

LTE

3G Long Term Evolution

Dr. Erik Dahlman

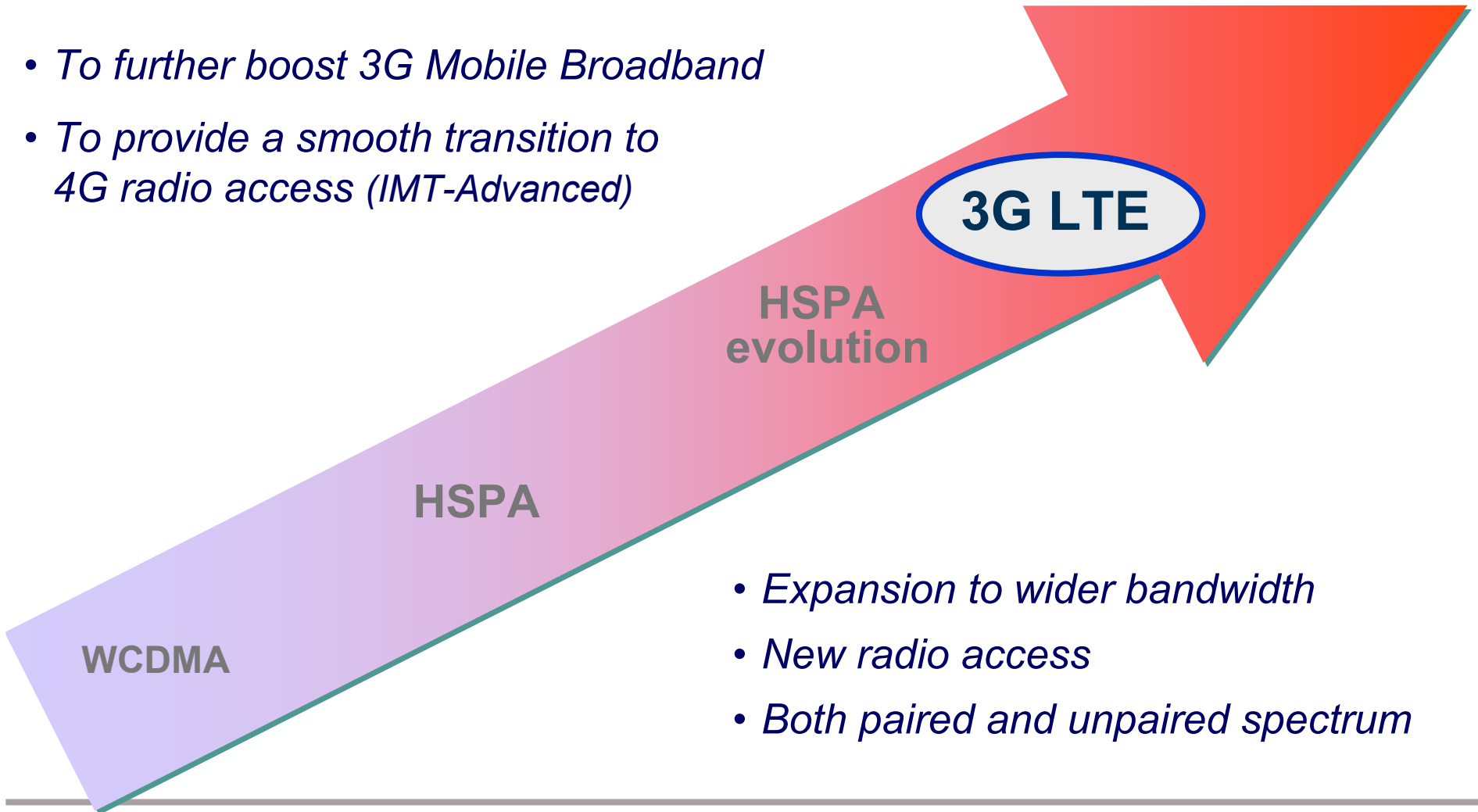
Expert Radio Access Technologies

Ericsson Research

3G Long Term Evolution

2003/4	2005/6	2007/8	2009/10	2011/12
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- *To further boost 3G Mobile Broadband*
- *To provide a smooth transition to 4G radio access (IMT-Advanced)*

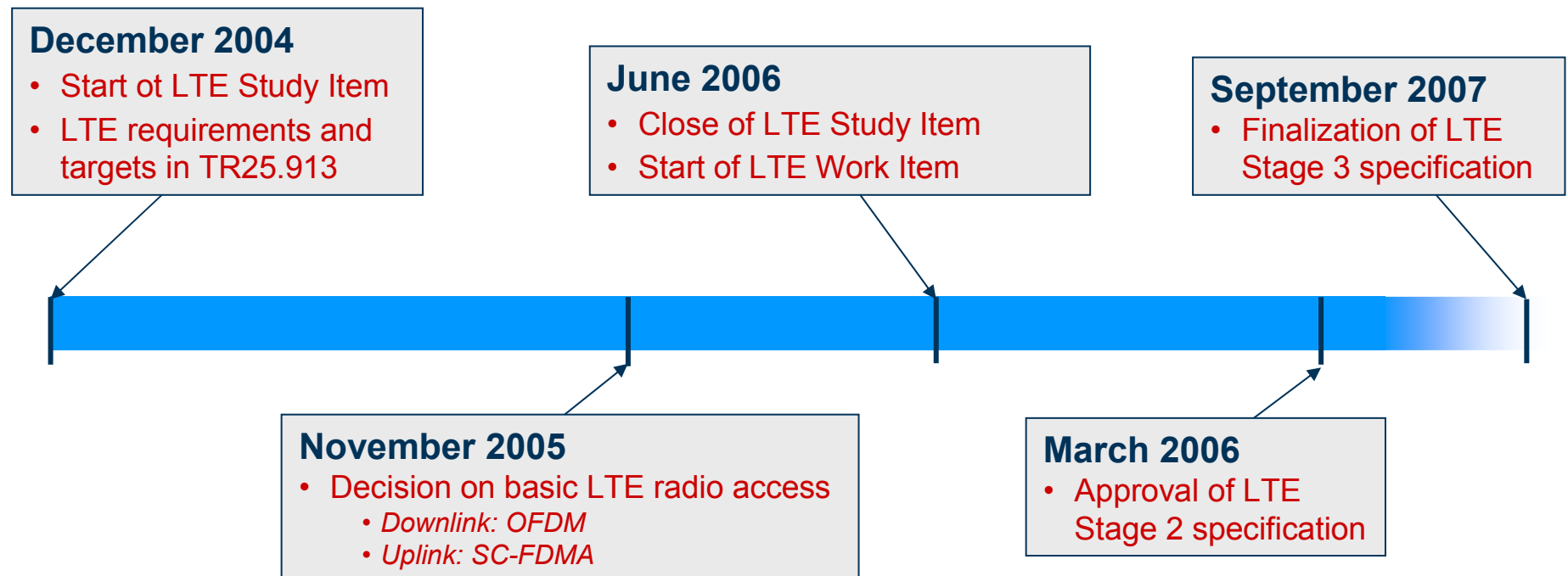


- *Expansion to wider bandwidth*
- *New radio access*
- *Both paired and unpaired spectrum*

3G LTE – *Requirements and targets*

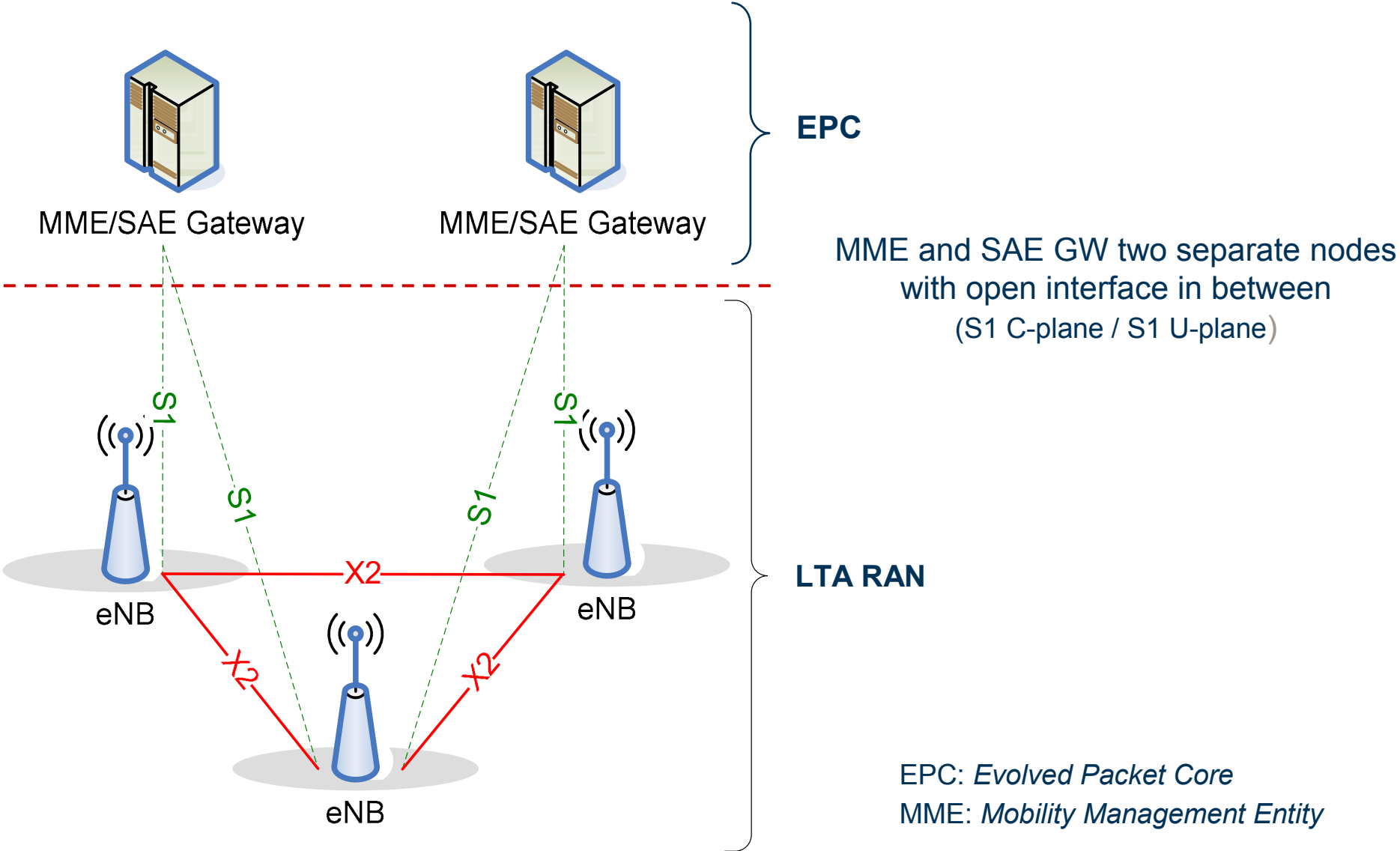
- **Defined in 3GPP TR25.913**
- **Very high data rates**
 - *Peak data rates: More than 100 Mbps (downlink) / More than 50 Mbps (uplink)*
 - *Improved cell-edge user throughput*
- **Very low latency**
 - *Less than 10 ms (User-plane RAN RTT)*
 - *Less than 50 ms (Control-plane dormant-to-active transition)*
- **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

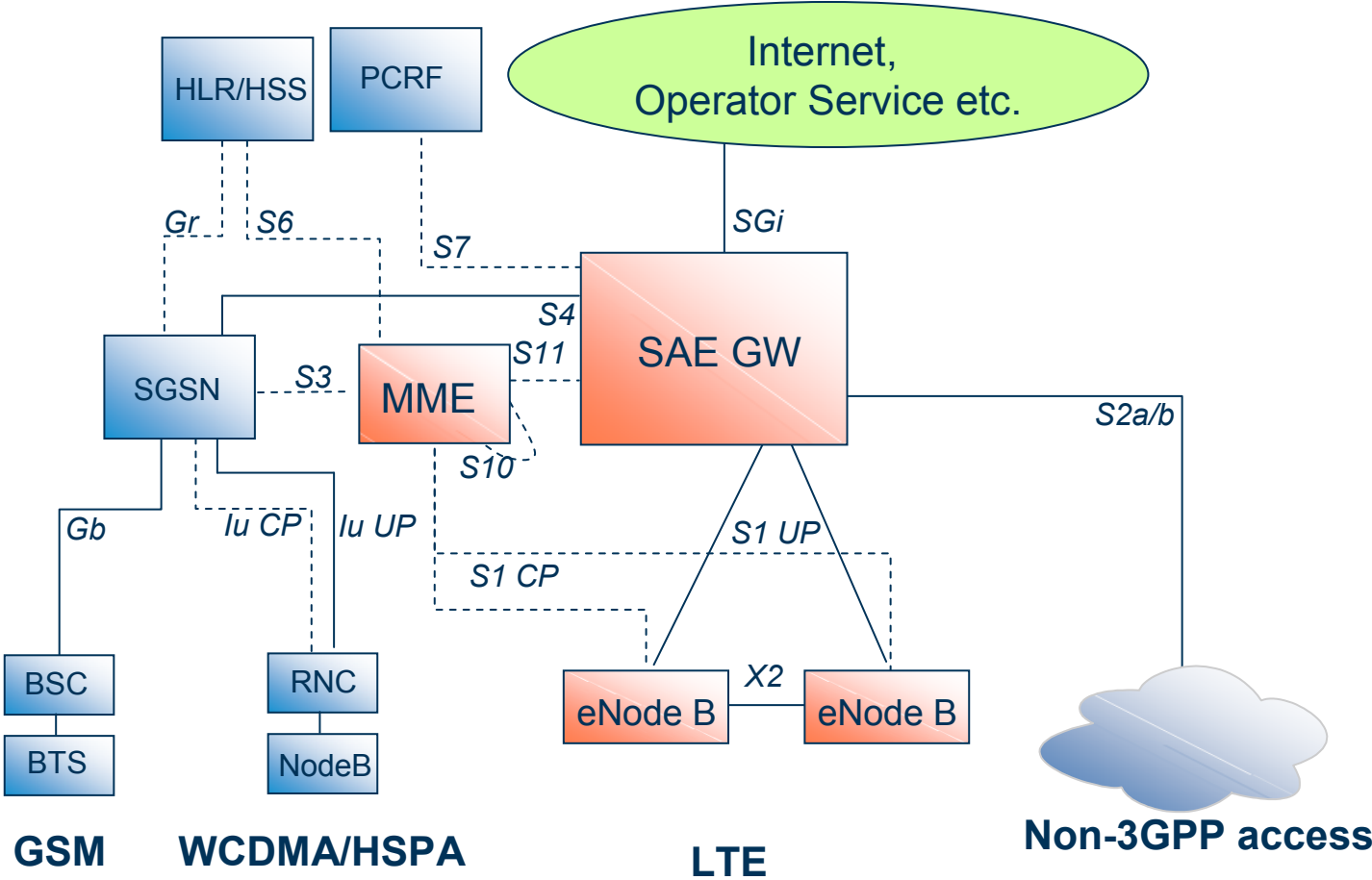


- SAE (System Architecture Evolution) in parallel to LTE

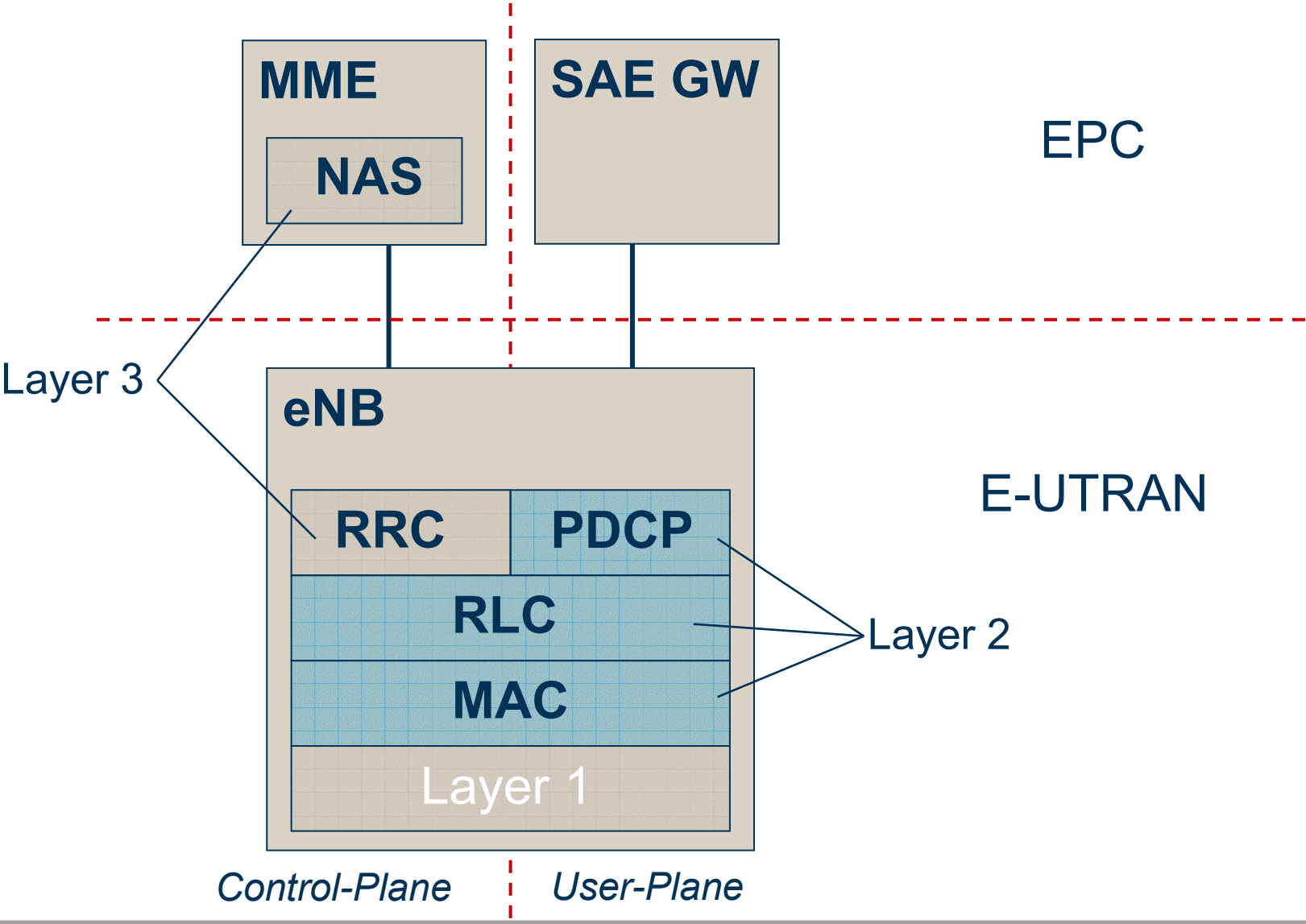
LTE/SAE – Overall Architecture



SAE/LTE – Overall architecture



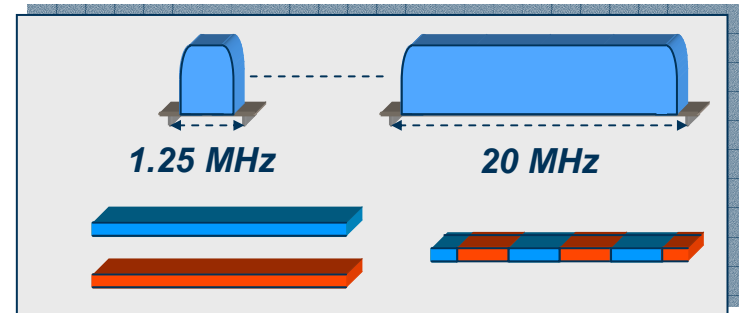
LTE/SAE – Protocol Architecture



3G LTE – Key radio-access features

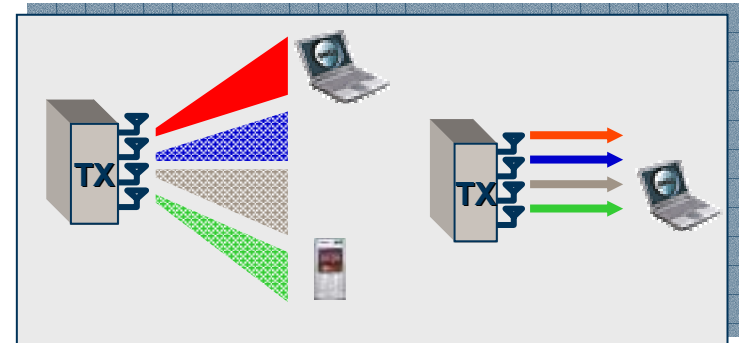
- **Spectrum flexibility**

- Flexible bandwidth
- Duplex flexibility



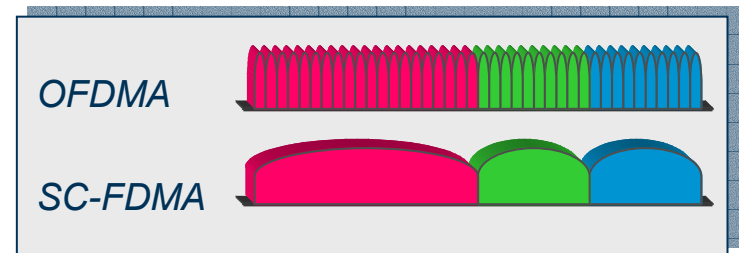
- **Advanced antenna solutions**

- Diversity
- Beam-forming
- Multi-layer transmission (MIMO)



- **New radio access**

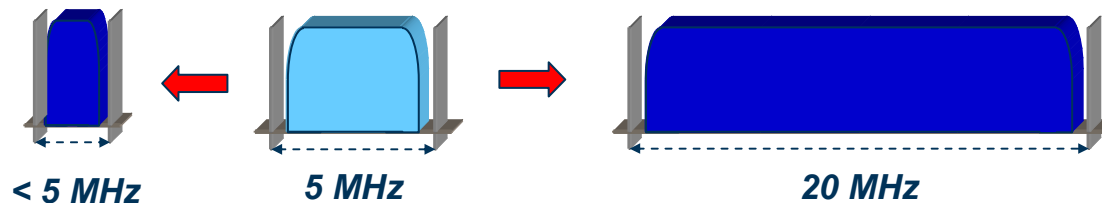
- Downlink: OFDM
- Uplink: SC-FDMA



3G LTE – *Spectrum flexibility*

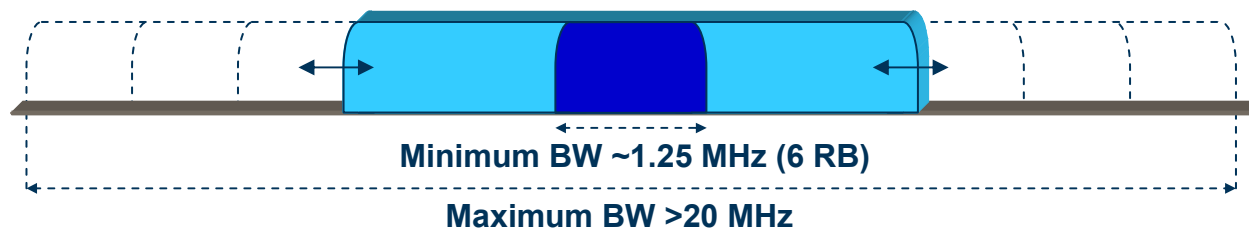
- Allow for operation in a wide range of different spectrum
 - *Current and future 3G spectrum (2 GHz, 2.6 GHz, ...)*
 - *Migration of 2G spectrum (e.g. 900 MHz)*
 - *Re-farming of other spectrum, e.g. UHF bands*
- Uncertain size of future spectrum assignments
- Efficient operation in differently-sized 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 straightforward to extend to additional bandwidths e.g. to match new spectrum assignments

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

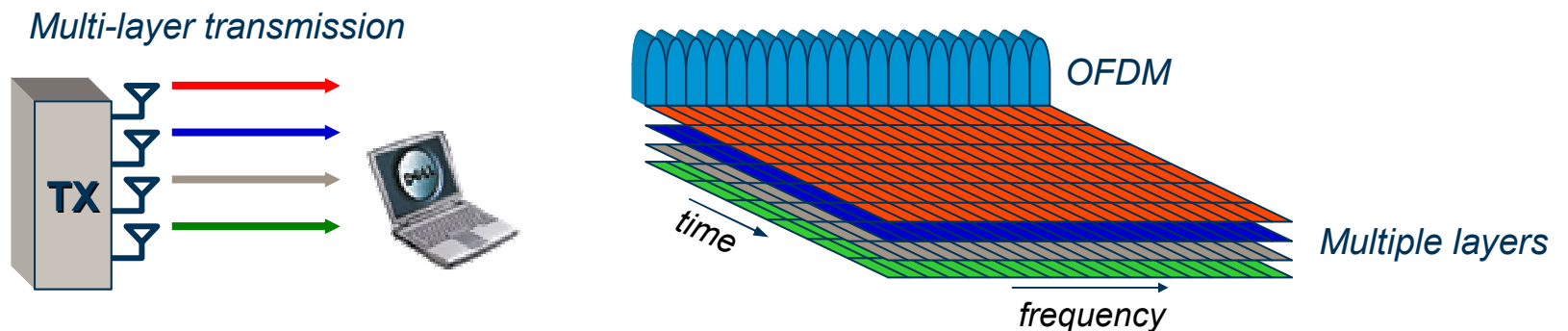
3G LTE – Duplex arrangement



- **FDD:** Simultaneous downlink/uplink transmission in separate frequency bands
 - Paired spectrum required
 - Used in all commercial cellular systems
- **TDD:** Non-overlapping downlink/uplink transmission 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**

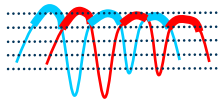
3G LTE – Downlink radio access

- **A Ad aptive M ulti L ayer O F D M**
- ***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

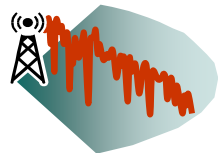


Frequency-domain channel adaptation

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



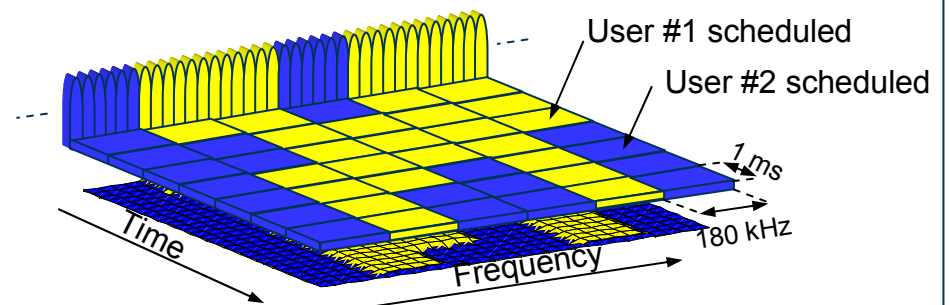
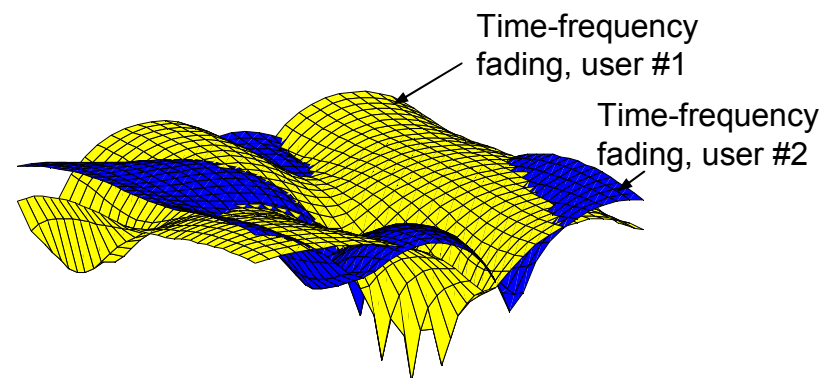
Channel-dependent scheduling



Link adaptation

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

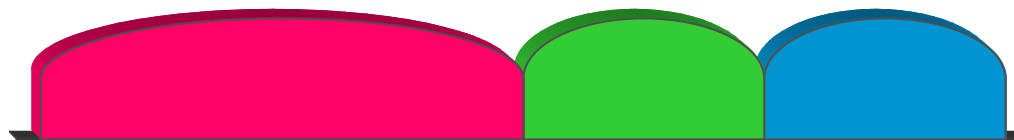
LTE: Additional scheduling/adaptation in the *frequency* domain



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”, ...)*

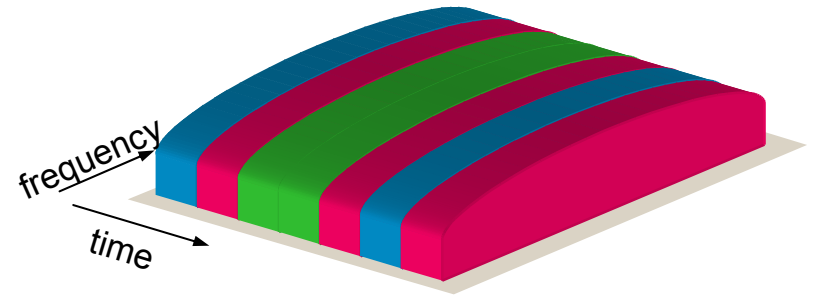


SC-FDMA

Time/frequency-domain orthogonality

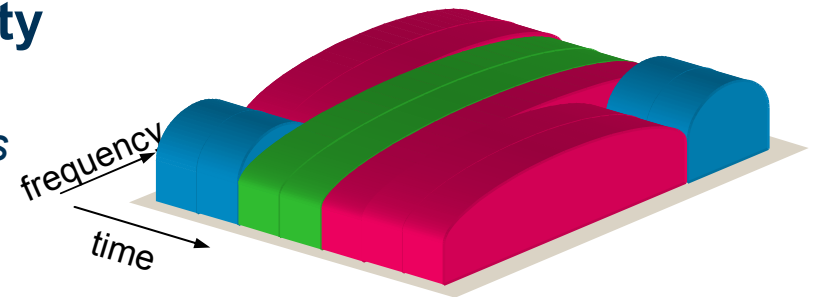
Only time-domain orthogonality

- *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*



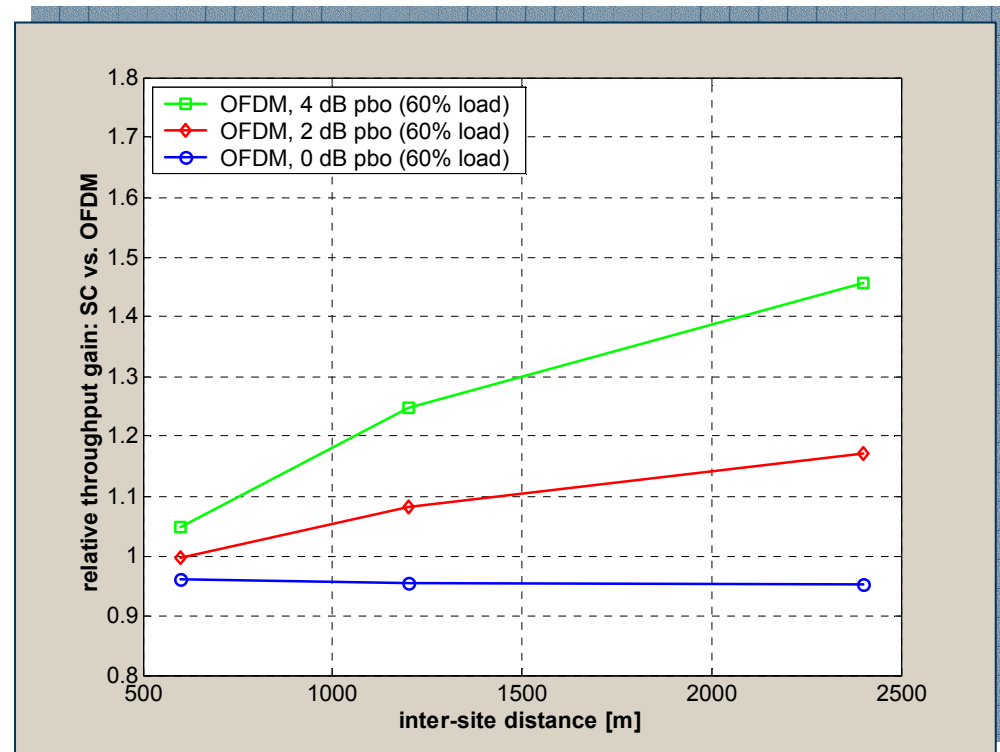
Why single-carrier transmission ?



- OFDM 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**

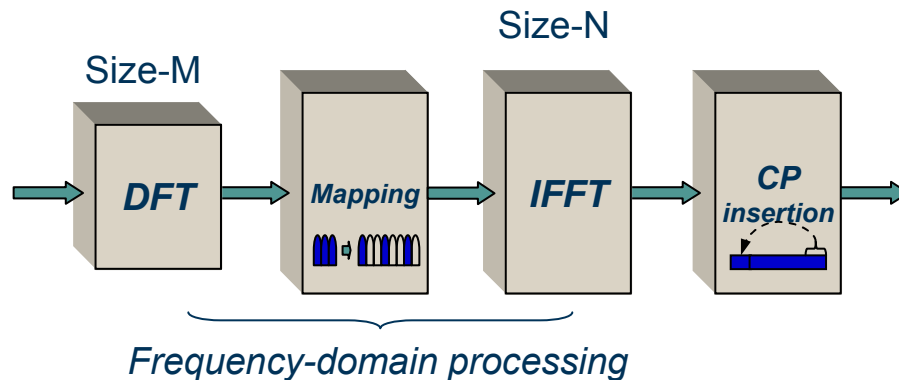
SC-FDMA vs. OFDM?

Relative throughput
Single-carrier vs. OFDM

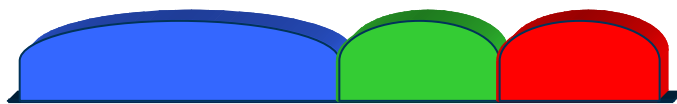


- Ignoring power-amplifier limitations OFDM has slight advantage
 - Assuming realistic power amplifier, single-carrier transmission has advantage especially in case of larger inter-site distance
- ⇒ ***Single-carrier transmission preferred due to coverage advantage***

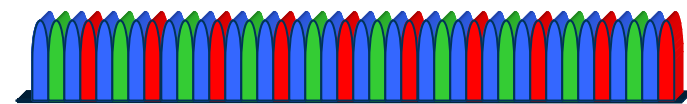
LTE SC-FDMA – *DFT-spread OFDM*



- Mapping to consecutive IFFT inputs ➔ “*Localized*” transmission
- Mapping to distributed IFFT inputs ➔ “*Distributed*” transmission



Localized transmission



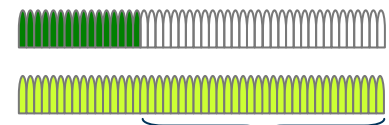
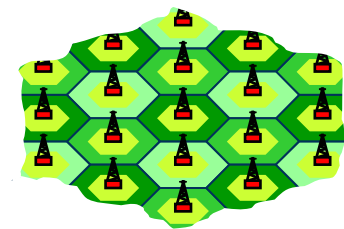
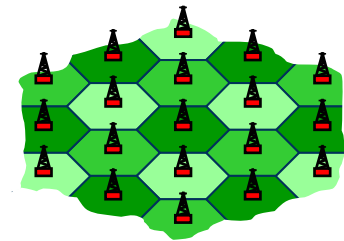
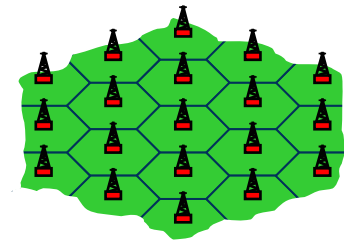
Distributed transmission

- 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



Reduced Tx power

3GPP LTE – Multi-antenna solutions

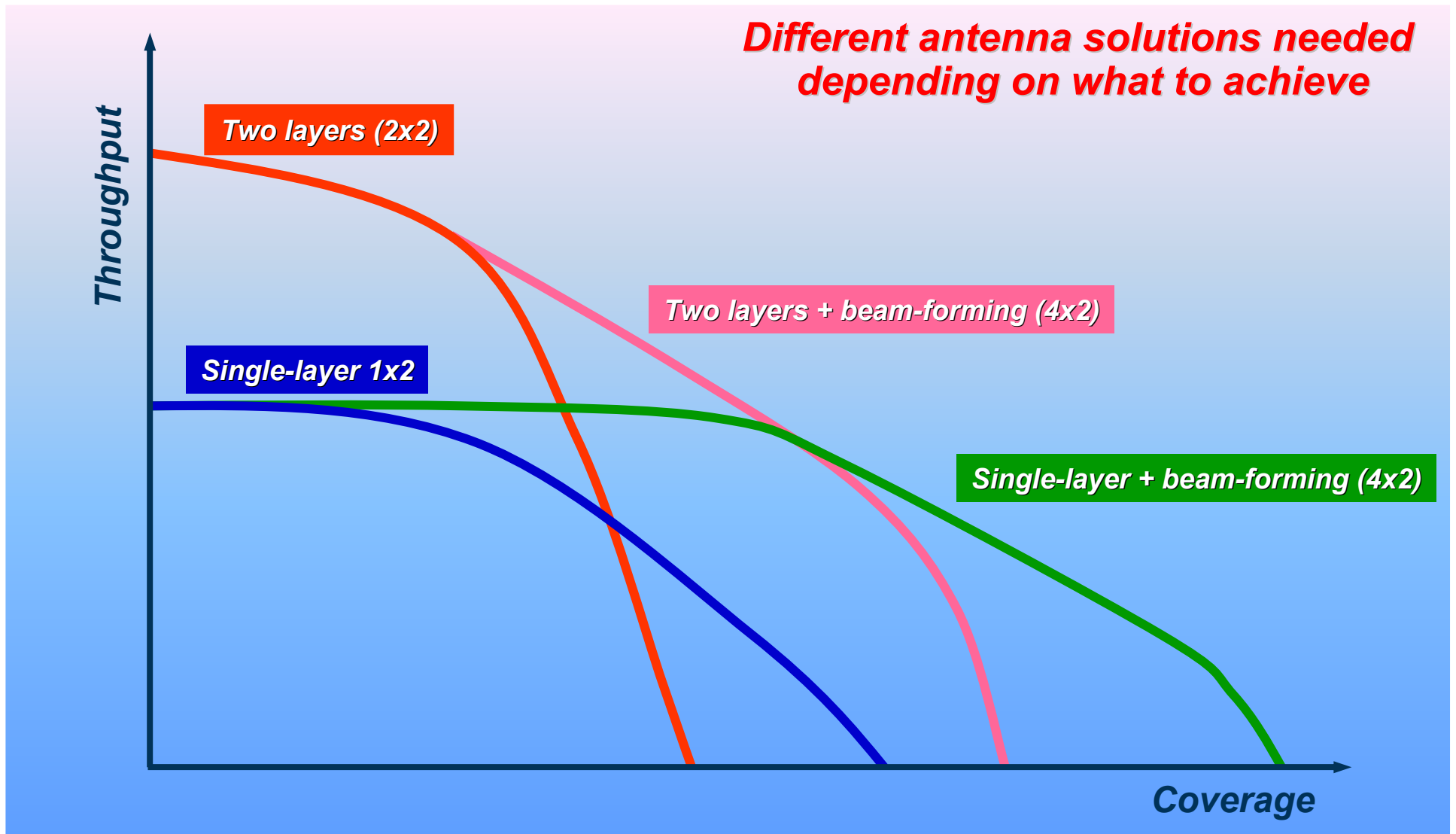
- LTE targets extreme performance in terms of
 - Capacity
 - Coverage
 - Peak data rates

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)

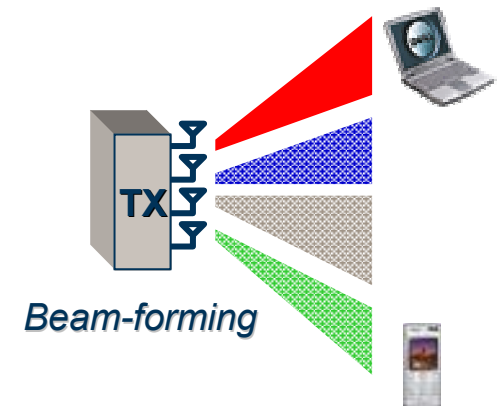
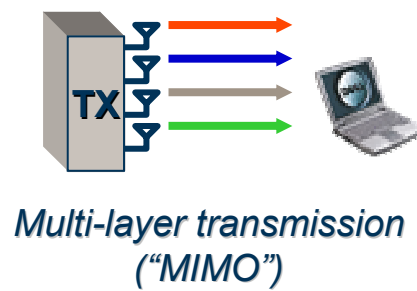


3GPP LTE – Advanced antenna solutions



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 \Rightarrow Spatial multiplexing
 - 2×2 , 2×4 , 4×4
 - *Rank adaptation \Rightarrow Single-layer beam-forming as special case*

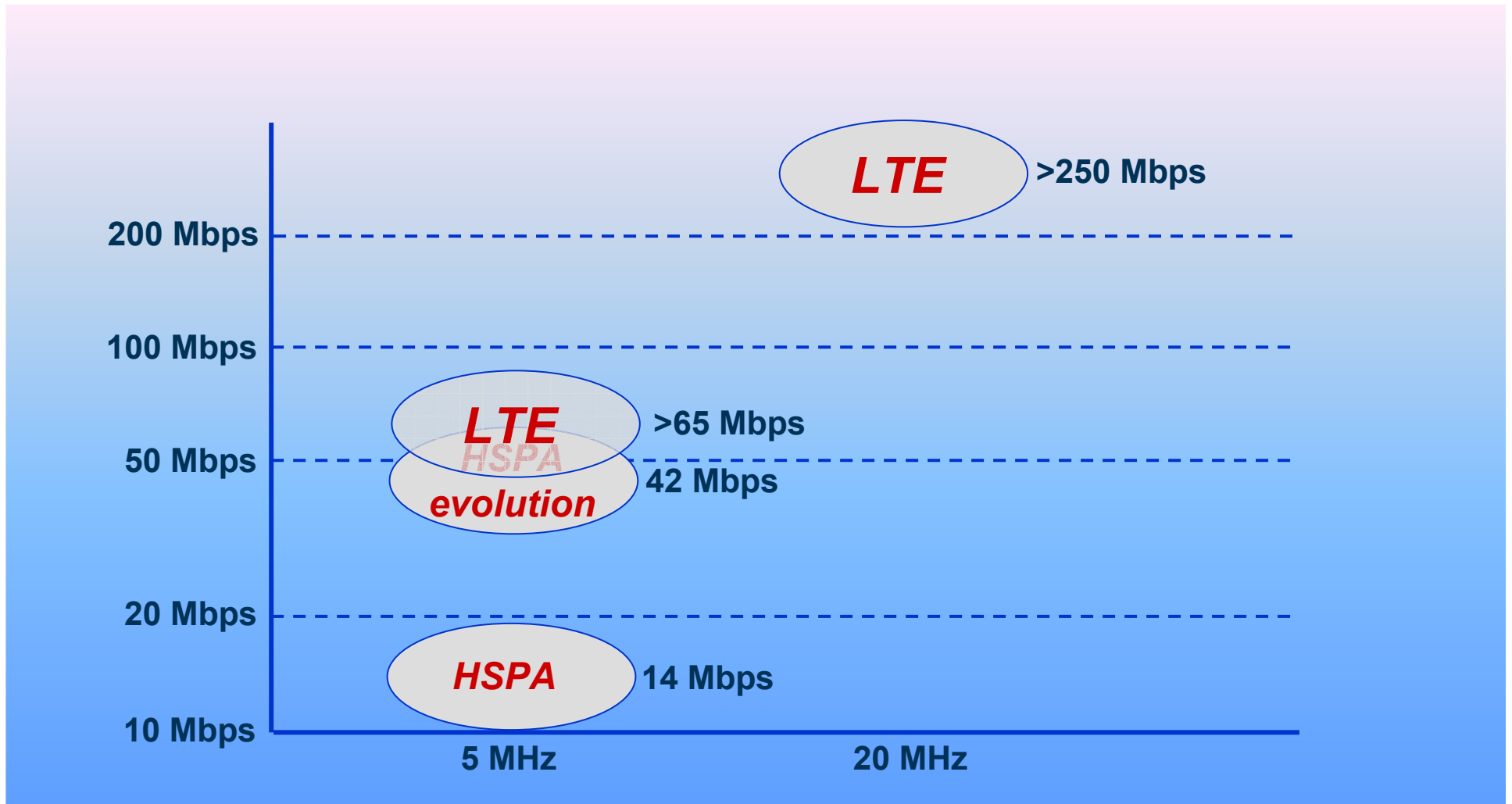


3G LTE – *Multicast/Broadcast*

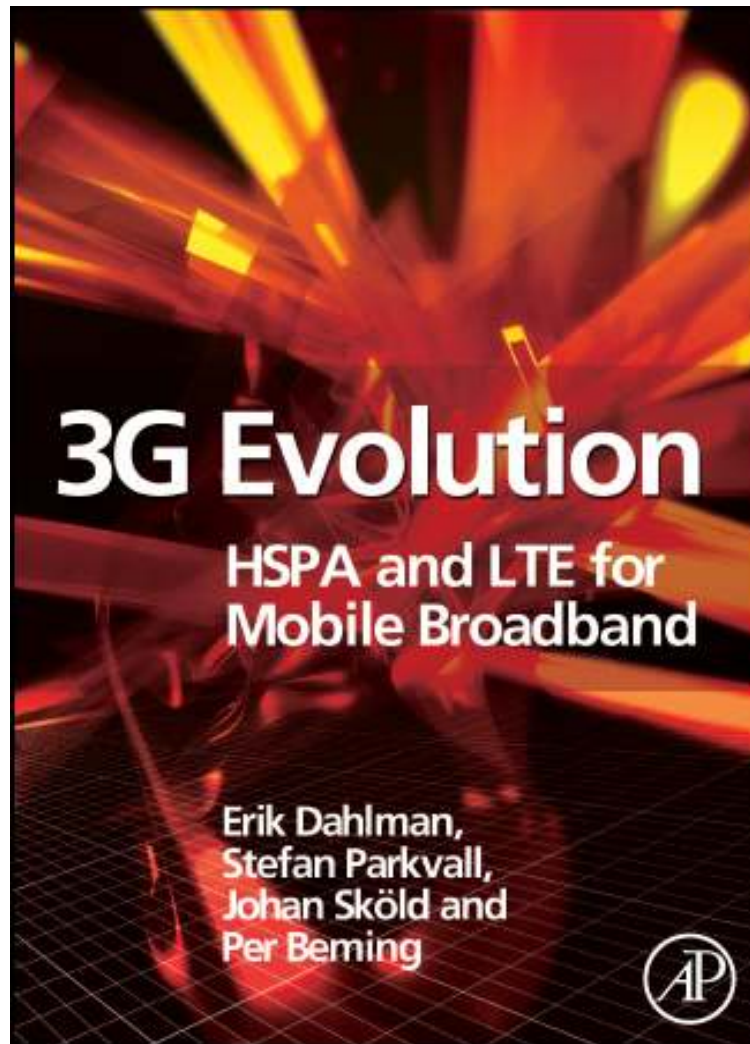
- MBMS – Multimedia Broadcast/Multicast Service
- OFDM allows for high-efficient MBSFN operation
 - *Multicast/Broadcast Single-Frequency Networking*
 - *Identical transmissions from set of tightly synchronized cells*
 - *Increased received power and reduced interference*
 - ⇒ **Substantial boost of 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 capabilities*



To learn more ...



Thank you for your attention!

erik.dahlman@ericsson.com