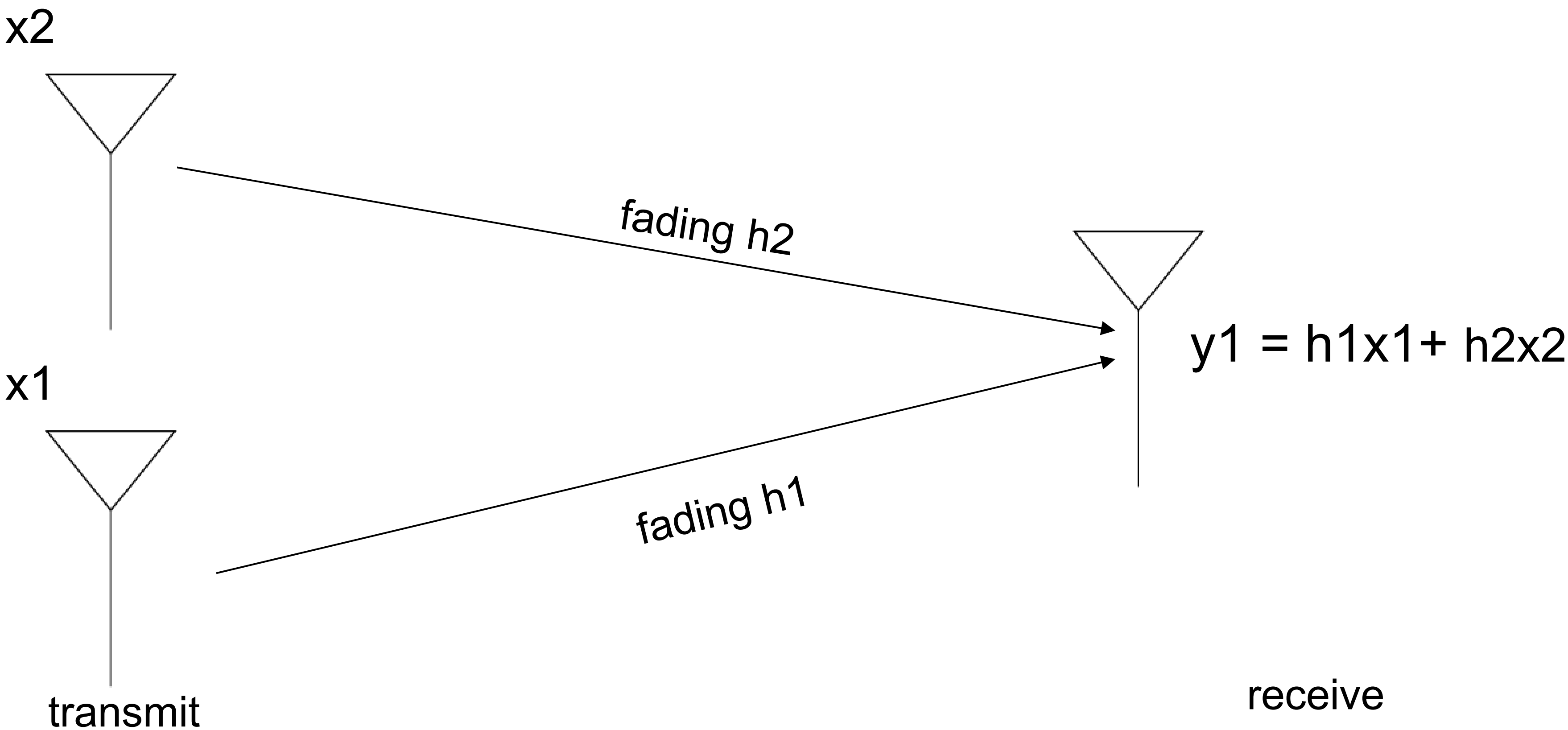
# SIMO Single Input Multiple Output



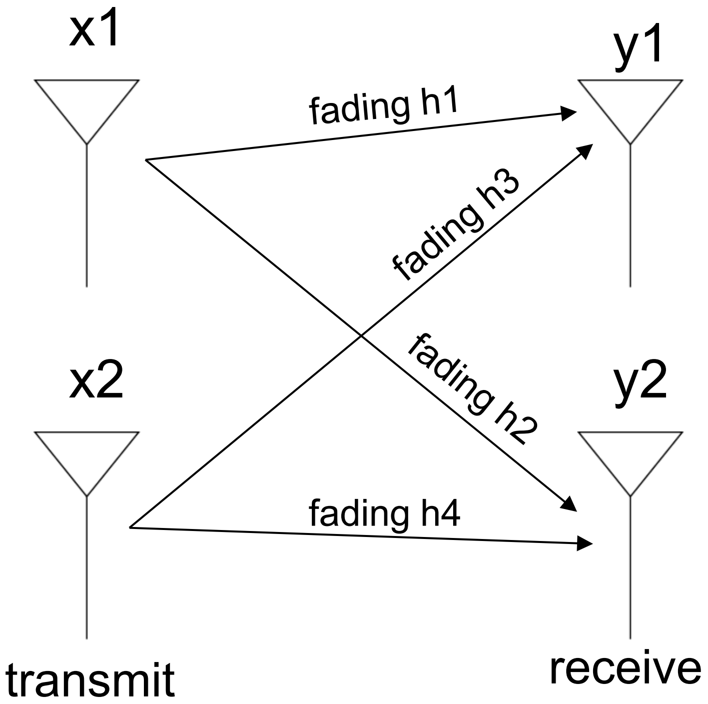
# Mitigating fading with receiver diversity



# MISO Multiple Input Single Output



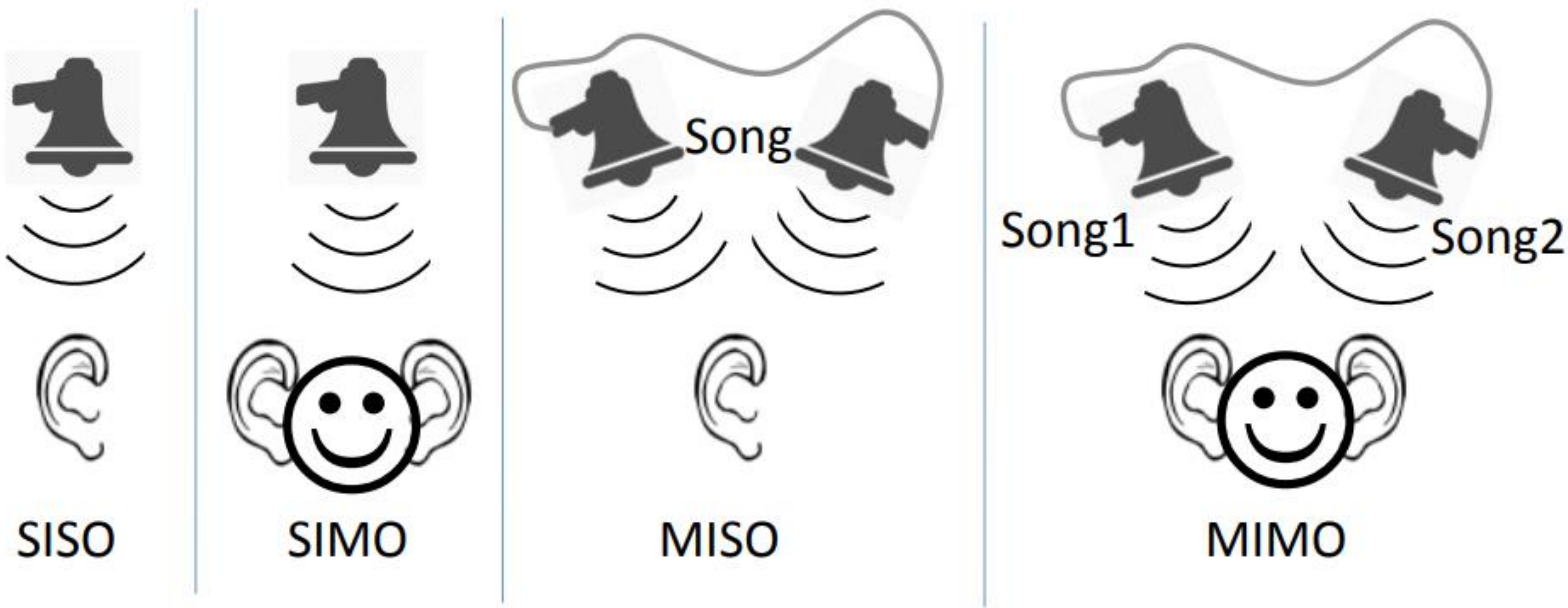
# MIMO Multiple Input Multiple Output

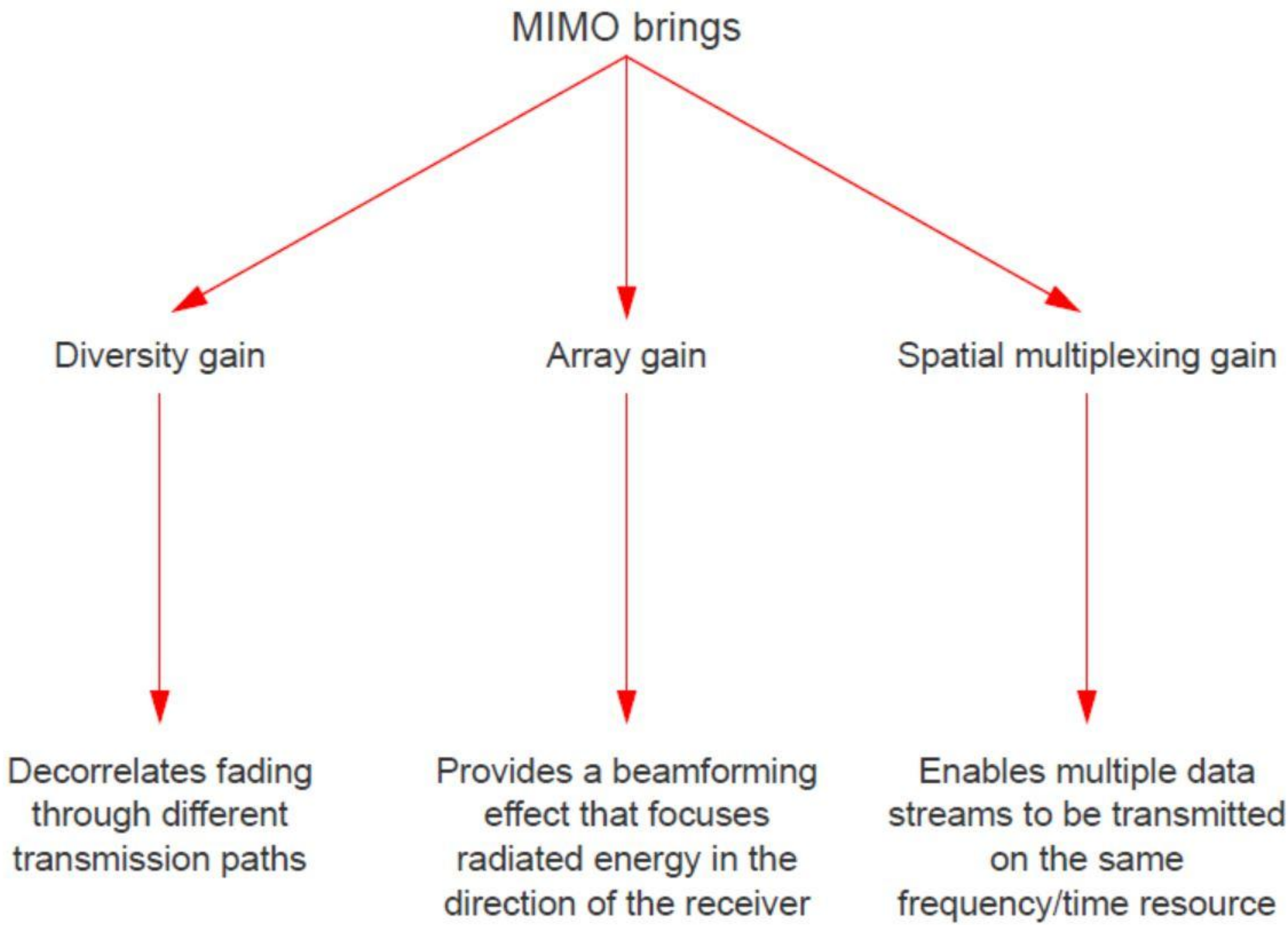



$$y1 = h1x1 + h2x2$$

$$y2 = h3x1 + h4x2$$

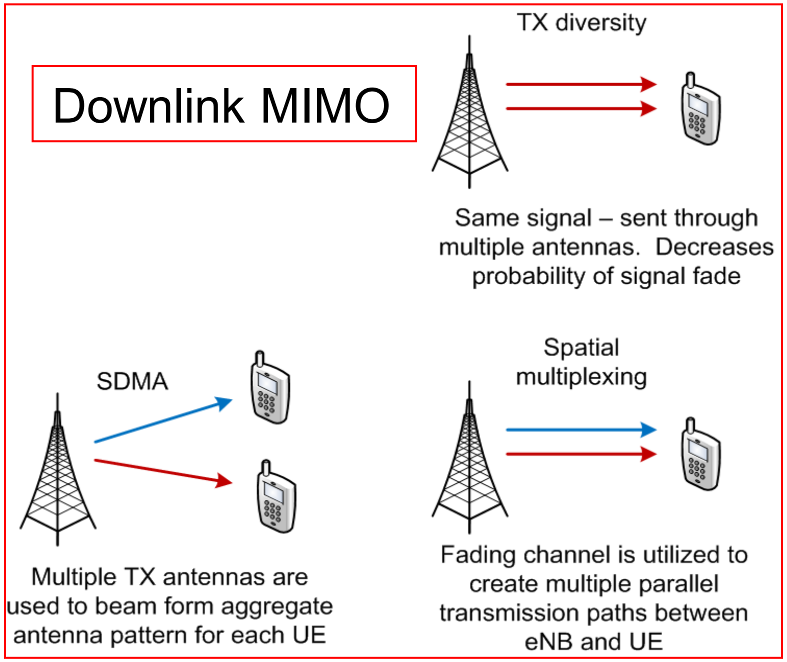
# An audio metaphor



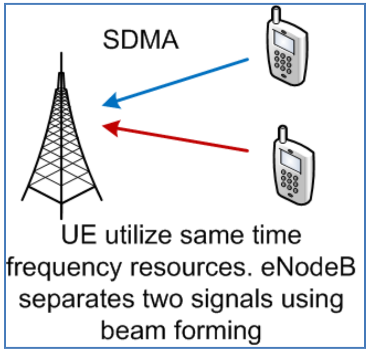

MIMO brings
Diversity gain
Array gain
Spatial multiplexing gain
Decorrelates fading through different transmission paths
Provides a beamforming effect that focuses radiated energy in the direction of the receiver
Enables multiple data streams to be transmitted on the same frequency/time resource

# Multi antenna configuration

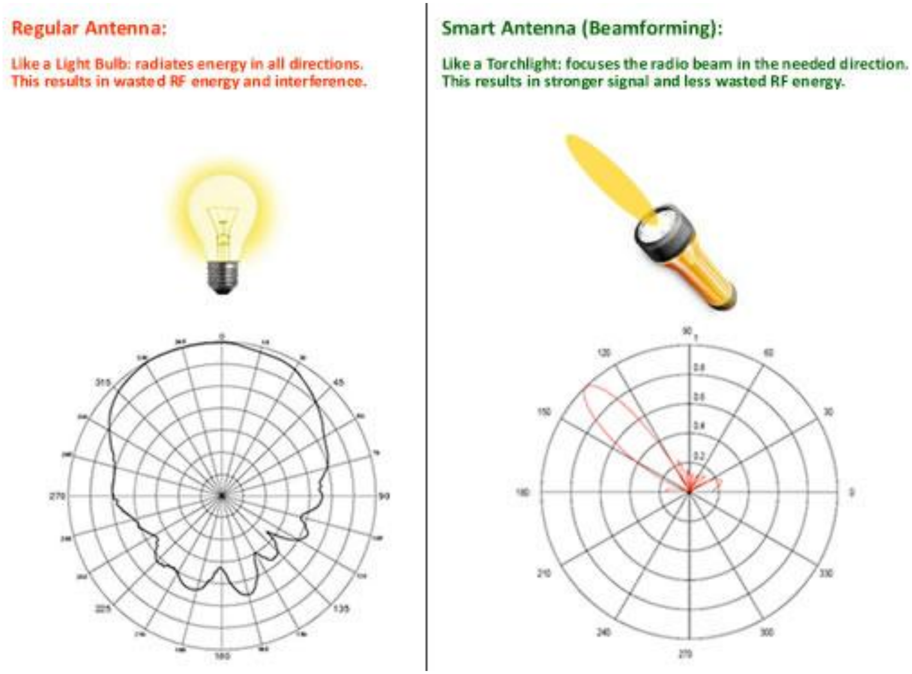
- LTE uses of multiple antennas at both communication ends
- LTE-A standard supports for
  - 8 antennas at the eNodeB
  - 4 antennas at the UE
- Multiple antennas may be used in three principle ways
  - Reception/transmission diversity
  - Beam forming
  - Spatial multiplexing (MIMO antenna processing)
- Downlink MIMO
  - TX diversity
  - Beam forming
  - Spatial multiplexing
- Uplink MIMO
  - Multi user MIMO (SDMA)




Uplink MIMO



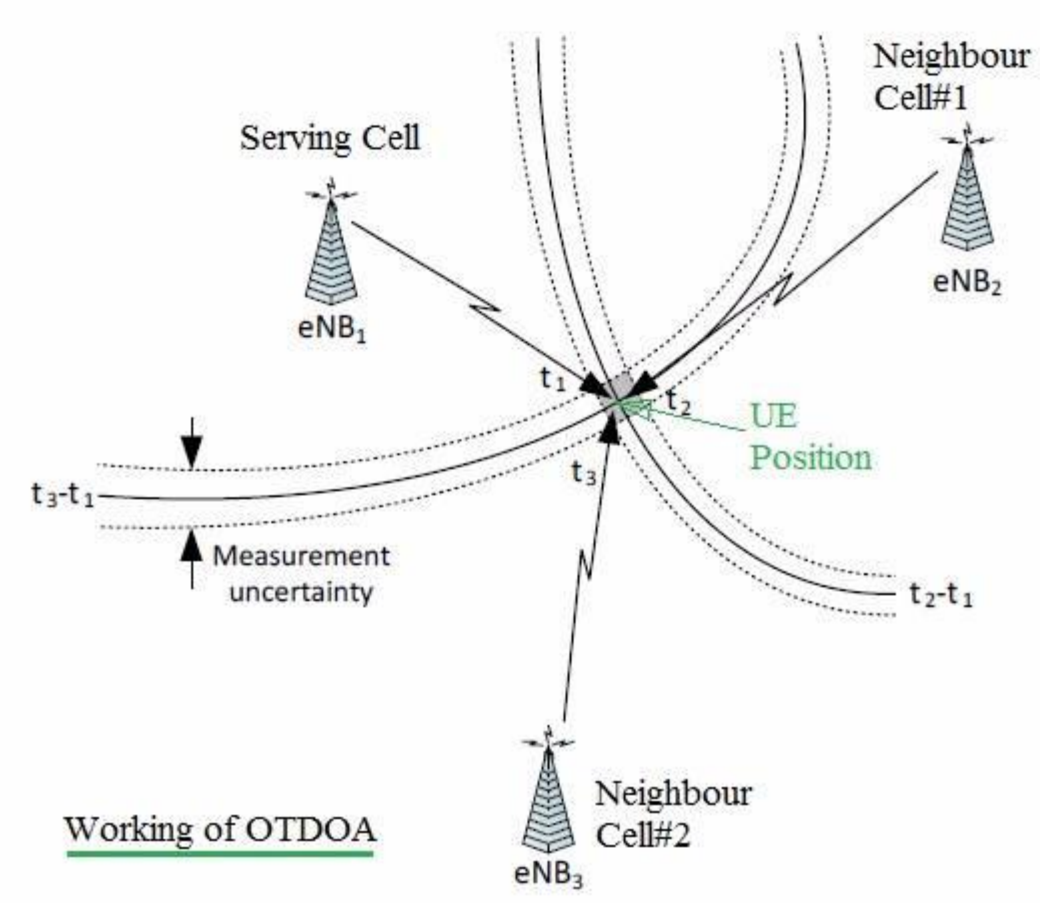
# Beamforming



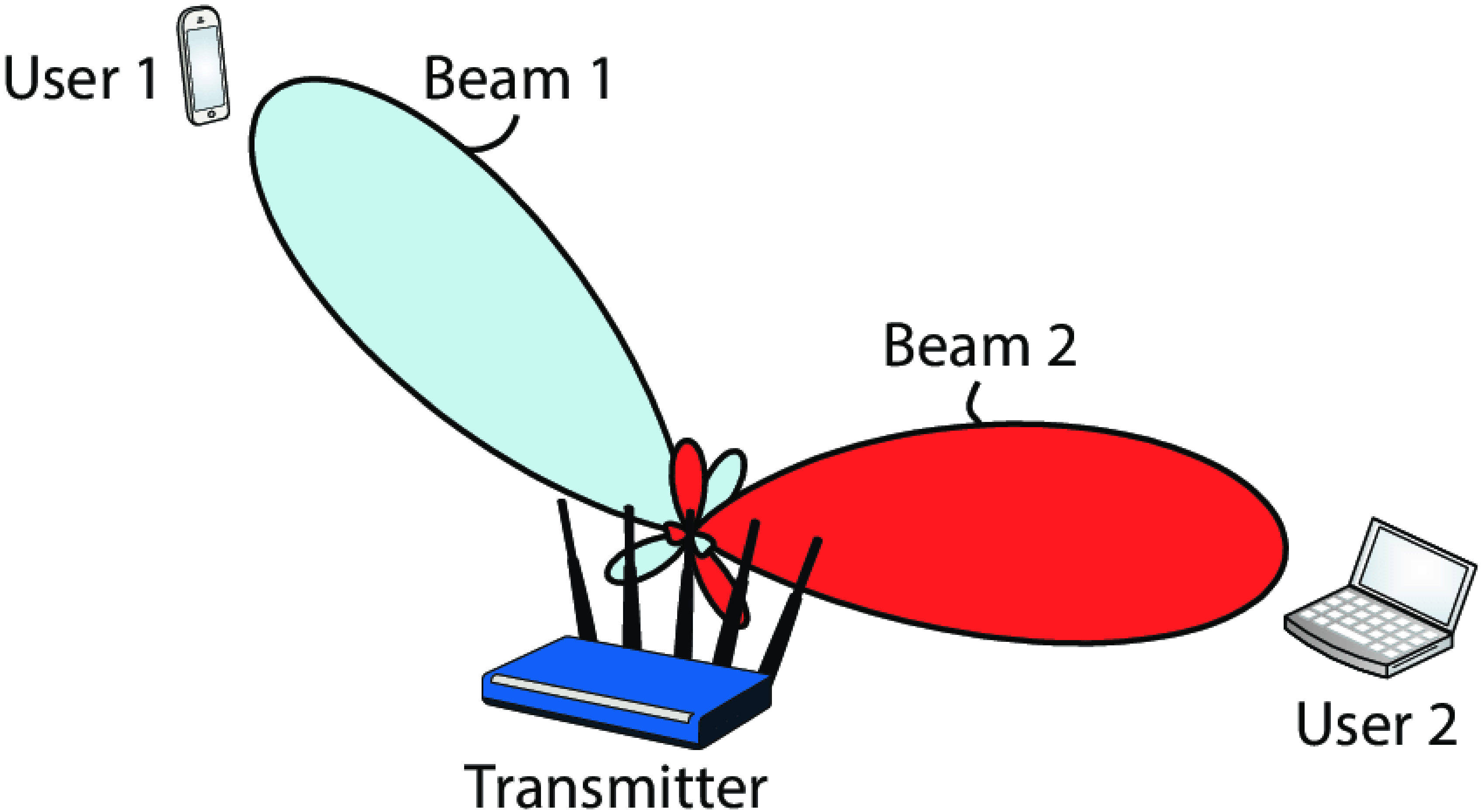

- Transmitter detects the positions of reception devices and transmits focused point-to-point signals with directionality
- Mitigates interference and reinforces signal of interest
- Strong stable transmission covering longer range

# Positioning in LTE

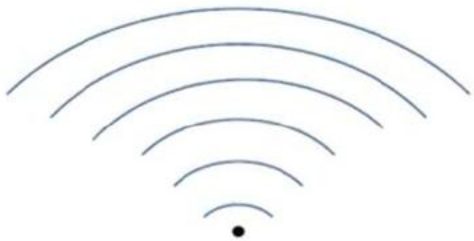
- OTDOA (**Observed Time Difference of Arrival**)

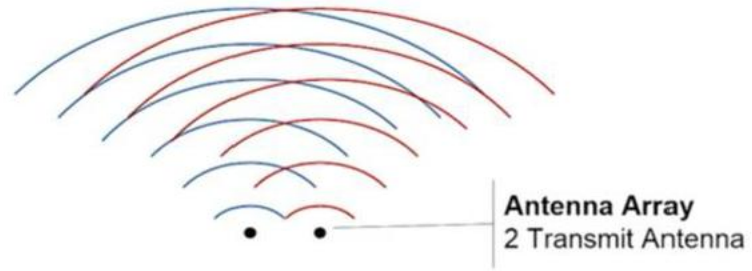


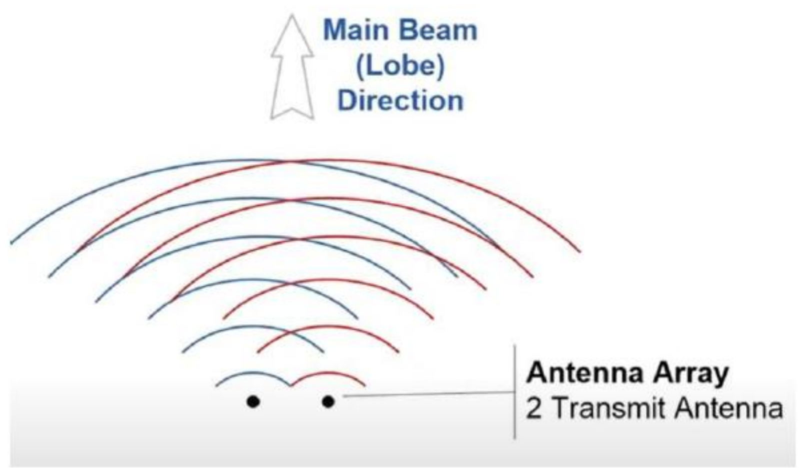
# Beamforming



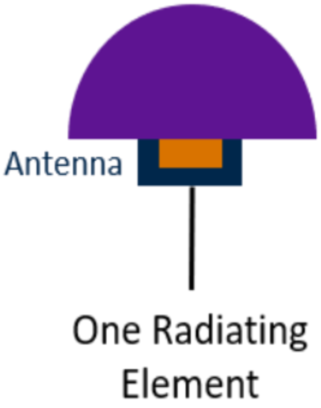
# Beamforming



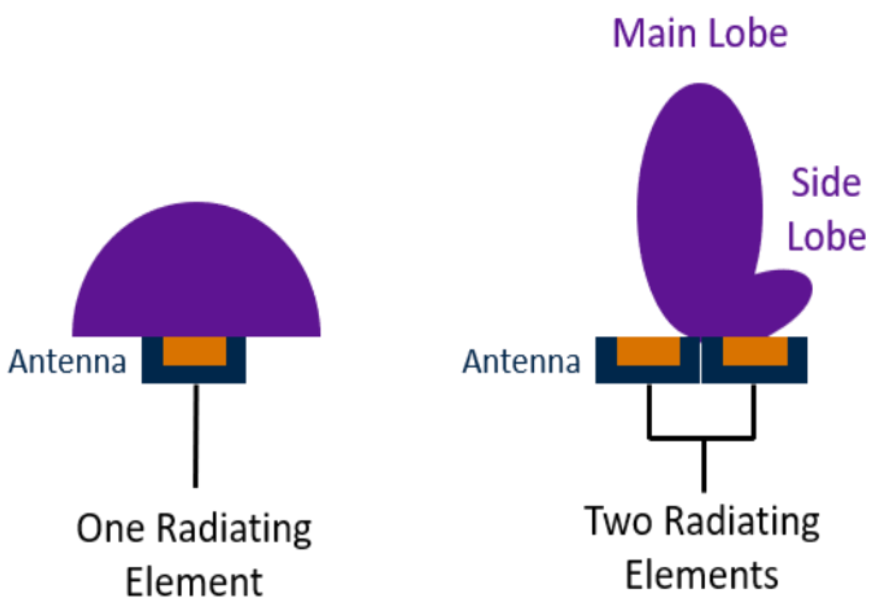


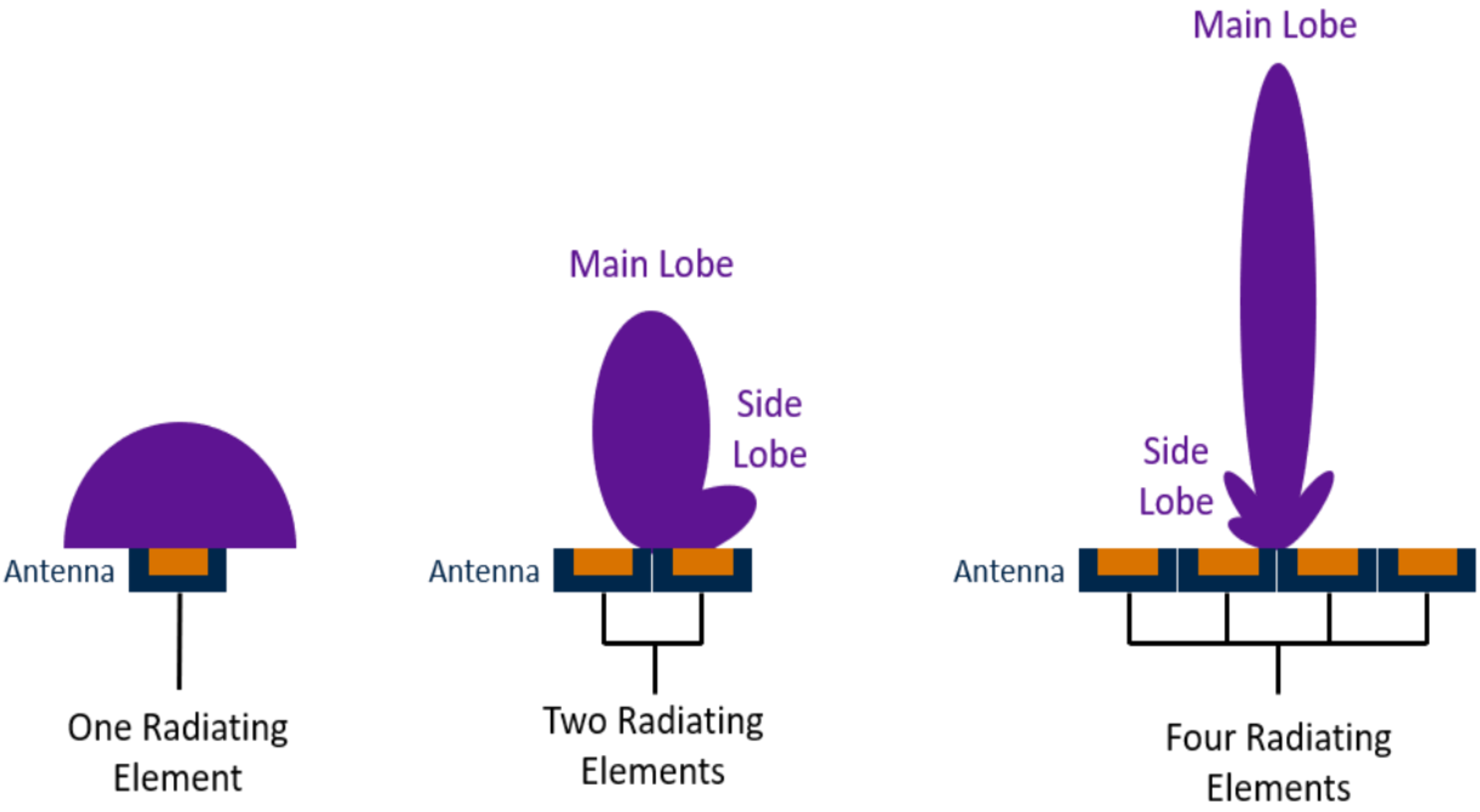
# Radiating Elements and Antennas



# Radiating Elements and Antennas

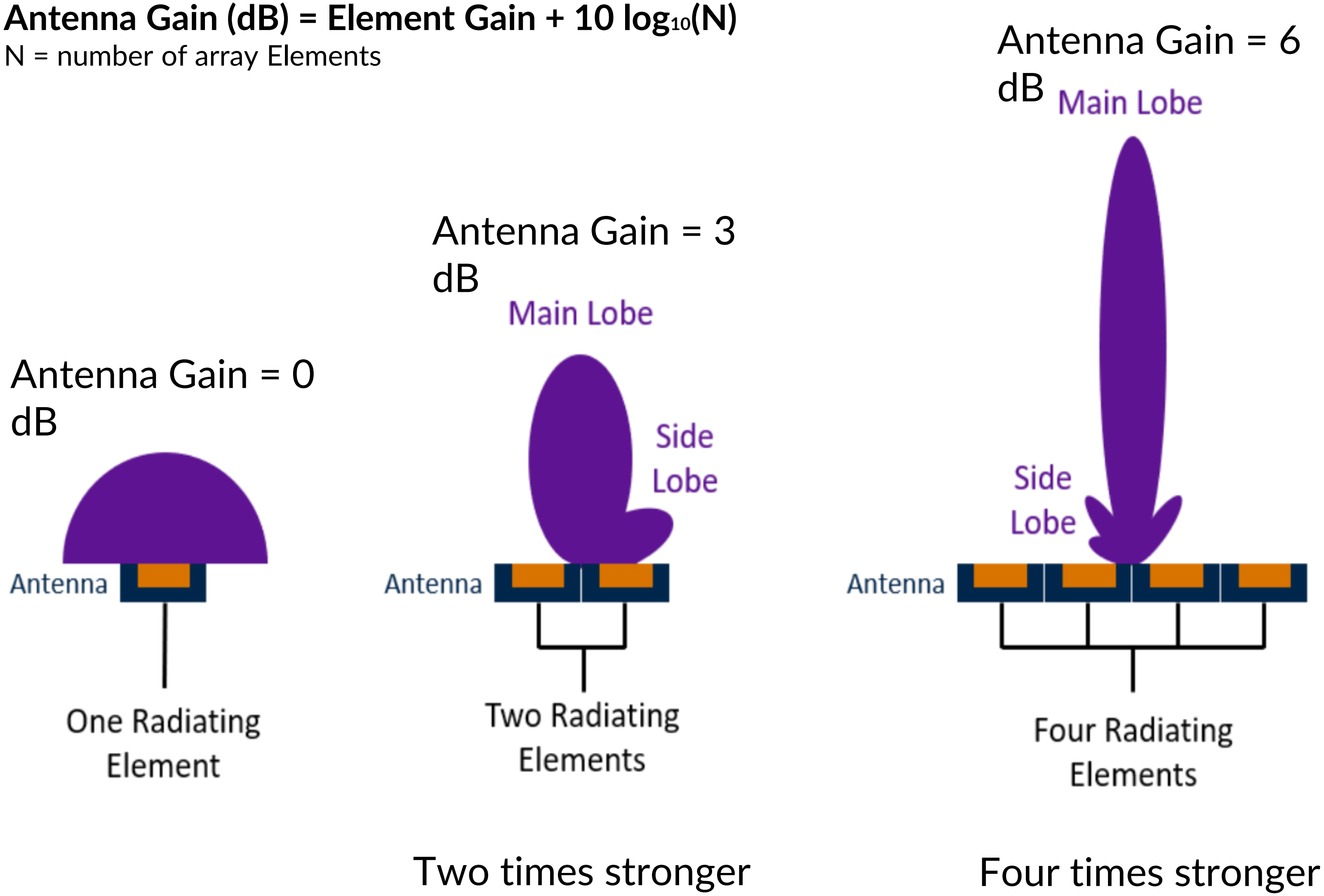


# Radiating Elements and Antennas

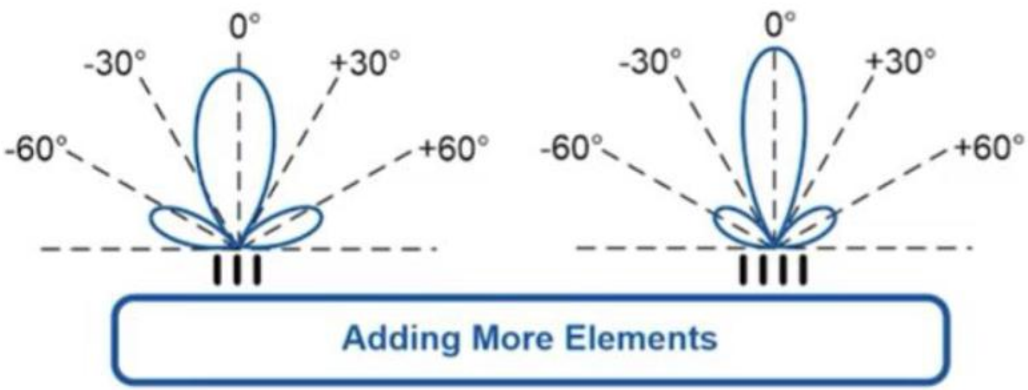


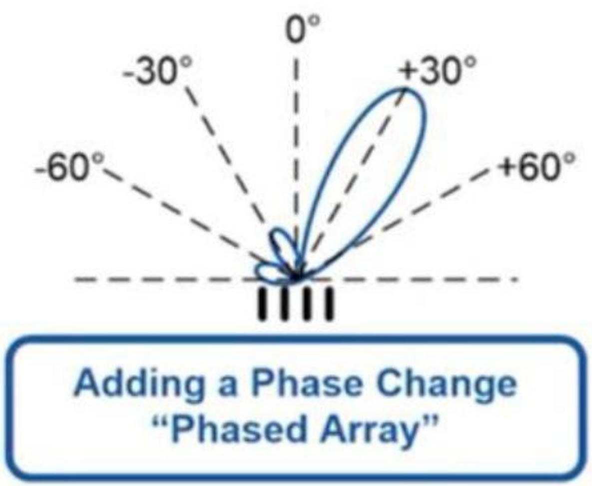
**Antenna Gain (dB) = Element Gain + 10 $\log_{10}$(N)**

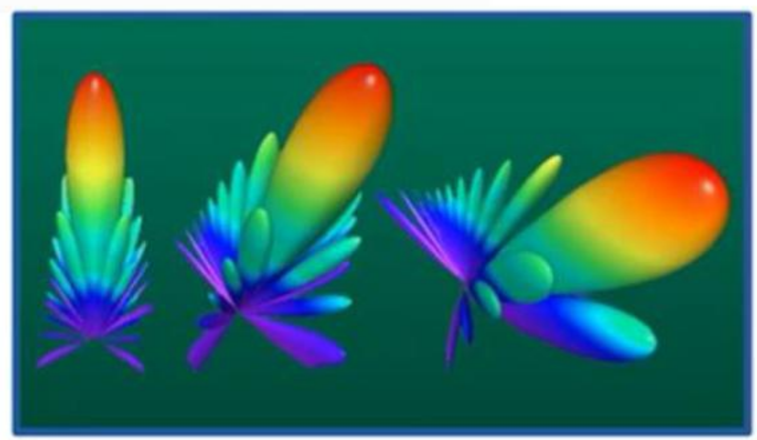
N = number of array Elements

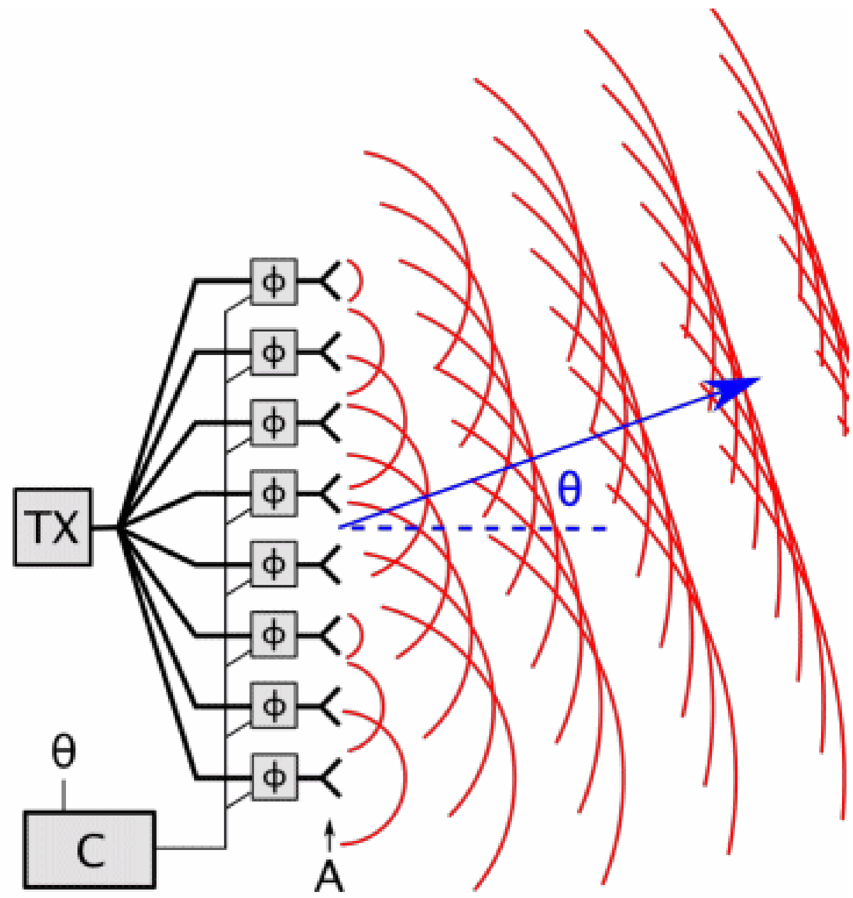


# Beamforming

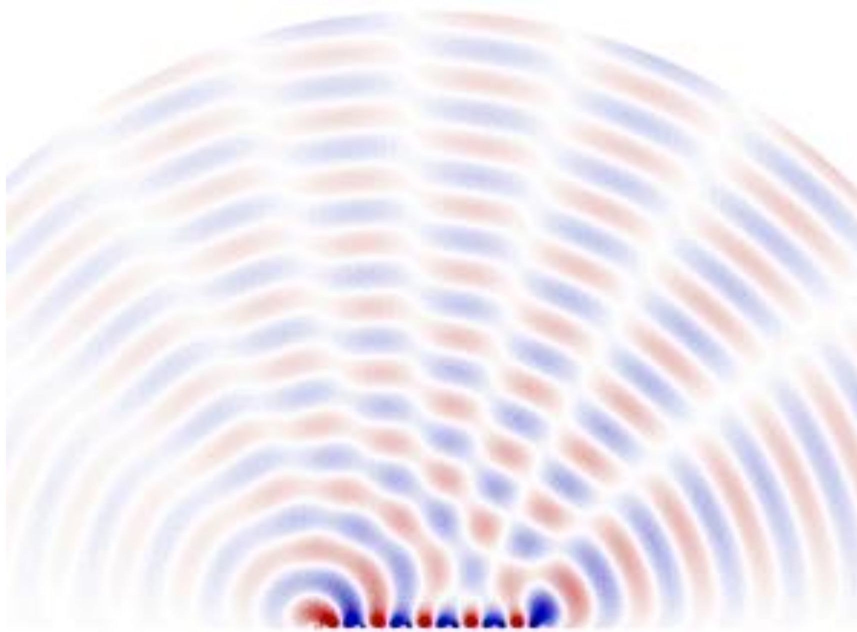


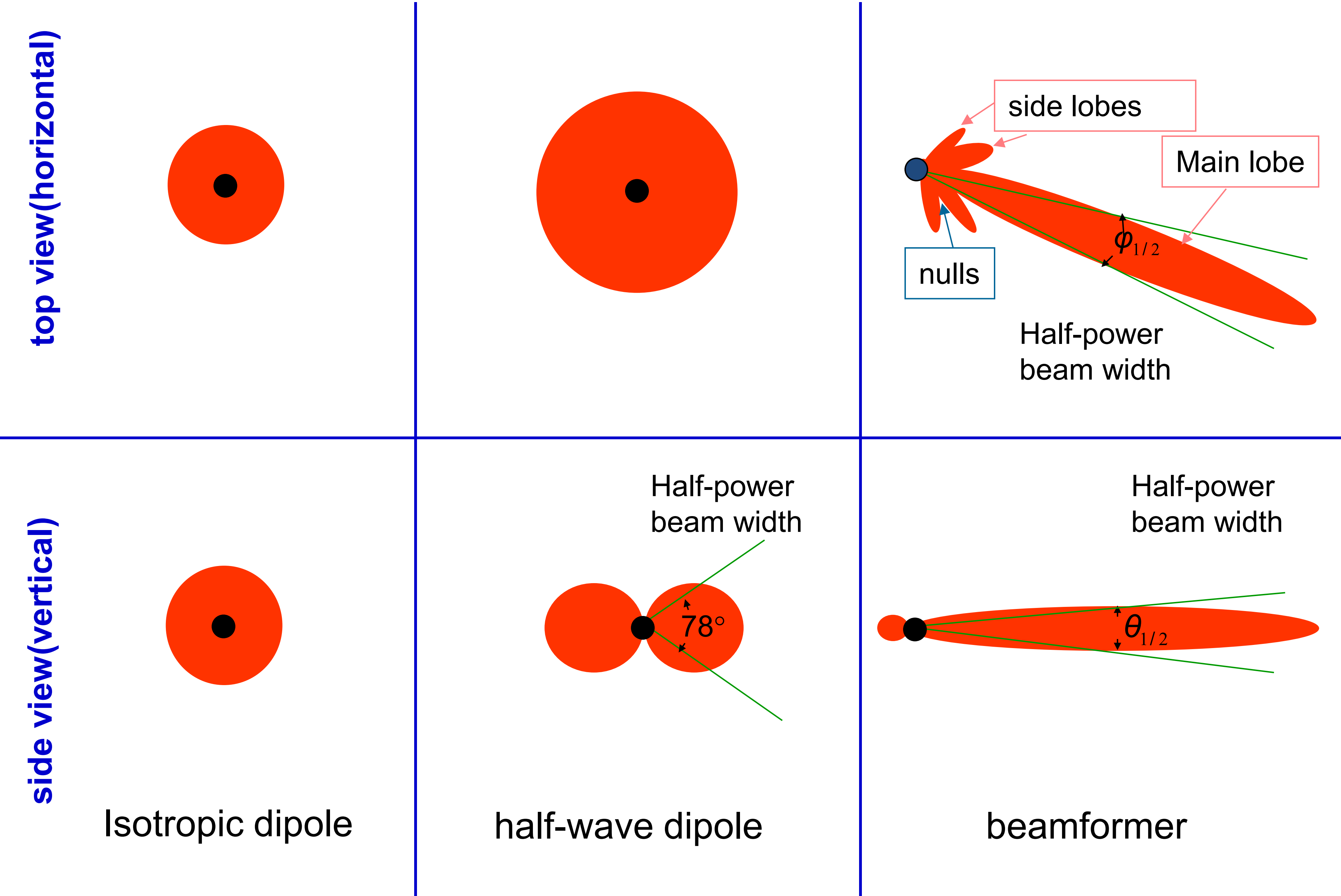



Visual representation of Phased Array

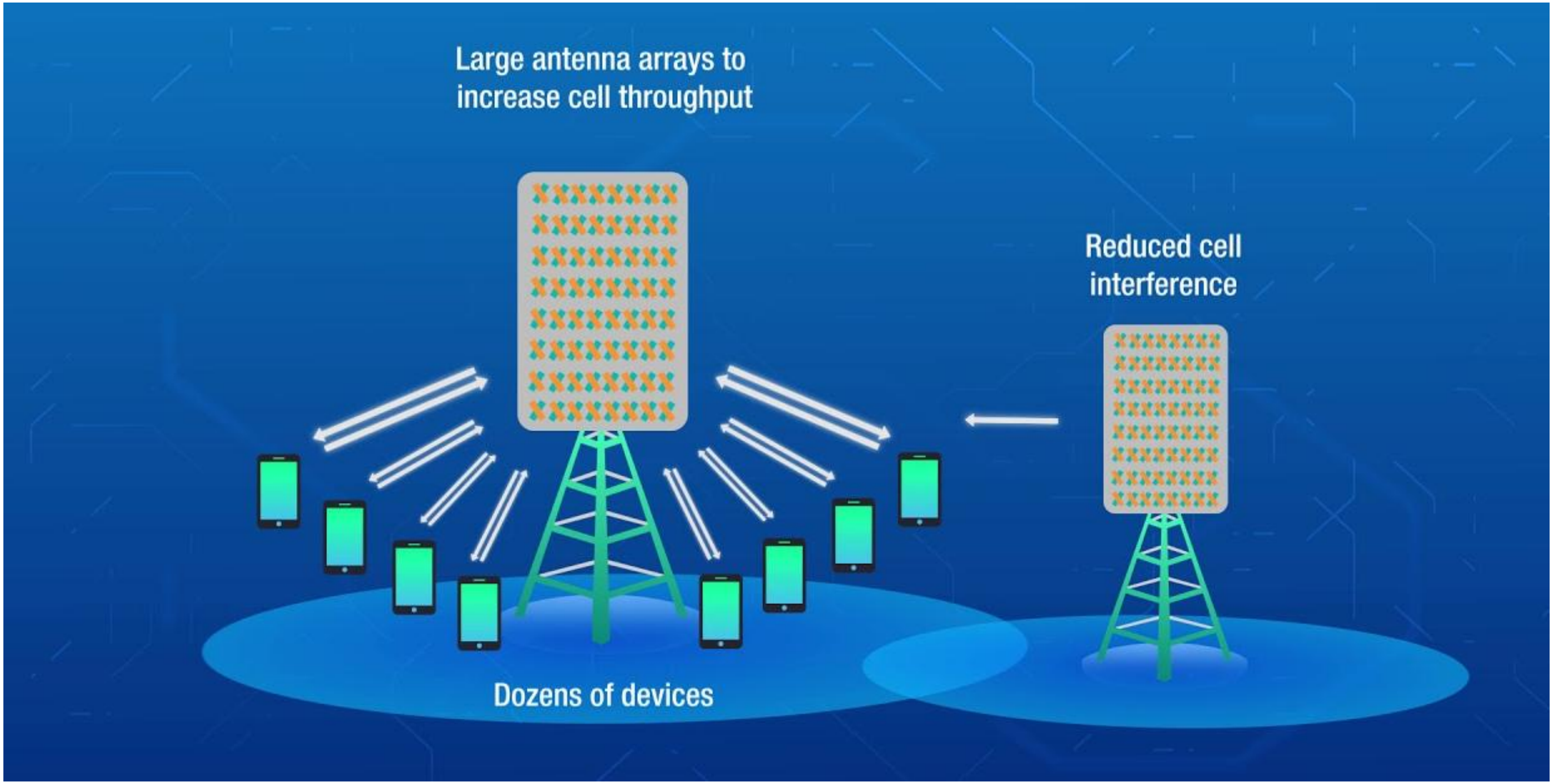


Visual representation of Phased Array

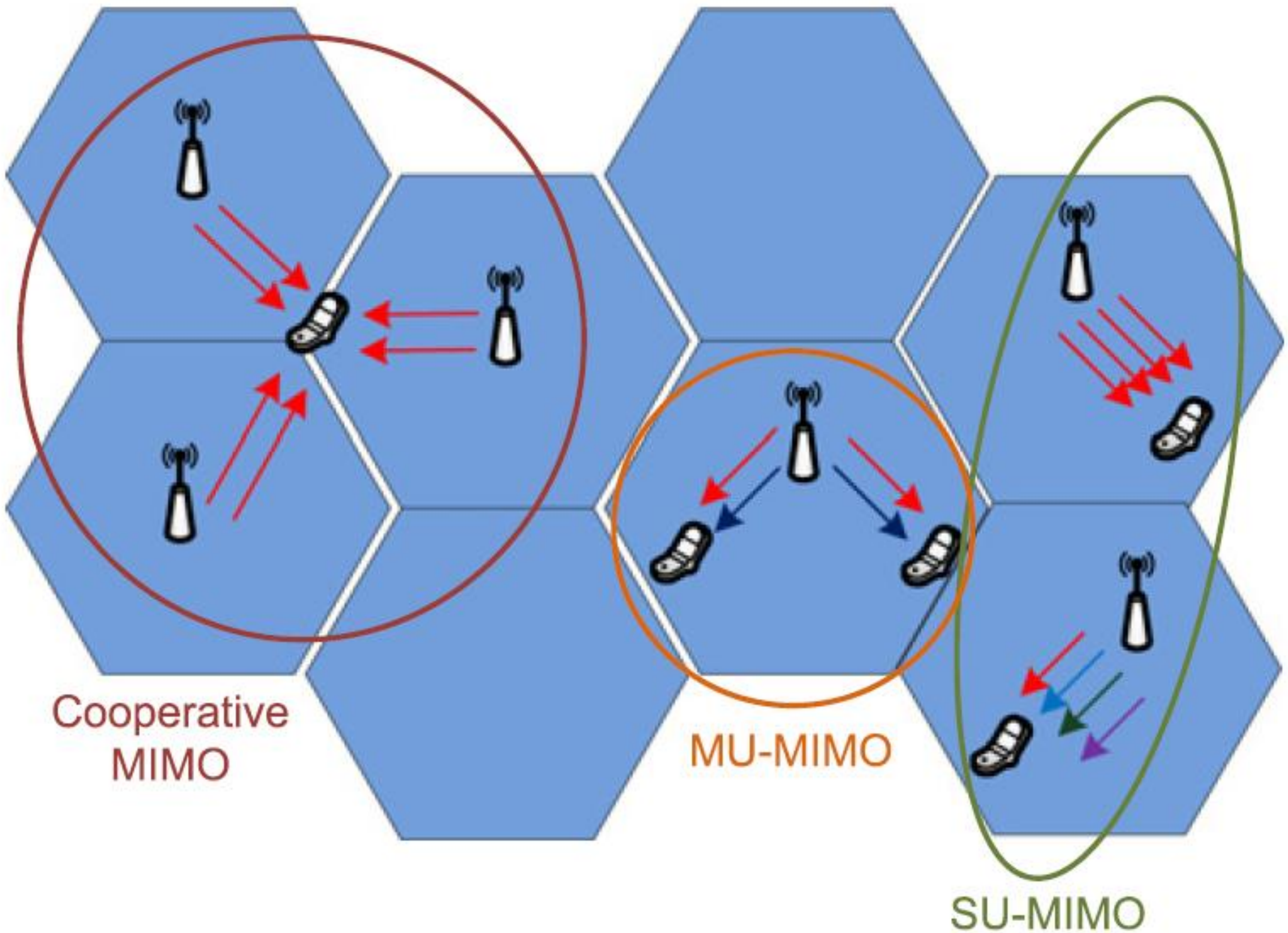
# Patterns, beamwidth & Gain



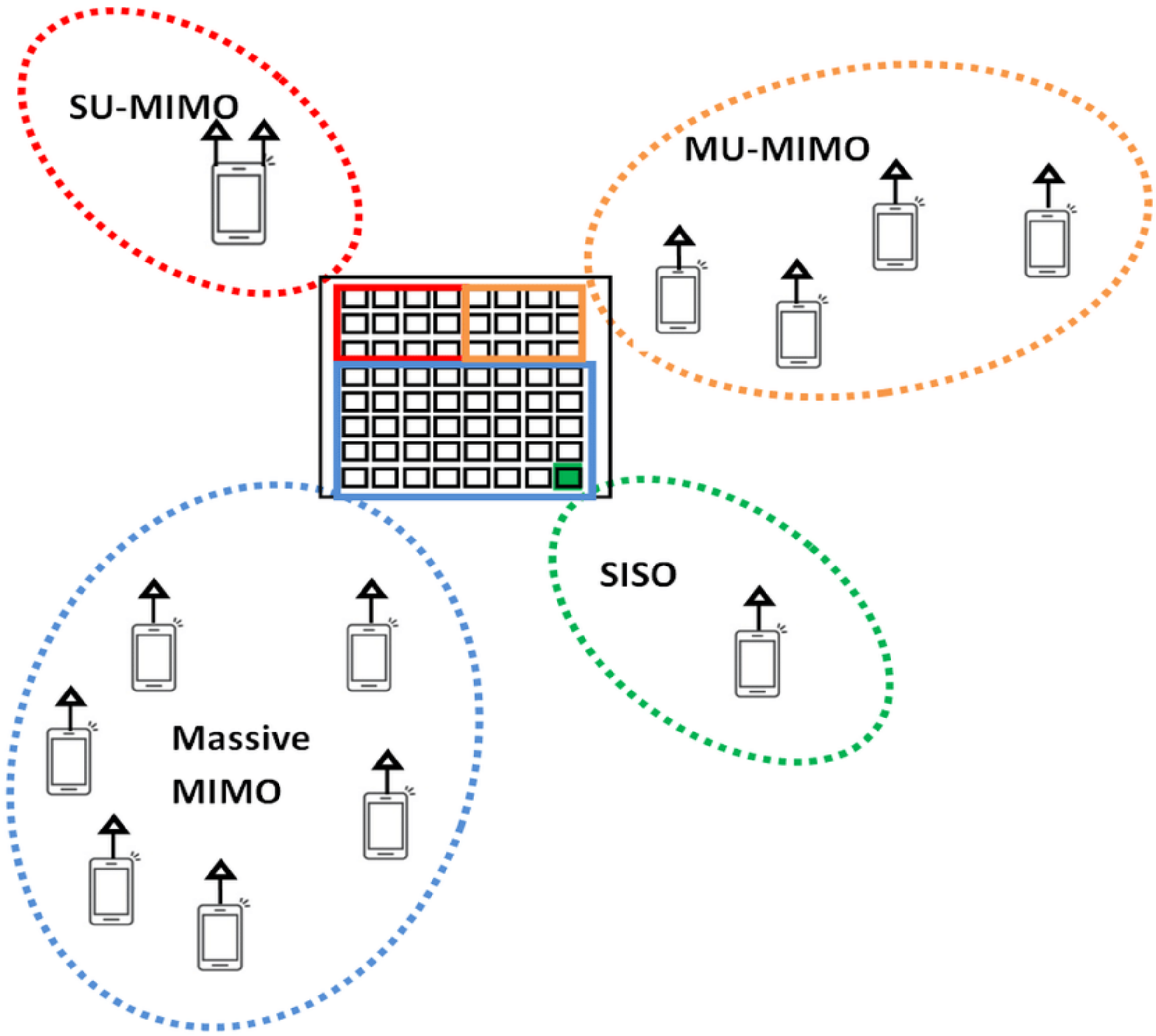
# Towards 5G: Massive MIMO and beamforming



# Different MIMO capabilities



# Different MIMO capabilities



## A. Beamforming

Serve single users by directing the energy toward the user.

## B. Generalized beamforming

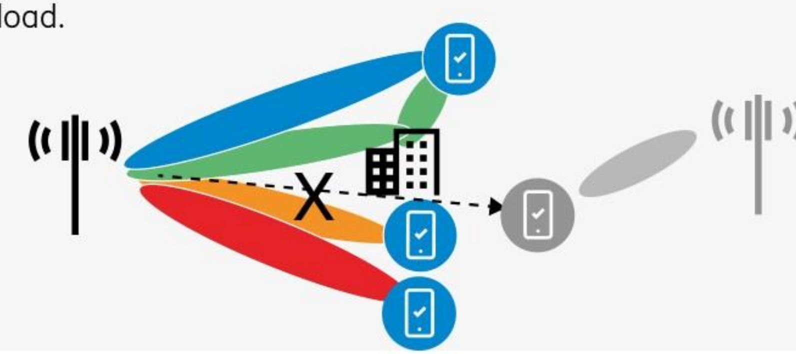
Serve single users by sending the same data stream in different directions and possibly forming zero (nulls) in the directions of other users.

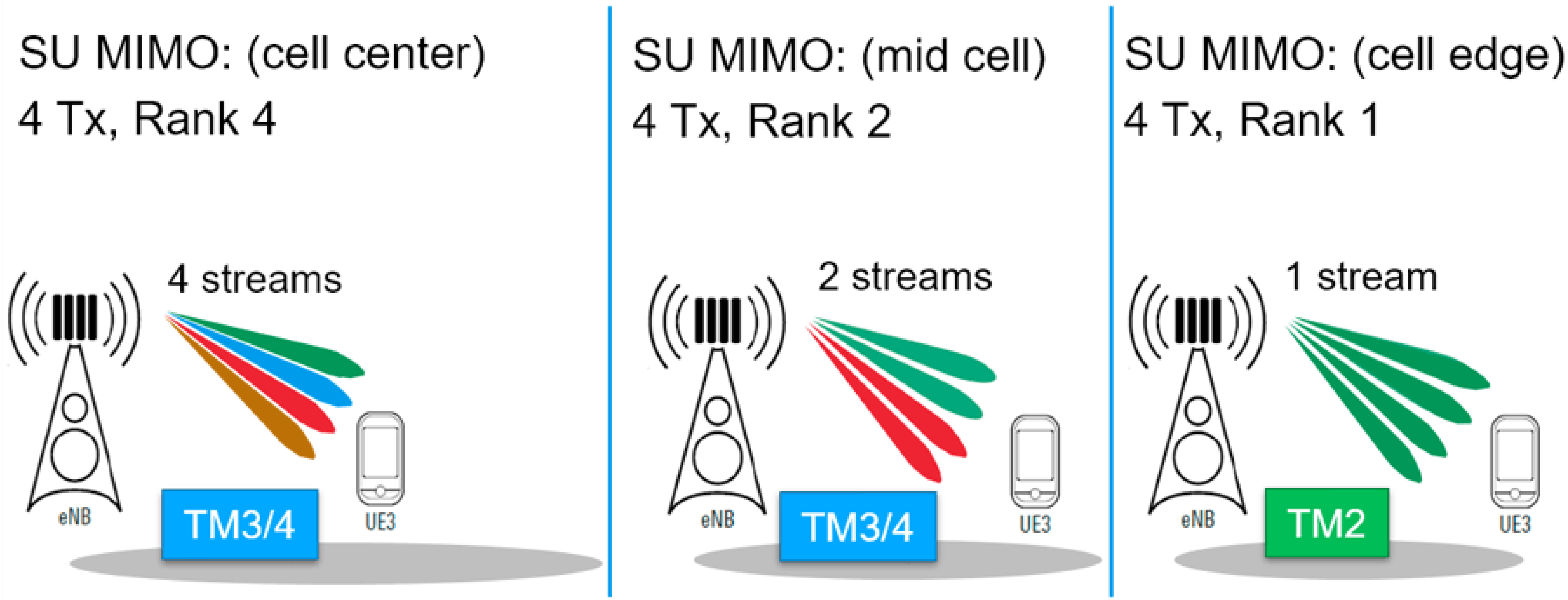
## C. SU-MIMO

Increase data rates by transmitting several data streams to a user.

## D. MU-MIMO

At high load, serve more users simultaneously at high load.




SU MIMO: (cell center)
4 Tx, Rank 4
4 streams
eNB
TM3/4
UE3
SU MIMO: (mid cell)
4 Tx, Rank 2
2 streams
eNB
TM3/4
UE3
SU MIMO: (cell edge)
4 Tx, Rank 1
1 stream
eNB
TM2
UE3

# Transmission modes

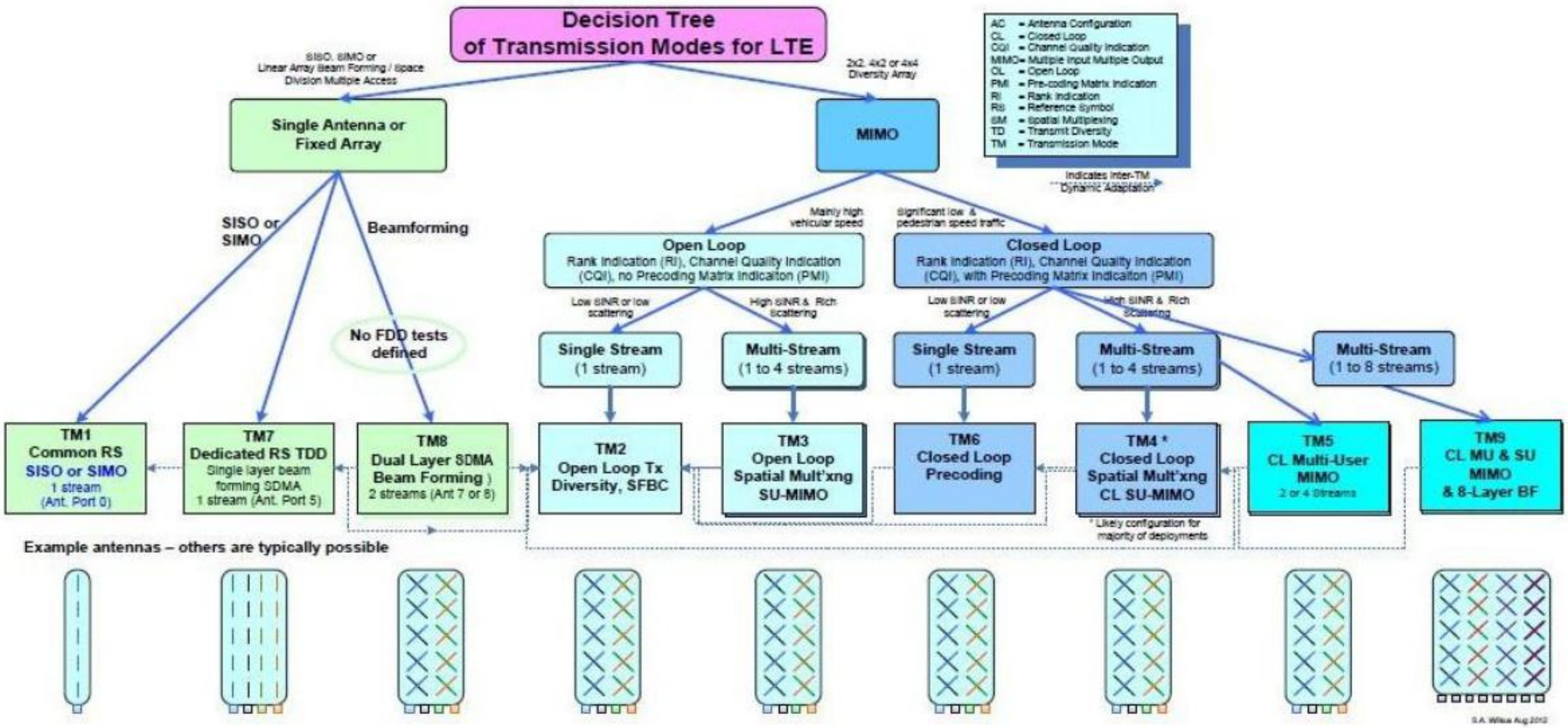
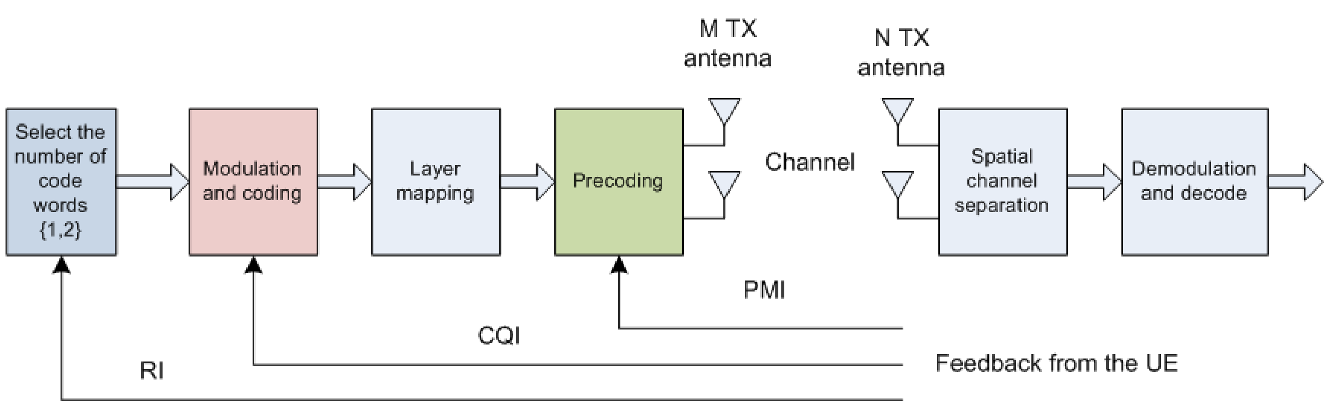



Figure 3 – Taxonomy of smart antenna processing algorithms in LTE Release 10. Shadows behind blocks indicate that they are capable of transmitting multiple streams. (LTE Release 11 recently added Transmit Mode 10 with explicit support for CoMP (Coordinated MultiPoint Transmission Reception) use which is not shown.)

# Spatial multiplexing in LTE

- Two types
  - Open loop (used high speed scenarios)
    - Large delay Cyclic Delay Diversity (CDD)
  - Closed loop (used in low speed scenarios)
    - Mobile provides channel feedback to eNode B

| Feedback | Closed loop spatial multiplexing | Open loop spatial multiplexing |
|---|---|---|
| PMI (Pre-coded matrix indicator) | PMI feedback from UE based on instantaneous channel state | No feedback from UE. Fixed pre-coding at eNode B implementing cyclic delay diversity (CDD) |
| CQI (Channel quality indicator) | Separate CQI for each code word | Aggregate CQI (one value) |
| RI (Rank indicator) | Based on the rank of estimated channel matrix (indicates number of spatial channels) | Based on the rank of estimated channel matrix when SFBCs are used |




Closed loop spatial multiplexing

# Antenna configurations (LTE)

- LTE defines 7 transmission modes
- Decision on transmission mode – scheduler at eNode B
- Implementation equipment vendor dependent
- Later LTE releases added more MIMO modes

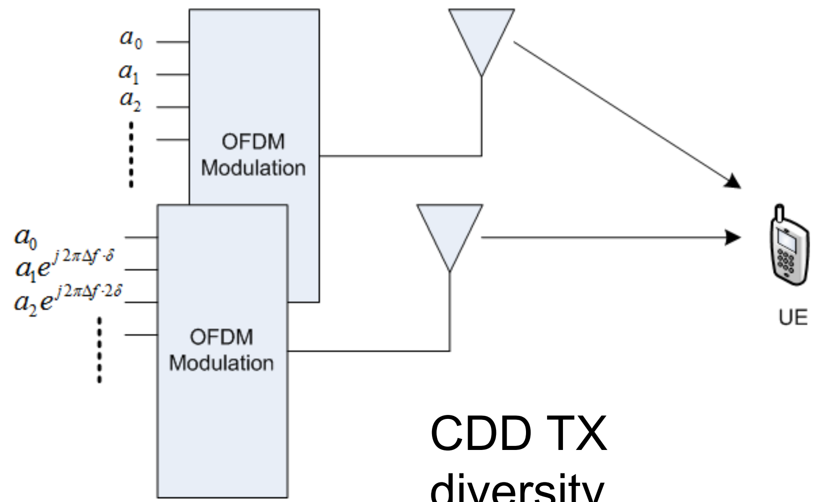
| Transmission modes | Description | Comments |
|---|---|---|
| 1 | Single antenna (Port 0) | Used for SISO and SIMO transmission |
| 2 | Transmit diversity | Used in low SNR and high mobility |
| 3 | Open loop spatial multiplexing | Beneficial in high SNR and rich multipath environment |
| 4 | Closed loop spatial multiplexing | Beneficial in high SNR and rich multipath environment |
| 5 | Multi-user MIMO | Beneficial in high SNR environment for interference reduction |
| 6 | Closed loop | Beneficial in low SNR environments |
| 7 | Single antenna port | Used for beam forming of antenna arrays |

# TM1: SIMO mode

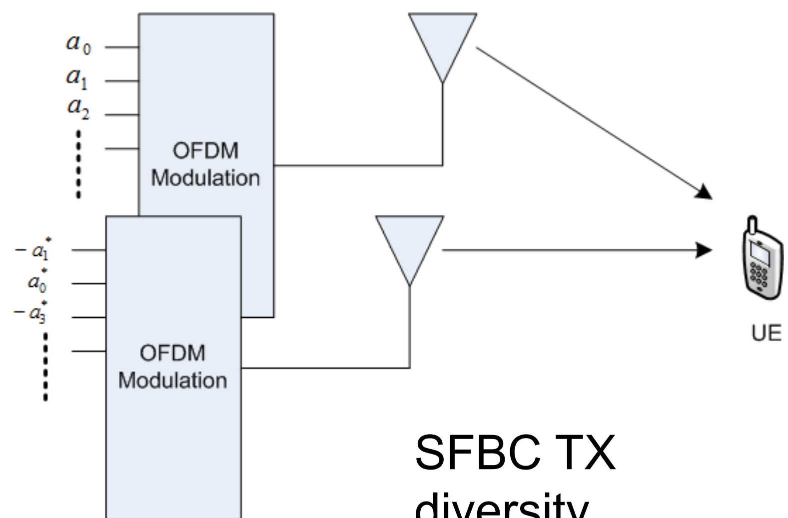
- Default transmission mode
- Every other mode – explicit signaling
- Assumes one TX port (i.e. one antenna)
- Mobile still may use diversity reception
- Not used often – limits the performance of DL
- Typical uses:
  - eNode B with one physical antenna
  - Simple UE with a very low traffic requirements
  - M2M communication (simplified signaling)
  - Limited coverage area

# TM 2: DL transmit diversity

- Two implementations
  - Cyclic Delay Diversity (CDD)
  - Space-Time Transmit Diversity (STTD)
- CDD
  - Multiple antenna elements are used to introduce additional versions of the signal that are cyclically delayed
  - UE perceives these signals as additional multi-paths
  - Assuming low correlations between TX antennas –created "multi-paths" fade independently – source of diversity
- STTD
  - Uses Space-Frequency Block Codes
  - Special encoding (SFBC) makes the channel matrix unitary (full rank)
  - Reference symbols are used to estimate and invert channel matrix



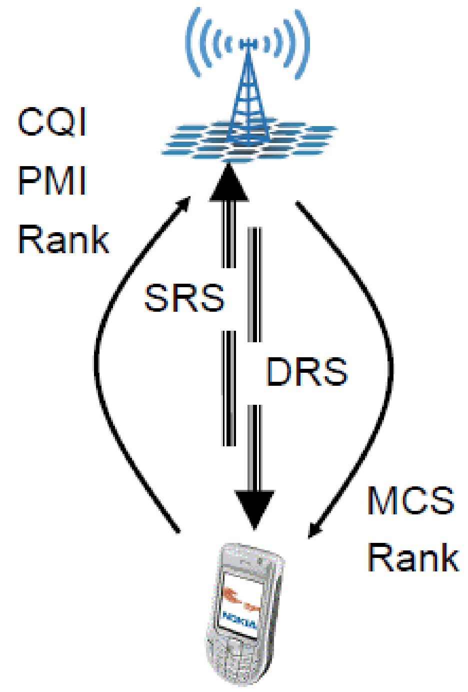

CDD TX diversity




SFBC TX diversity

# TM 3/4: Open/Closed loop spatial multiplexing

- Open loop = no PMI, CQI and Rank are still provided
- Closed loop = PMI, CQI and Rank provided by UE
- 2 layers with different information on each layer
- Rank of channel is 2
- May use 2 or 4 ports (antennas)
- If four antennas are used CDD is used on the same layer
- No PMI, eNodeB cycles through a pre-defined sequence of PMIs (TM3)
- PMI present = eNode B uses the UE recommended PMI (TM4)




PDSCH Channel estimation based on DRS

Note 1: UE recommends transmission mode configuration; UEs of different capabilities easily accommodated
Note 2: PMI estimates only valid for slow moving mobiles

# TM 5/6: MU-MIMO/Closed Loop

**TM 5**

- Users are multiplexed in spatial domain
- Scheduling for multiple users
  - Same frequency resources
  - Different layers
- Requires very precise channel estimation
- Not used much in practice

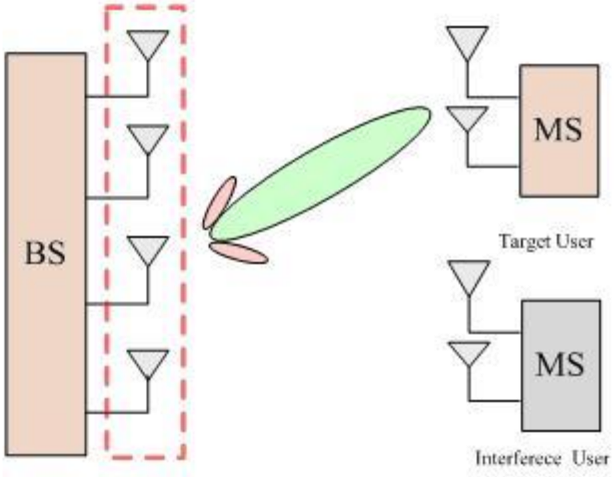
**TM 6**

- One layer (i.e. one code word)
- PMI selected by the UE
- Appropriate for slow moving mobiles
- Not used much in practice

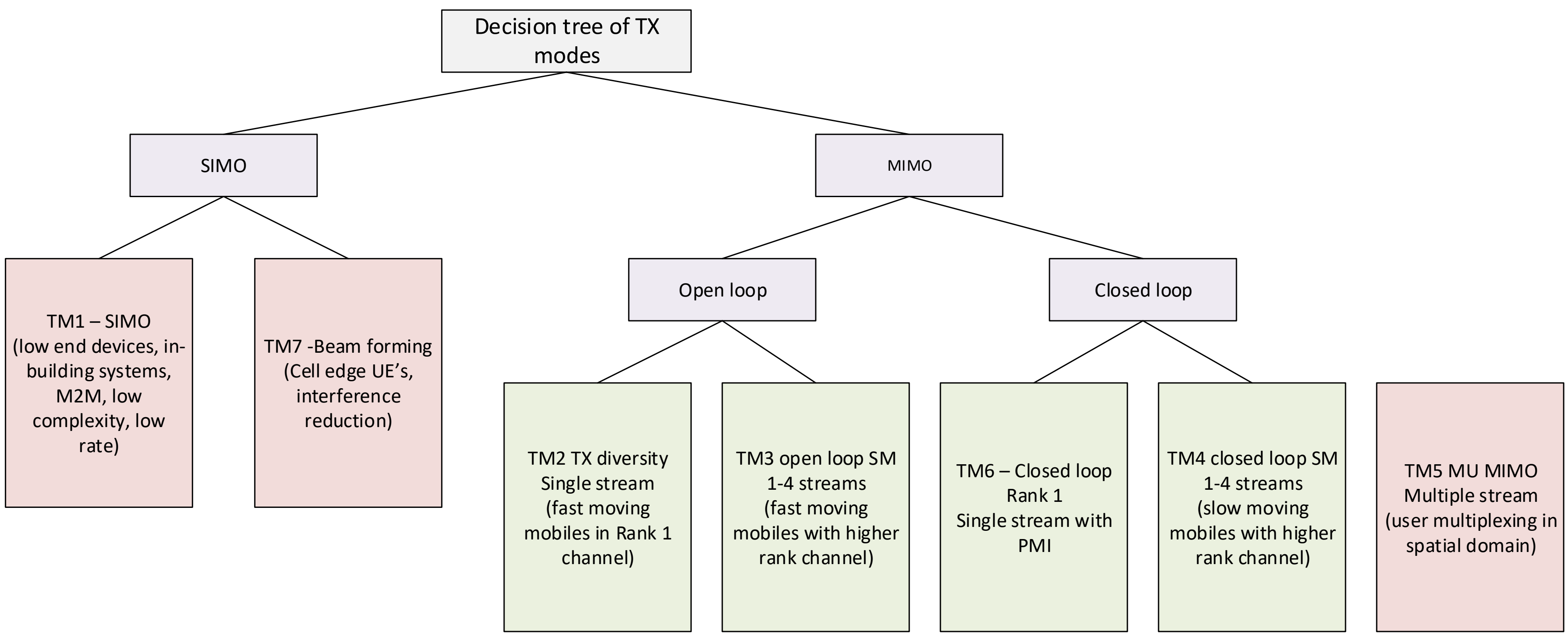
# TM 7: Beam forming

- Transmission mode used for beamforming
- Multiple antennas are used to form a higher gain beam towards the mobile
- This is accomplished through phase and amplitude scaling of individual ports
- This is rank 1 technique, i.e. it does not support spatial multiplexing
- Used predominantly as means to help UE's at cell edge

Note: transmission uses multiple antennas that are combined to act as a single high gain antenna



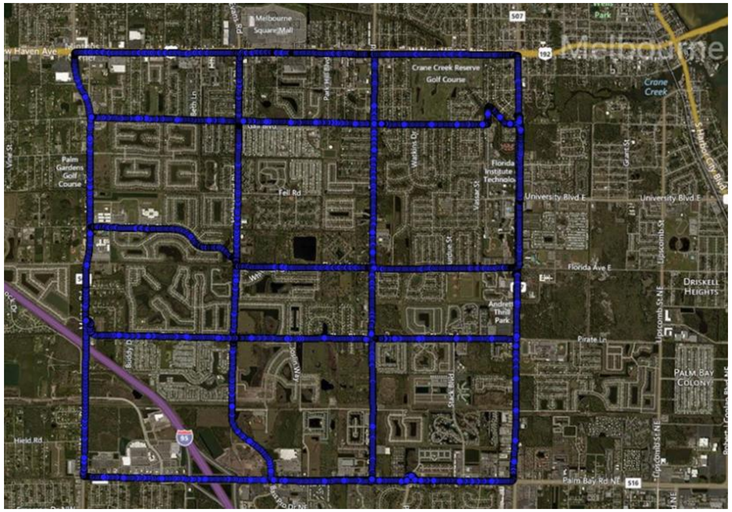
# MIMO mode selection in LTE

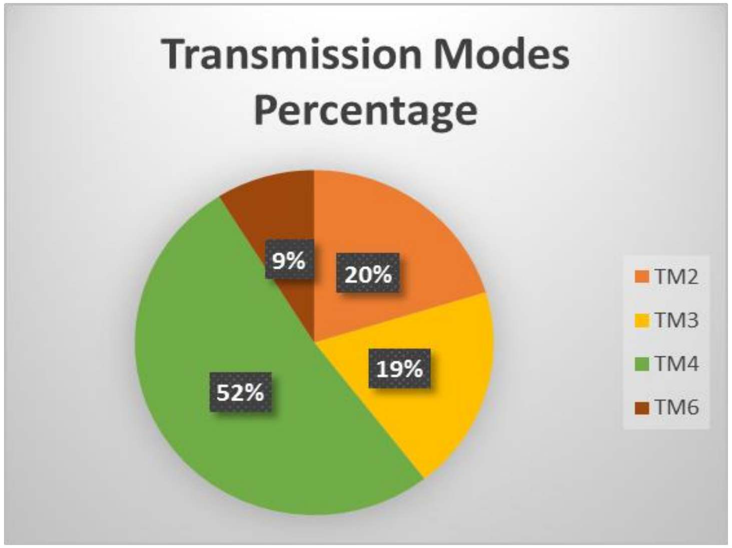



Note: "Green" modes are used more frequently than "red" modes.

# Typical distribution of MIMO modes

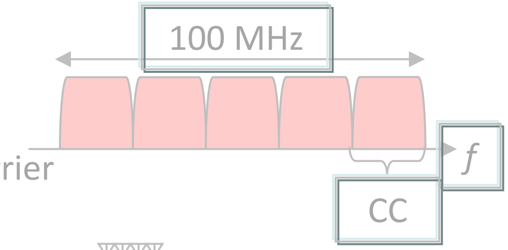
- Use of MIMO mode – scheduler decision
- Most useful modes:
  - TM4 (spatial multiplexing over rank 2 channel with precoding)
  - TM3 (spatial multiplexing over rank 2 channel without pre-coding)
  - TM2 (transmit diversity)
  - TM6 (closed loop MIMO over Rank 1 channel)



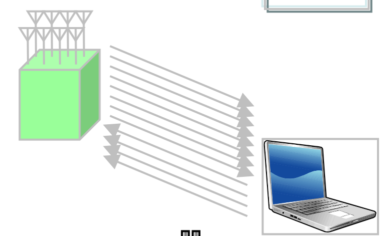



Example of an area and MIMO mode distribution

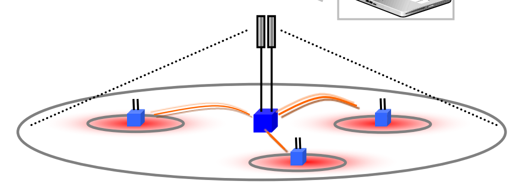
# LTE-A main features




- Support of Wider Bandwidth(Carrier Aggregation)
  - Use of multiple component carriers(CC) to extend bandwidth up to 100 MHz
  - Common physical layer parameters between component carrier and LTE Rel-8 carrier
  - → Improvement of peak data rate, backward compatibility with LTE Rel-8

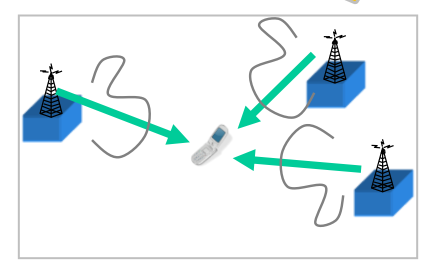


- Advanced MIMO techniques
  - Extension to up to 8-layer transmission in downlink
  - Introduction of single-user MIMO up to 4-layer transmission in uplink
  - Enhancements of multi-user MIMO
  - → Improvement of peak data rate and capacity



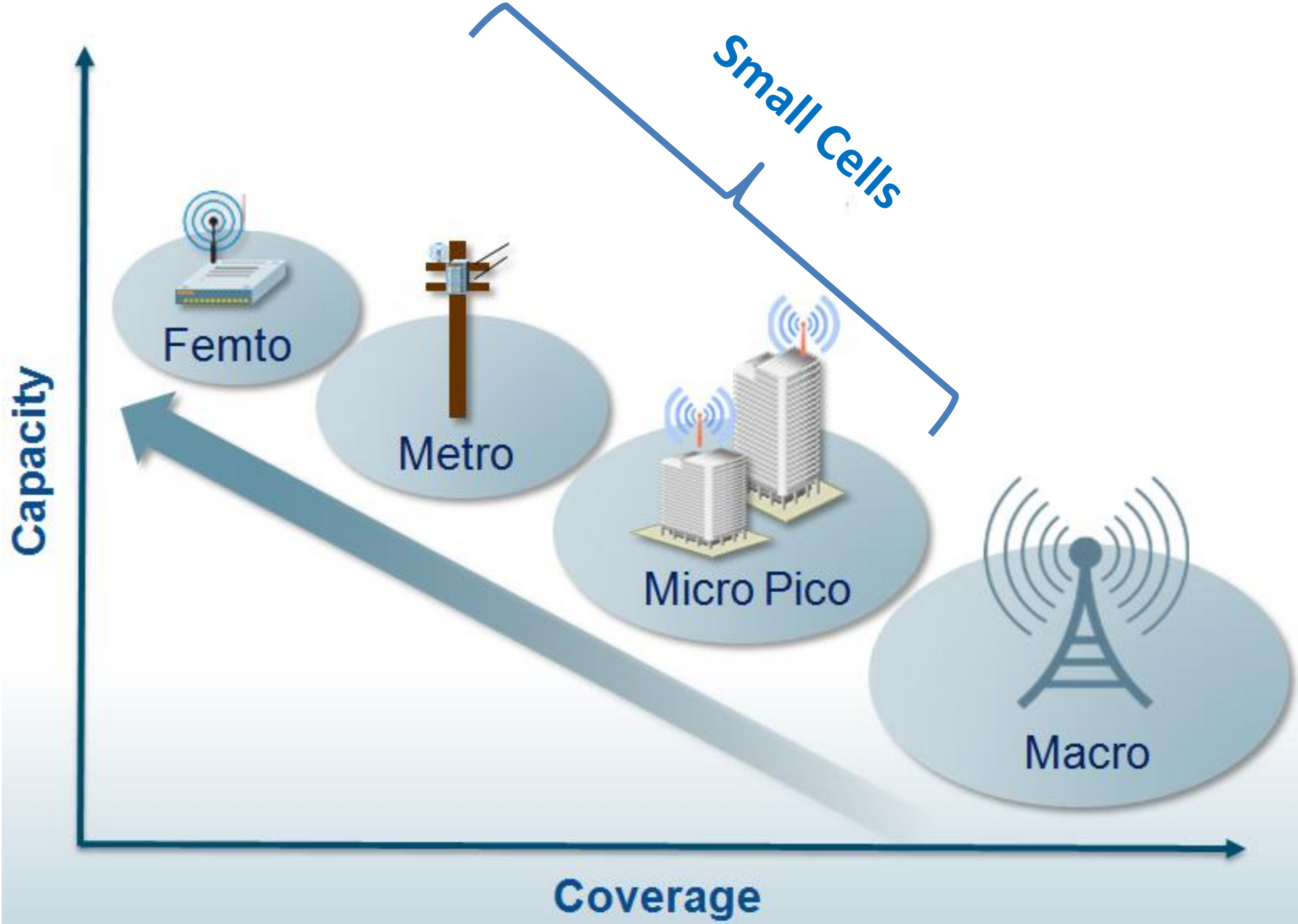
- Heterogeneous network and eICIC (enhanced Inter-Cell Interference Coordination)
  - Interference coordination for overlaid deployment of cells with different Tx power
  - → Improvement of cell-edge throughput and coverage

- Relay
  - Supports radio backhaul and creates a separate cell and appear as Rel. 8 LTE eNB to Rel. 8 LTE UEs
  - → Improvement of coverage and flexibility of service area extension

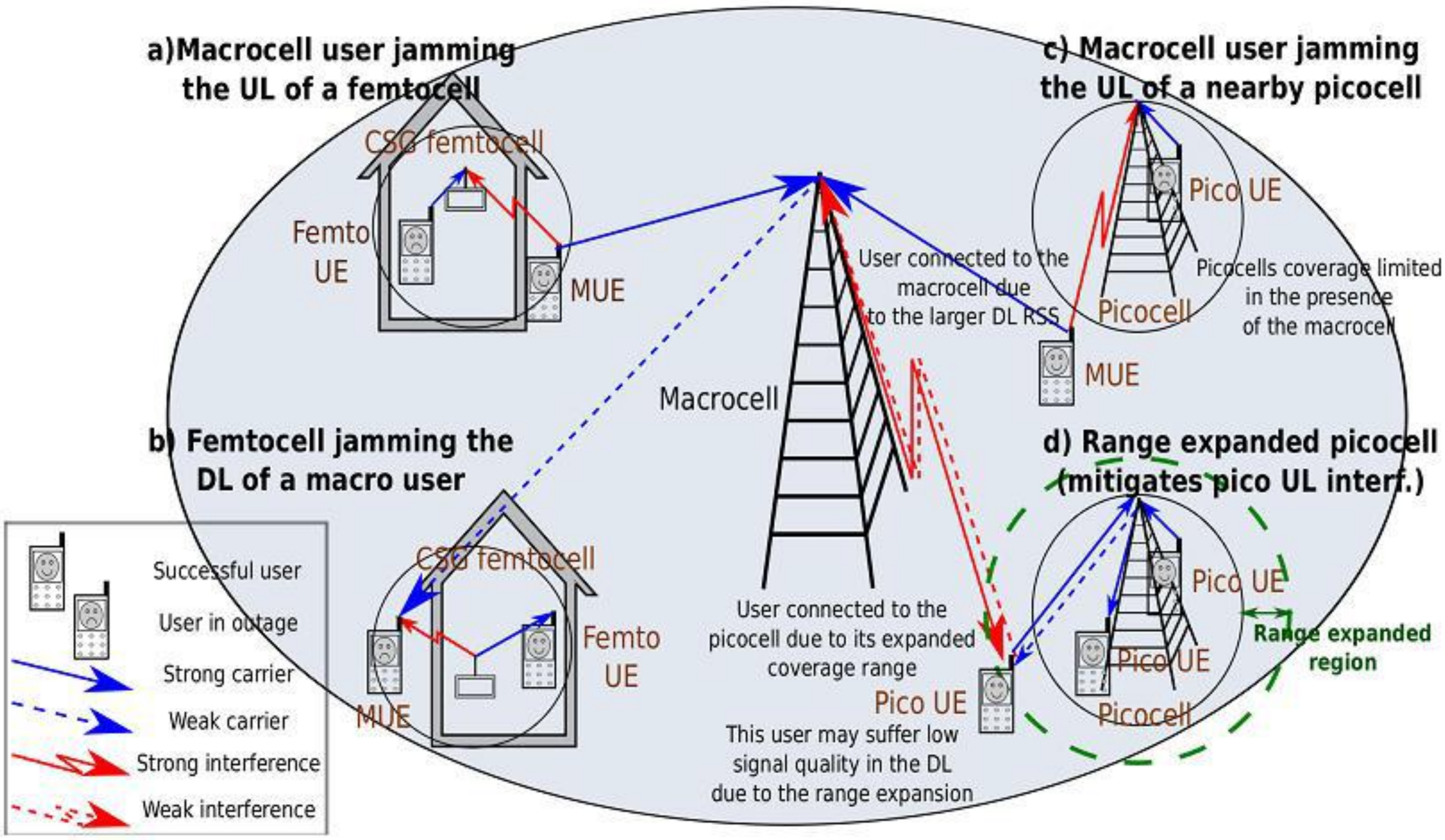


- Coordinated Multi-Point transmission and reception (CoMP)
  - Support of multi-cell transmission and reception
  - → Improvement of cell-edge throughput and coverage

# Heterogeneous networks in LTE-A



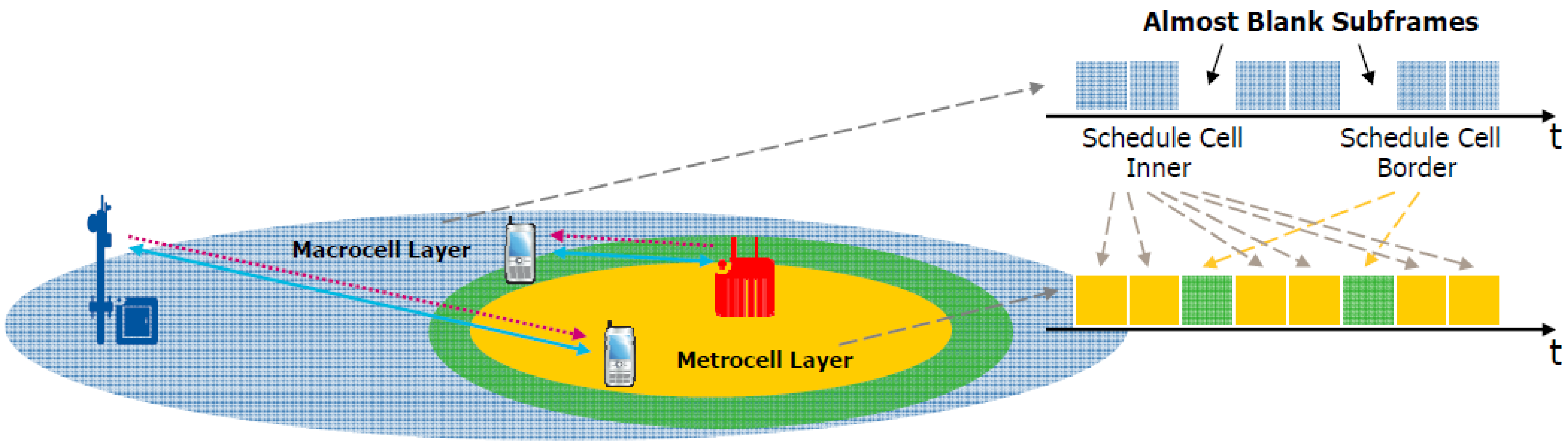
# Heterogeneous networks in LTE-A



# enhanced Inter-Cell Interference Coordination (eICIC)

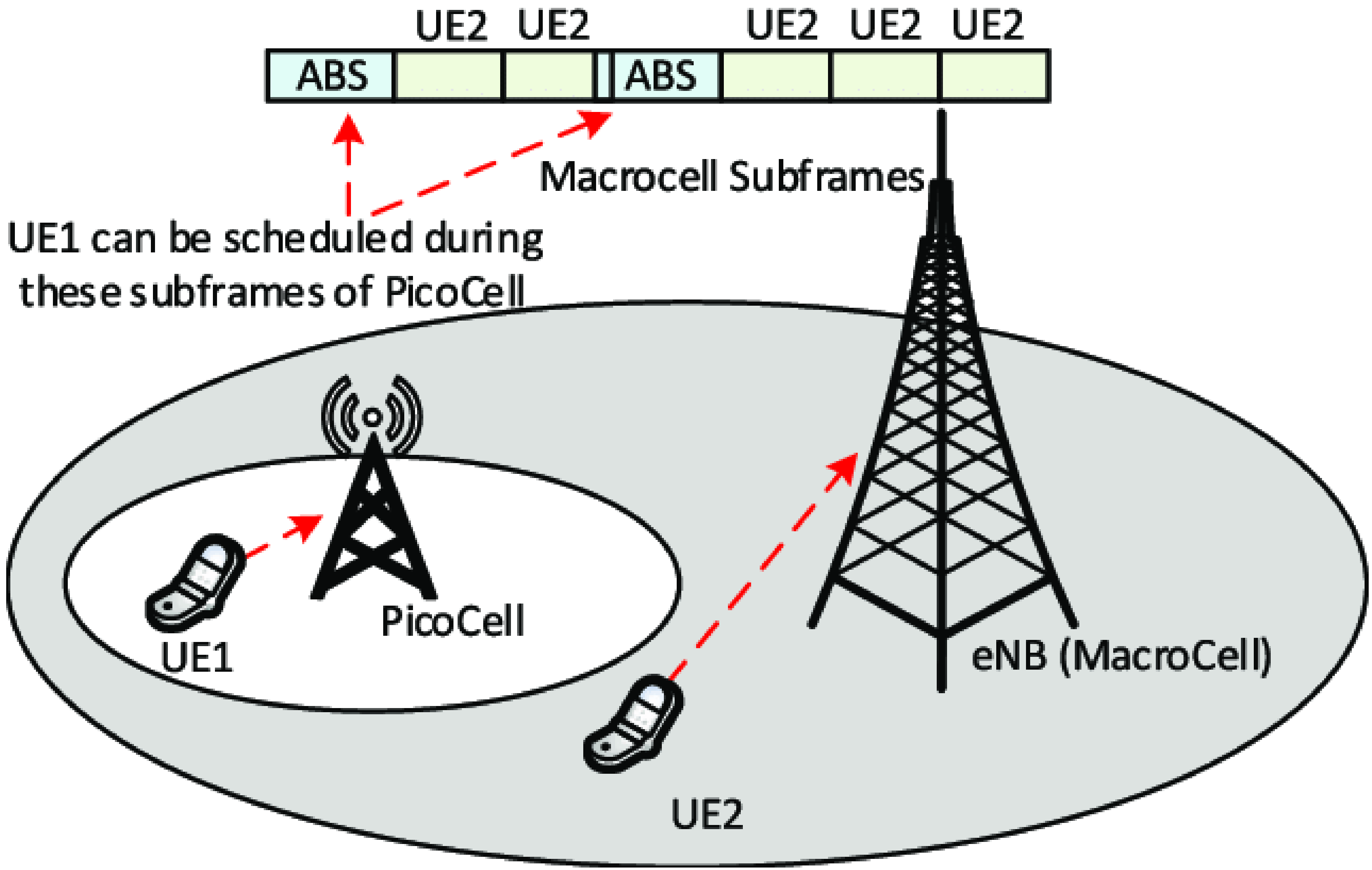
- Coordination between eNBs at different tiers (e.g. femto-marco) to mitigate interference
- Three categories
  - Time-domain: Almost Blank Subframes (ABSFs) at macrocells, where no control or data signals are transmitted.
  - Frequency-domain: Select different frequency channels for victim users in macro and femto
  - Power-domain: Reduce power in femtocell to mitigate interference to macrocell

# Almost Blank Subframes

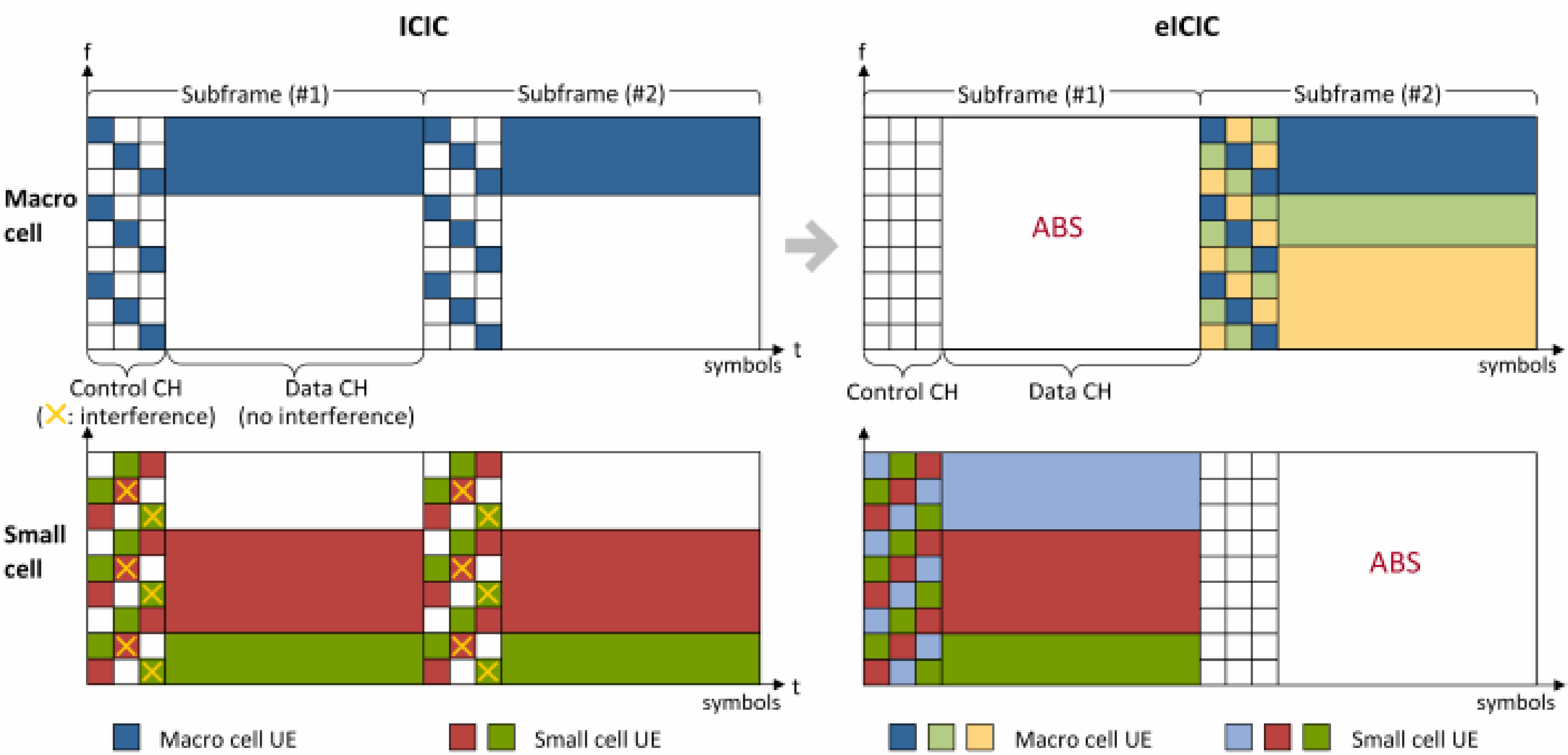



- Increased coverage
- Higher spectral efficiency
- Significant improvement in capacity and cell edge performance

# Almost Blank Subframes



# Almost Blank Subframes

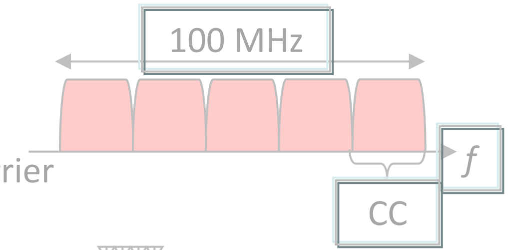



Release 8 (LTE)

Release 10 (LTE-A)

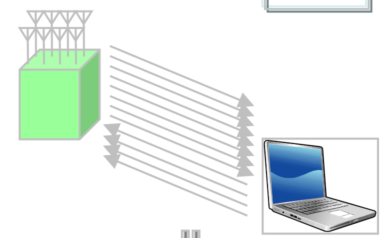
# LTE-A main features

## Support of Wider Bandwidth(Carrier Aggregation)



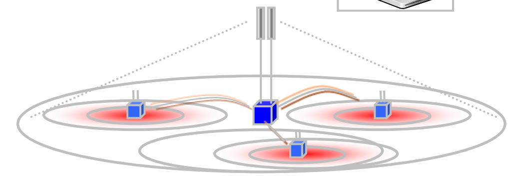

- Use of multiple component carriers(CC) to extend bandwidth up to 100 MHz
- Common physical layer parameters between component carrier and LTE Rel-8 carrier
- ➔ Improvement of peak data rate, backward compatibility with LTE Rel-8

## Advanced MIMO techniques



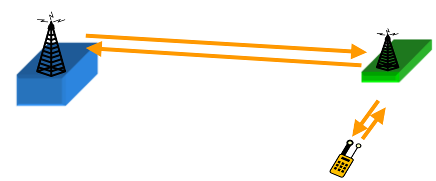
- Extension to up to 8-layer transmission in downlink
- Introduction of single-user MIMO up to 4-layer transmission in uplink
- Enhancements of multi-user MIMO
- ➔ Improvement of peak data rate and capacity

## Heterogeneous network and eICIC (enhanced Inter-Cell Interference Coordination)



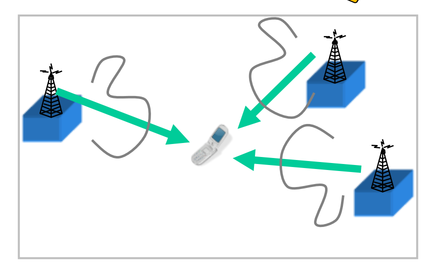
- Interference coordination for overlaid deployment of cells with different Tx power
- ➔ Improvement of cell-edge throughput and coverage

## Relay



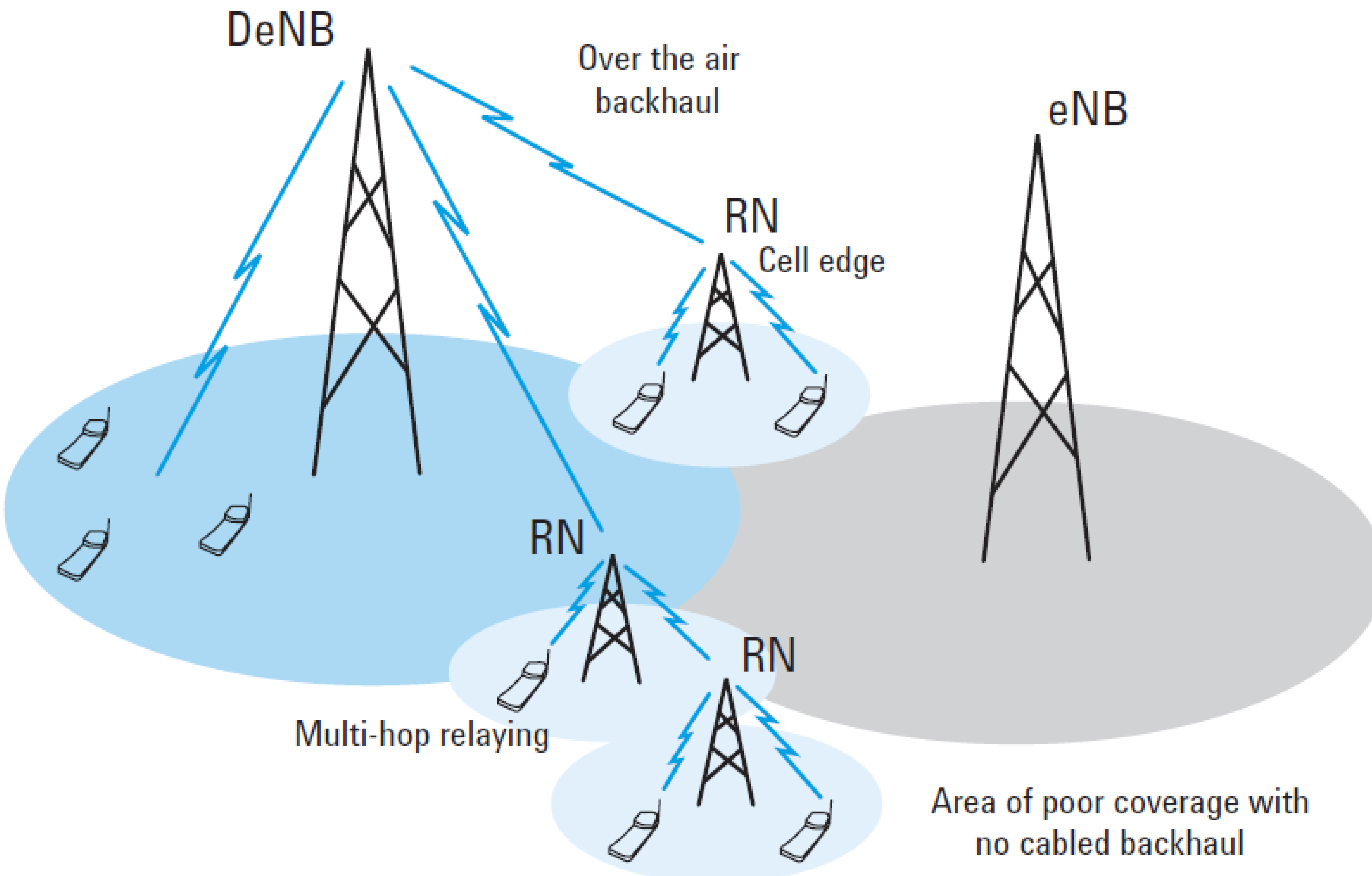
- Supports radio backhaul and creates a separate cell and appear as Rel. 8 LTE eNB to Rel. 8 LTE UEs
- ➔ Improvement of coverage and flexibility of service area extension

## Coordinated Multi-Point transmission and reception (CoMP)

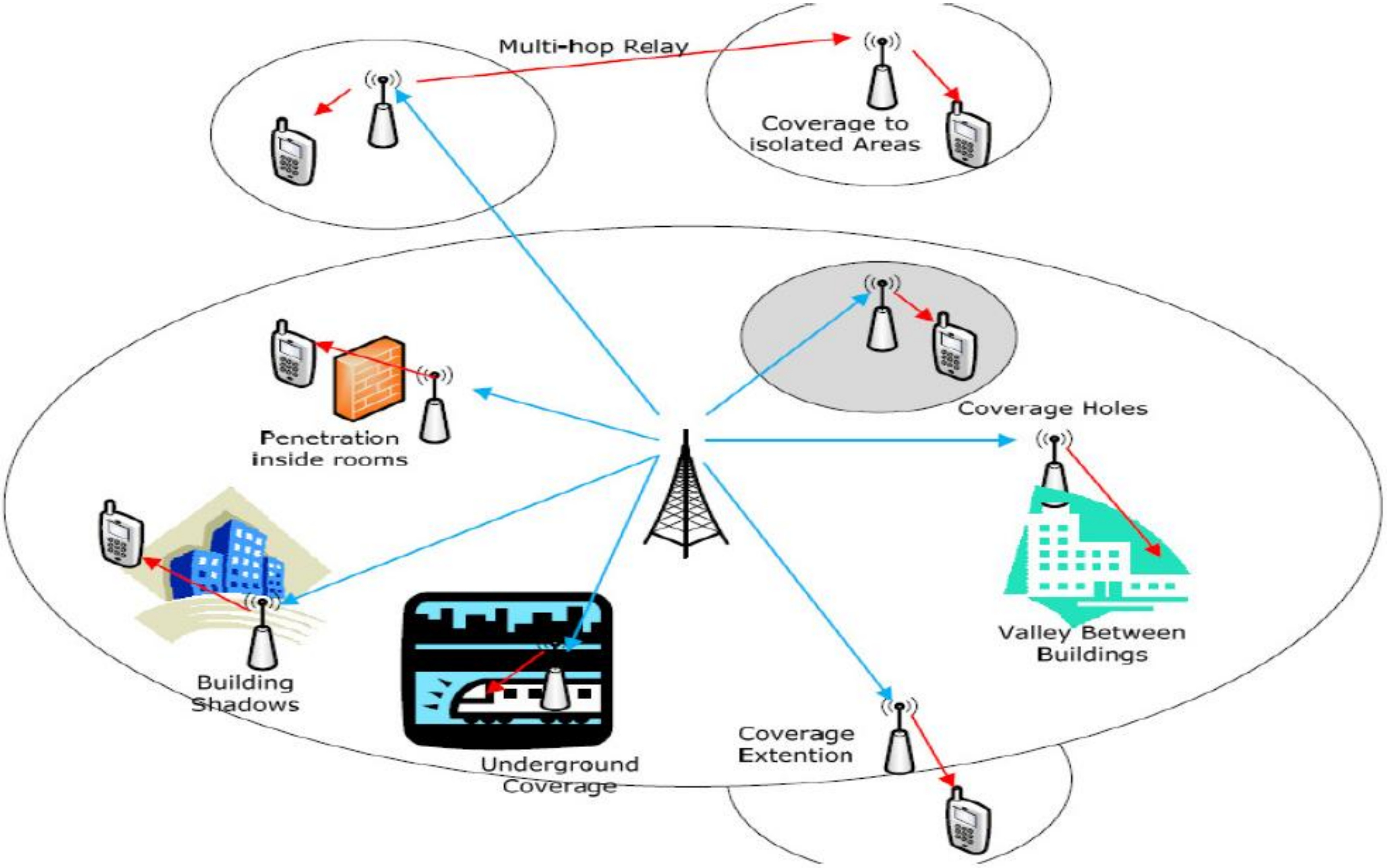


- Support of multi-cell transmission and reception
- ➔ Improvement of cell-edge throughput and coverage

# Relaying in LTE-A



# Where to use relaying

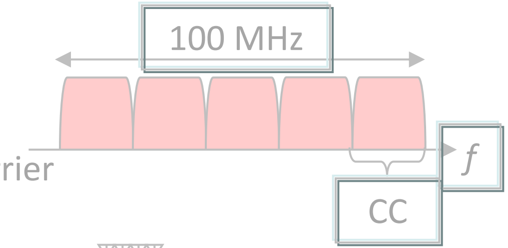


# LTE-A main features

## Support of Wider Bandwidth(Carrier Aggregation)

- Use of multiple component carriers(CC) to extend bandwidth up to 100 MHz
- Common physical layer parameters between component carrier and LTE Rel-8 carrier

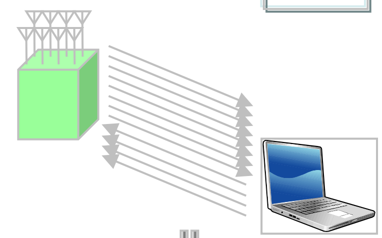
➔ Improvement of peak data rate, backward compatibility with LTE Rel-8




## Advanced MIMO techniques

- Extension to up to 8-layer transmission in downlink
- Introduction of single-user MIMO up to 4-layer transmission in uplink
- Enhancements of multi-user MIMO

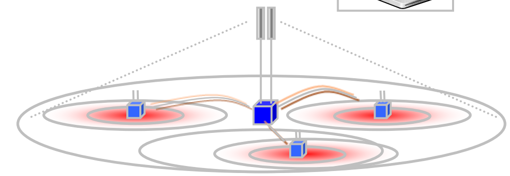
➔ Improvement of peak data rate and capacity



## Heterogeneous network and eICIC (enhanced Inter-Cell Interference Coordination)

- Interference coordination for overlaid deployment of cells with different Tx power

➔ Improvement of cell-edge throughput and coverage



## Relay

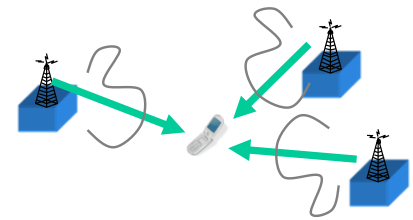
- Supports radio backhaul and creates a separate cell and appear as Rel. 8 LTE eNB to Rel. 8 LTE UEs

➔ Improvement of coverage and flexibility of service area extension

## Coordinated Multi-Point transmission and reception (CoMP)

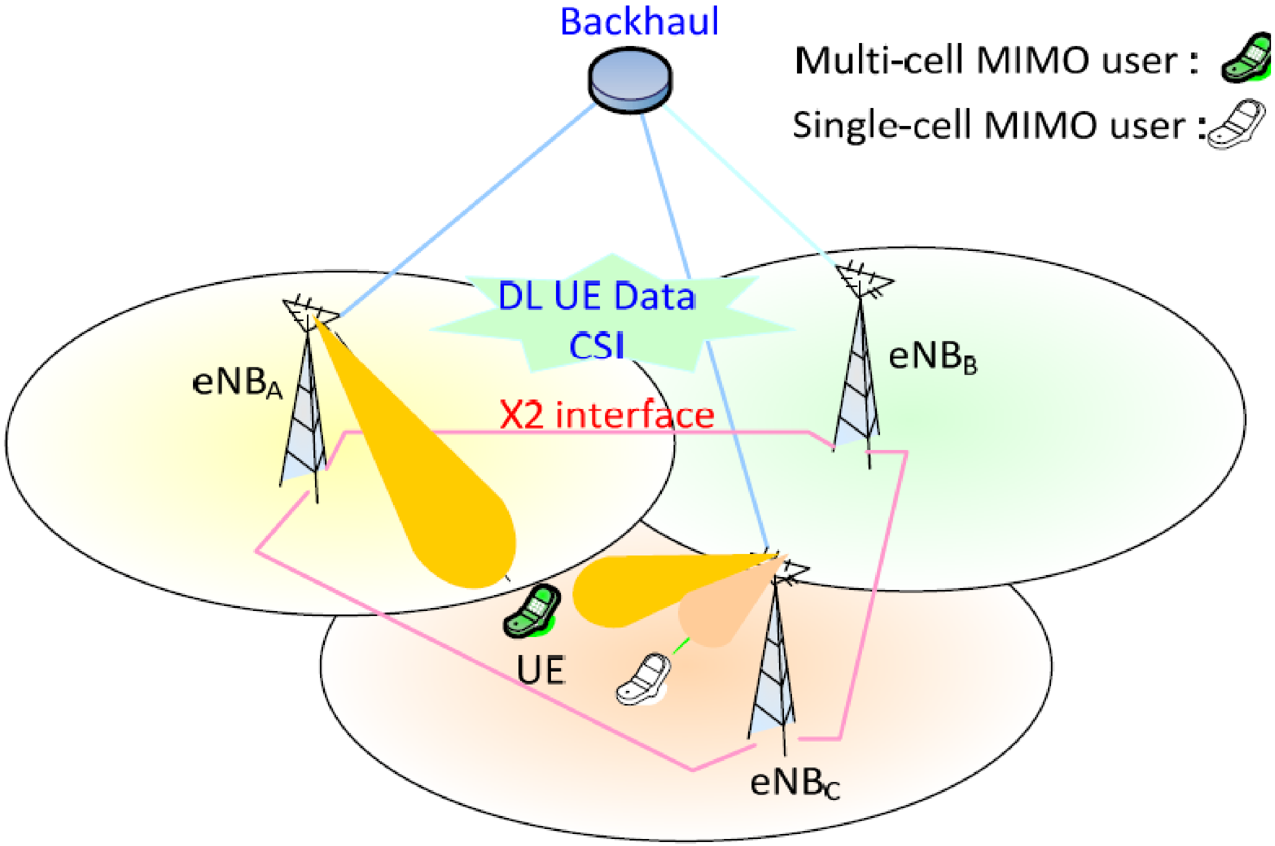
- Support of multi-cell transmission and reception

➔ Improvement of cell-edge throughput and coverage

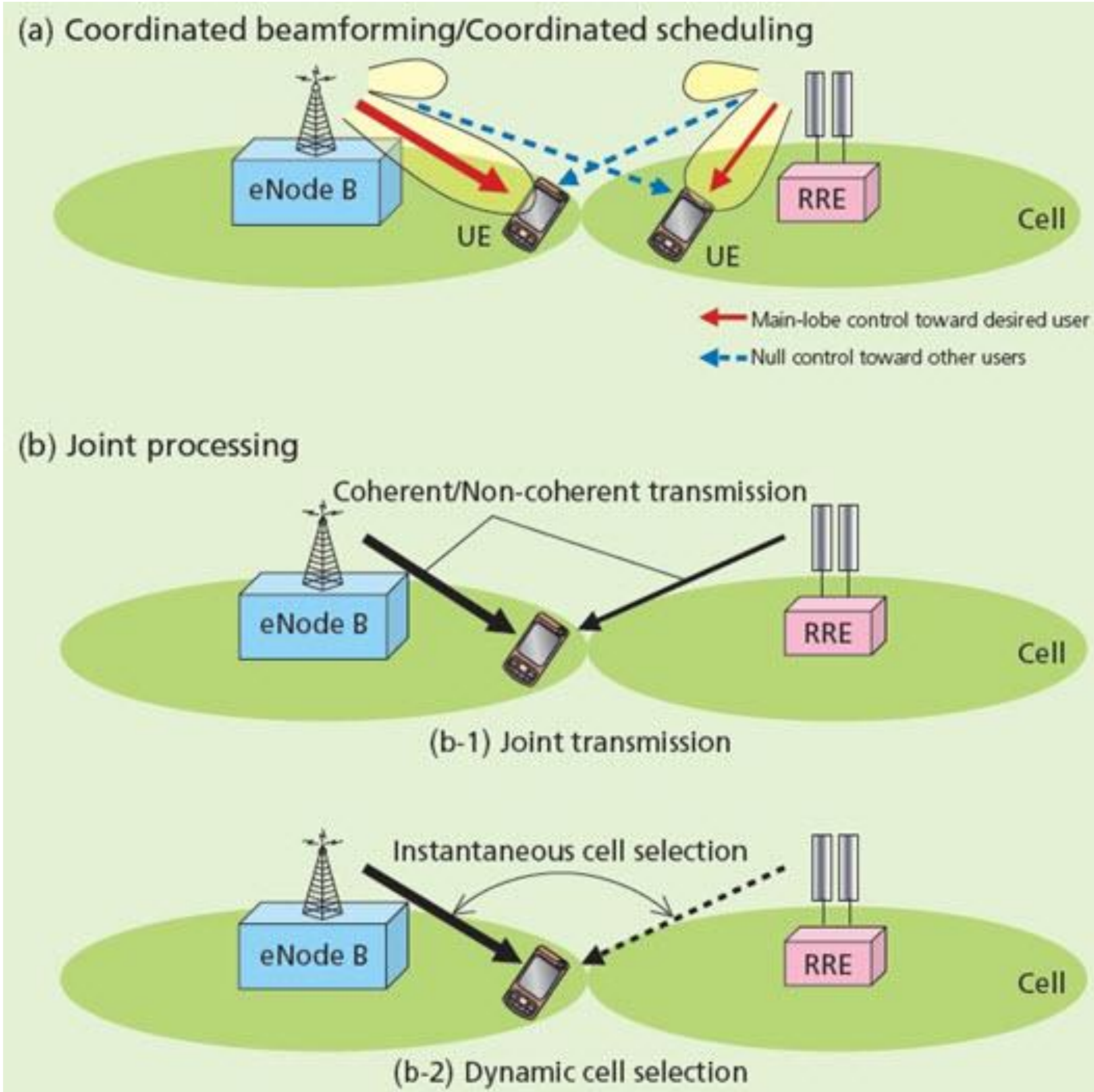


# Co-ordinated Multipoint

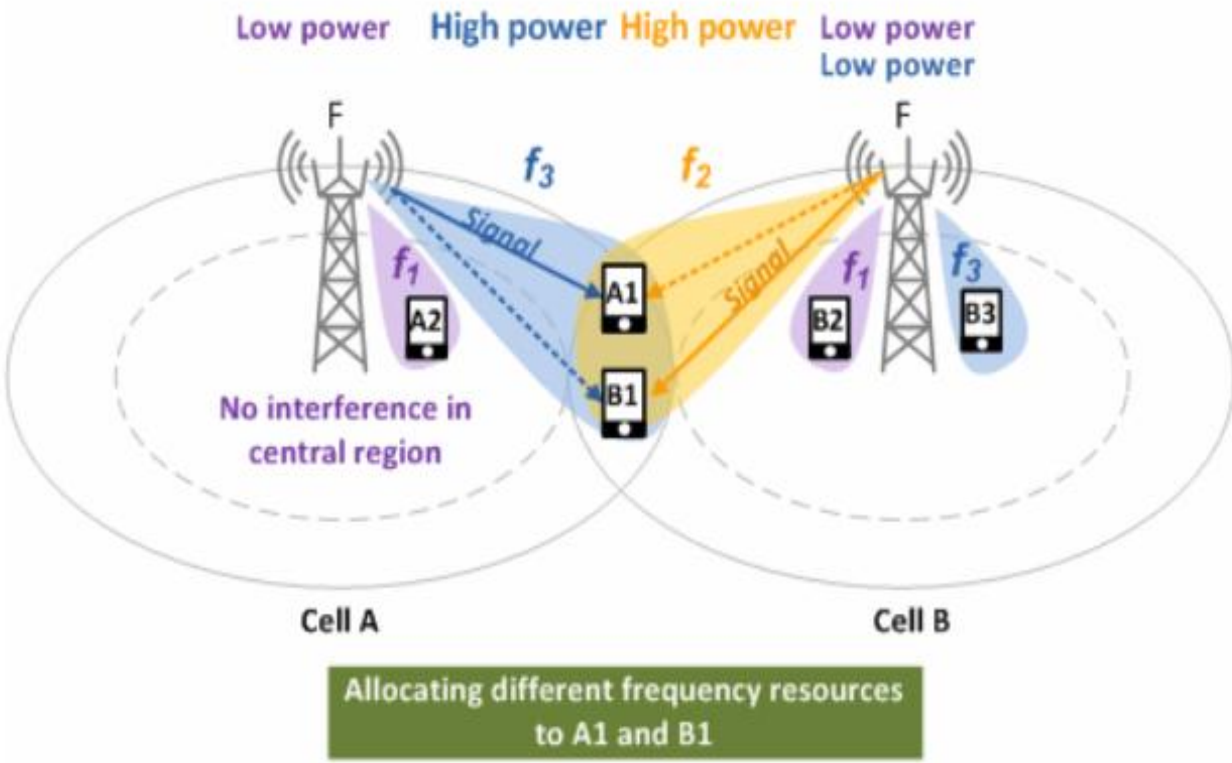
- **CoMP**
  - Stands for Coordinated Multipoint Transmission and Reception
  - Generally known as distributed MIMO or network MIMO



# Co-ordinated Multipoint



# CoMP – Coordinated scheduling




- Cell A and Cell B cooperate with each other to allocate different frequency resources ($f_3$, $f_2$) to A1 and B1 at cell edge, avoiding interference.
- A1 and B1 receive data, only from their respective serving cells, Cell A and Cell B.

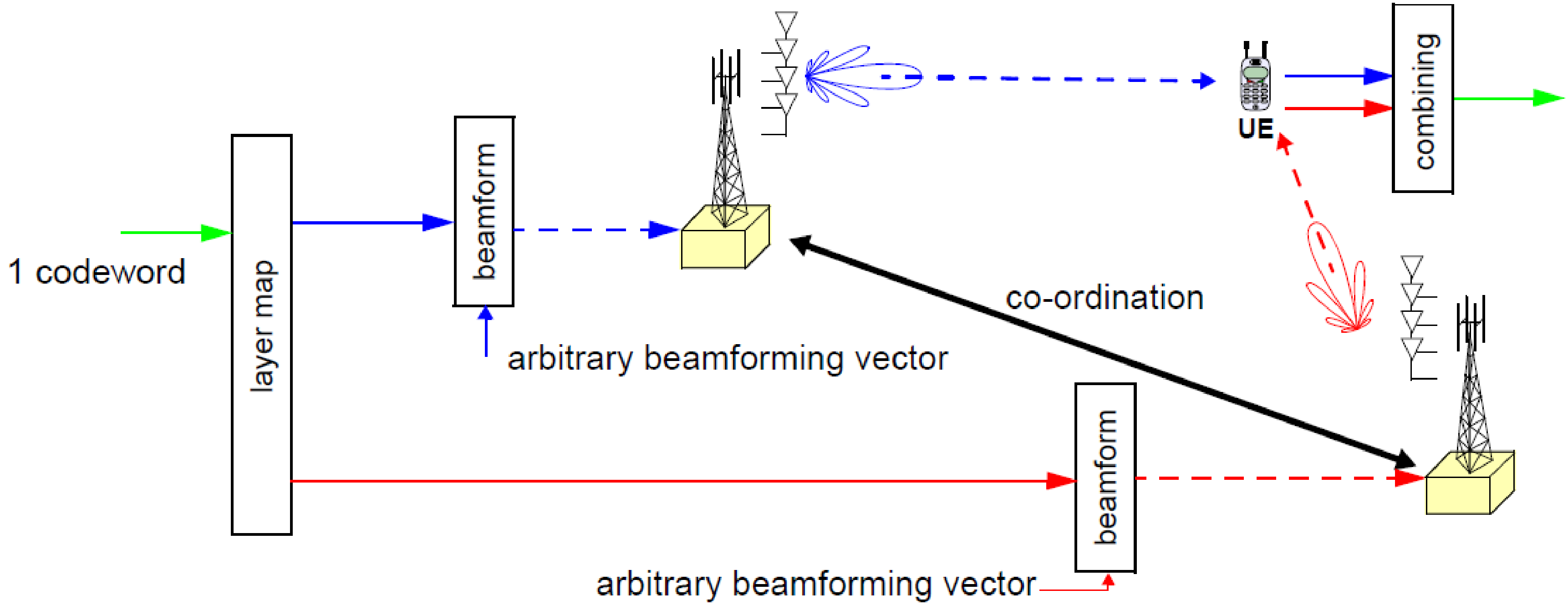
$F = \{f_1, f_2, \ldots, f_N\}$

$f_i$ : RBs or sub-carriers

RB: Resource Block

# CoMP – Joint transmission

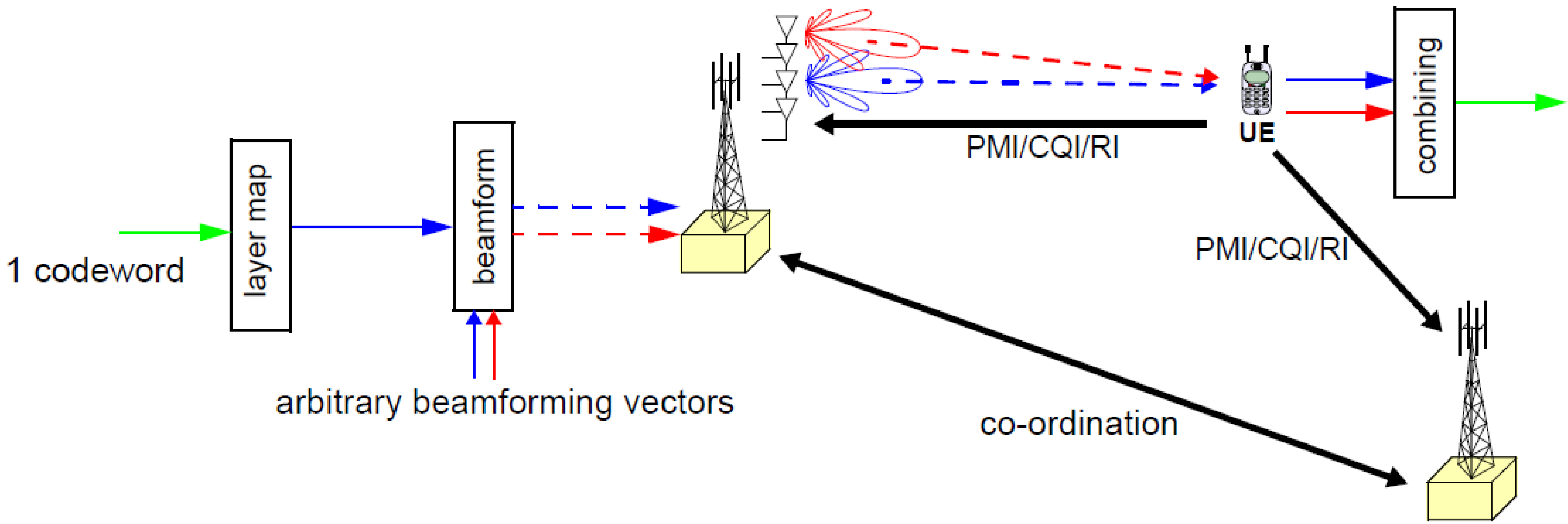
- Multiple eNBs transmit to one UE using UE-specific reference signals:



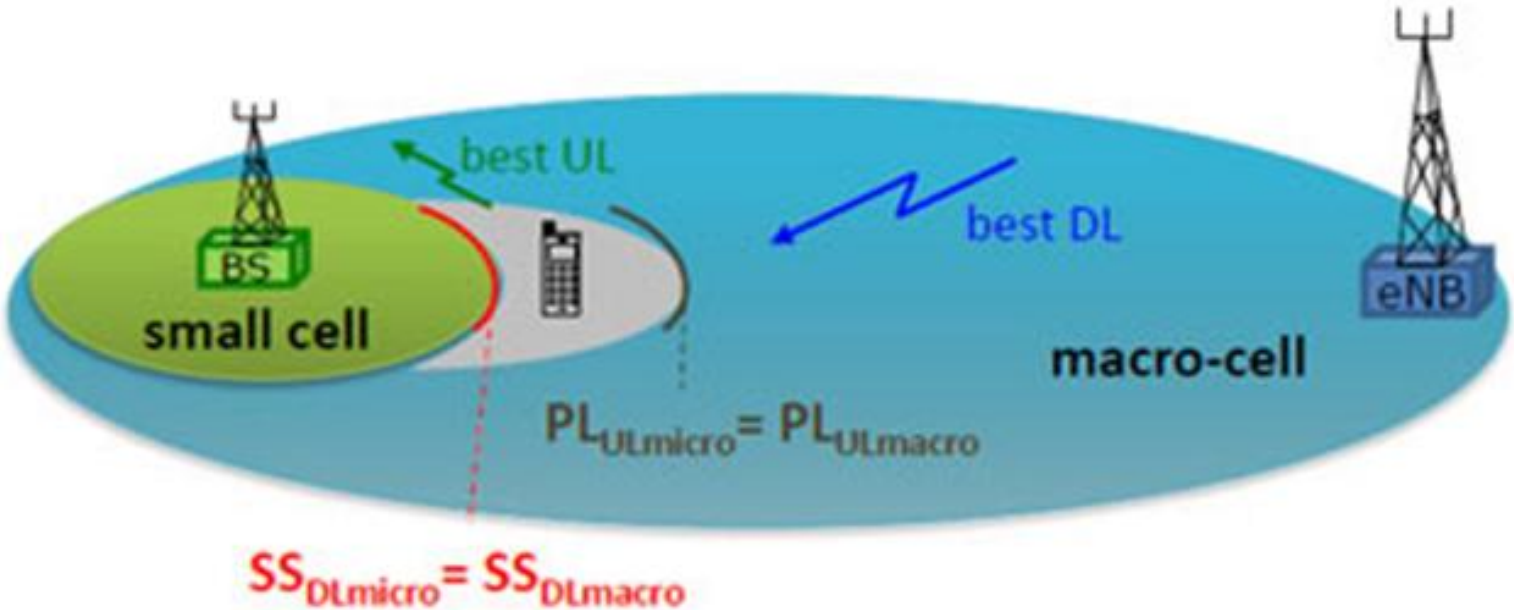

- eNB selection per transmission (UE connected to multiple eNB).

# CoMP – Dynamic cell selection

- Data only available at one eNB;
- eNBs jointly decide scheduling of transmission in time, frequency and space:

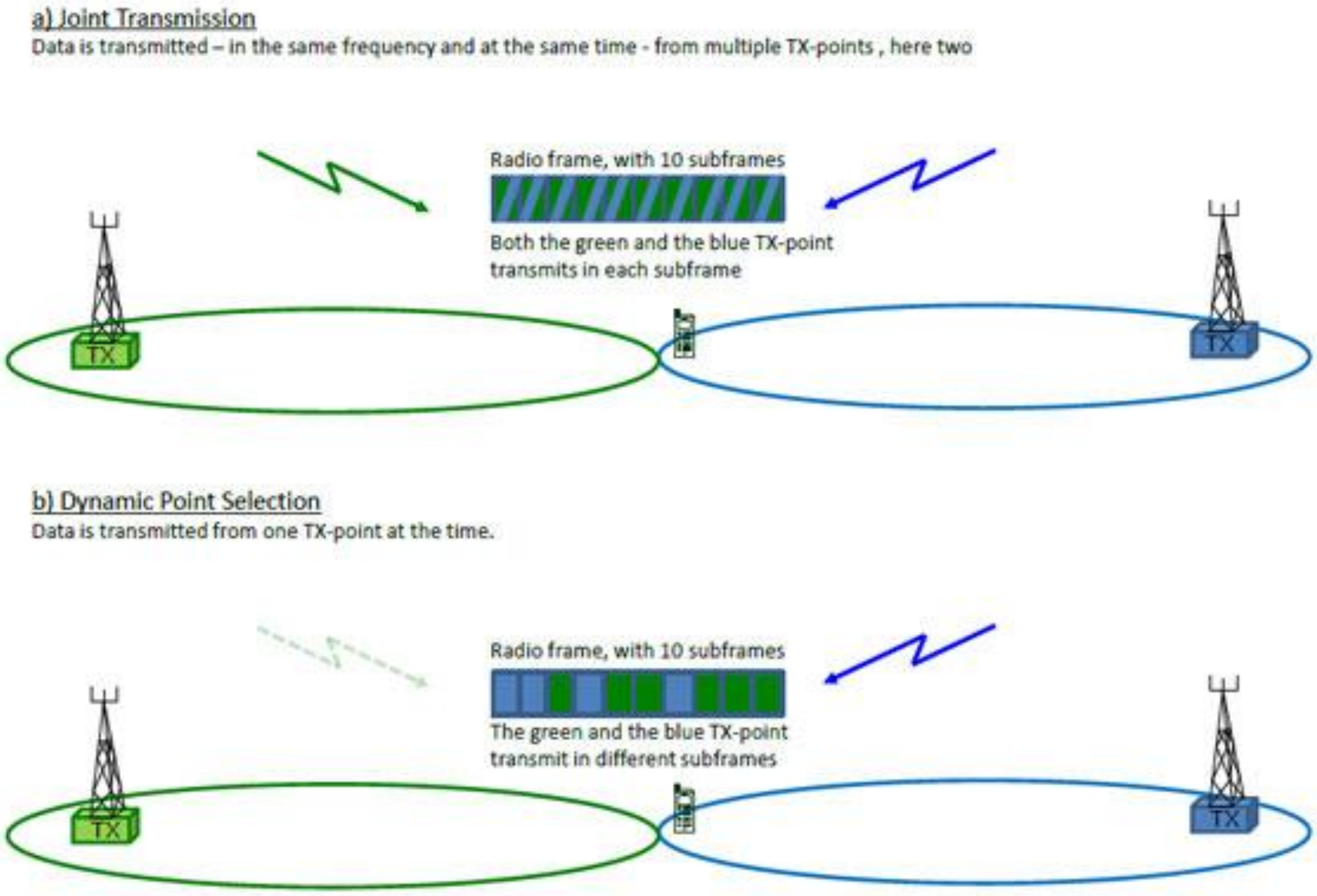


# Example of CoMP




- Using CoMP it is possible for the UE in the grey area to have both the best DL from the macro-eNB and the best UL to the base station of the the small cell

# Example of DL CoMP




a) Joint Transmission: two TX-points transmit to one UE in the same radio resource

b) Dynamic Point Selection: two TX points are ready to transmit, but only one will be scheduled in each subframe

# LTE-Advanced Improvements

- **A schematic view on LTE-Advanced improvements**