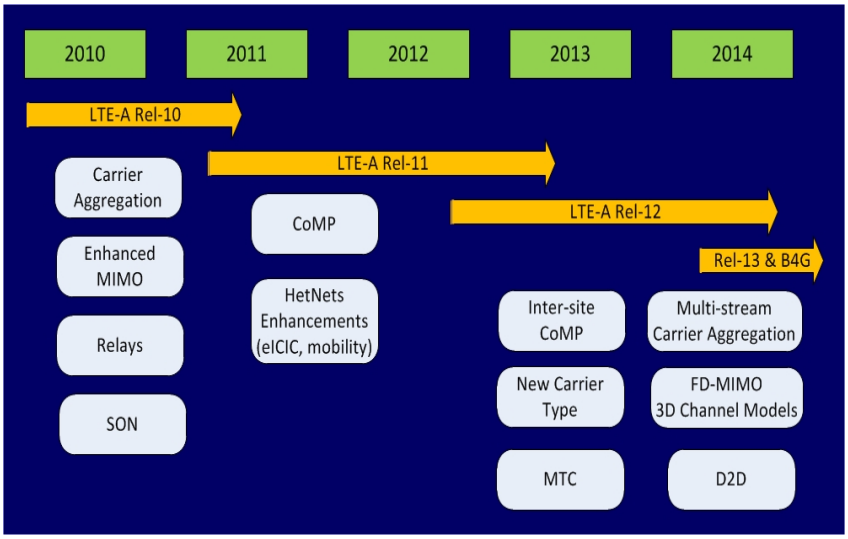
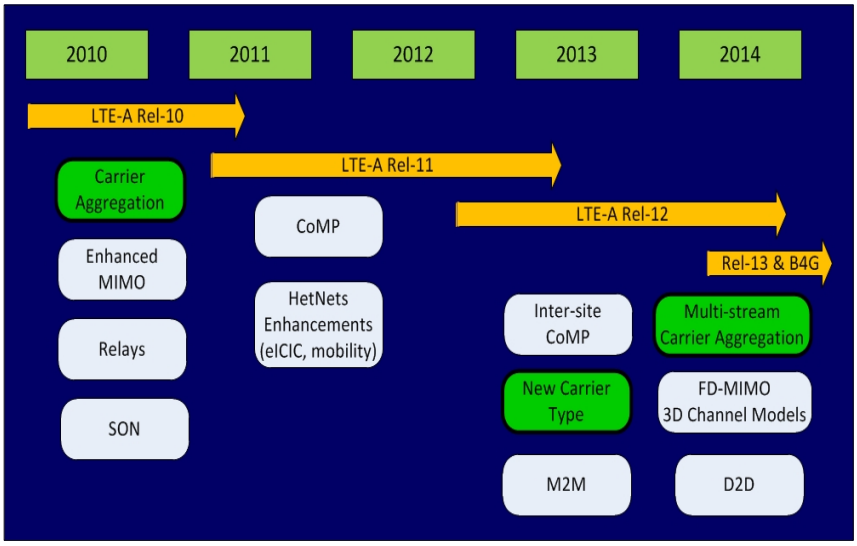
LTE vs LTEA

		LTE	LTE-Advanced
Data Rate	DL	300 Mbps	1 Gbps
	UL	75 Mbps	500 Mbps
Spectrum Efficiency (bps/Hz)	DL	15	30
	UL	3.75	15
Bandwidth (MHz)		1.4 to 20	1.4 to 100
Antenna Configuration		Up to 4x4	Up to 8x8
Coverage		Full performance up to 5 km	Same as LTE. Optimized for local area environments
Mobility		High performance up to 120 km/hr	Same as LTE

Key Technologies in LTEA



Key Technologies in LTEA



Carrier aggregation

- Purpose: increase the amount of utilized bandwidth?
- LTE-A uses BWs of up to 100 MHz in several freq. bands:
  - 450-470 MHz; 698-960 MHz, 1710-2025 MHz, 2110-2200 MHz;
  - 2300-2400 MHz; 2500-2690 MHz and 3400-3600 MHz
- Problem: UE that works in one country or region may not in another.
- One solution: design devices which can work on multiple freq. bands → costly

Carrier aggregation

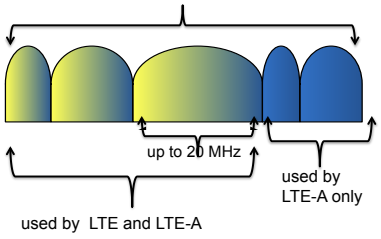
CA consists of grouping several COMPONENT CARRIERS (CC) to achieve wider BWs.

LTE-A device can aggregate up to 5 CCs, each up to 20 MHz.

LTE-A supports 3 CA schemes:

BASIC ONE: Single Spectrum Band

Easy to implement but not practical as operators do not have contigious spectrums.

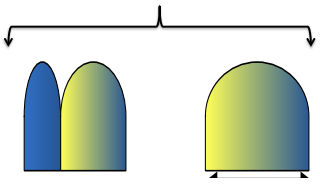


Aggregation of 5 CCs of diff. BWs

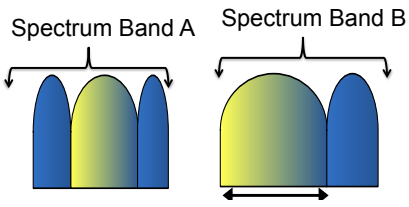
Carrier aggregation

Intraband Non-Contiguous Carrier Aggregation

Single Spectrum Band



Interband Non-Contiguous Carrier Aggregation



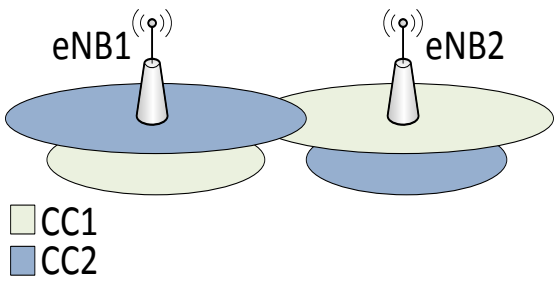
Useful for operators since they can effectively reuse their spectrum fragments and obtain more capacity.

Carrier aggregation: current status

- Around 40 operating bands for LTE and LTE-A
  - Supporting CA across all bands is complex & costly.
- Possible Combinations:
  - For Contiguous CA → 5 bands studied in Rel-11; 3 bands under study.
  - For Non-contiguous CA (INTRABAND)
    → 4 bands under study (Rel-12).
  - For Non-contiguous CA (INTERBAND)
    → 20 bands studied in Rel-11; 11 bands under study in Rel-12.

Carrier aggregation: Benefits

- Higher Throughput
  - Wider BWs lead to very high bit rates (up to 1Gbps)
- Inter-Cell Interference and Mobility Improvements:
  - Continuous and non-interfering coverage is provided by power adjustments for each carrier

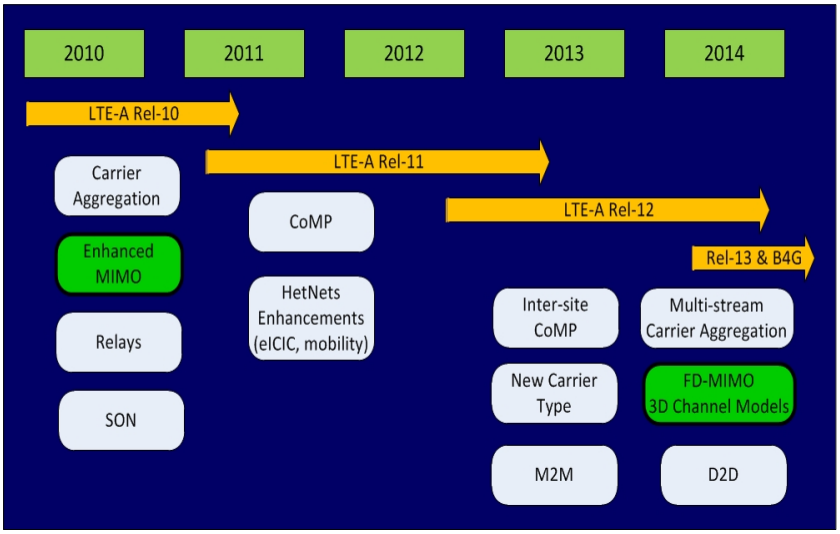


Carrier aggregation: Benefits

- Load Balancing
  - Load is distributed across multiple carriers to reduce NW congestion
- Energy Savings
  - Current specification allows dynamically turning on and off the carriers

    → Energy consumption can be adjusted according to NW load

Key Technologies in LTEA



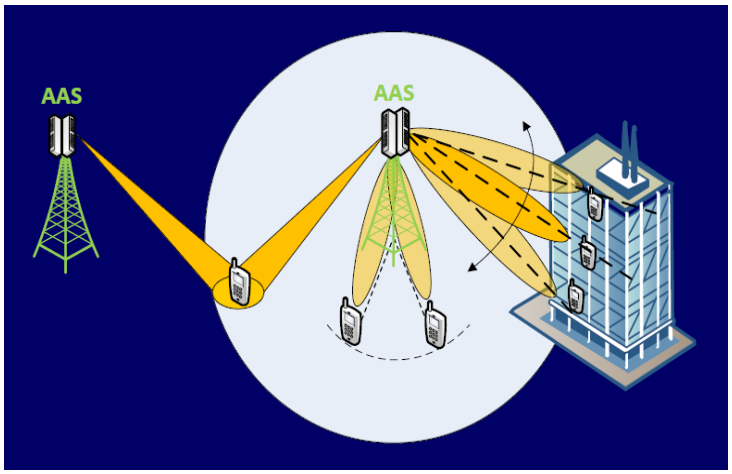
Enhanced MIMO for LTEA

- Novel Features:
  - Antenna Configuration
    - 8x8 in DL; 4x4 in UL
  - Dynamic SU/MU-MIMO Switching
    - Fast timescale adaptation transparent to higher layers
  - Advanced beamforming and scheduling techniques
    - Proprietary and implementation-specific
  - Implications on reference signals, feedback design, precoding codebooks, MIMO detector, etc.
    - Very active research is being carried out

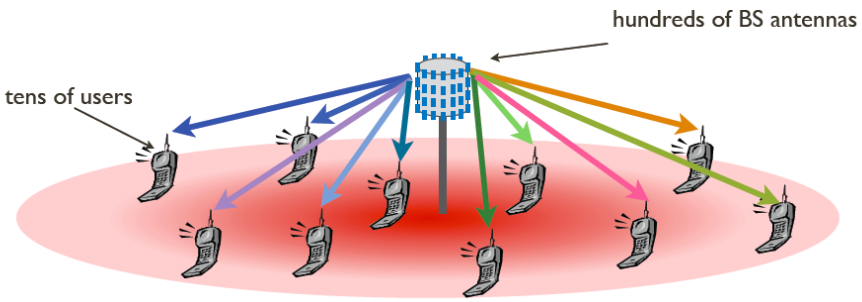
Full Dimension (FD) MIMO

- A large two-dimensional array of transmit antenna ports (16, 32, or 64) at the eNB makes use of the so-called Active Antenna System (AAS) to provide accurate 3D beamforming to targeted users.
- FD MIMO allows tx beams to be steered by the eNBs in both the azimuth and elevation dimensions,
  - -> a higher degree of flexibility than traditional beamforming.

Full Dimension (FD) MIMO

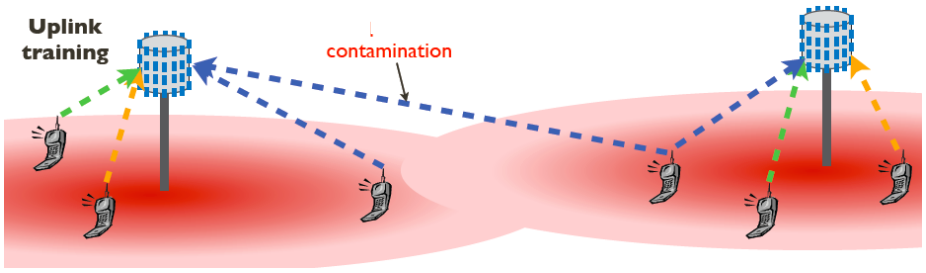


Massive MIMO



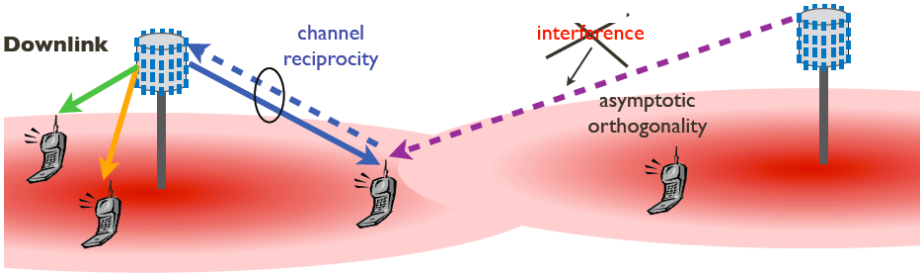
- A very large antenna array at each base station
  - An order of magnitude more antenna elements in conventional systems
- A large number of users are served simultaneously
- An excess of base station (BS) antennas

Massive MIMO



- Benefits from the (many) excess antennas
  - Simplified multiuser processing
  - Reduced transmit power
  - Thermal noise and fast fading vanish
- Differences with MU MIMO in conventional cellular systems
  - Time division duplexing used to enable channel estimation
  - Pilot contamination limits performance

Massive MIMO



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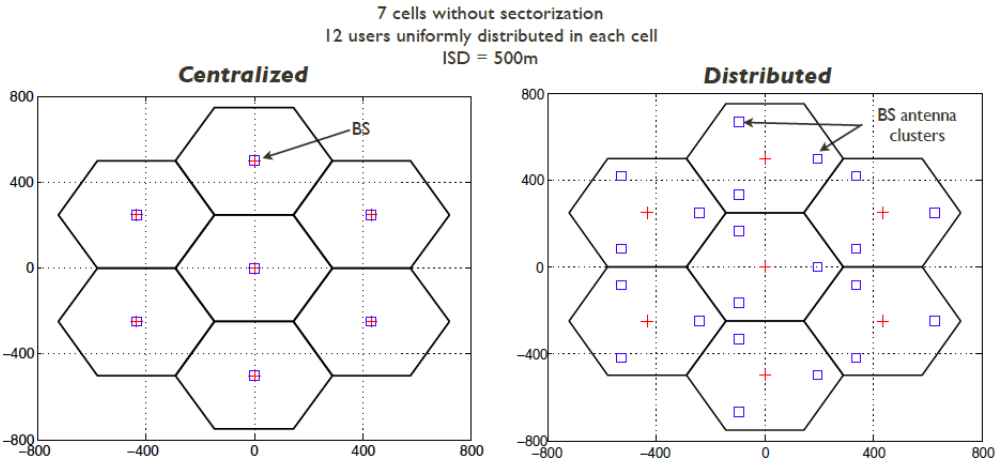
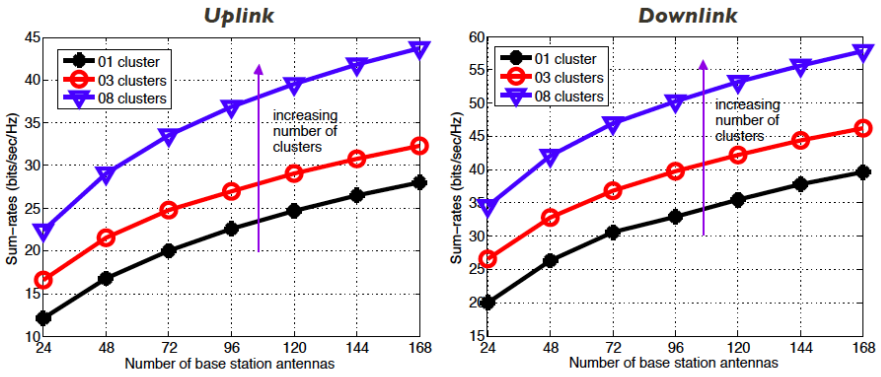
Centralized vs. Distributed



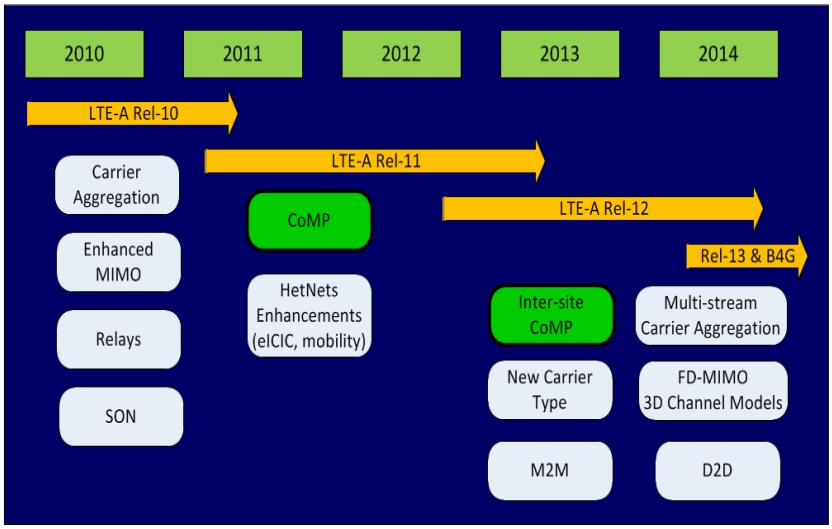
Potential Gains from Massive MIMO



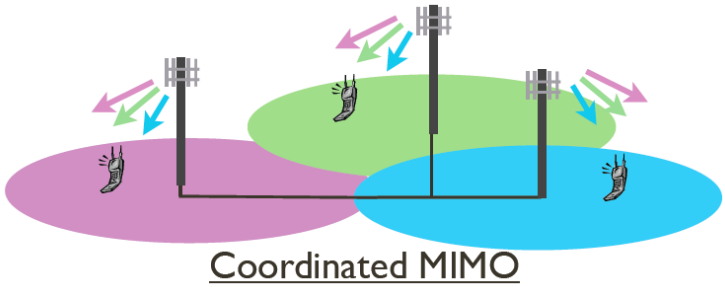
7 cells without sectorization, 12 users uniformly distributed in each cell, ISD = 500m

- Distributing antennas achieves higher gains
- Saturation is not observed without huge # of antennas

Key Technologies in LTEA



Coordinated MIMO & CoMP

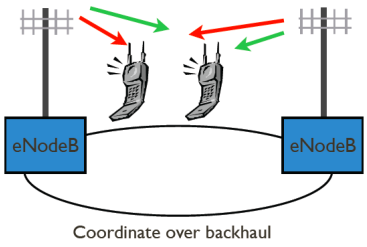


- Coordinated transmission from multiple base stations
- Known as
  - CoMP (Cooperative Multipoint Transmission & Reception)
  - or Cooperative MIMO
  - or Base station coordination

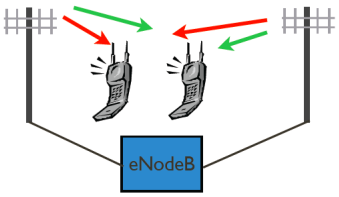
Coordinated MIMO & CoMP

- Set of techniques to improve coverage, cell-edge throughput and system efficiency.
- Principle: UEs at the cell-edge can communicate with several cell sites, both for the DL and UL.
  - Also viewed as Distributed MIMO
  - Coordination can be simple (e.g. signaling to avoid interference) or complex.
    (e.g., data is transmitted from multiple cell sites)
- Moved to Rel-11 due to challenges in practical implementation

CoMP Architecture

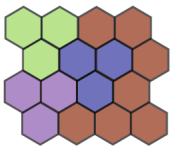


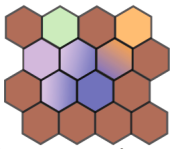
Coordinate over backhaul



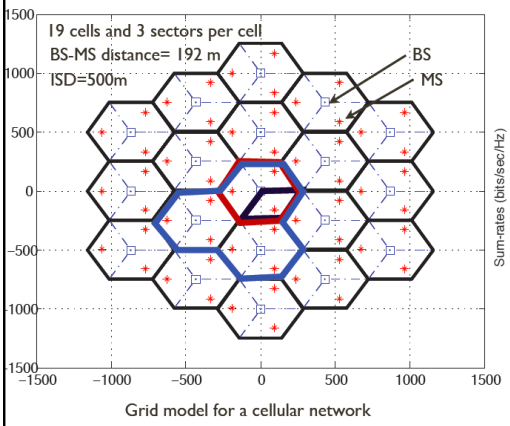
Like DAS uses local coordination

Processing for many base stations using cloud

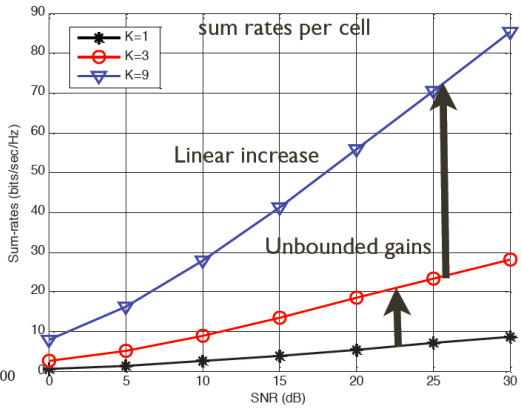

Coordination clusters


Dynamic coordination

Potential Gains from Coordination

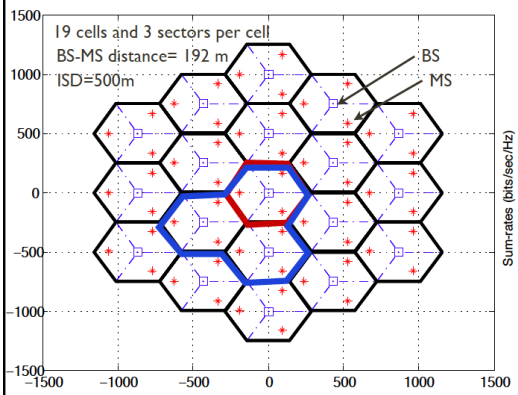


Grid model for a cellular network

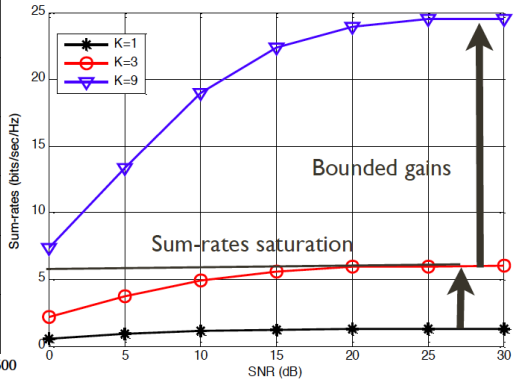


- Throughput gains when out-of-cluster interference is ignored
- More cooperation leads to higher gains
- Cell edge pushed further out, no uncoordinated interference in the cell

Addressing Out-of-Cell Interference

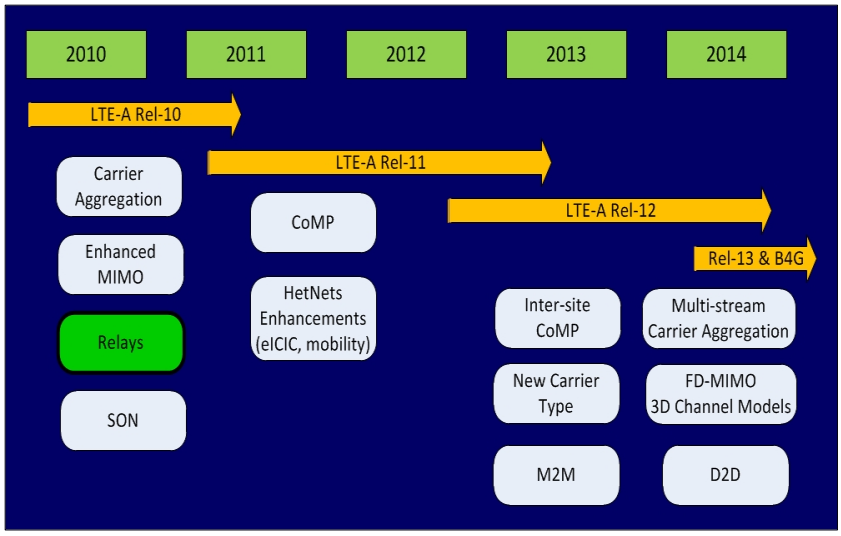


Grid model for a cellular network



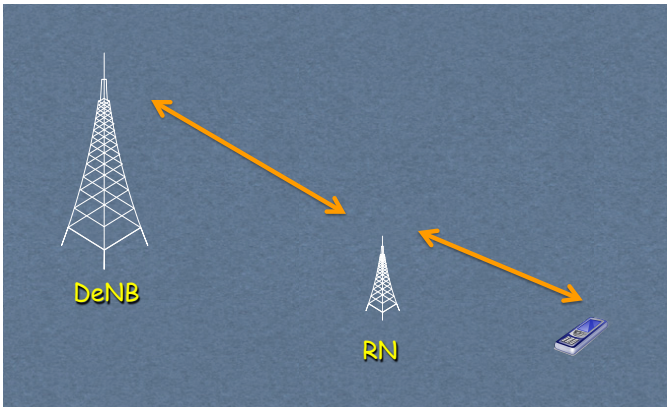
- Performance saturates with out-of-cluster interference
- 30% performance gains observed in industrial settings

Key Technologies in LTEA



Relays

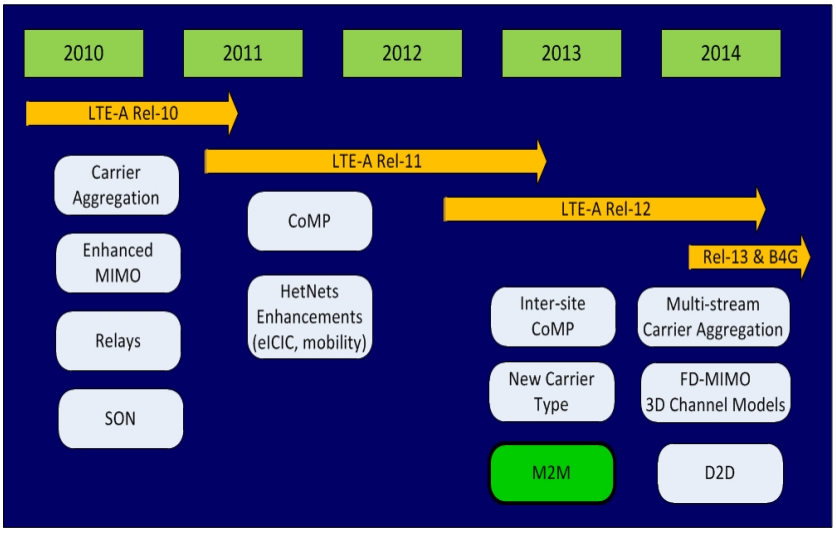
Introduce intermediate relay node (RN) to forward traffic from a Donor eNB (DeNB) to areas of no coverage (notspots) or high traffic demand (hotspots)



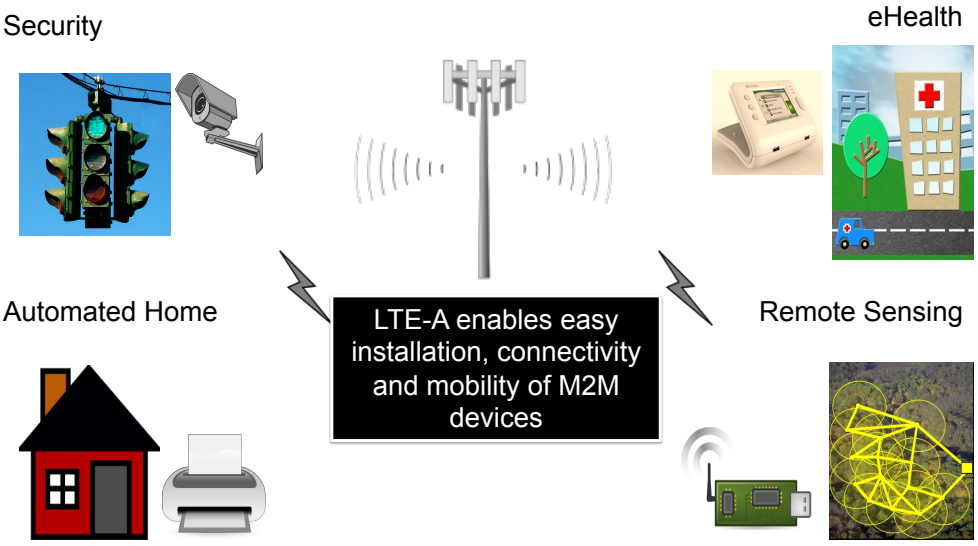
Benefits of Relays

- Improved performance
  - Coverage and data rate
- Lower OPEX and CAPEX
  - Lower H/W requirements than eNB's
  - Easier to install
  - Do not require dedicated locations
- Reach new areas
  - Can be deployed in locations where eNBs cannot
- Temporary network deployment
  - Their ease of installation allows faster deployment and removal

Key Technologies in LTEA



Machine to machine communication (M2M)



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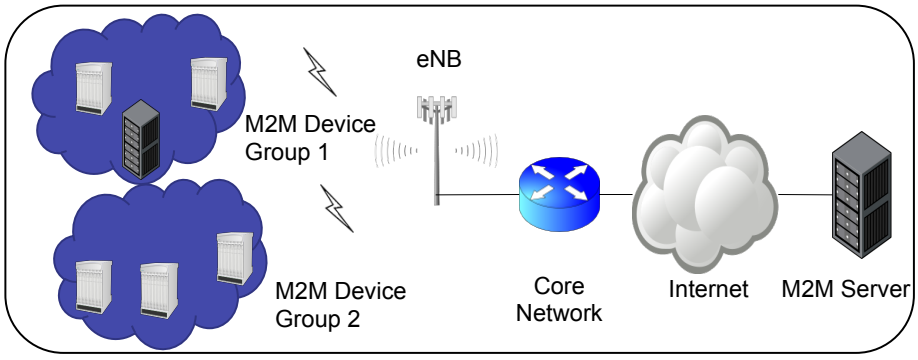
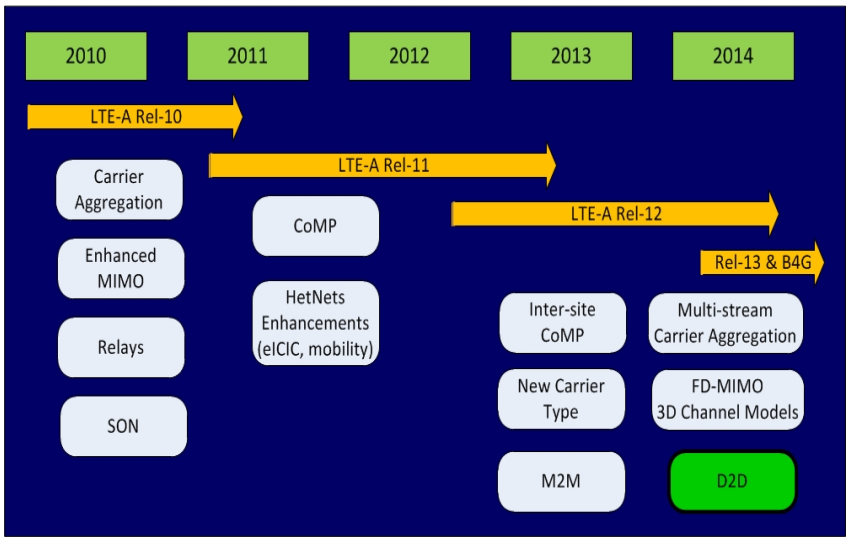


M2M Key Issues

- Massive Deployment of M2M Devices
  - Huge amount of signaling/data overload of the access and core NW
  - High Collision Probability during Channel Access
  - Insufficient control resources to respond to resource request

Need: Efficient congestion handling, mainly, in the control plane.

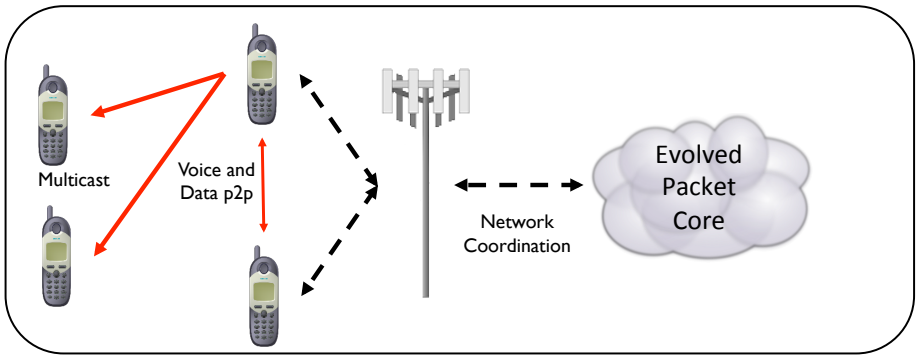
Key Technologies in LTEA



D2D vs M2M

- M2M:
  - Communications between non-human devices
  - Requires a cellular infrastructure, i.e., a core NW & a BS
- D2D (Device-to-Device Communications):
  - Ad-hoc peer-to-peer communication between devices
  - Does not require communication through the core NW

D2D

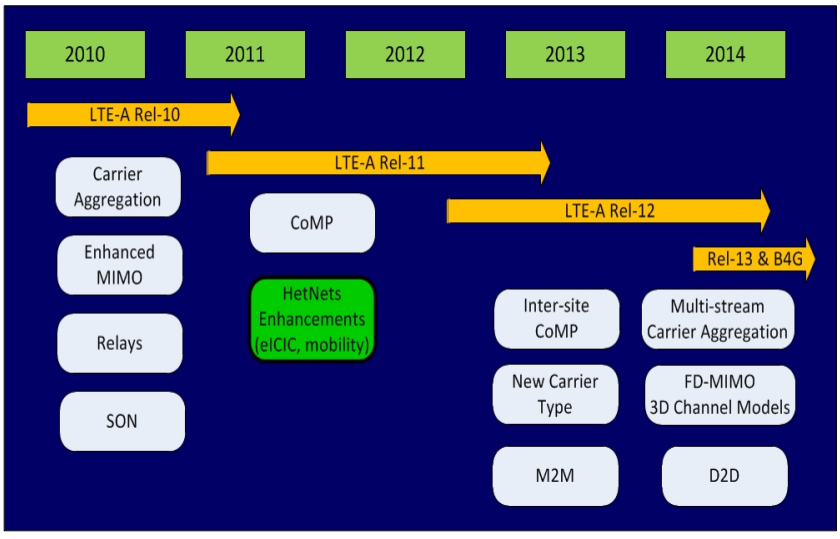


- NW coordinated communication between local devices bypassing core NW for data traffic
- Reduce NW capacity demand, provide higher QoS and increased security over unlicensed D2D like Bluetooth
- FCC will start using LTE for Public Safety NWs (natural disasters)

D2D

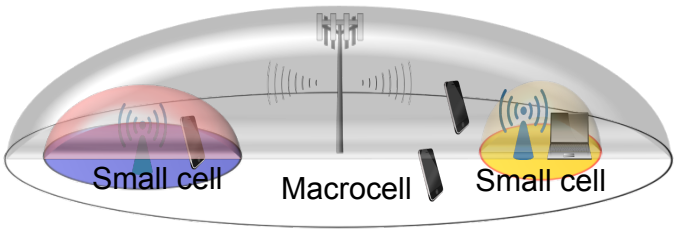
- Unlicensed Operation
  - Operators can add automated device pairing, authentication, and global identity
- Licensed Operation
  - Same benefits as unlicensed, plus:
  - Can better guarantee availability
  - Requires expensive spectrum and interference coordination
  - Public Safety devices can operate with zero core NW interaction

Key Technologies in LTEA



Heterogeneous Networks (HetNets)

- Macrocell area underlaid with number of small cells



Outdoor Deployments:
Picocells, Metrocells

Indoor Deployments:
Femtocells

- Over 2000x increase in network capacity
- Cost-effective coverage extension and green radio solution

Heterogeneous Networks (HetNets)

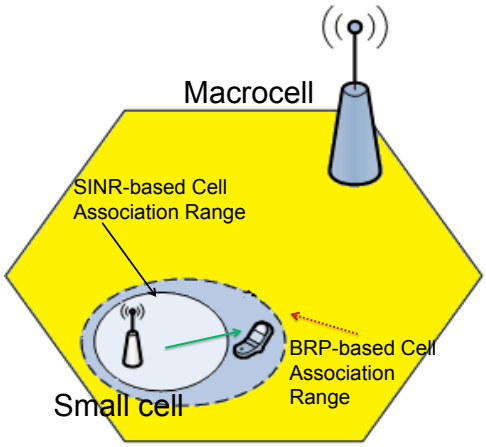
Conditions:		Association Policy:
High UL data rate	→	BS with minimum pathloss
High load	→	Offload to small cells
Low Load	→	BS with best DL SINR

Largest Downlink (DL) SINR based Cell Association

- Does not apply anymore to HetNets!

HetNets: Cell Association

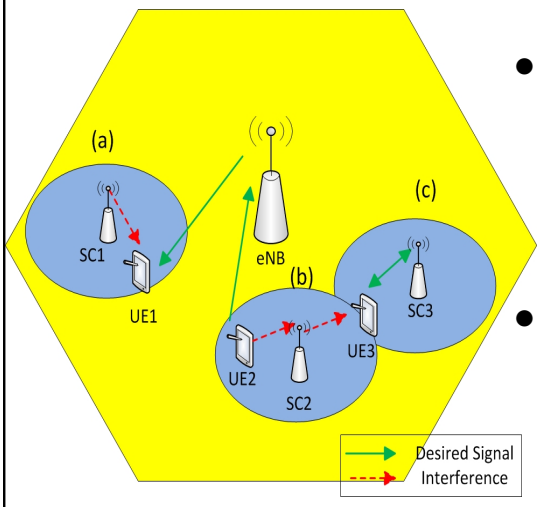
Maximum Biased Received Power (BRP) Based Cell Association



Advantage:
* Increased network capacity

Disadvantage:
* Low per-user throughput (due to interference)

HetNets: Inter Cell Interference



- Scenarios (a) and (c):
  - DL interference to a user coming from the small cell and macrocell.
- Scenario (b):
  - Interference in the UL caused by a macrocell user to a small cell BS

HetNets: Inter Cell Interference Cancellation (ICIC)

- Rel-8 and Rel-9: ICIC
  - Use different carrier freqs. for diff. cell layers
  - Power control schemes
  - Adaptive fractional frequency reuse
  - Spatial antenna techniques includ. MIMO &SDMA
  - Adaptive Beamforming

- Rel-11: Enhanced ICIC (eICIC) (due to Carrier Aggeregation)
  - Time-domain based schemes
  - Frequency domain based schemes