LTE

3G Long Term Evolution

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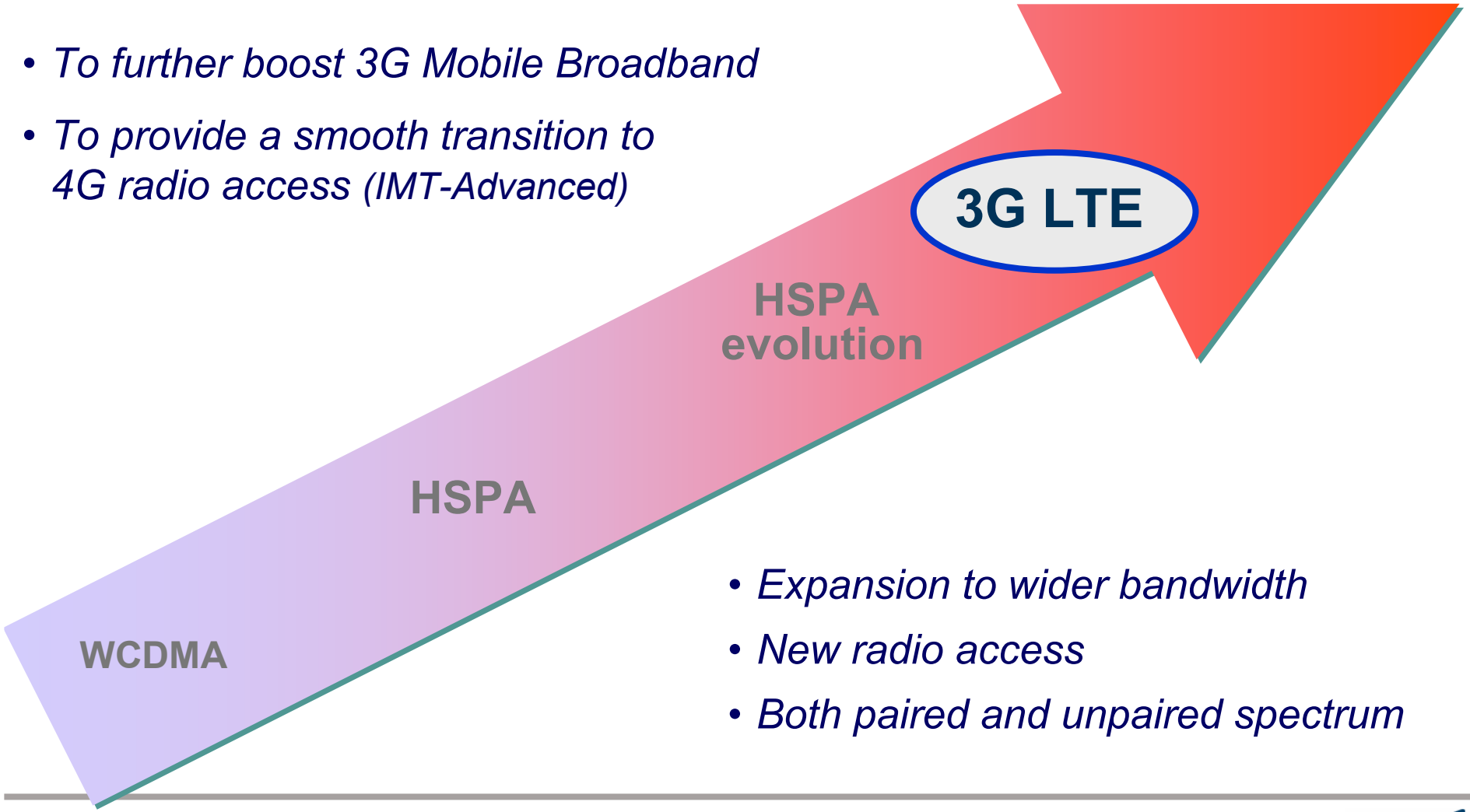
3G Long Term Evolution

2003/4	2005/6	2007/8	2009/10	2011/12

- *To further boost 3G Mobile Broadband*
- *To provide a smooth transition to 4G radio access (IMT-Advanced)*



- *Expansion to wider bandwidth*
- *New radio access*
- *Both paired and unpaired spectrum*

3G LTE – *Requirements and targets*

- ***Defined in 3GPP TR25.913***

- **Very high data rates**
  - *Peak data rates: More than 100 Mbps (downlink) / More than 50 Mbps (uplink)*
  - *Improved cell-edge user throughput*

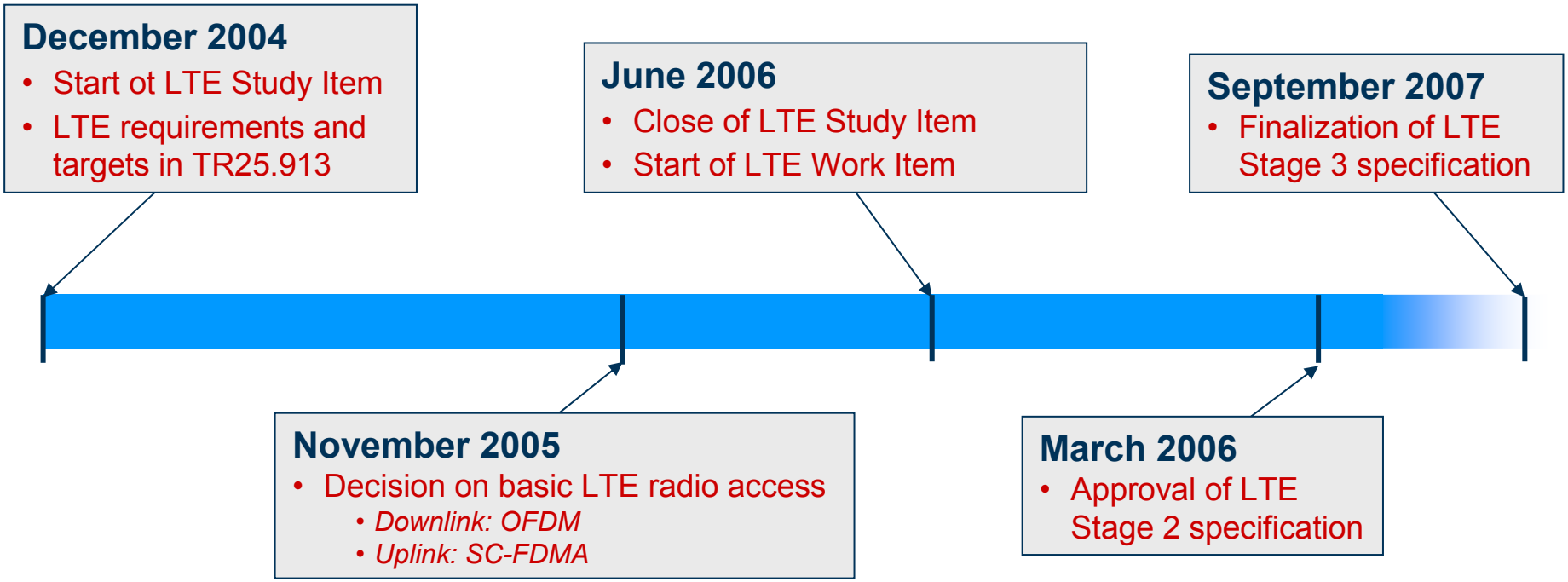
- **Very low latency**
  - *Less than 10 ms (User-plane RAN RTT)*
  - *Less than 50 ms (Control-plane dormant-to-active transition)*

- **Very high spectral efficiency**

- **Spectrum flexibility**
  - *Deployable in a wide-range of spectrum allocations of different sizes*
  - *Both paired and unpaired spectrum*

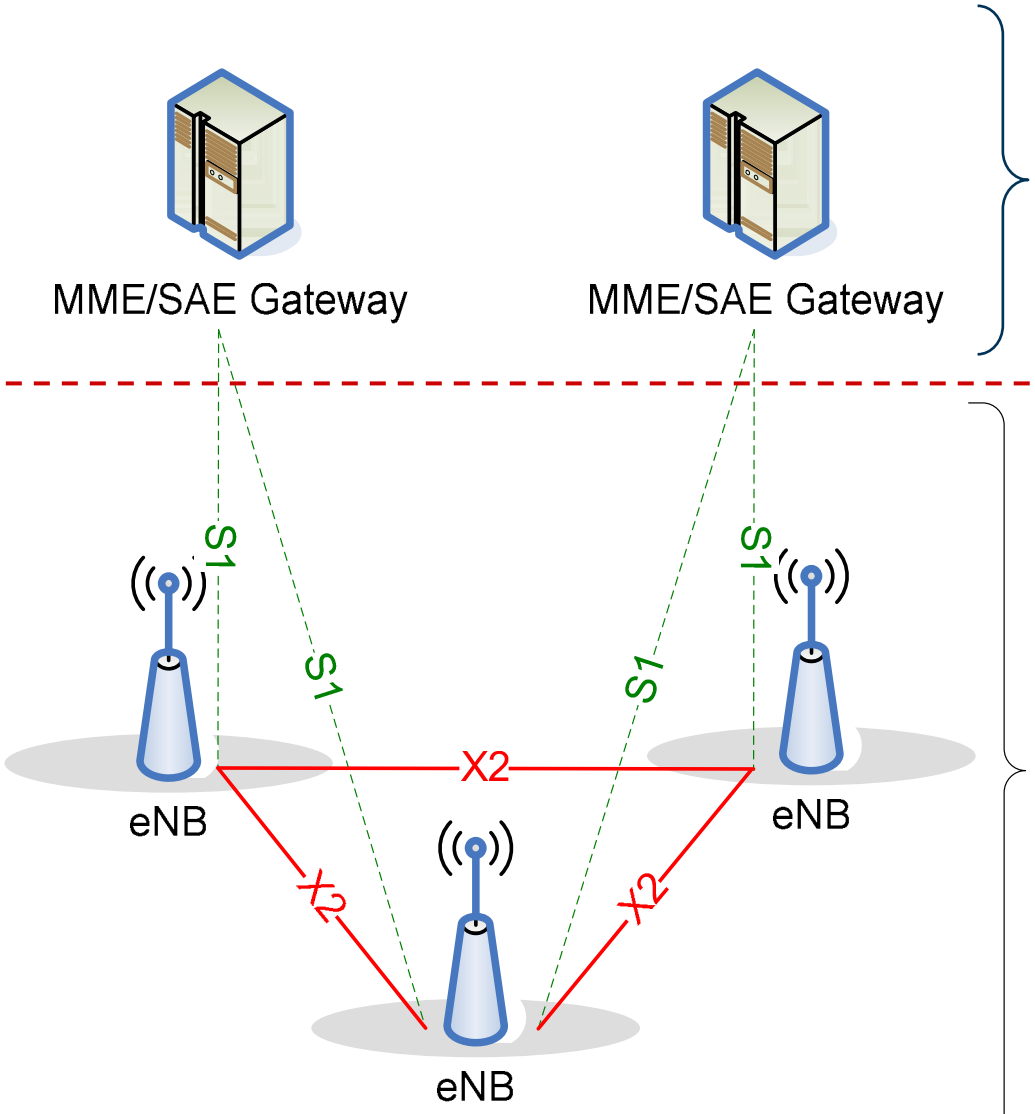
- **Cost-effective migration from current 3G systems**

3G LTE – *3GPP time line*



- SAE (*System Architecture Evolution*) in parallel to LTE

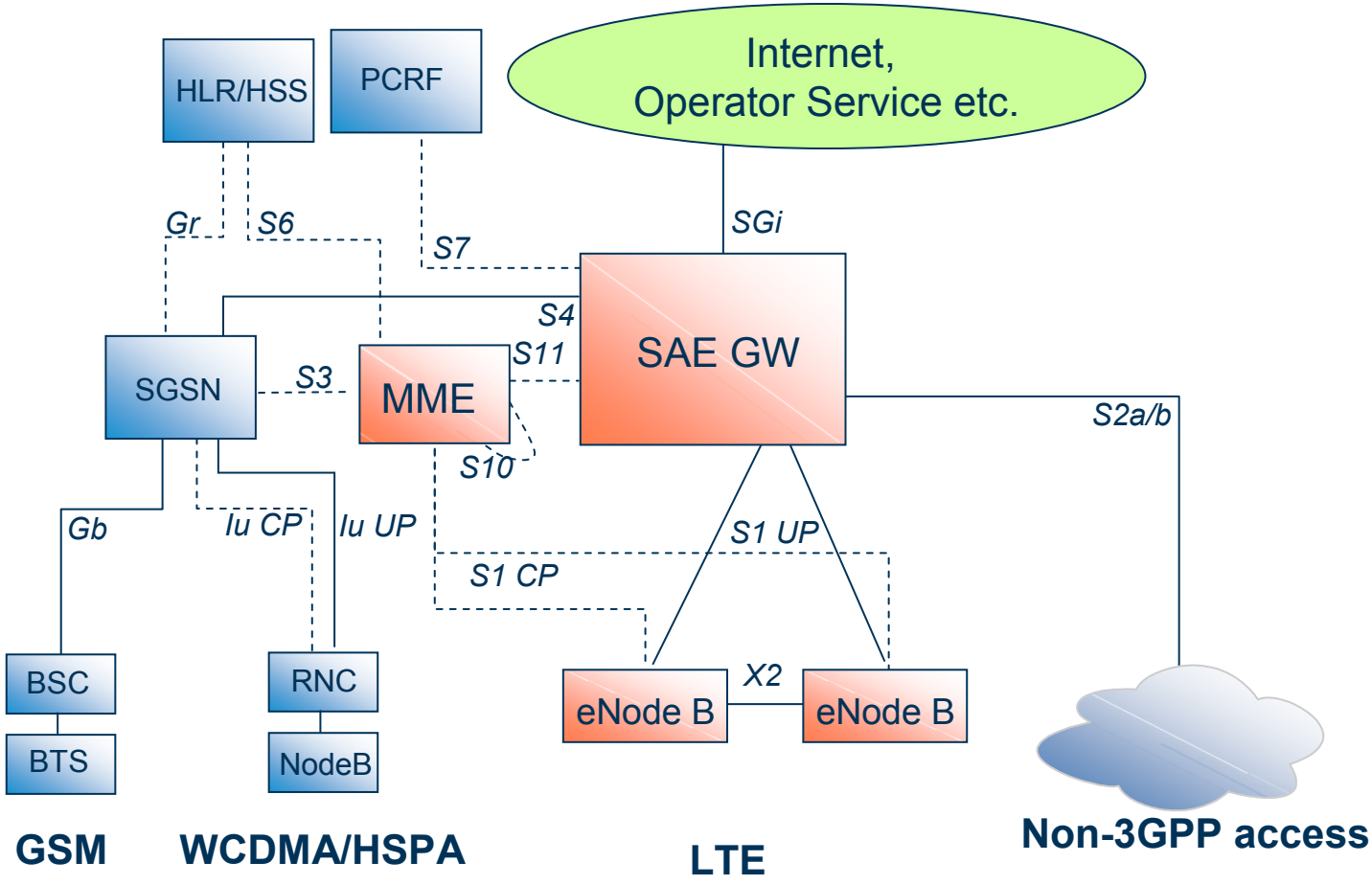
LTE/SAE – *Overall Architecture*



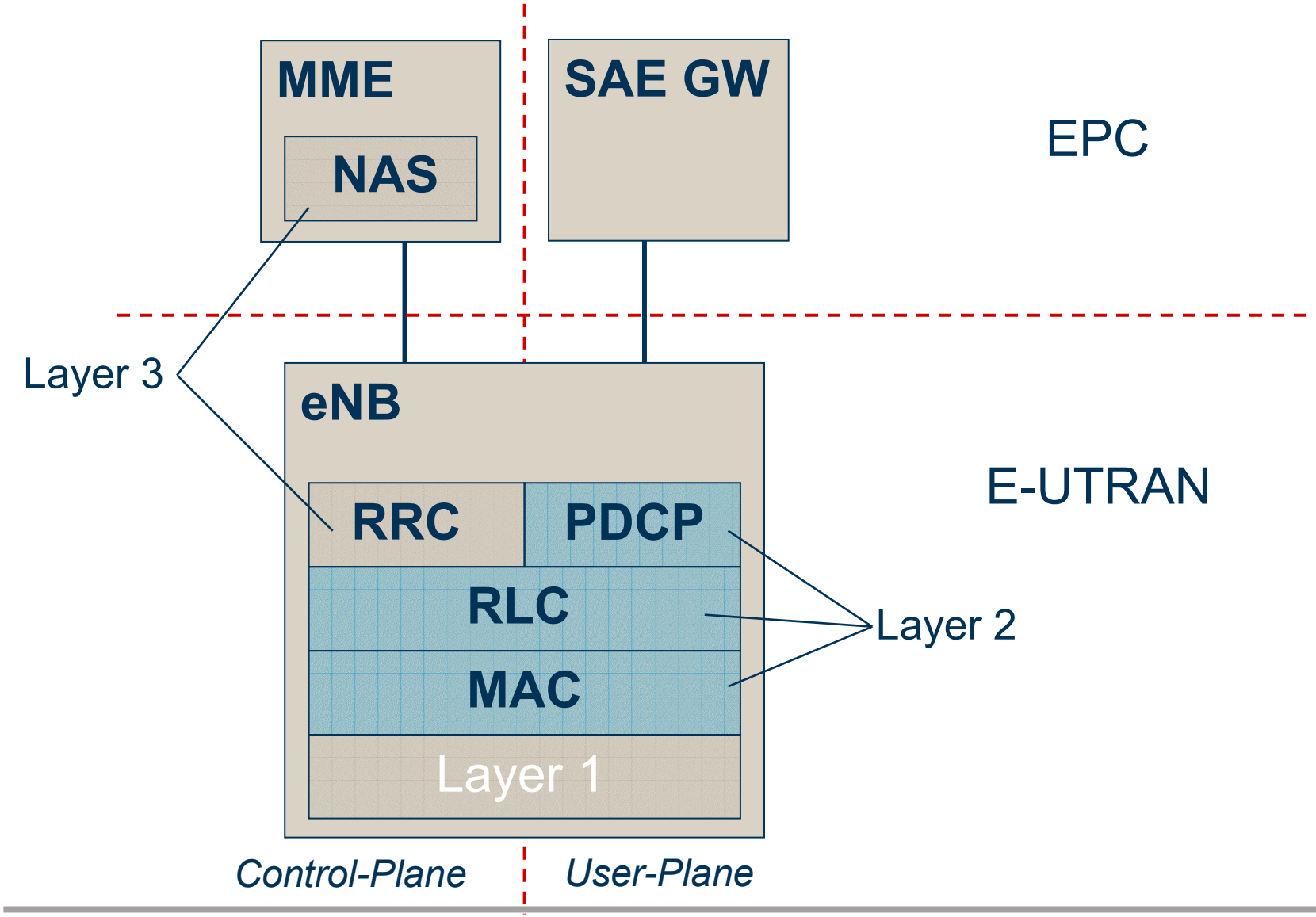
MME and SAE GW two separate nodes with open interface in between
(S1 C-plane / S1 U-plane)

EPC: *Evolved Packet Core*
MME: *Mobility Management Entity*

SAE/LTE – *Overall architecture*

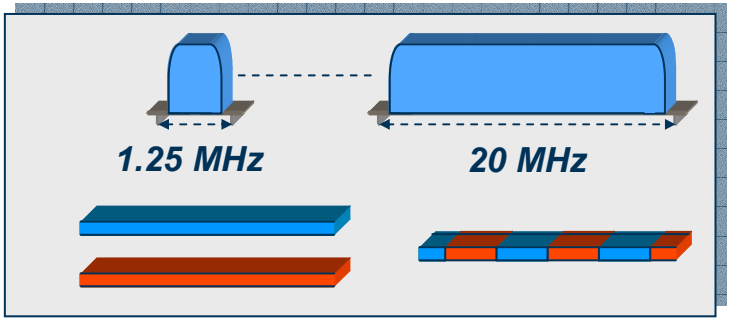


LTE/SAE – *Protocol Architecture*

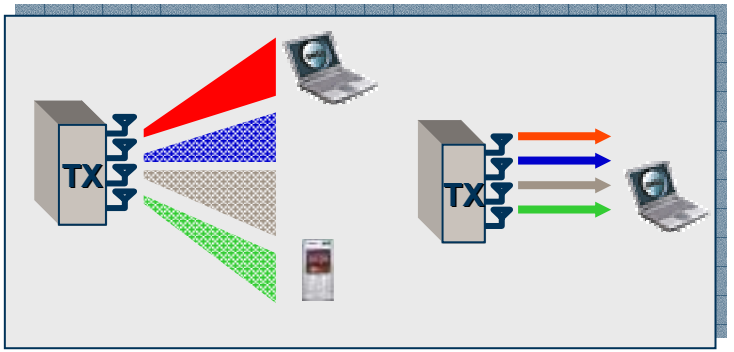


3G LTE – *Key radio-access features*

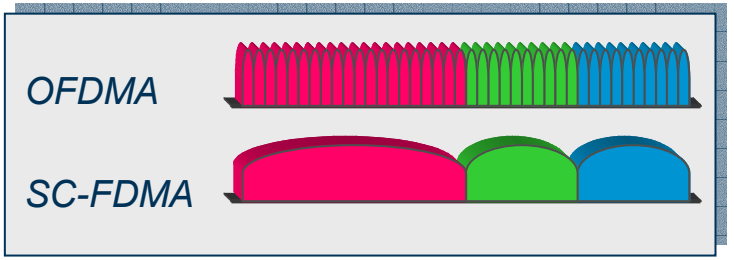
- **Spectrum flexibility**
  - *Flexible bandwidth*
  - *Duplex flexibility*



- **Advanced antenna solutions**
  - *Diversity*
  - *Beam-forming*
  - *Multi-layer transmission (MIMO)*



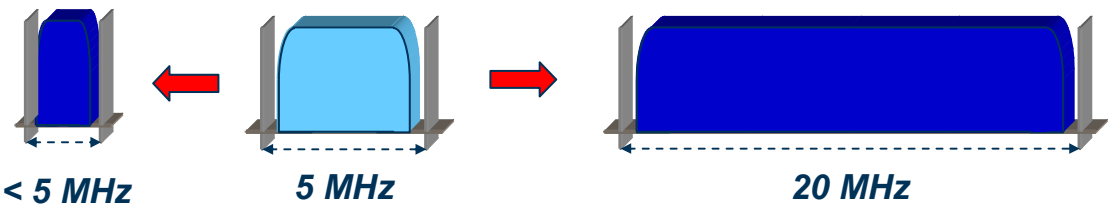
- **New radio access**
  - *Downlink: OFDM*
  - *Uplink: SC-FDMA*



3G LTE – *Spectrum flexibility*

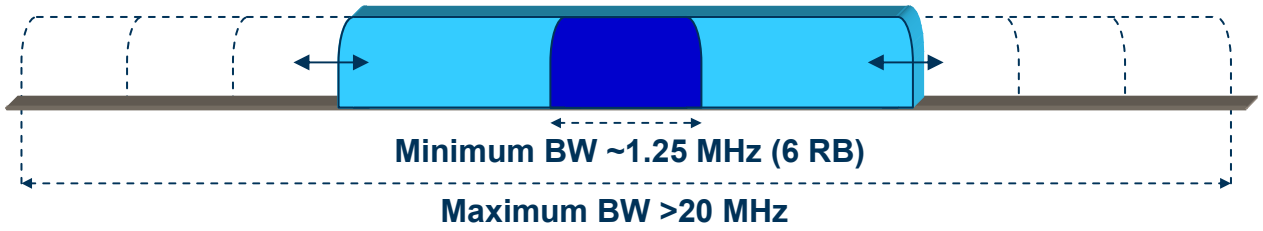
- Allow for operation in a wide range of different spectrum
  - *Current and future 3G spectrum (2 GHs, 2.6 GHz, …)*
  - *Migration of 2G spectrum (e.g. 900 MHz)*
  - *Re-farming of other spectrum, e.g. UHF bands*
- Uncertain size of future spectrum assignments
- Efficient operation in differently-sized spectrum allocations
  - *Up to 20 MHz to enable very high data rates*
  - *Less than 5 MHz to enable smooth spectrum migration*

Need for flexible transmission bandwidth



3G LTE – *Bandwidth flexibility*

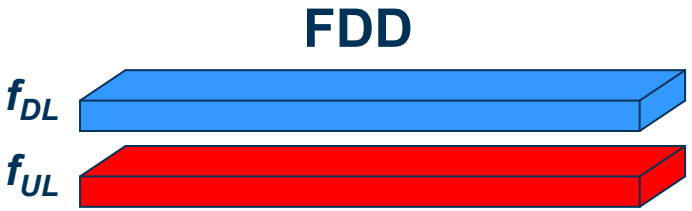
- LTE physical layer supports any bandwidth from ~1.25 MHz to well beyond 20 MHz in steps of ~200 kHz (one "*Resource Block*")

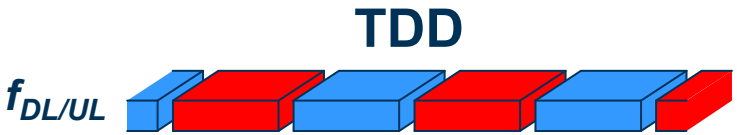


- RF complexity/requirements limit set of bandwidths actually supported
  - *e.g. 1.25 MHz, 1.8 MHz, 5 MHz, 10 MHz, 20 MHz*
- ... but relatively straighforward to extend to addtional bandwidths
  e.g. to match new spectrum assignments

All LTE terminals must support the maximum bandwidth (up to 20 MHz)

3G LTE – *Duplex arrangement*

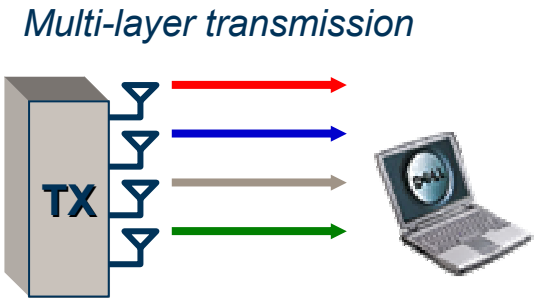


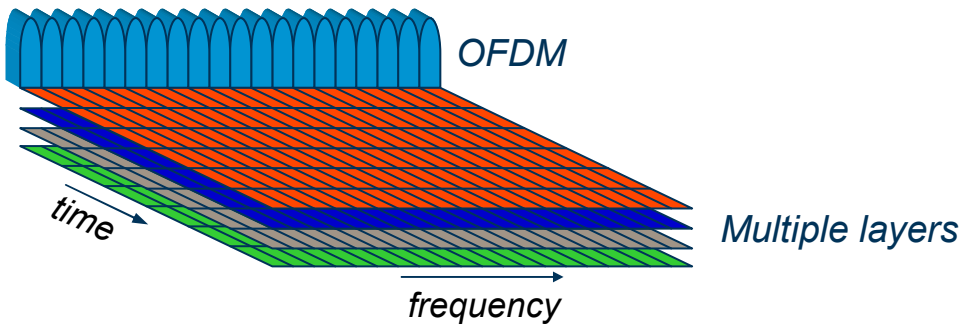


- **FDD:** *Simultaneous downlink/uplink transmission in separate frequency bands*
  - *Paired spectrum requried*
  - *Used in all commercial cellular systems*
- **TDD:** *Non-overlapping downlink/uplink transmisson in the same frequency band*
  - *Possibility for deployment in single (unpaired) spectrum*
  - *Need for tight inter-cell synchronization/coordination*
  - *Reduced coverage due to non-continuous transmission (duty cycle < 1)*
- ***FDD preferred if paired spectrum available***
- ***TDD as complement to support deployment in unpaired spectrum***
- *Maximum FDD/TDD commonality to ensure TDD terminal availability*

3G LTE – *Downlink radio access*

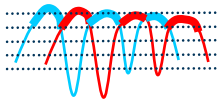
- ***Adaptive Multi-Layer OFDM***
- ***Adaptive*** to channel conditions and spectrum scenarios
  - *Time and frequency-domain channel adaptation*
  - *Multiple frequency bands, flexible bandwidth, duplex flexibility*, …
- ***Multi-layer transmission*** to provide *very high data rates* and *high spectrum efficiency*
- ***OFDM*** for robust broadband transmission, for lower-complexity multi-layer transmission, and to enable frequency-domain channel adaptation



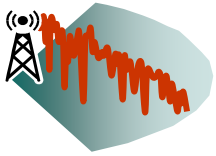


Frequency-domain channel adaptation

- Select user and data rate based on *instantaneous* channel quality
- Scheduling/adaptation in time-domain already for HSPA



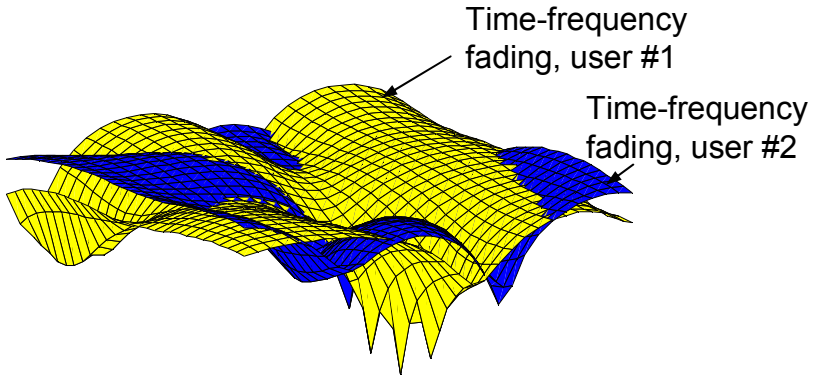
Channel-dependent scheduling

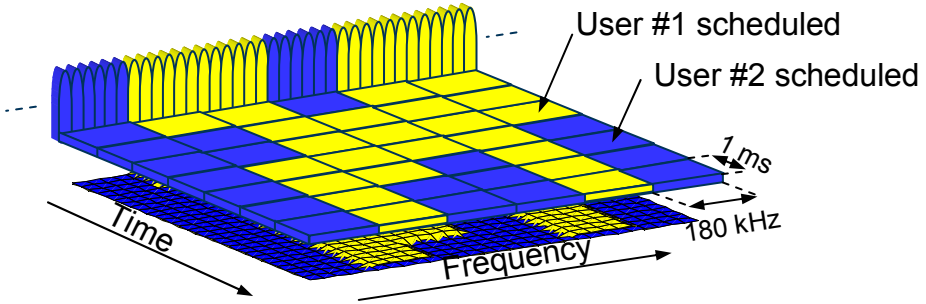


Link adaptation

LTE scheduling/adaptation on a 1 ms × 180 kHz basis
(one ”*Resource Block*”)

LTE: Additional scheduling/adaptation in the ***frequency*** domain

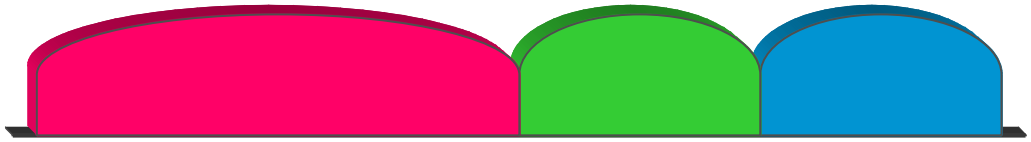




Both for downlink and uplink

3G LTE – *Uplink radio access*

- ***Single-carrier FDMA***
- **"Single-carrier"** ⇨ *Improved power-amplifier efficiency*
  ⇨ *Reduced terminal power consumption and cost, and improved coverage*
- **FDMA** ⇨ *Intra-cell orthogonality in time **and** frequency domain*
  ⇨ *Improved uplink coverage and capacity*
- **High degree of commonality with LTE downlink access**
  – *Can be seen as pre-coded OFDMA, more specifically "DFT-S-OFDM"*
  – *Same basic transmission parameter (frame length, "sub-carrier spacing", …)*

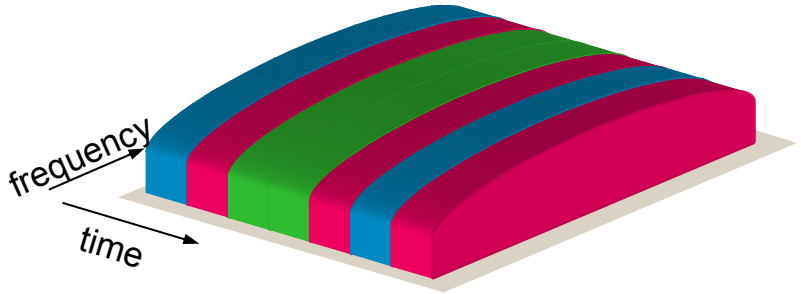


SC-FDMA

Time/frequency-domain orthogonality

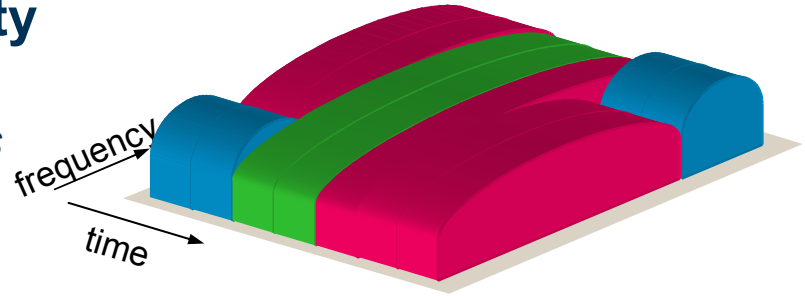
Only time-domain orthogonality

- *Time Division Multiple Access (TDMA)*
- *Entire bandwidth assigned to one user at a time*
  ⇨ High peak data rates
- *Potentially in-efficient for small available payloads and power-limited user terminals*



Additional frequency-domain orthogonality

- *Frequency Division Multiple Access (FDMA)*
- *Overall bandwidth can be shared by multiple users*
- *Efficient support for small payloads and power-limited user terminals*
- *Variable instantaneous transmit bandwidth*



Why single-carrier transmission ?

OFDM

or

SC-FDMA

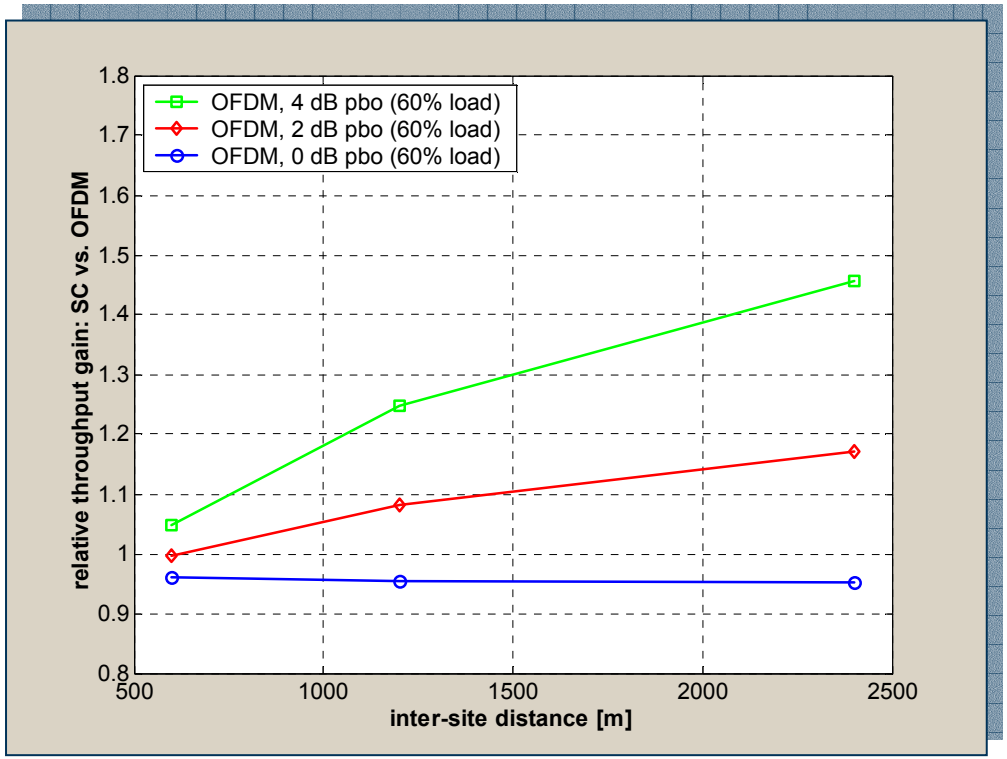
- OFDM has good performance for broadband communication due to inherent robustness to radio-channel time dispersion
- ... but *also suffers from well-known drawbacks such as*
  - *High peak-to-average power ratio ⇨* ***Power-amplifier in-efficiency***
  - *Sensitivity to frequency errors*
  - *Robustness to time dispersion can also be achieved with single-carrier transmission together with receiver-side frequency-domain equalization*
- **Downlink**:
  - *Power-amplifier efficiency less critical at base-station side*
  - *Avoid excessive user-terminal receiver complexity*

  } ⇨ ***OFDM***
- **Uplink:**
  - *High power-amplifier complexity is critical in terms of terminal cost and power consumption, and uplink coverage*
  - *Receiver complexity less critical at base-station side*

  } ⇨ ***Single-carrier***

SC-FDMA vs. OFDM?

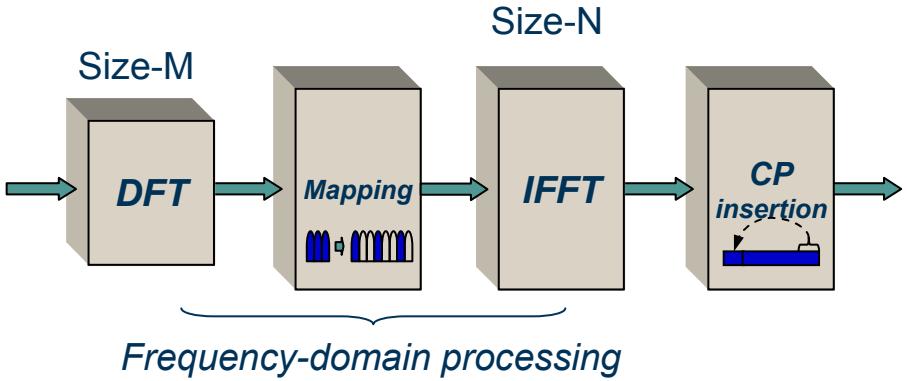
Relative throughput
Single-carrier vs. OFDM



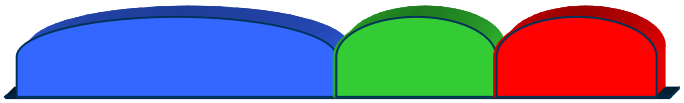
- Ignoring power-amplifier limitations OFDM has slight advantage
- Assuming realistic power amplifier, single-carrier transmission has advantage especially in case of larger inter-site distance

⇨ ***Single-carrier transmission preferred due to coverage advantage***

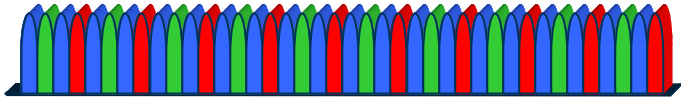
LTE SC-FDMA – *DFT-spread OFDM*



- Mapping to consecutive IFFT inputs ➡ *"Localized" transmission*
- Mapping to distributed IFFT inputs ➡ *"Distributed" transmission*



Localized transmission

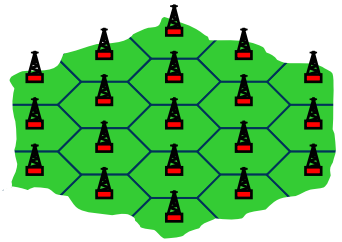


Distributed transmission

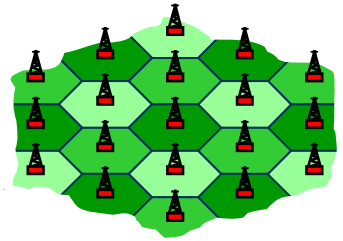
- Low-PAPR "single-carrier" transmission ⇨ *High power-amplifier efficiency*
- … but can also be seen as ***pre-coded OFDM***

Interference coordination
(“*adaptive reuse*”, “*soft reuse*”, …)

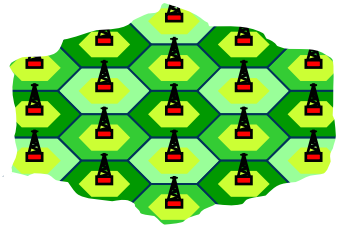
- High data rates in limited spectrum allocations
  - *Entire spectrum must be available in each cell*
    - ➡ *One-cell frequency reuse*



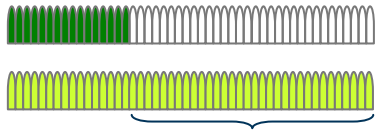
- Reduced inter-cell interference with frequency reuse > 1
  - *Improved cell-edge SIR ➡ Higher cell-edge data rates*



- Adaptive reuse
  - *Cell-center users:* Reuse = 1
  - *Cell-edge users:* Reuse > 1



- Relies on access to frequency domain
  - ⇨ *Applicable for both downlink OFDM and uplink SC-FDMA*

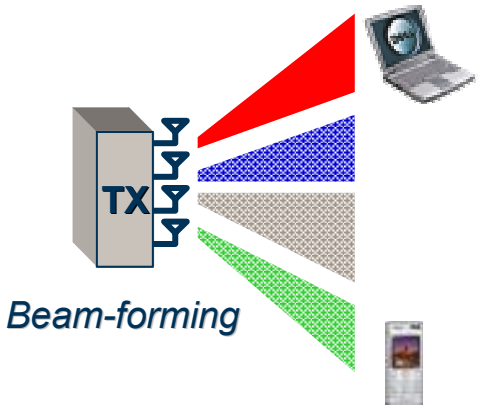


3GPP LTE – *Multi-antenna solutions*

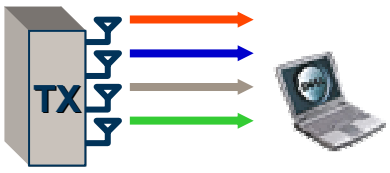
- LTE targets extreme performance in terms of
  - *Capacity*
  - *Coverage*
  - *Peak data rates*

  *Advanced multi-antenna solutions is **the** key tool to to achieve this*

- Different antenna solutions needed for different scenarios/targets
  - *High peak data rates ➡ Multi-layer transmission*
  - *Good coverage ➡ Beam-forming*
  - *High capacity ➡ Beam forming (and multi-layer transmission)*

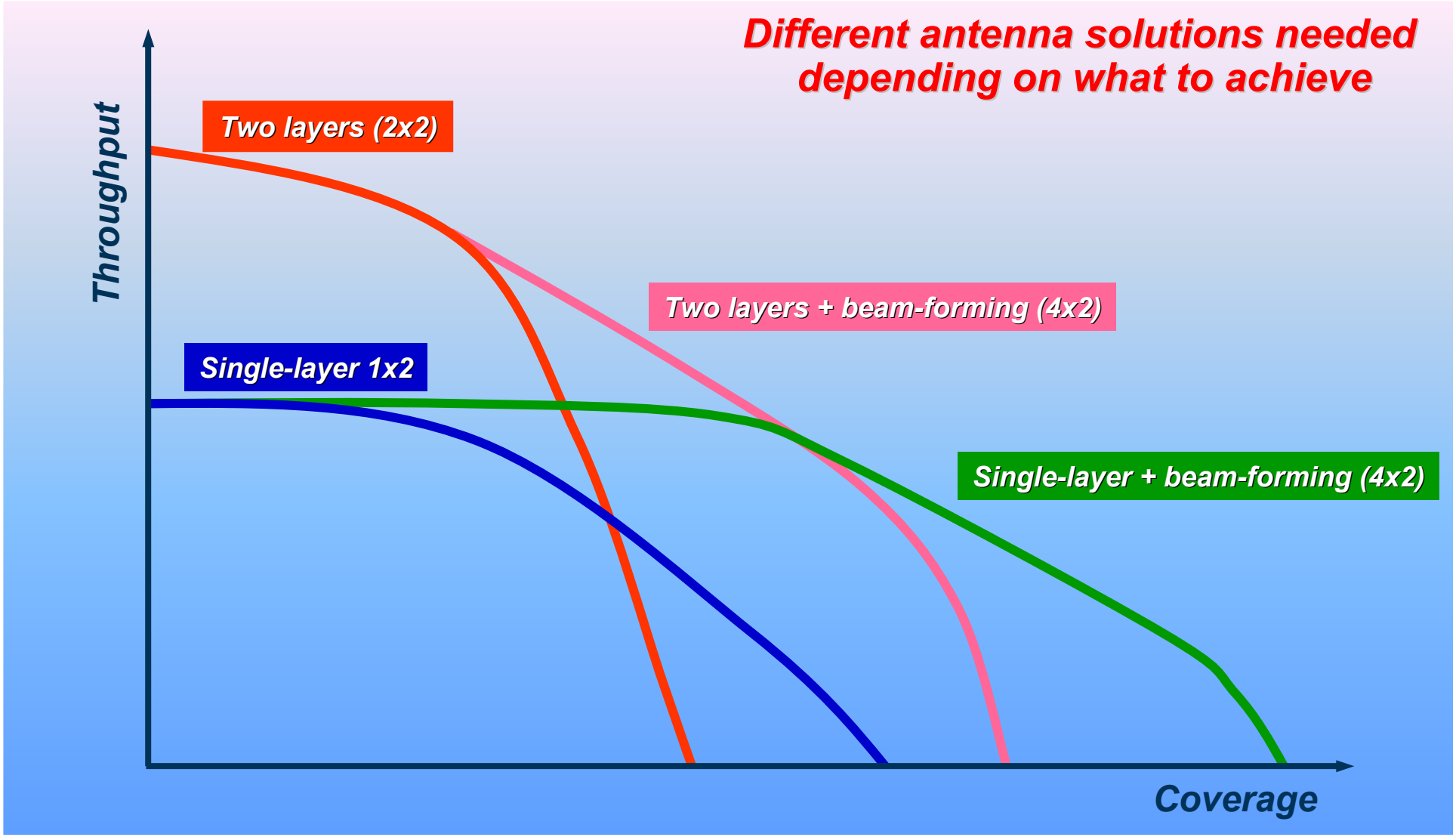


Beam-forming



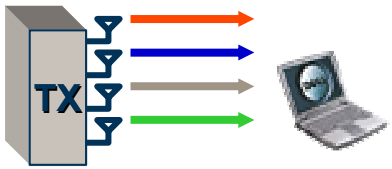
Multi-layer transmission ("MIMO")

3GPP LTE – *Advanced antenna solutions*

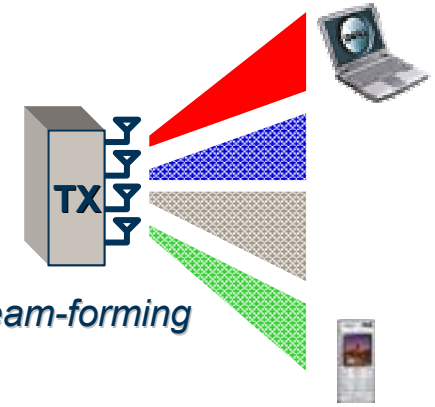


3G LTE – *Multi-antenna solutions*

- Multiple RX antennas: *Two-antenna RX diversity mandatory at the mobile terminal*
- Downlink transmit diversity: *SFBC* (*Space-Frequency Block Coding)*
- Code-book-based pre-coding ⇨ Spatial multiplexing
  - *2×2, 2×4, 4×4*
  - *Rank adaptation ⇨ Single-layer beam-forming as special case*



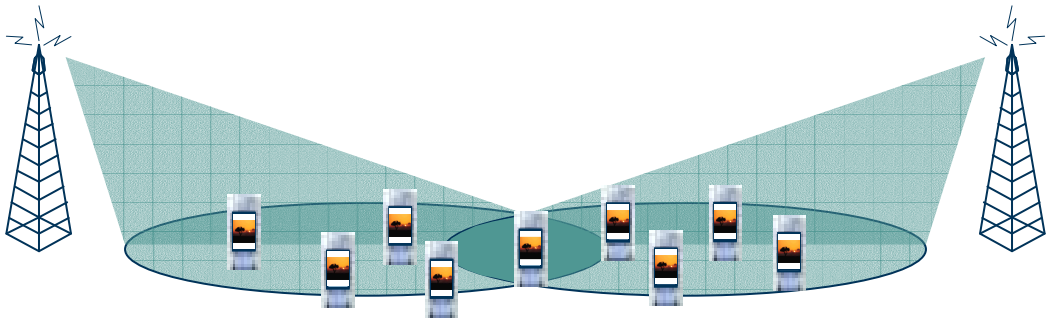
Multi-layer transmission ("MIMO")



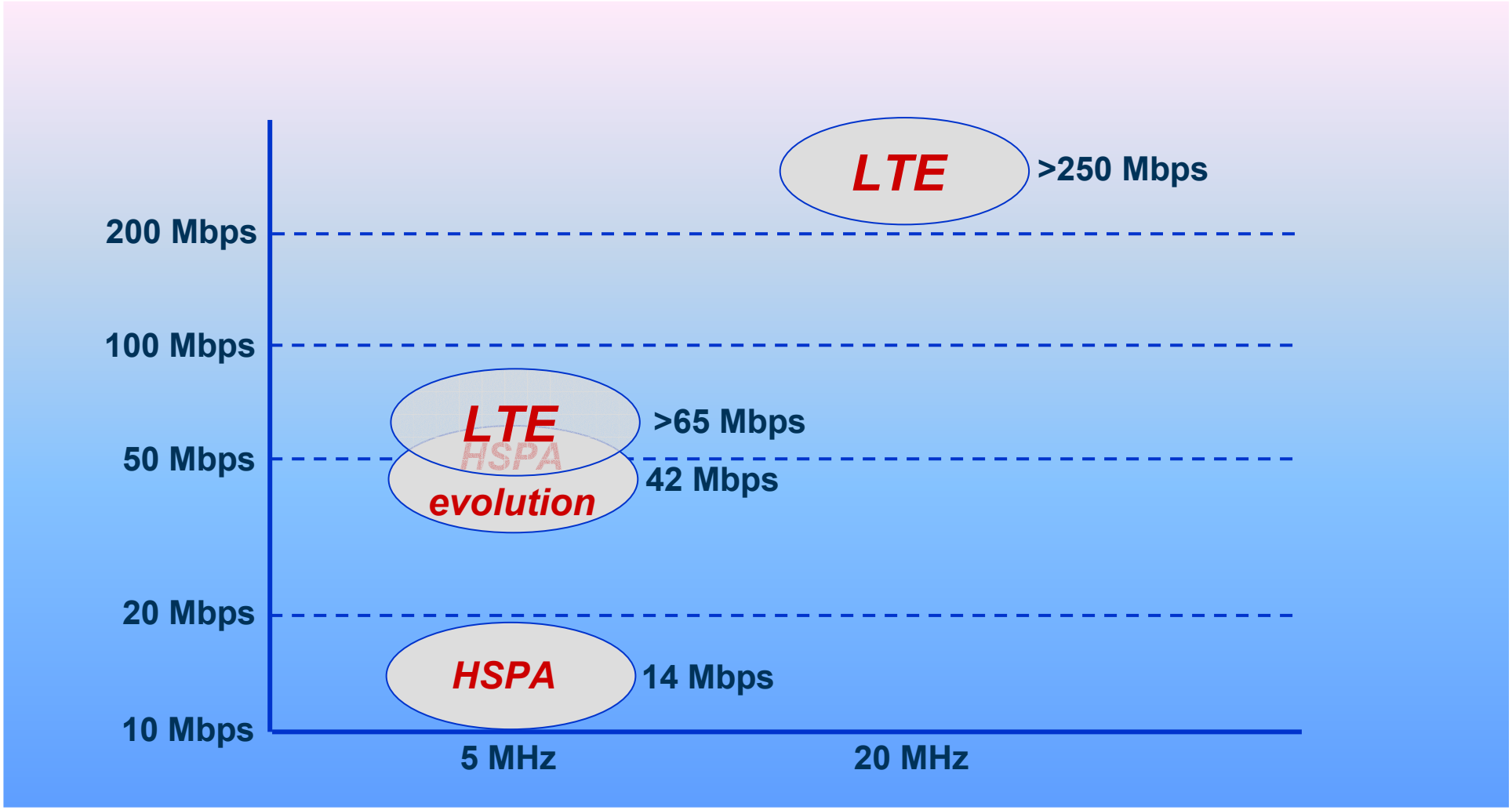
Beam-forming

3G LTE – *Multicast/Broadcast*

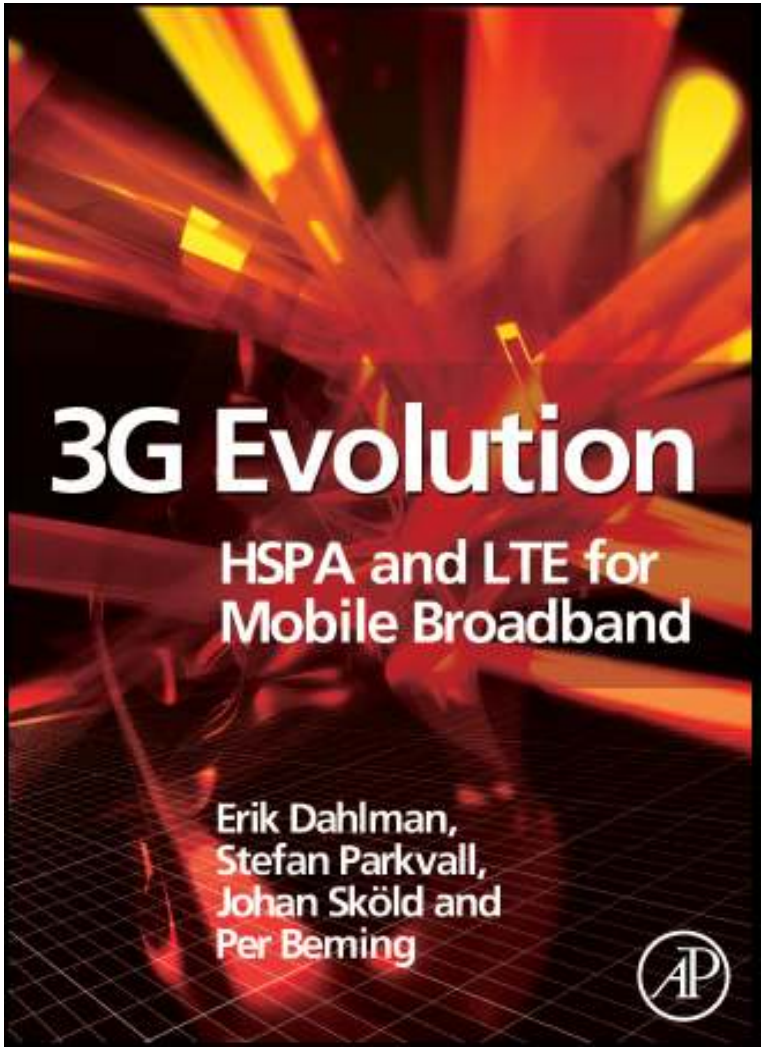
- MBMS – Multimedia Broadcast/Multicast Service
- OFDM allows for high-efficient MBSFN operation
  - *Multicast/Broadcast Single-Frequency Networking*
  - *Identical transmissions from set of tightly synchronized cells*
  - *Increased received power and reduced interference*
  - ⇨ ***Substantial boost of MBMS system throughput***
- LTE allows for multicast/broadcast and unicast on the same carrier as well as dedicated multicast/broadcast carrier



HSPA and LTE – *Data rate capabilites*



To learn more …



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