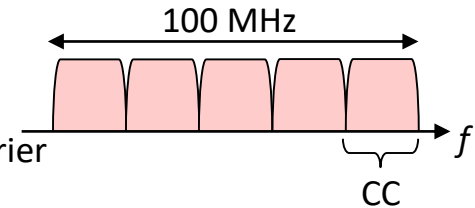


Long Term Evolution (LTE)
Long Term Evolution – Advanced (LTE-A)
Cont.

LTE-A main features

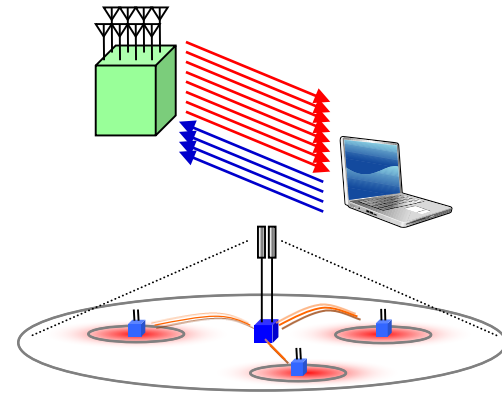
Support of Wider Bandwidth(Carrier Aggregation)

- 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**

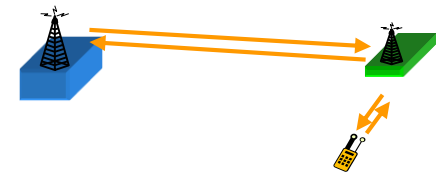


Heterogeneous network and eICIC (enhanced Inter-Cell Interference Coordination)

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

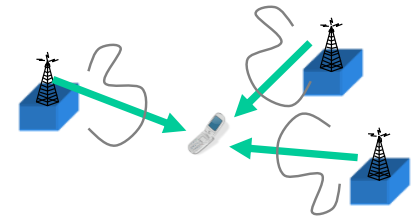
Relay

- 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**



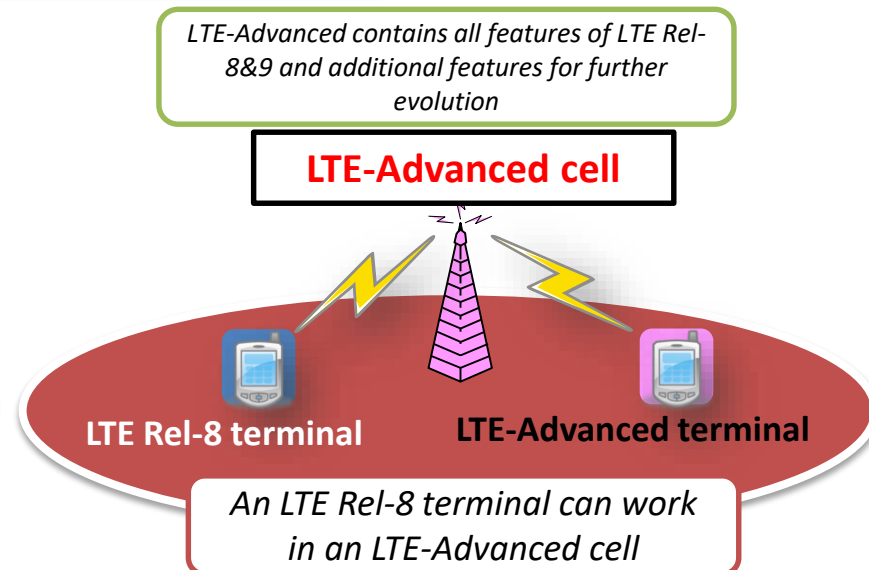
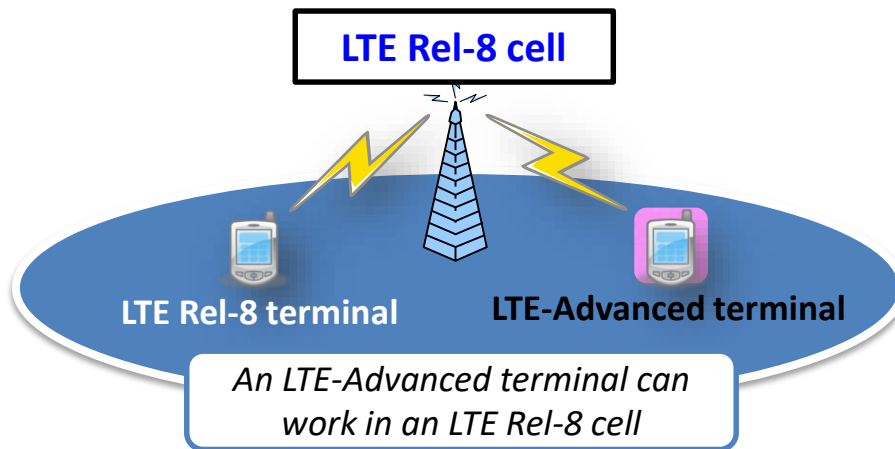
Coordinated Multi-Point transmission and reception (CoMP)

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



Backward compatibility

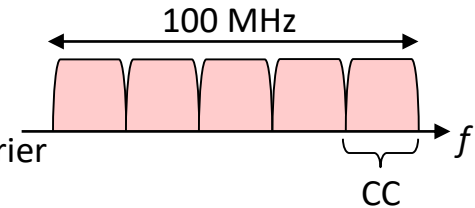
LTE-Advanced backward compatibility with LTE Rel-8



LTE-A main features

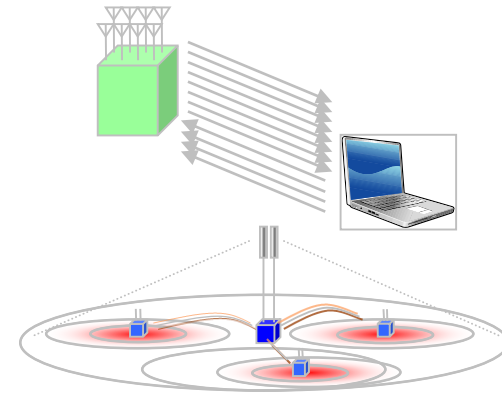
Support of Wider Bandwidth(Carrier Aggregation)

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- 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

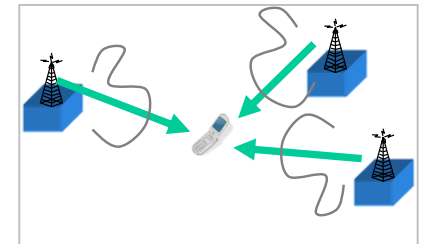
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- ➔ Improvement of coverage and flexibility of service area extension



Coordinated Multi-Point transmission and reception (CoMP)

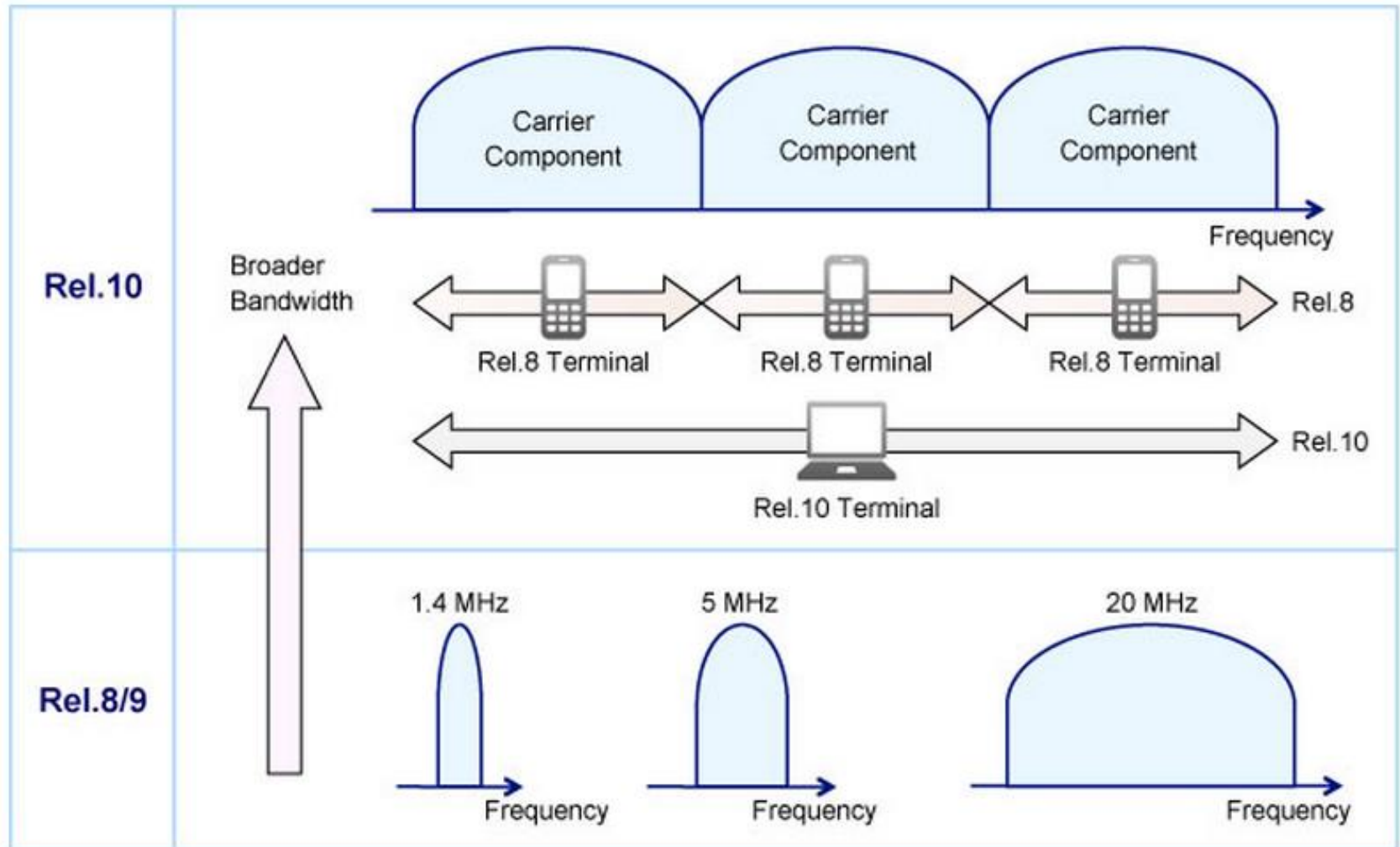
- Support of multi-cell transmission and reception
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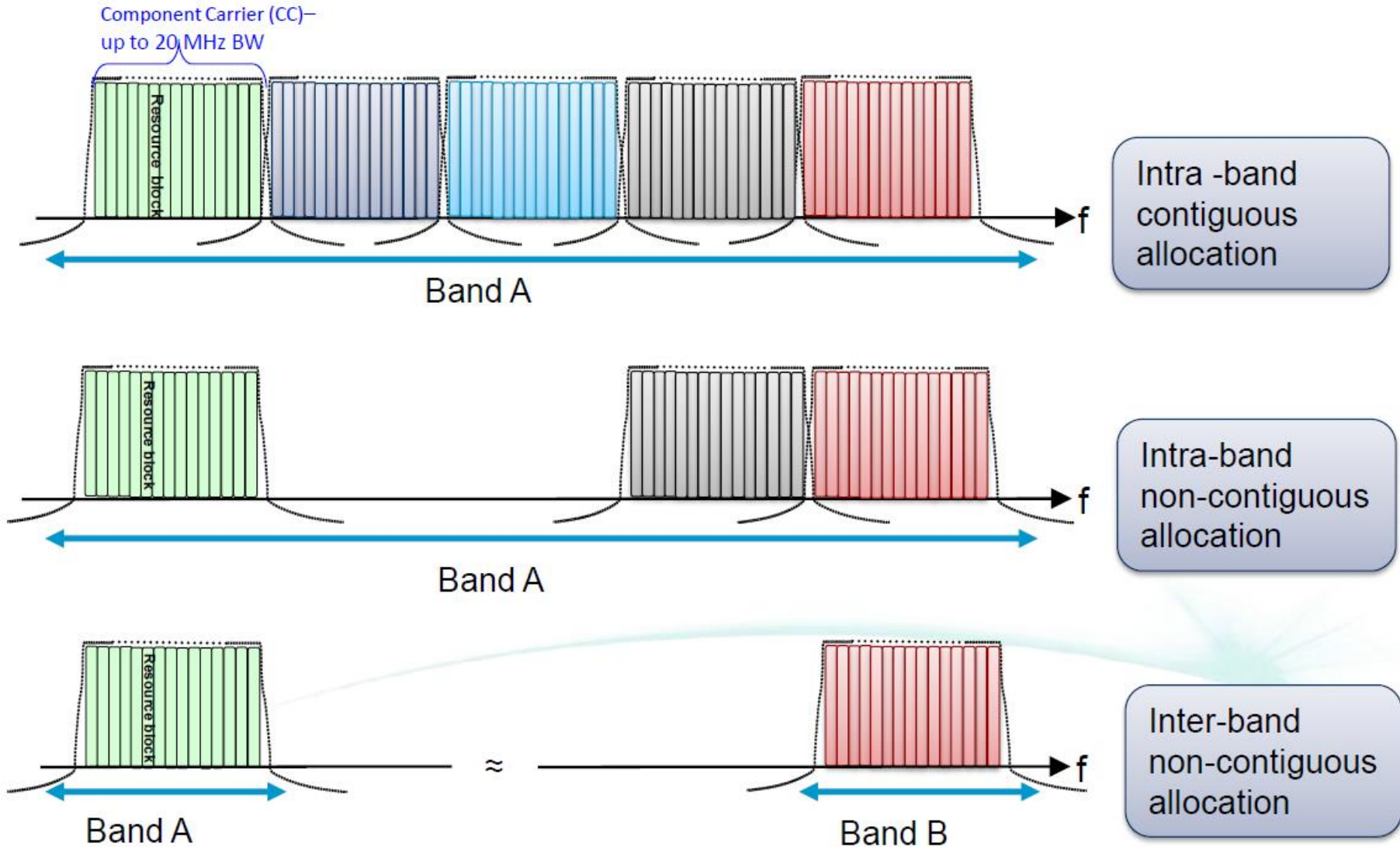
Carrier aggregation

- 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



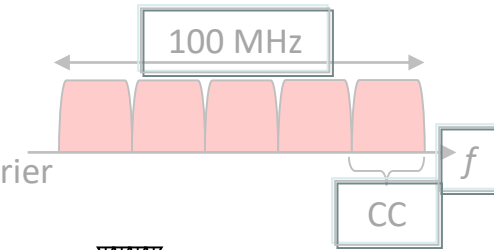
Carrier aggregation modes



LTE-A main features

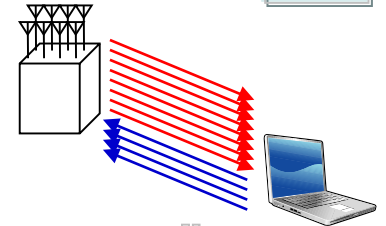
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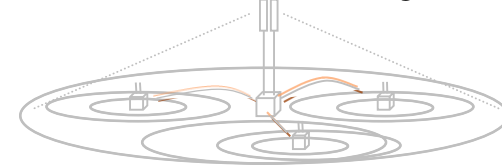
Advanced MIMO techniques

- Extension to up to 8-layer transmission in downlink
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- Enhancements of multi-user MIMO
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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



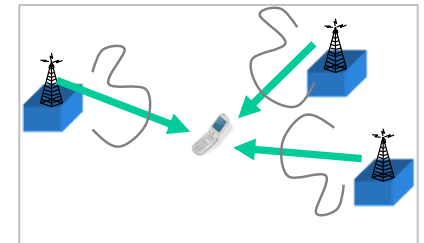
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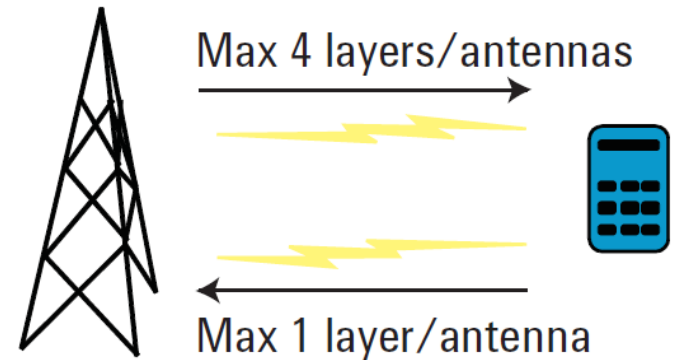
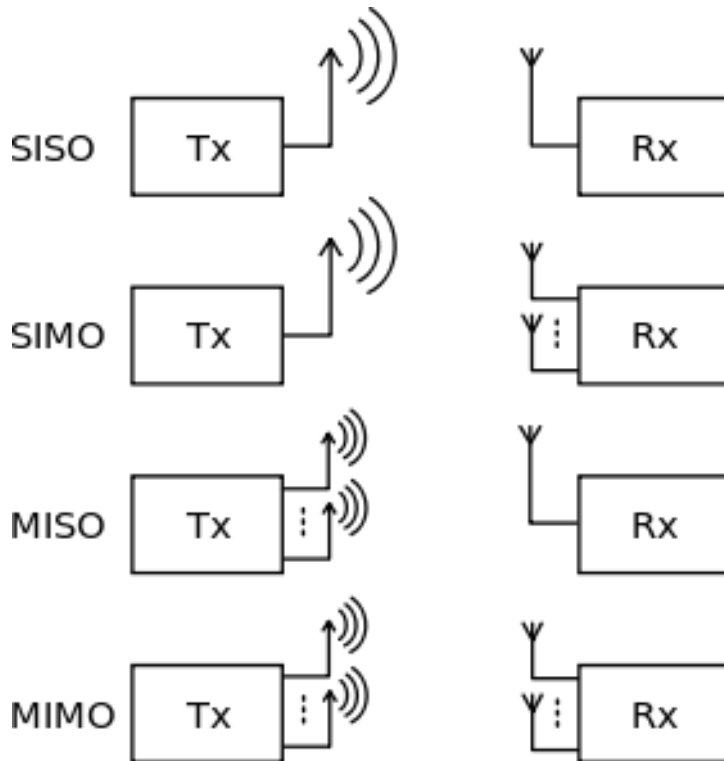


Coordinated Multi-Point transmission and reception (CoMP)

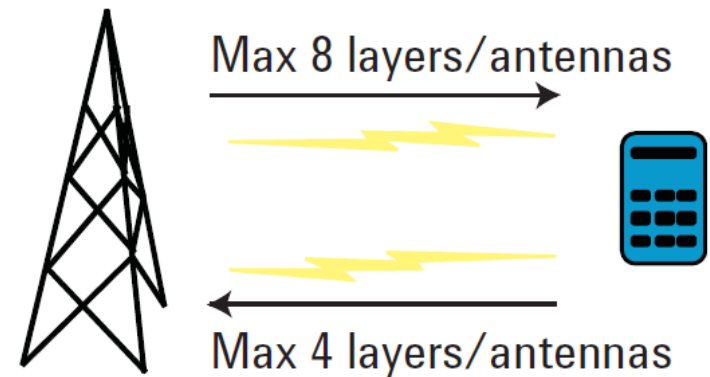
- Support of multi-cell transmission and reception
- ➔ Improvement of cell-edge throughput and coverage



MIMO capabilities



LTE



LTE-A

MIMO brings

```
graph TD; A[MIMO brings] --> B[Diversity gain]; A --> C[Array gain]; A --> D[Spatial multiplexing gain]; B --> E[Decorrelates fading through different transmission paths]; C --> F[Provides a beamforming effect that focuses radiated energy in the direction of the receiver]; D --> G[Enables multiple data streams to be transmitted on the same frequency/time resource];
```

Diversity gain

Decorrelates fading through different transmission paths

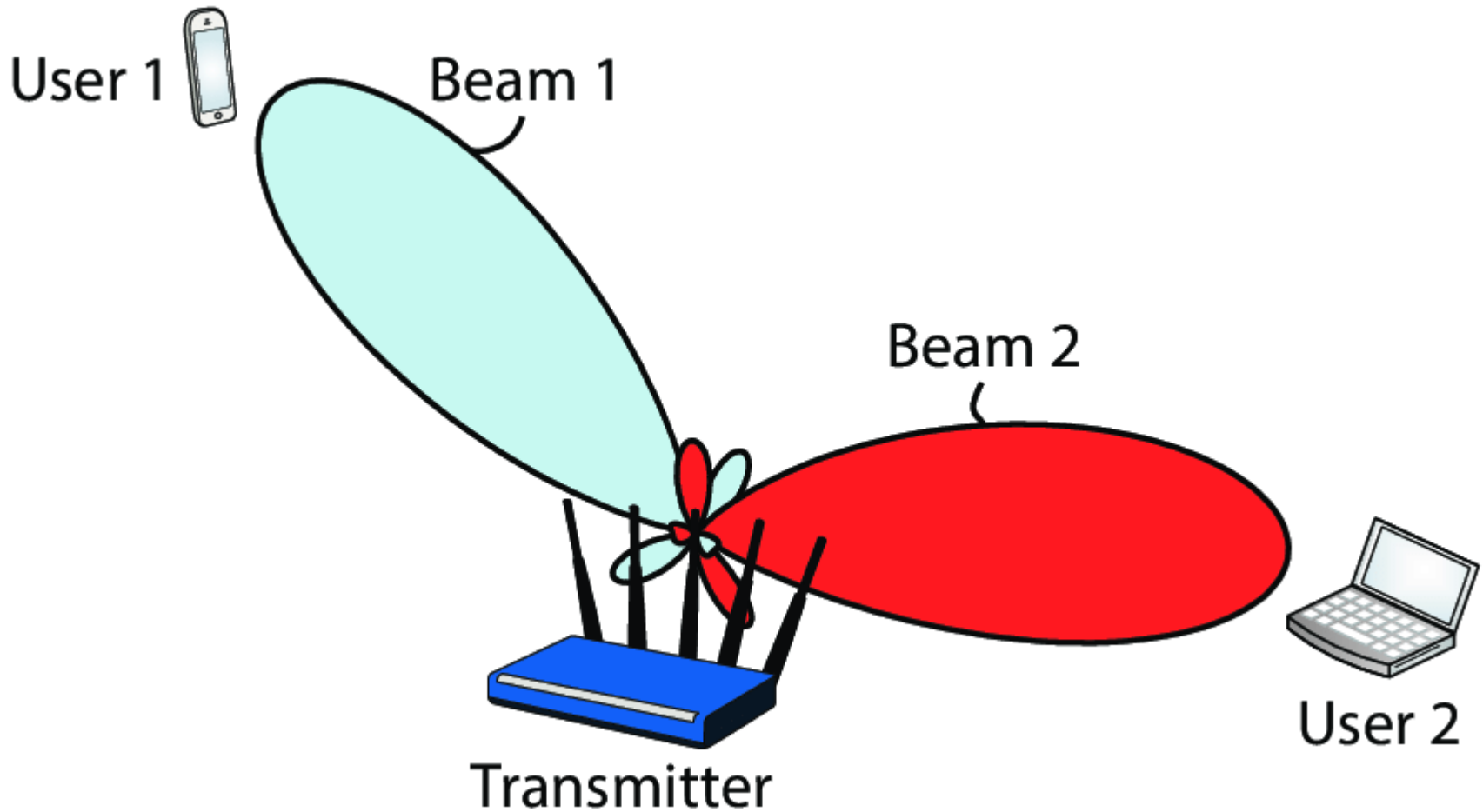
Array gain

Provides a beamforming effect that focuses radiated energy in the direction of the receiver

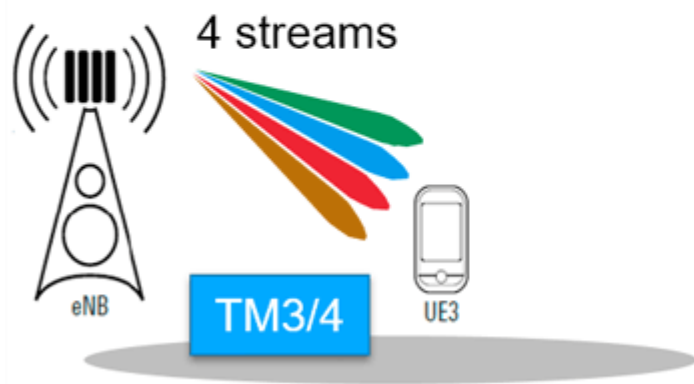
Spatial multiplexing gain

Enables multiple data streams to be transmitted on the same frequency/time resource

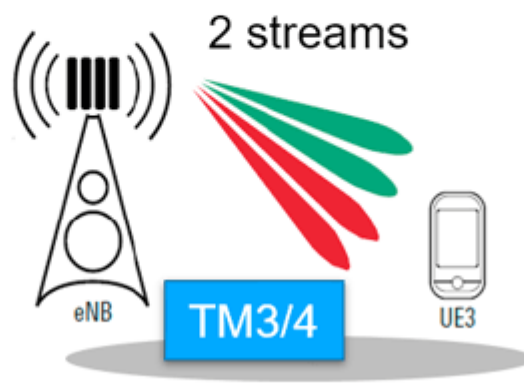
Beamforming



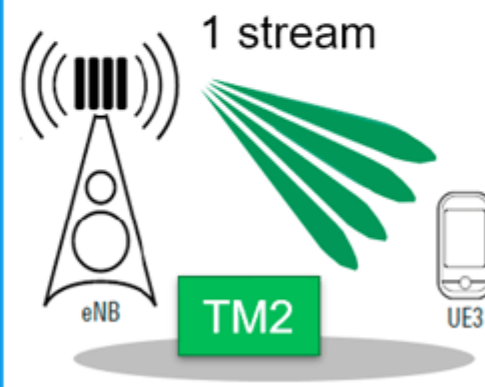
SU MIMO: (cell center)
4 Tx, Rank 4



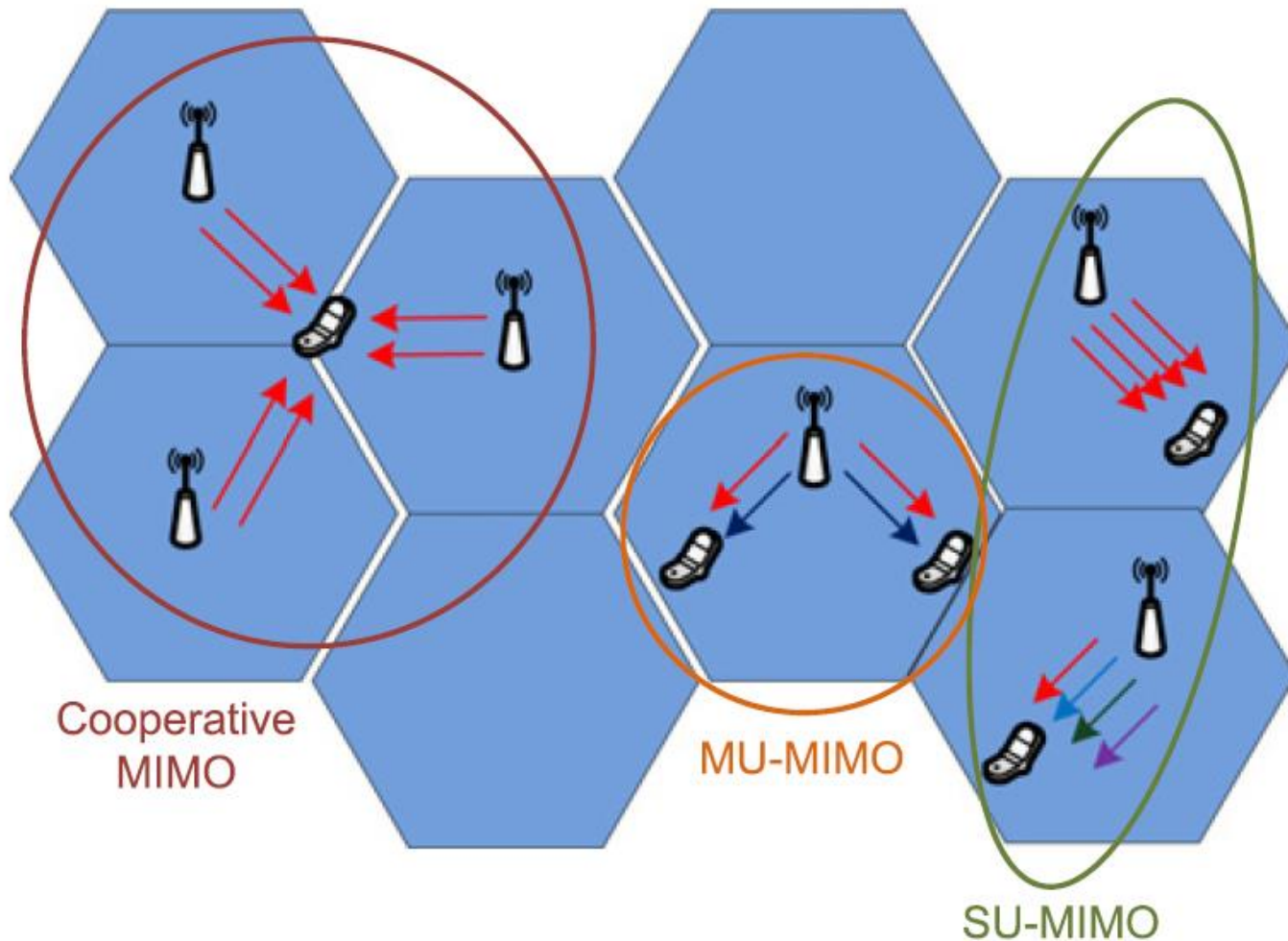
SU MIMO: (mid cell)
4 Tx, Rank 2



SU MIMO: (cell edge)
4 Tx, Rank 1



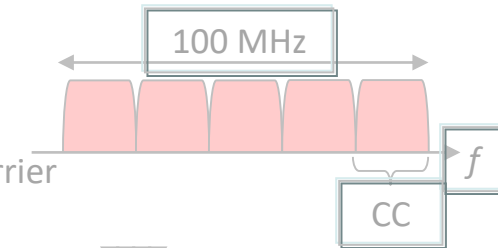
3 different MIMO capabilities



LTE-A main features

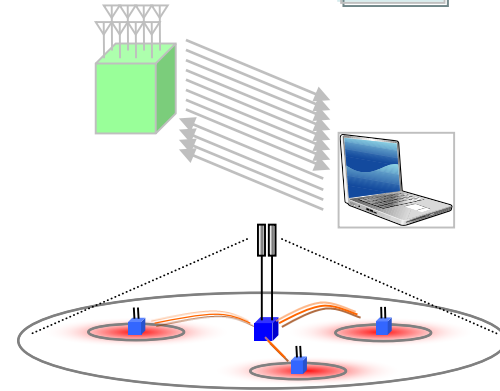
Support of Wider Bandwidth(Carrier Aggregation)

- 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**

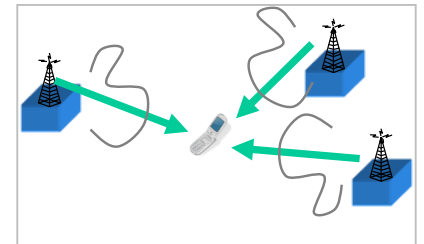
Relay

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- ➔ Improvement of coverage and flexibility of service area extension

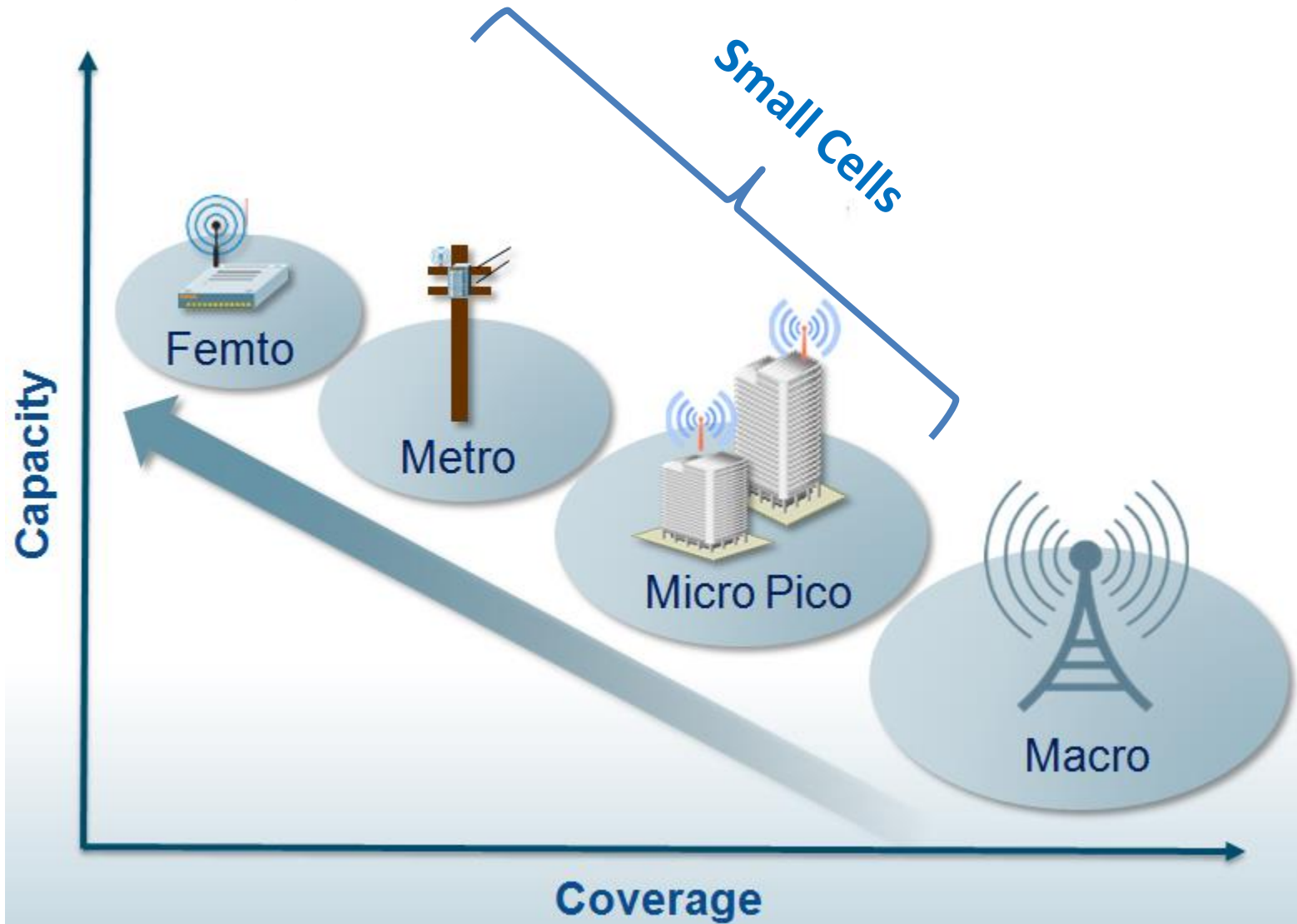


Coordinated Multi-Point transmission and reception (CoMP)

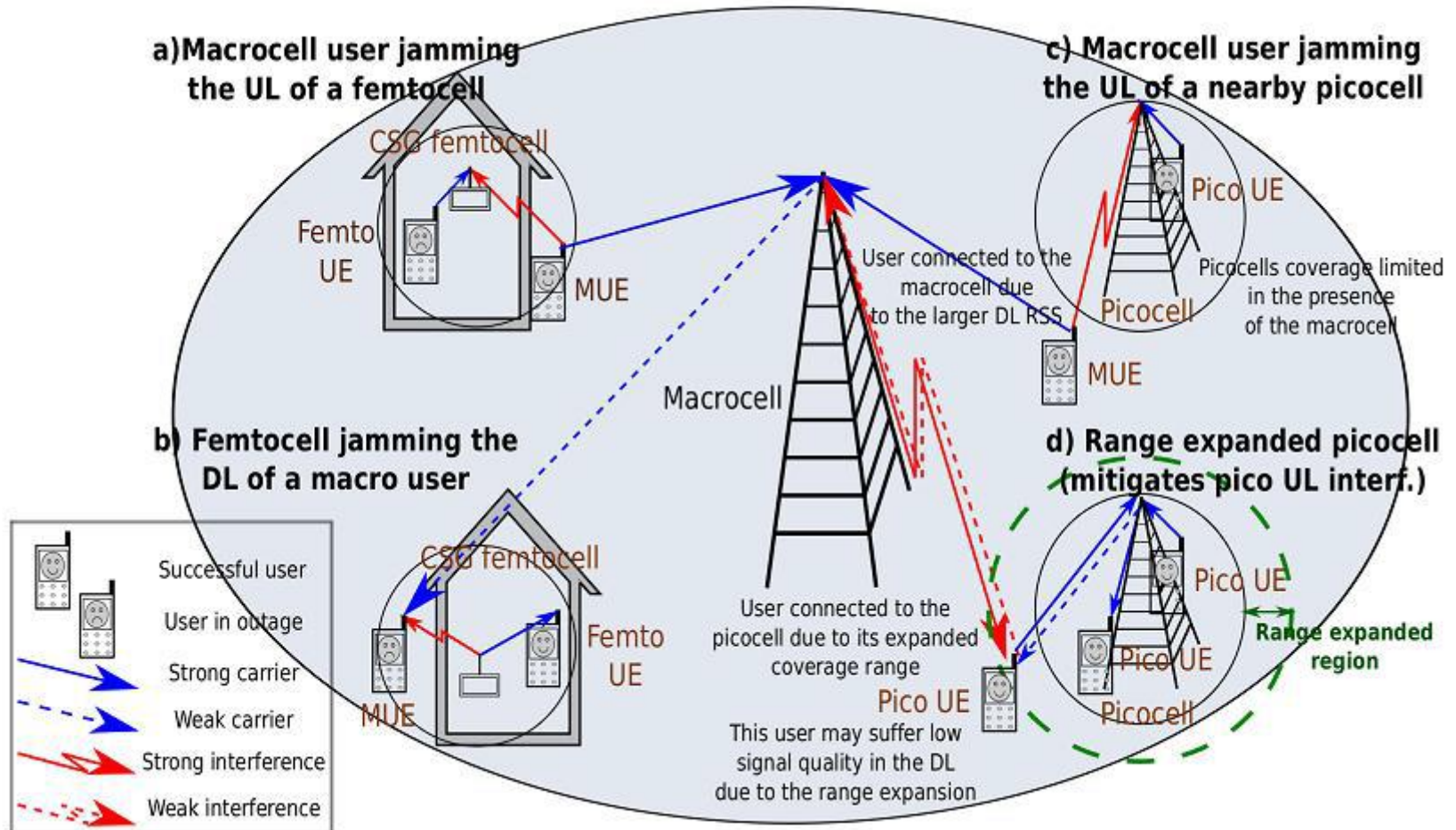
- Support of multi-cell transmission and reception
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Heterogeneous networks in LTE-A



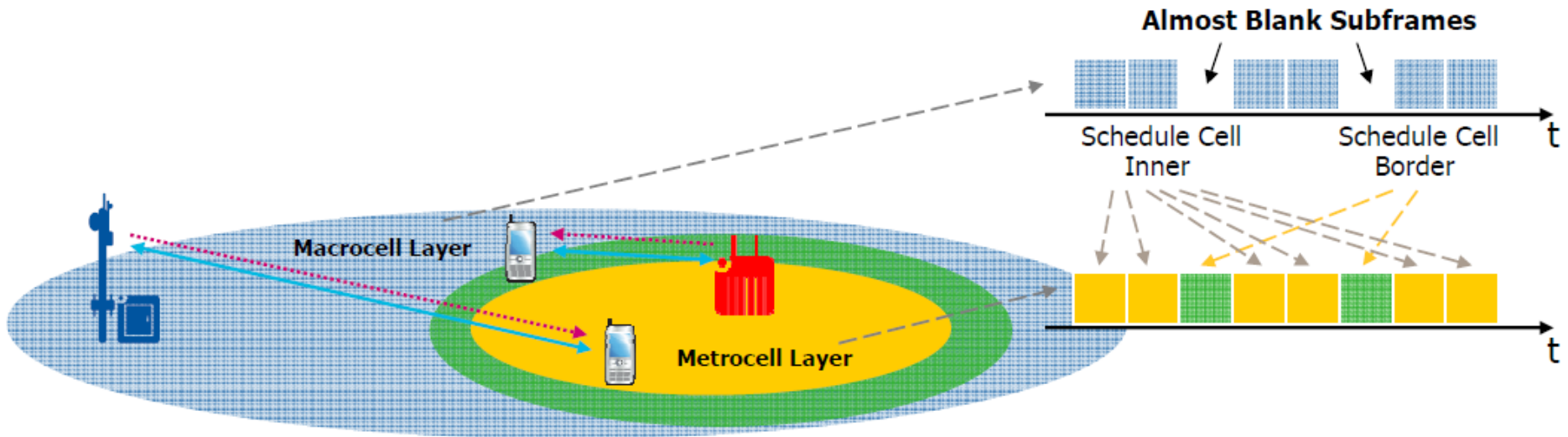
Heterogeneous networks in LTE-A



enhanced Inter-Cell Interference Coordination (eICIC)

- Coordination between eNBs at **different tiers** (e.g. femto-macro) 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

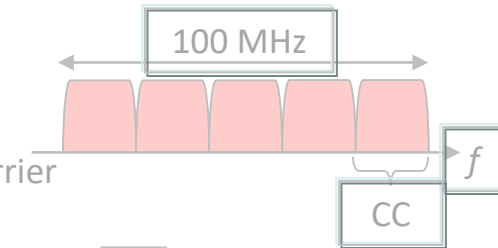


- Increased coverage
- Higher spectral efficiency
- Significant improvement in capacity and cell edge performance

LTE-A main features

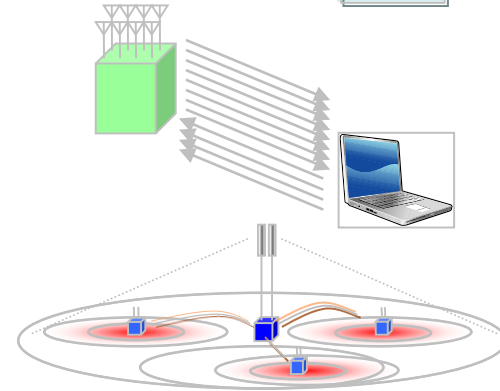
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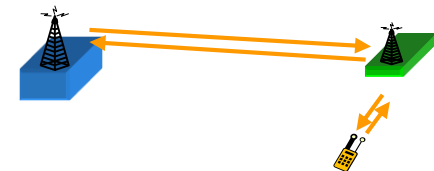


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- Interference coordination for overlaid deployment of cells with different Tx power
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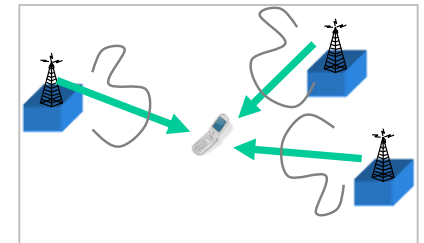
Relay

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- ➔ **Improvement of coverage and flexibility** of service area extension

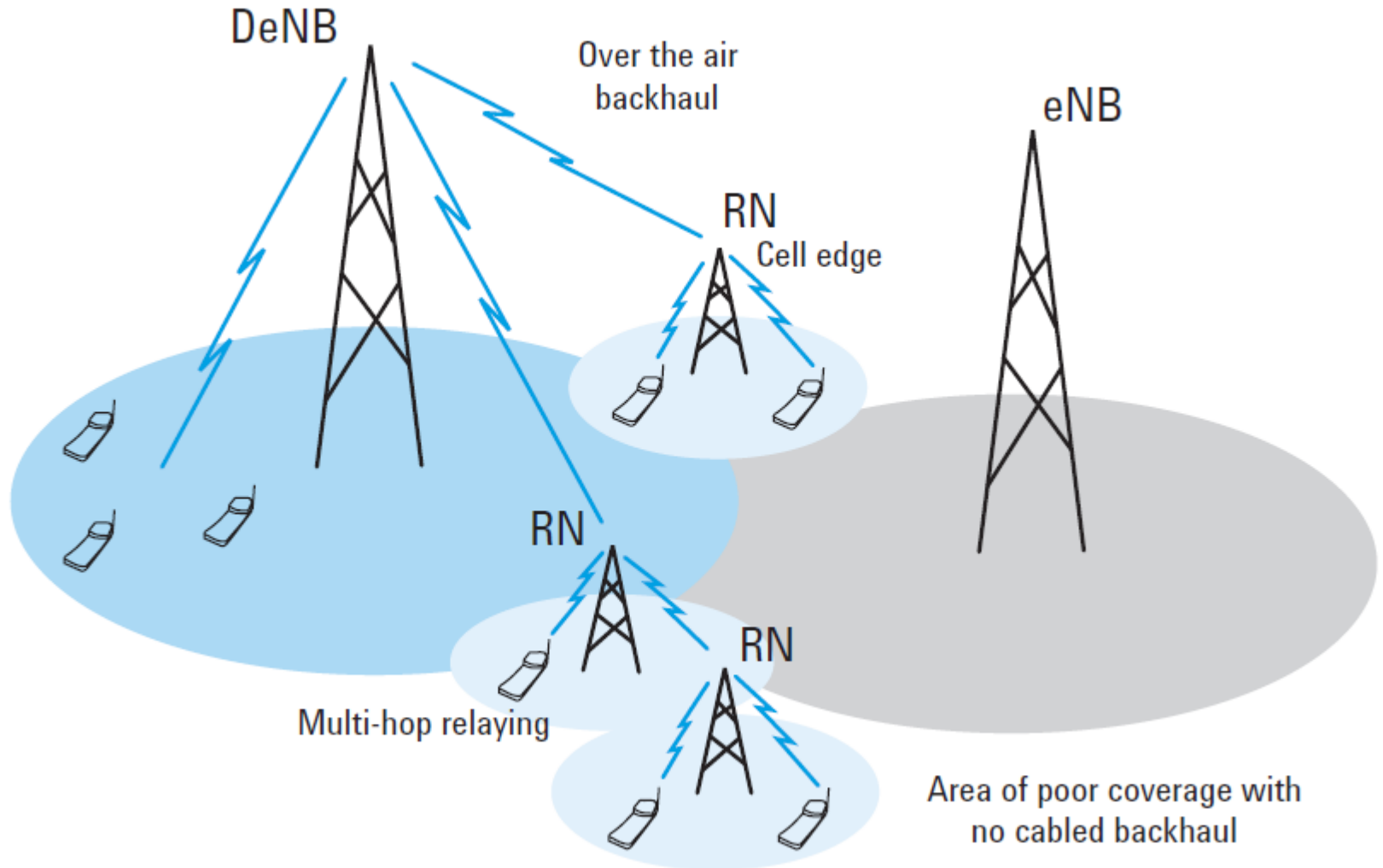


Coordinated Multi-Point transmission and reception (CoMP)

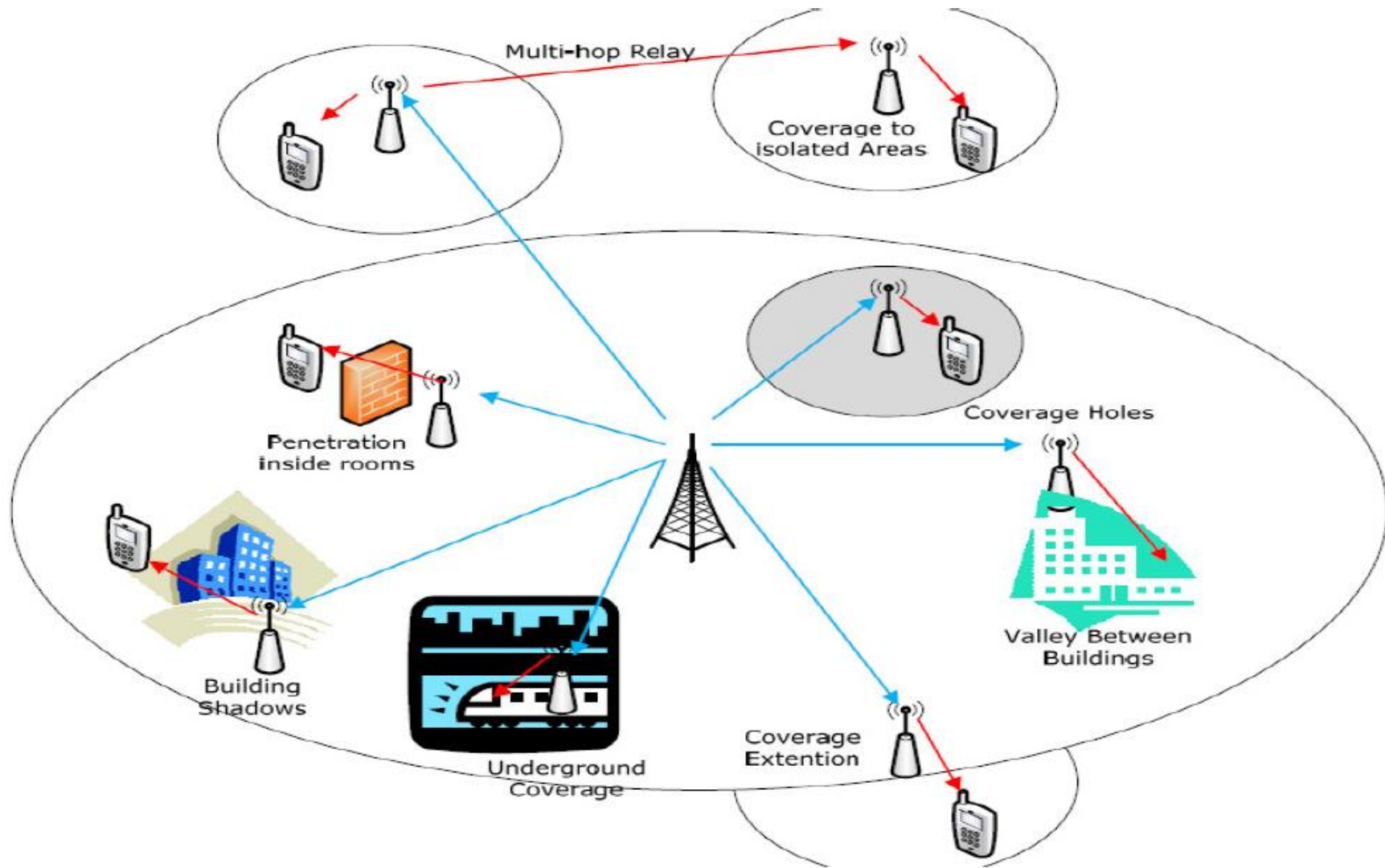
- Support of multi-cell transmission and reception
- ➔ Improvement of cell-edge throughput and coverage



Relaying in LTE-A



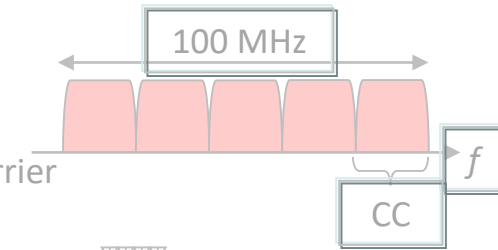
Where to use relaying



LTE-A main features

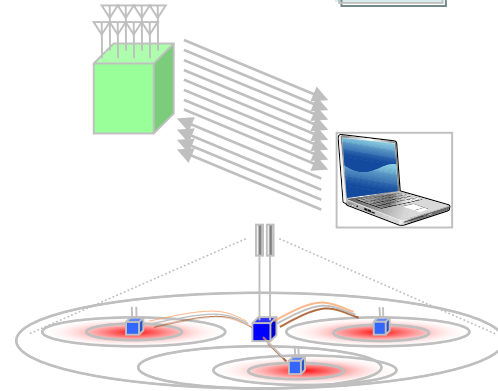
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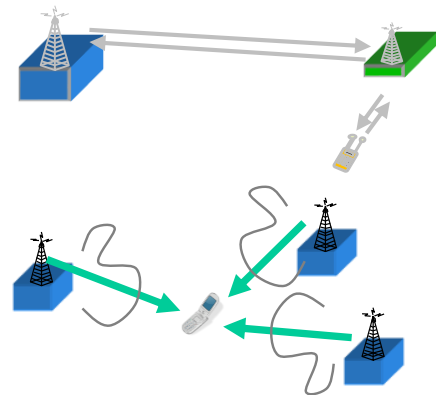


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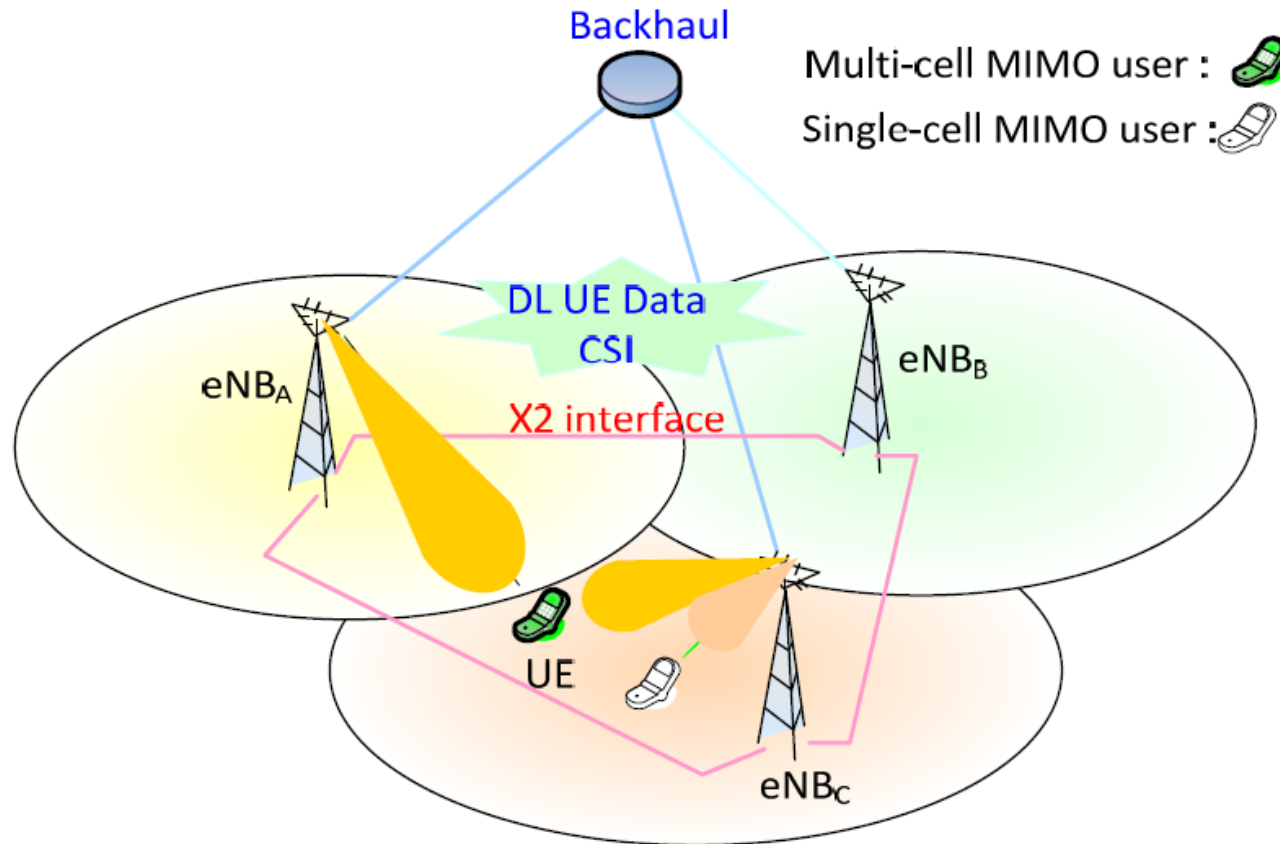
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- Support of **multi-cell transmission and reception**
- ➔ **Improvement of cell-edge throughput and coverage**

Co-ordinated Multipoint

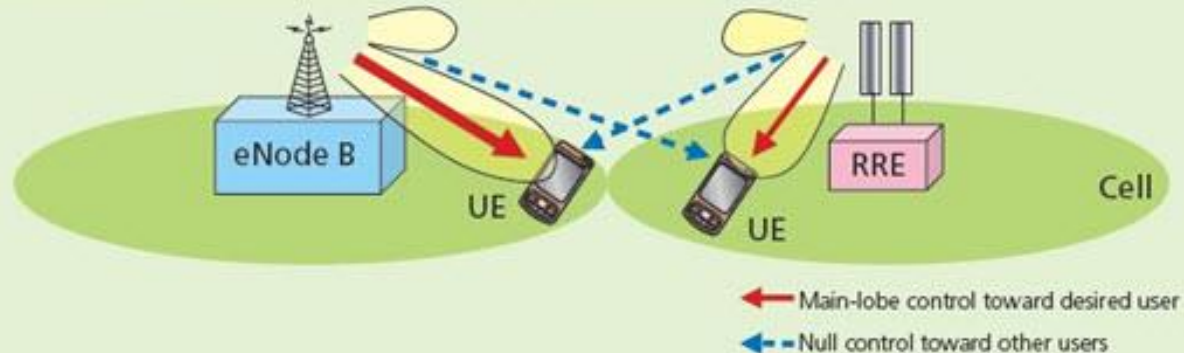
■ CoMP

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



Co-ordinated Multipoint

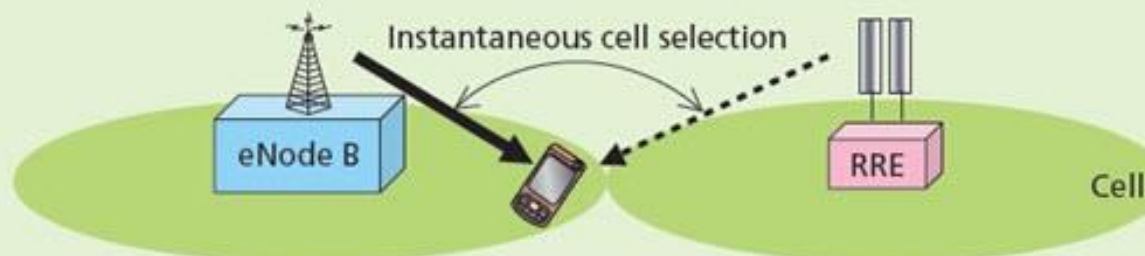
(a) Coordinated beamforming/Coordinated scheduling



(b) Joint processing

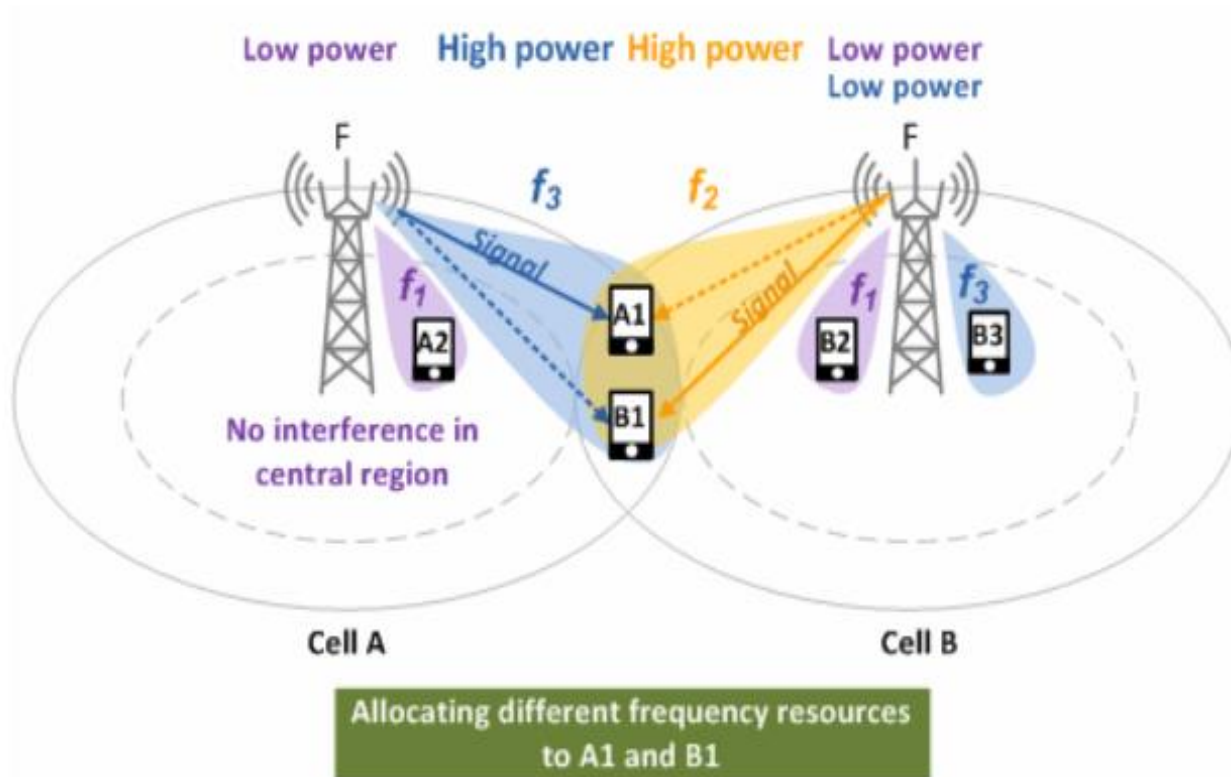


(b-1) Joint transmission



(b-2) Dynamic cell selection

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.

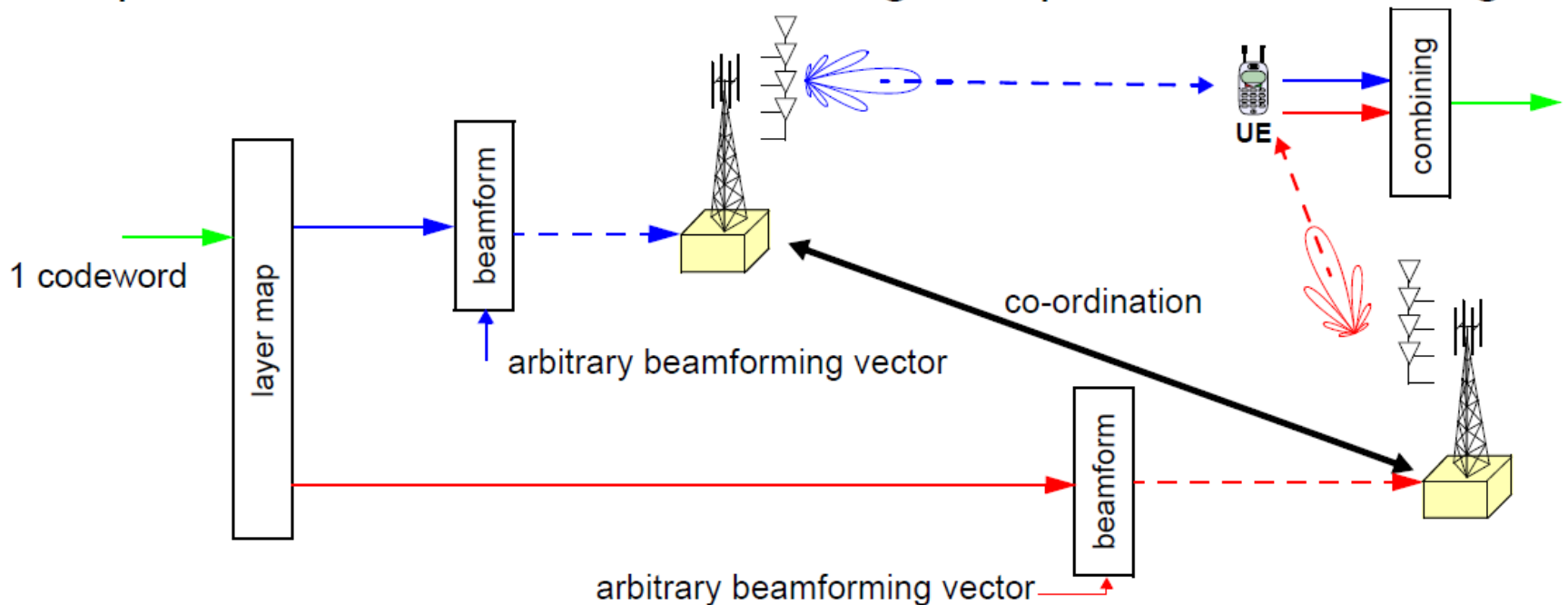
$$F = \{f_1, f_2, \dots, f_N\}$$

f_i : RBs or sub-carriers

RB: Resource Block

CoMP – Joint transmission

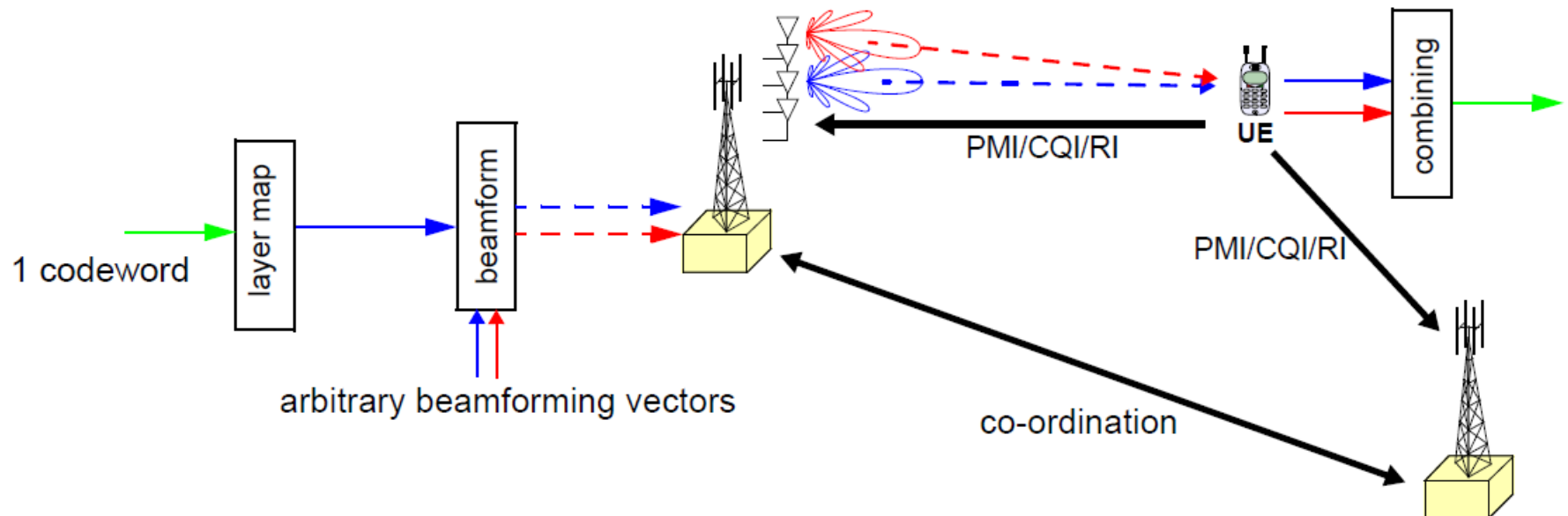
- Multiple eNBs transmit to one UE using UE-specific reference signals:



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

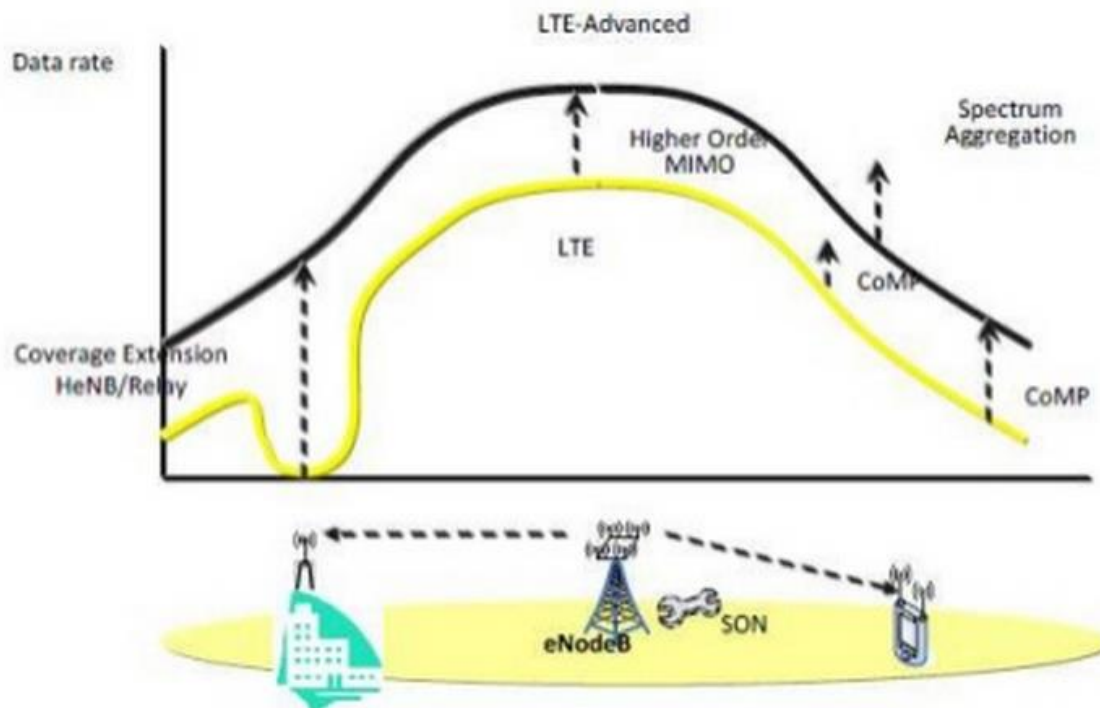
CoMP – Dynamic cell selection

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



LTE-Advanced Improvements

- A schematic view on LTE-Advanced improvements



UMTS Long Term Evolution

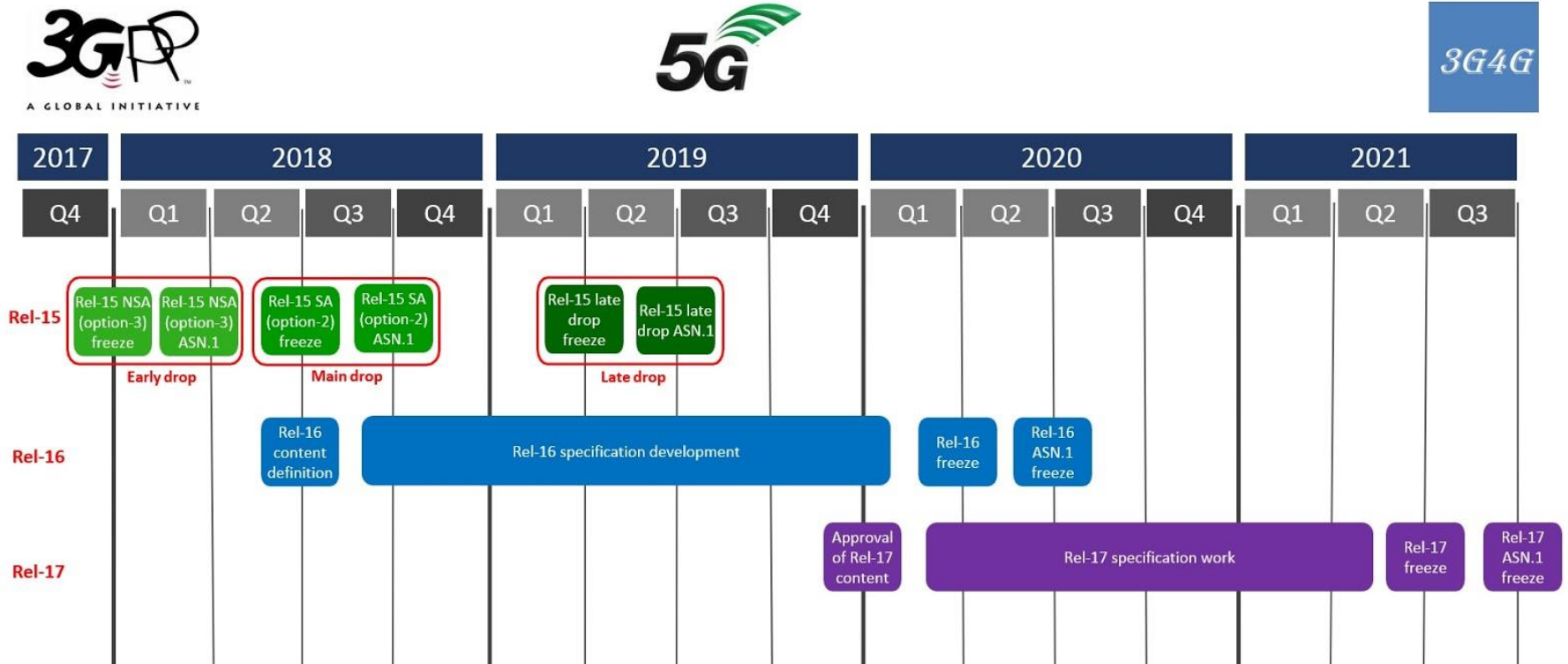
1999



2016

Release	Stage 3: Core specs frozen	Main feature of Release
Rel-99	March 2000	UMTS 3.84 Mcps (W-CDMA FDD & TDD)
Rel-4	March 2001	1.28 Mcps TDD (aka TD-SCDMA)
Rel-5	June 2002	HSDPA
Rel-6	March 2005	HSUPA (E-DCH)
Rel-7	Dec 2007	HSPA+ (64QAM DL, MIMO, 16QAM UL). LTE & SAE Feasibility Study, Edge Evolution
Rel-8	March 2009	LTE Work item – OFDMA air interface SAE Work item – New IP core network UMTS Femtocells, Dual Carrier HSDPA
Rel-9	March 2010	Multi-standard Radio (MSR), Dual Carrier HSUPA, Dual Band HSDPA, SON, LTE Femtocells (HeNB) LTE-Advanced feasibility study, MBSFN
Rel-10	Sept. 2011	LTE-Advanced (4G) work item, CoMP Study Four carrier HSDPA
Rel-11	March 2013	CoMP, eDL MIMO, eCA, MIMO OTA, HSUPA TxD & 64QAM MIMO, HSDPA 8C & 4x4 MIMO, MB MSR
Rel-12	June 14 -> March 15	3DL CA, D2D, MTC, NAICS, Dual connectivity, small cells...
Rel-13	March 2016	LAA (LTE-U), 4 CA, >5 CA study, MIMO OTA, FD MIMO

5G specifications



Designed by 3G4G, based on roadmap from 3GPP, July 2019