Exploring the Evolution of Wireless Technologies Towards 3G LTE

3G Mobile Broadband using HSPA and LTE

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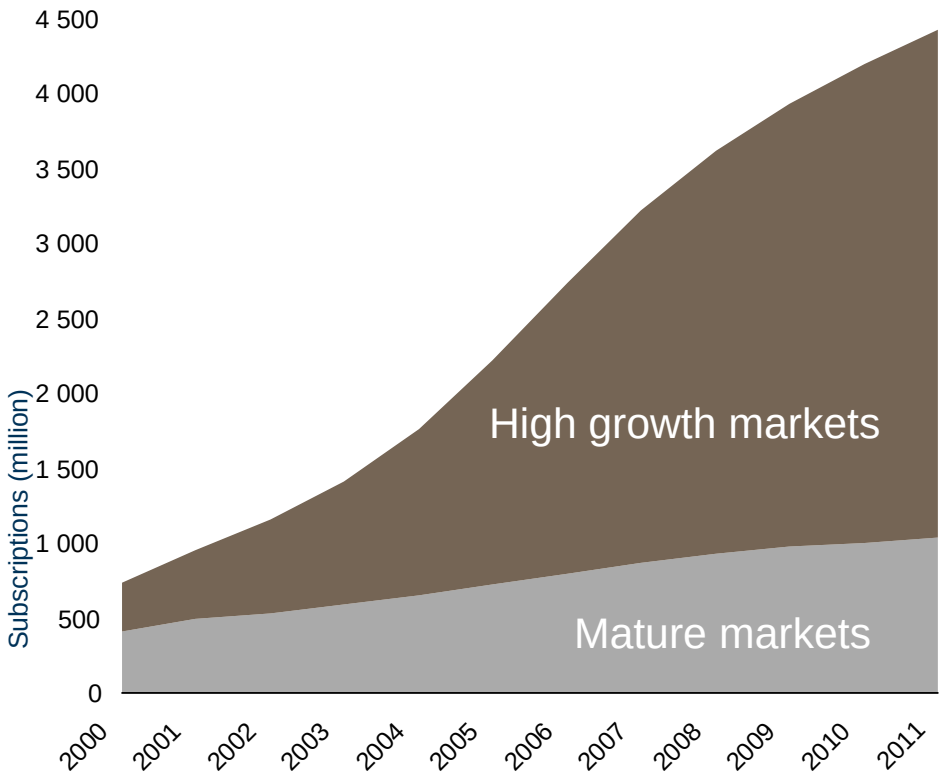
TAKING YOU FORWARD

Mobile Broadband is changing the industry

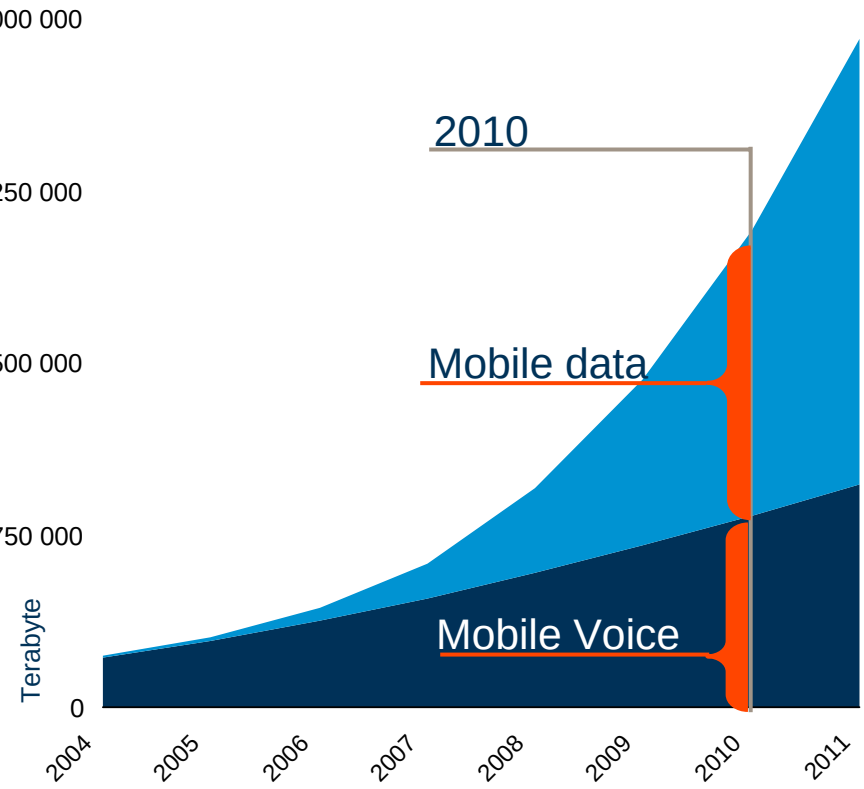
Just like mobile telephony once did

Mobile Broadband growth

Global cellular reported subscriptions



Traffic in mobile networks



Mobile data to pass voice 2010 ! (fixed data passed voice 2000)

The Mobile Broadband situation

- 3G HSPA (High Speed Packet Access) – 3GPP
  - 5 MHz carrier frequency
  - 14 Mbps user data rate – further evolving
  - Widely deployed in US (AT&T) and globally
  - Phones, Laptops, PC-cards, ...

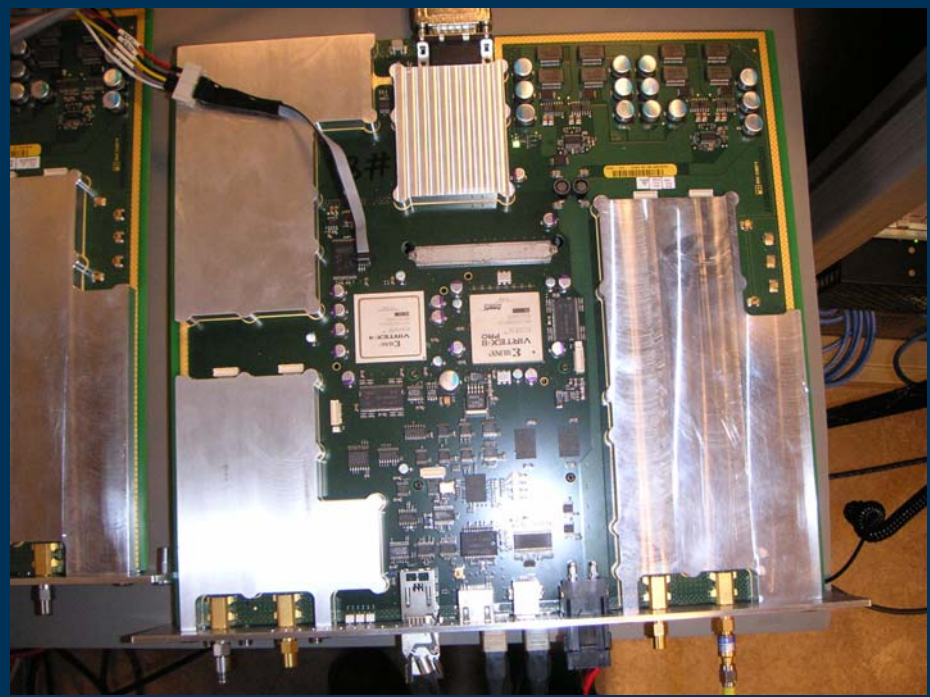
- 3G cdma2000 EV-DO (Data Only) – 3GPP2
  - 1.25 MHz carrier frequency
  - 3 Mbps user data rate – further evolving
  - Widely deployed in US (Verizon Wireless/Sprint) and globally
  - Phones, Laptops, PC-cards, ...

Next step: 3G LTE - Mainstream open standard with products 2009

3G LTE

The new RBS transciever board for 3G LTE

- 20 MHz carrier bandwidth
- 3G LTE modulation (OFDM)
- MIMO
- Covering LTE bandwidth up to 20 MHz

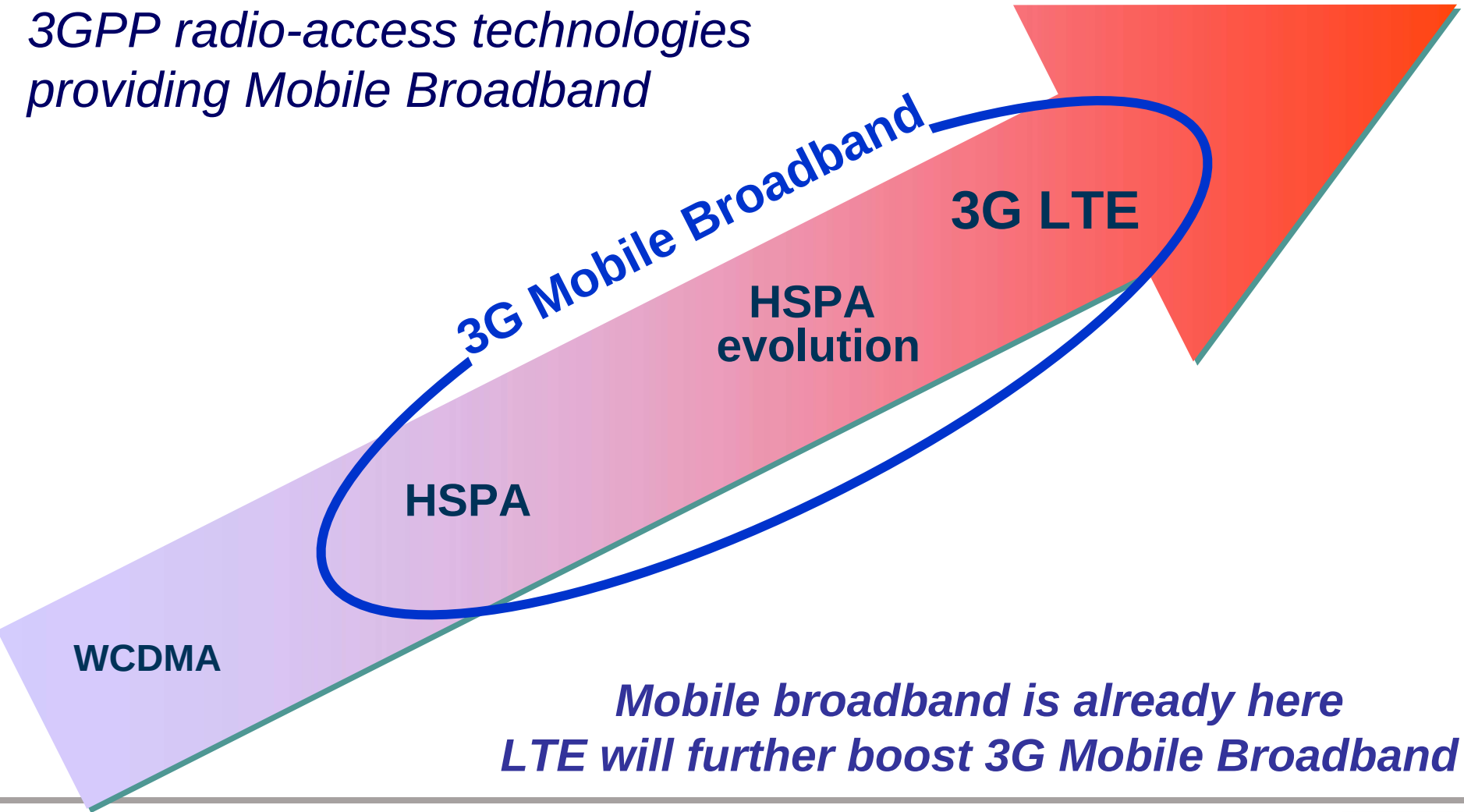


144 Mbps demonstrated in Barcelona early 2007

3G Mobile Broadband

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

3GPP radio-access technologies providing Mobile Broadband



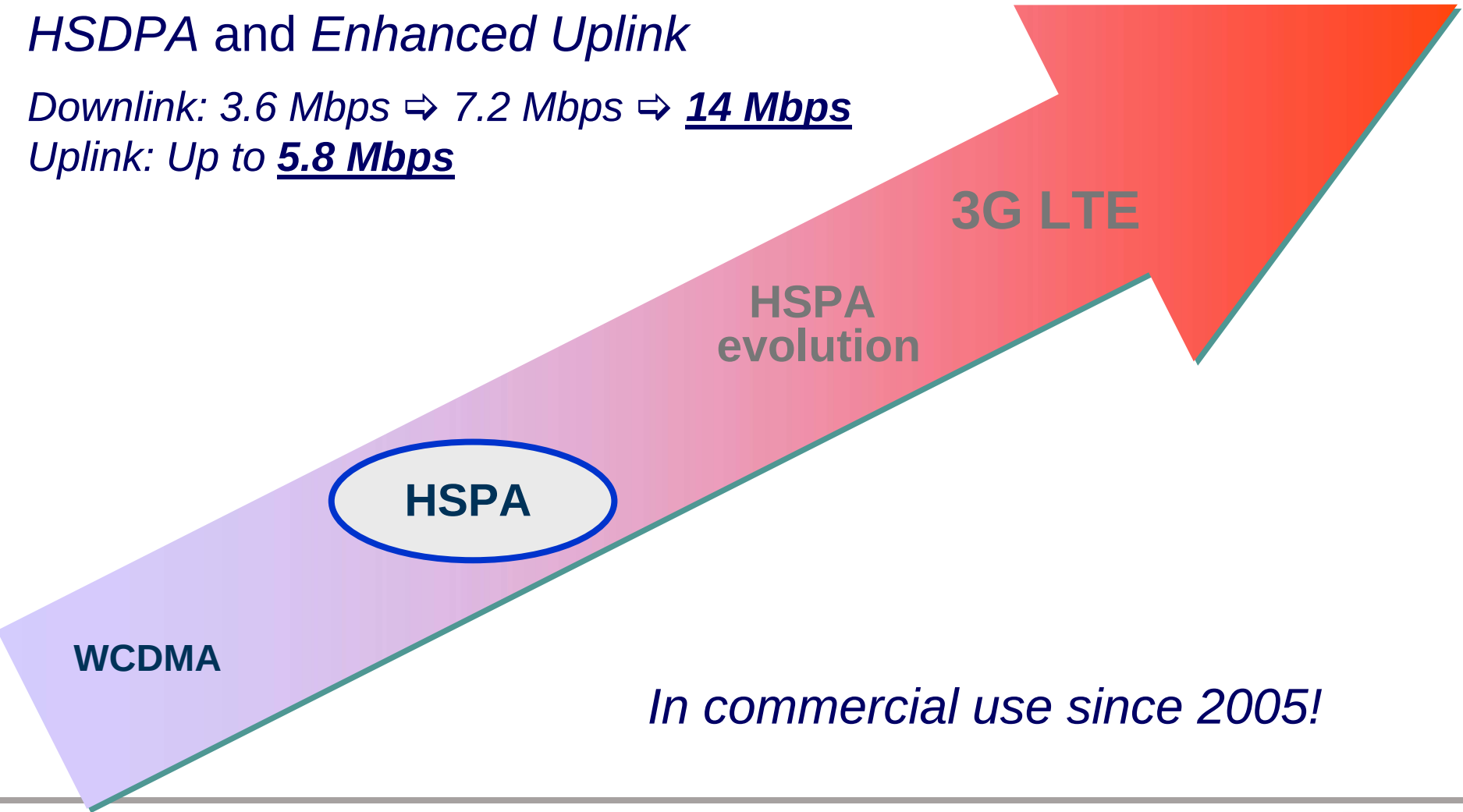
Mobile broadband is already here
LTE will further boost 3G Mobile Broadband

HSPA – *High Speed Packet Access*

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

HSDPA and *Enhanced Uplink*

Downlink: 3.6 Mbps ⇨ 7.2 Mbps ⇨ ***14 Mbps***
Uplink: Up to ***5.8 Mbps***



In commercial use since 2005!

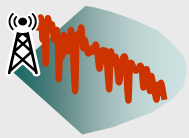
HSDPA and *Enhanced Uplink*

- *HSDPA (High Speed Downlink Packet Access)*
  - *Downlink data rates up to 14 Mbps*
  - *Higher downlink capacity (+100-200%)*
  - *Reduced latency (less than 75 ms RTT)*
  - *Higher average data rates*

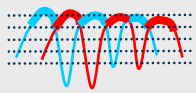
3GPP release 5

Higher-order modulation (16QAM)

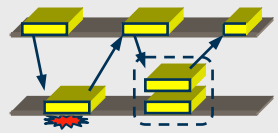
Link adaptation



Fast scheduling



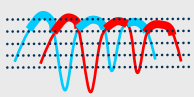
Hybrid ARQ with soft combining



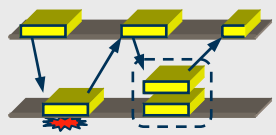
- *Enhanced Uplink (a.k.a. HSUPA)*
  - *Uplink data rates up to 5.8 Mbps*
  - *Higher uplink capacity (+50-100%)*
  - *Further reduced latency (less than 50 ms RTT)*
  - *Improved coverage*

3GPP release 6

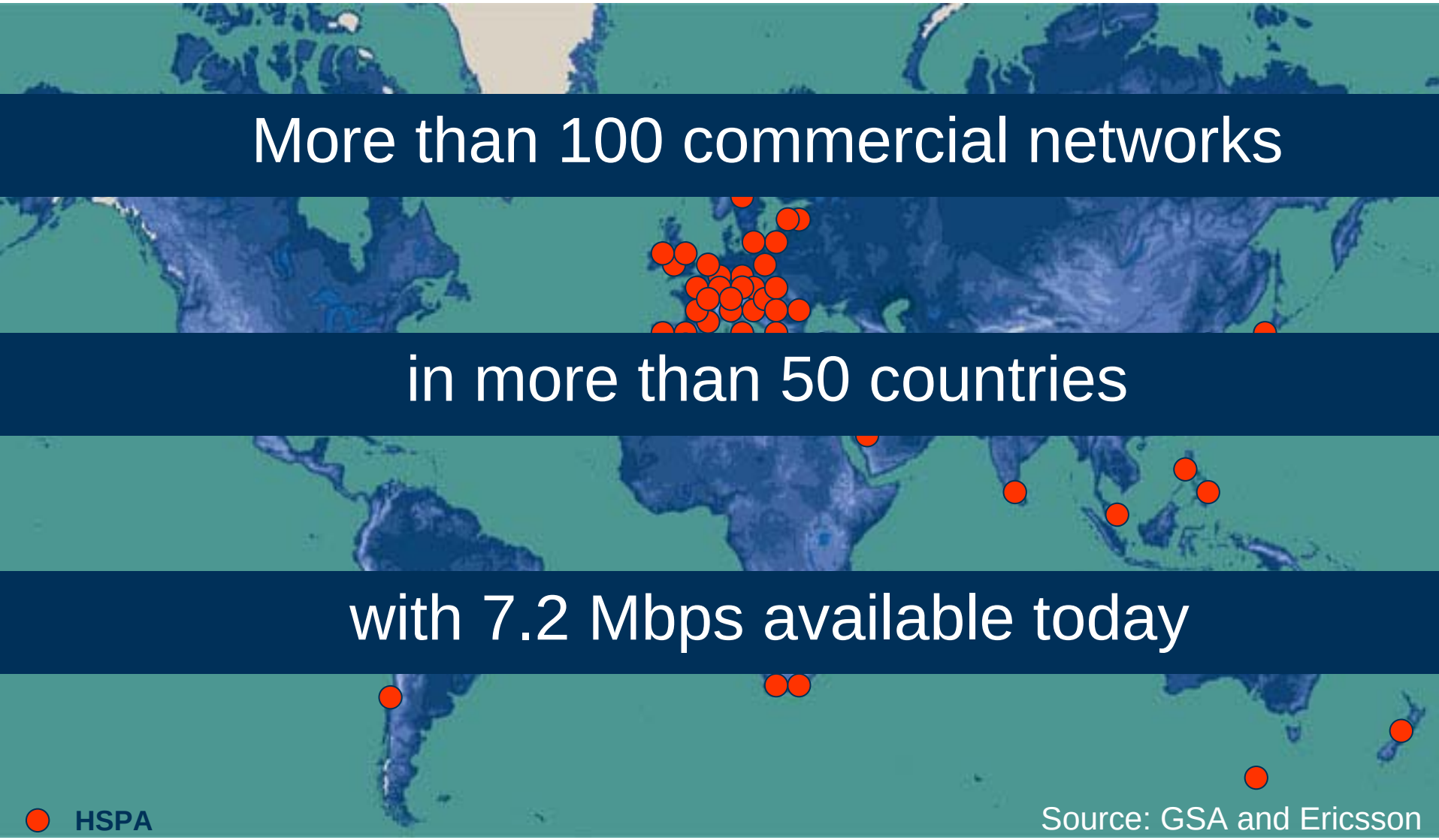
Fast scheduling



Hybrid ARQ with soft combining



HSPA deployment



HSPA – *End-user devices*

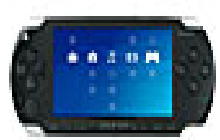
More than 100 HSPA-enabled devices available (end of 2006)

32 PC cards and modules

19 Modems

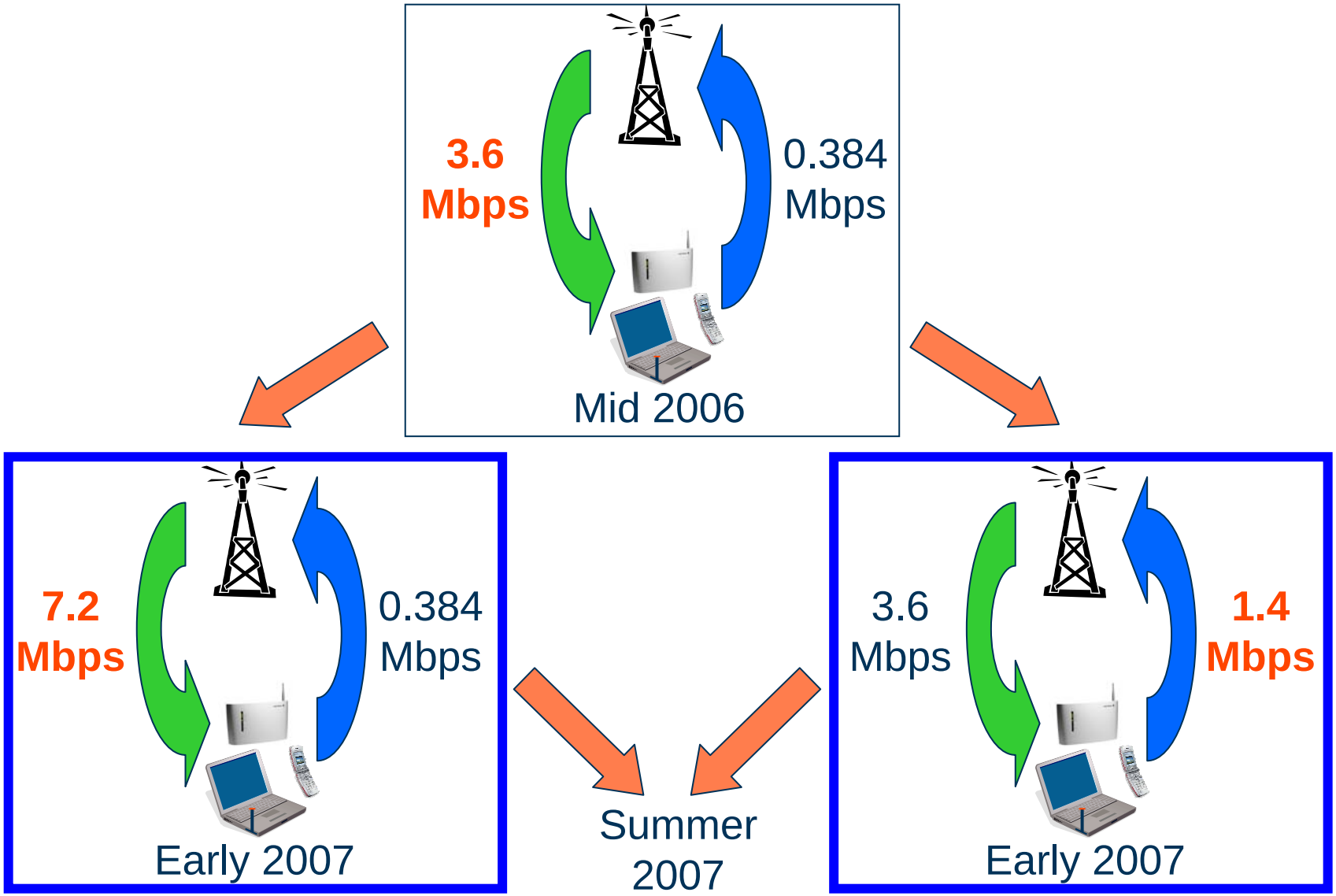
30 laptops

46 handsets



1 Personal media player

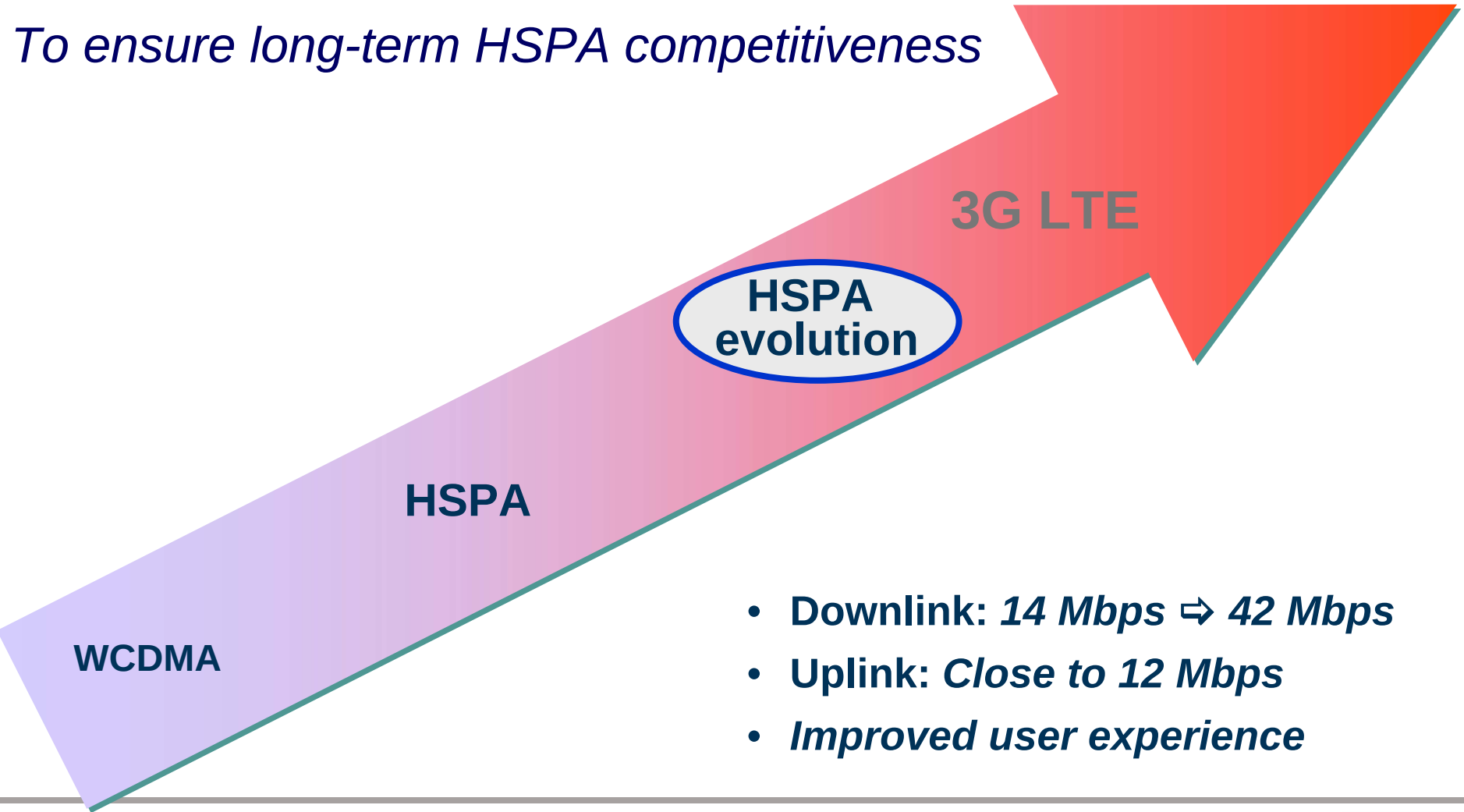
HSPA end-user devices – *Data rates*



HSPA evolution

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

To ensure long-term HSPA competitiveness

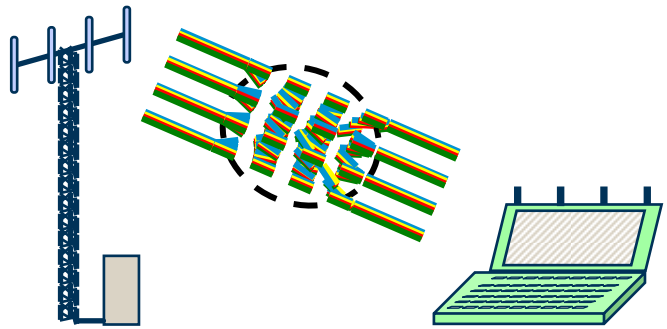


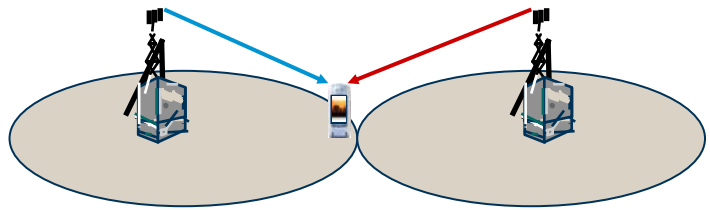
- **Downlink: *14 Mbps ⇨ 42 Mbps***
- **Uplink: *Close to 12 Mbps***
- ***Improved user experience***

HSPA evolution

- Higher-order modulation ✓
  - *Downlink – 64QAM*
  - *Uplink - 16QAM*
- MIMO, 2x2 downlink ✓
- "Continuous Packet Connectivity" ✓
- Enhanced Broadcast/Multicast

Specifications finalized





- ***Higher data rates***
- ***Higher capacity***
- ***Reduced user-experience latency / faster access***

Enhanced system performance and end user experience

HSPA evolution – *Data rates*

Downlink

3.6 Mbps

15 codes

14 Mbps

64QAM | 2x2 MIMO

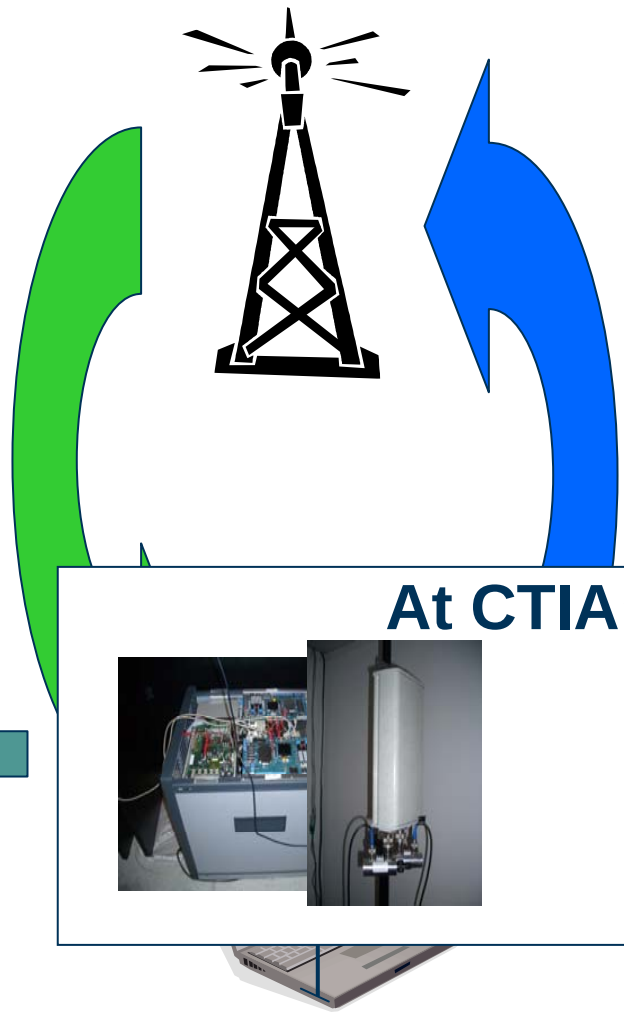
21 Mbps | 28 Mbps

Both

42 Mbps

4x4 MIMO

80 Mbps



At CTIA'06

Uplink

0.384 Mbps

HSPA on the uplink

1.4 Mbps

2 ms TTI

5.8 Mbps

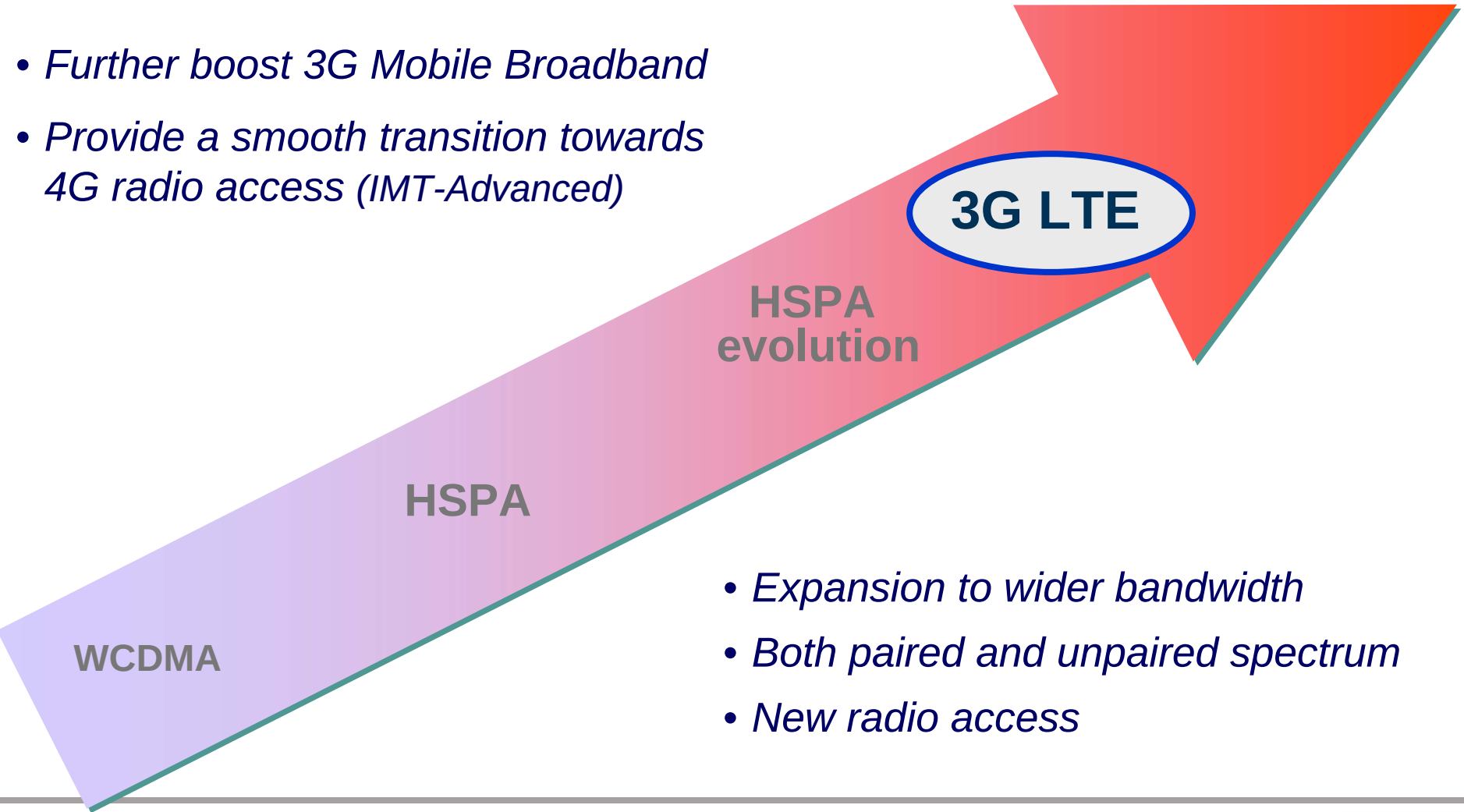
16QAM

12 Mbps

3G Long Term Evolution

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

- *Further boost 3G Mobile Broadband*
- *Provide a smooth transition towards 4G radio access (IMT-Advanced)*



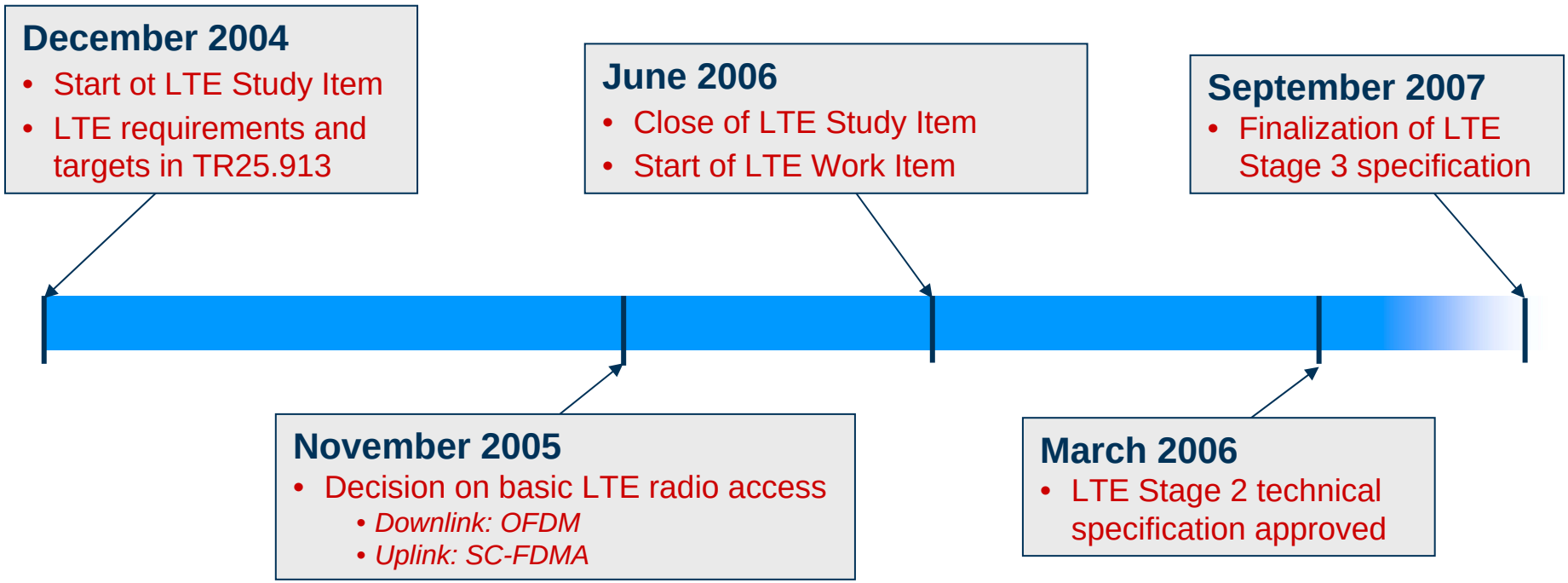
- *Expansion to wider bandwidth*
- *Both paired and unpaired spectrum*
- *New radio access*

3G LTE – *Requirements and targets*

- ***Defined in 3GPP TR25.913 (end 2004)***

- **Very high data rates**
  - *Downlink: More than 100 Mbps / Uplink: More than 50 Mbps*
  - *Improved cell-edge user throughput*
- **Very low latency**
  - *Less than 10 ms (User-plane RAN RTT)*
  - *Less than 50 ms (Control plane dormant → active)*
- **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/future 3G/HSPA systems**

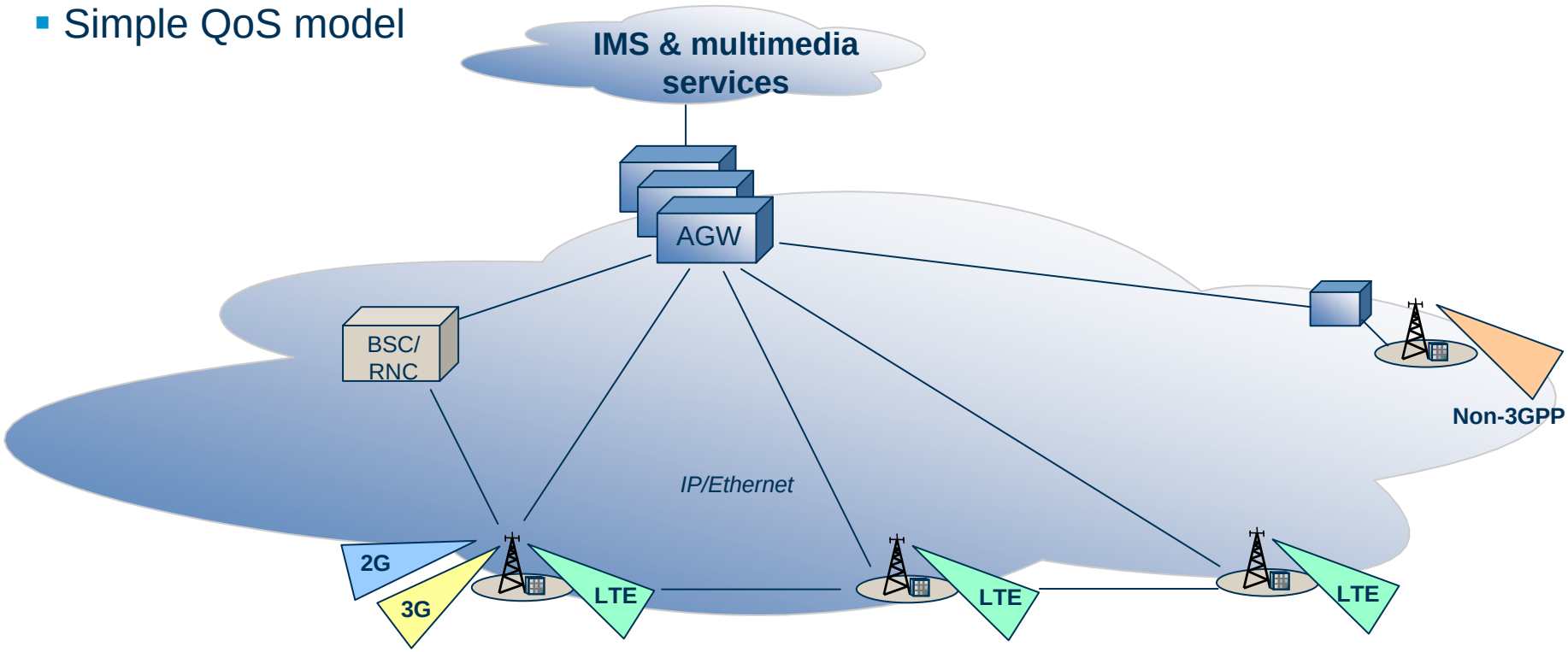
3G LTE – *3GPP time line*



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

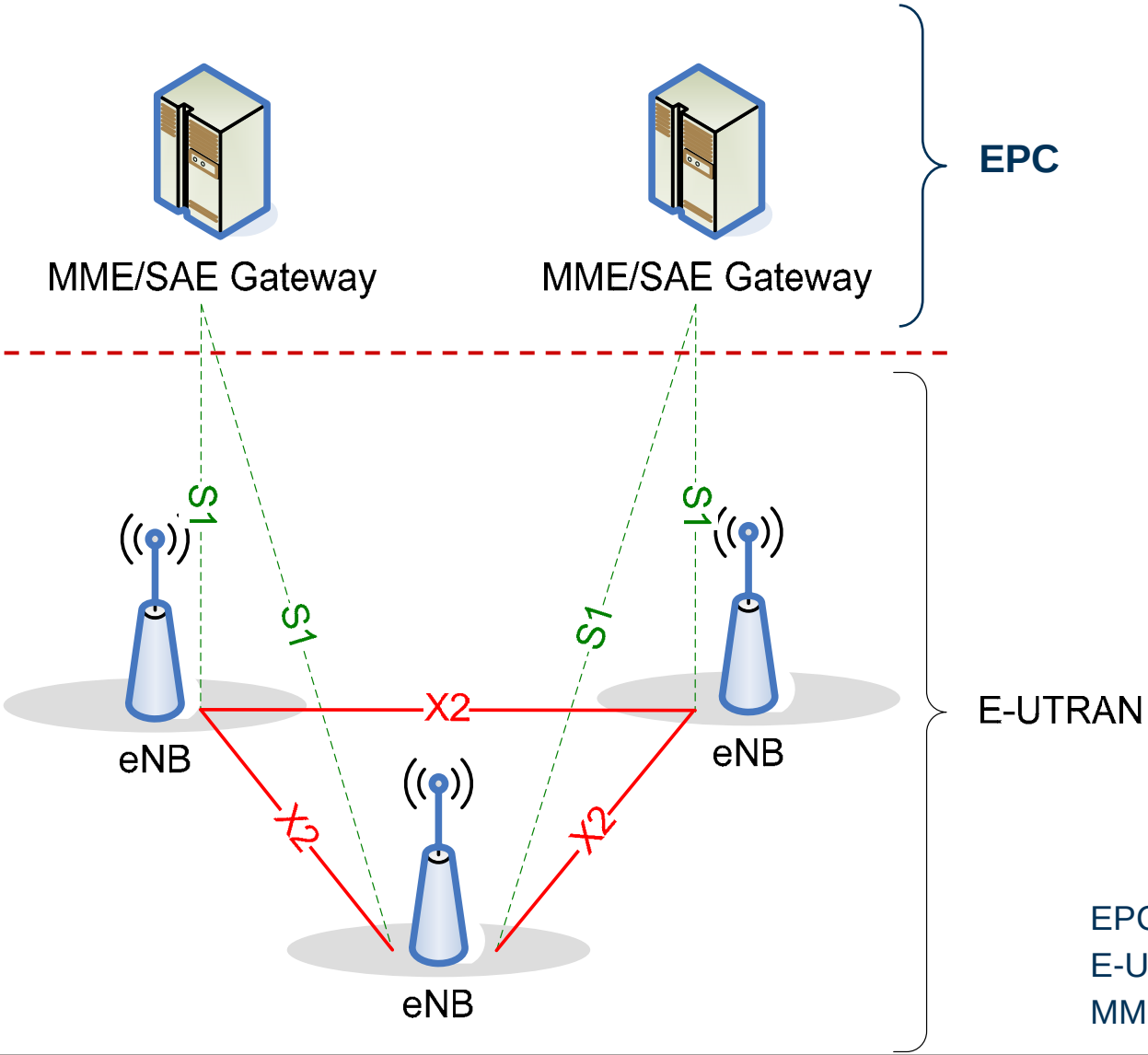
3GPP SAE/LTE Architecture

- Flat 2-node architecture
- Efficient interworking with 2G/3G
- Allowing reuse of key operator assets
- High level of security
- Simple QoS model



Note: "GW" corresponds to 3GPP anchor+SAE anchor+UPE

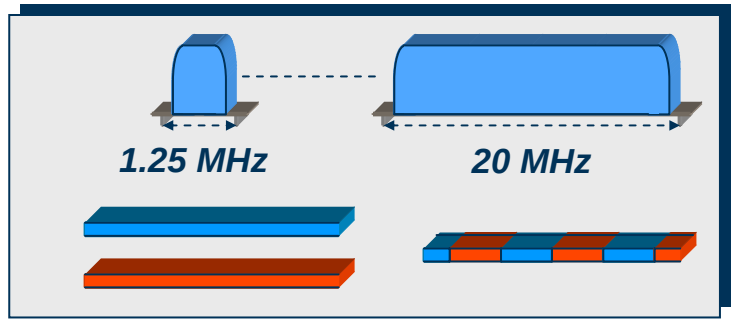
LTE/SAE Architecture – 3GPP terms...



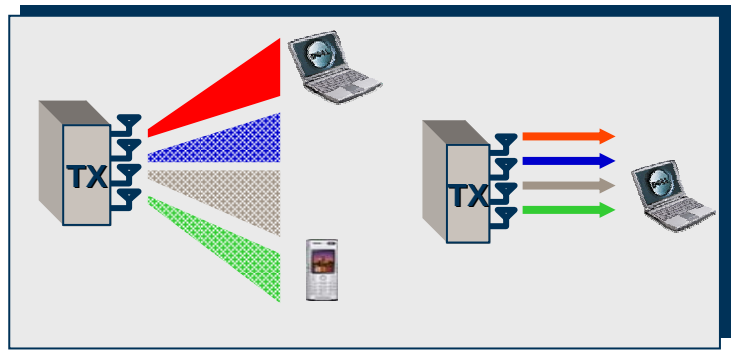
EPC: *Evolved Packet Core*
E-UTRAN: *LTE Radio Access Network*
MME: *Mobility Management Entity*

3G LTE – *Key radio-access features*

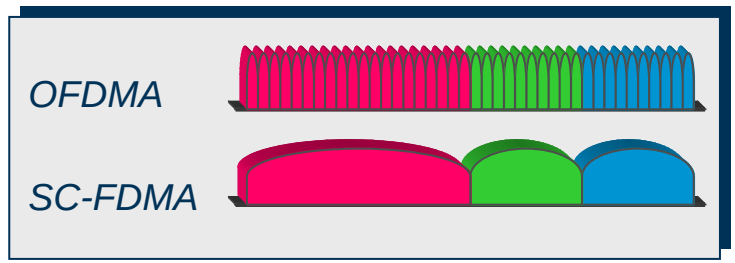
- **Spectrum flexibility**
  - *Flexible bandwidth*
  - *Duplex flexibility*



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



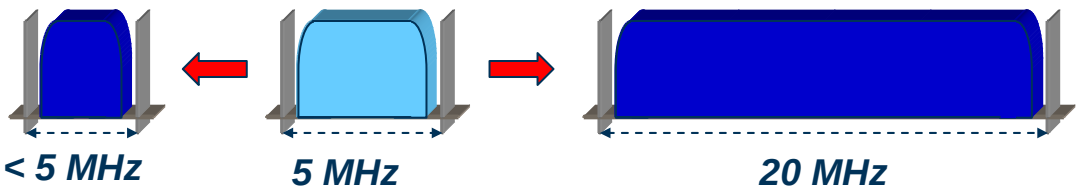
- **LTE radio access**
  - *Downlink: OFDM*
  - *Uplink: SC-FDMA*



3G LTE – *Spectrum flexibility*

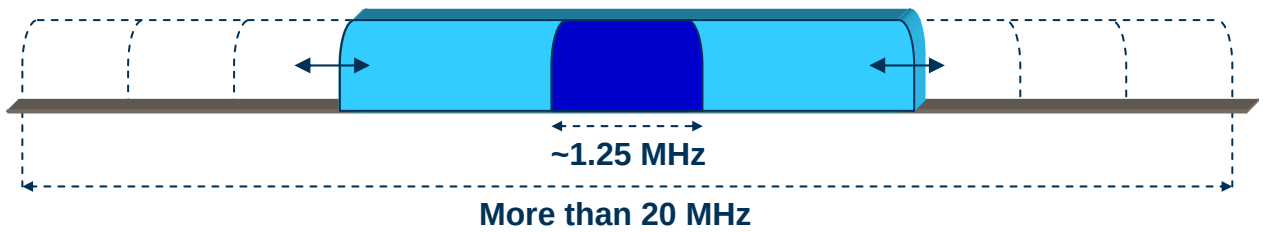
- Allow for operation in a wide range of different spectrum
  - *Current and future 3G spectrum (2 GHz, 2.6 GHz, …)*
  - *Migration of 2G spectrum*
  - *Re-farming of other spectrum, e.g. digital dividend*
- Unknown size of future spectrum allocations
- Efficient operation in differently-sized spectrum 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 discrete increments



- In practice a limited set of bandwidths will be supported
  - *Due to RF limitations*
  - *Examples 1.25 MHz, 1.8 MHz, 2.5 MHz, 5 MHz, 10 MHz, 20 MHz*
- ... but straighforward to extend specification to additional bandwidths
  e.g. to match new spectrum assignments

All LTE terminals support maximum cell bandwidth

3G LTE – *Duplex arrangement*

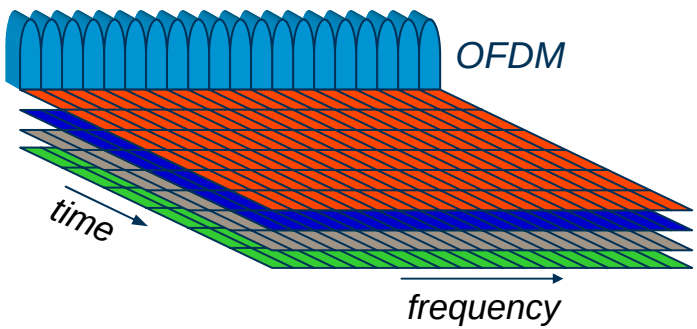
- **FDD:** *Simultaneous downlink/uplink transmission in separate frequency bands*
  - *Need for paired spectrum*
  - *Used in all commercial cellular systems*
- **TDD:** *Non-overlapping downlink/uplink transmisson in the same frequency band*
  - *Deployment in single (unpaired) spectrum*
  - *Need for tight inter-cell synchronization/coordination*
  - *Reduced coverage due to non-continuous transmission*

- ***FDD preferred if paired spectrum available***
- ***TDD as complement to support deployment in unpaired spectrum***

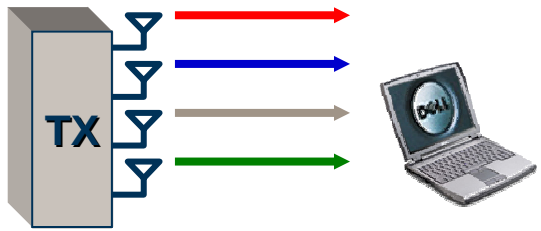
- *Maximum commonality between FDD and TDD to ensure TDD terminal availability*

3G LTE – *Downlink radio access*

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

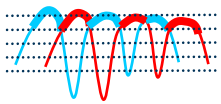


Multi-layer transmission

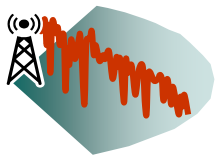


Frequency-domain channel adaptation

- Select user and data rate based on *instantaneous* channel quality
- Time-domain scheduling/adaptation already in HSPA



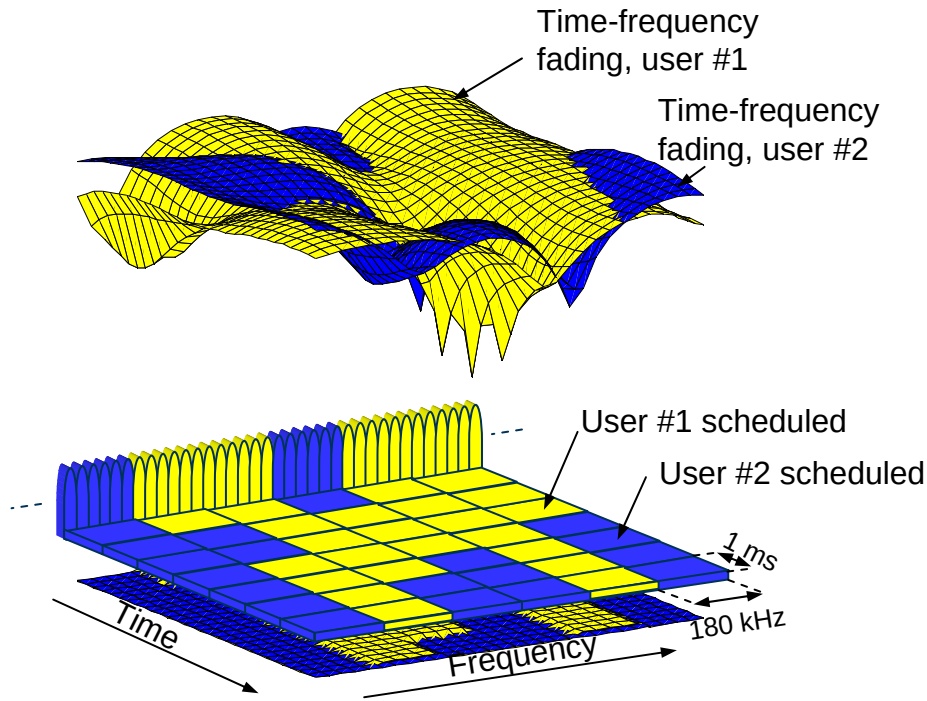
Channel-dependent scheduling



Link adaptation

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

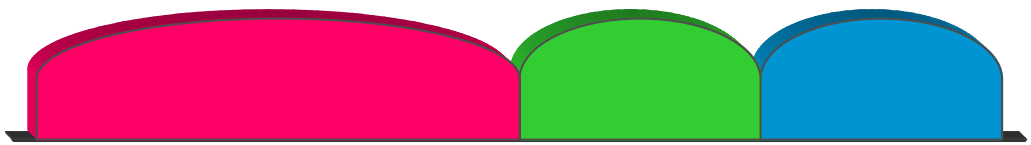
LTE: Additional scheduling/adaptation in the ***frequency*** domain



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, …)*

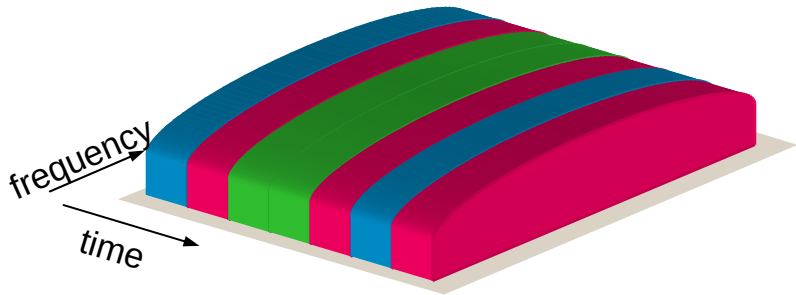


SC-FDMA

Time/frequency-domain orthogonality

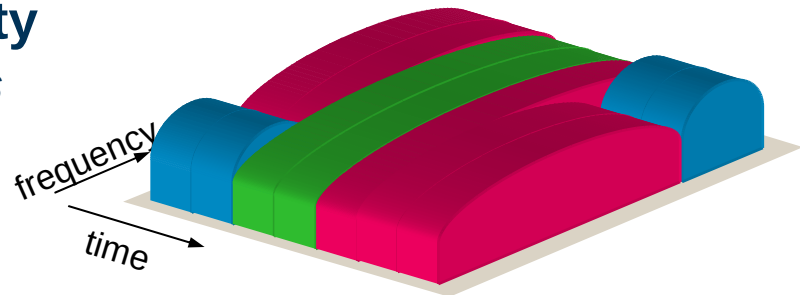
Only time-domain orthogonality

- *Entire bandwidth assigned to one user at a time*
  ➡ *High peak data rates*
- *Potentially inefficient for small payloads and power-limited user terminals*



Additional frequency-domain orthogonality

- *Overall bandwidth can be shared by multiple users by means of FDMA*
- *Efficient support for small payloads and power-limited user terminals*
- *Variable instantaneous transmit bandwidth*



OFDM or SC-FDMA?

OFDM

or

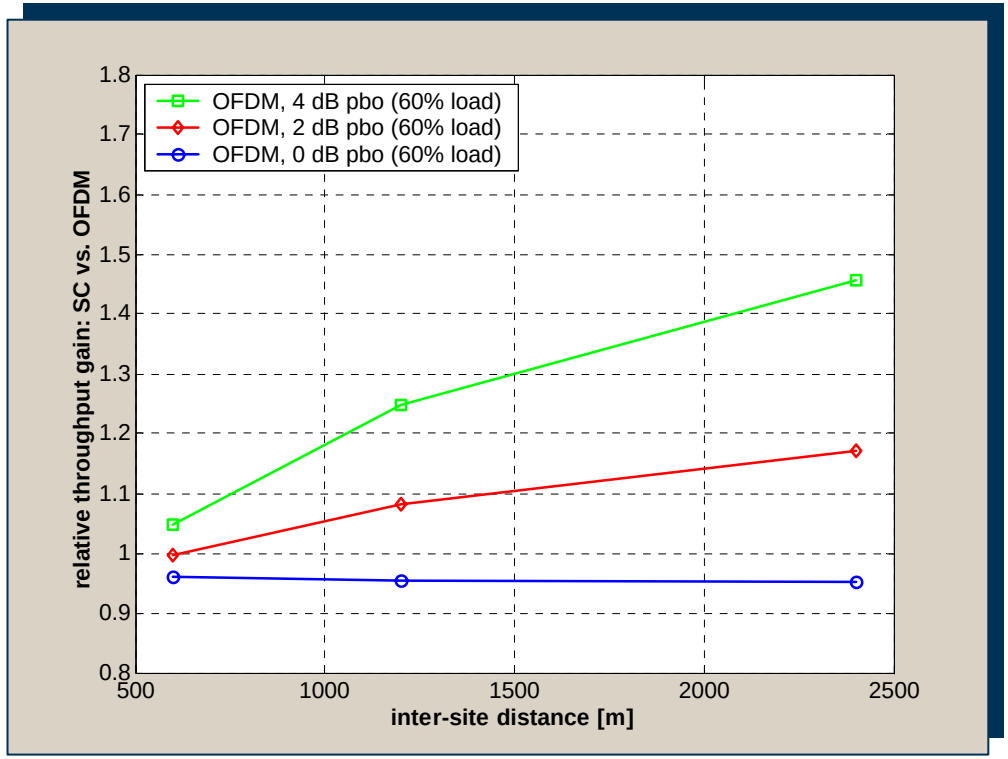
SC-FDMA

- 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*

  } ⇨ ***SC-FDMA***

OFDM or SC-FDMA?

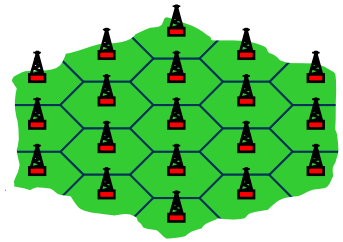


- Ignoring power-amplifier limitations OFDM has slight advantage
- Assuming realistic power amplifier, SC-FDMA has advantage especially in noise-limited scenarios

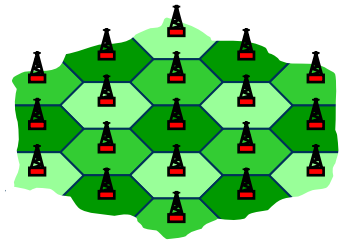
⇨ ***Superior performance with SC-FDMA due to coverage advantage***

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

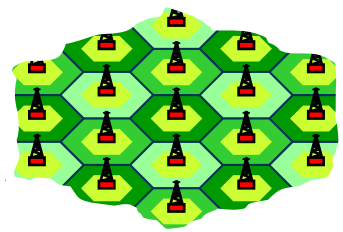
- High data rates in limited spectrum allocations
  - *Entire spectrum must be available in each cell*
    ➡ *One-cell frequency reuse*



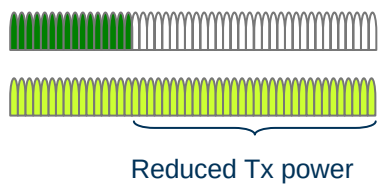
- Reduced inter-cell interference with frequency reuse > 1
  - *Improved cell-edge SIR ➡ Higher cell-edge data rates*



- 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*

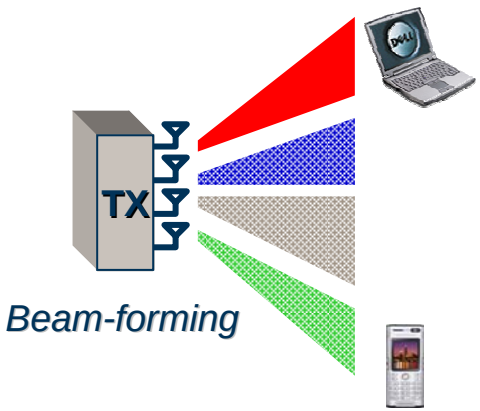


3GPP LTE – *Multi-antenna solutions*

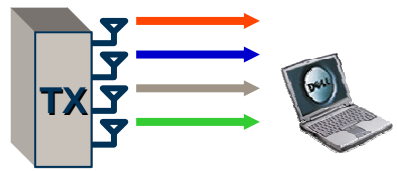
- LTE targets extreme performance in terms of
  - *Capacity*
  - *coverage*
  - *Peak data rates*

  *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)*

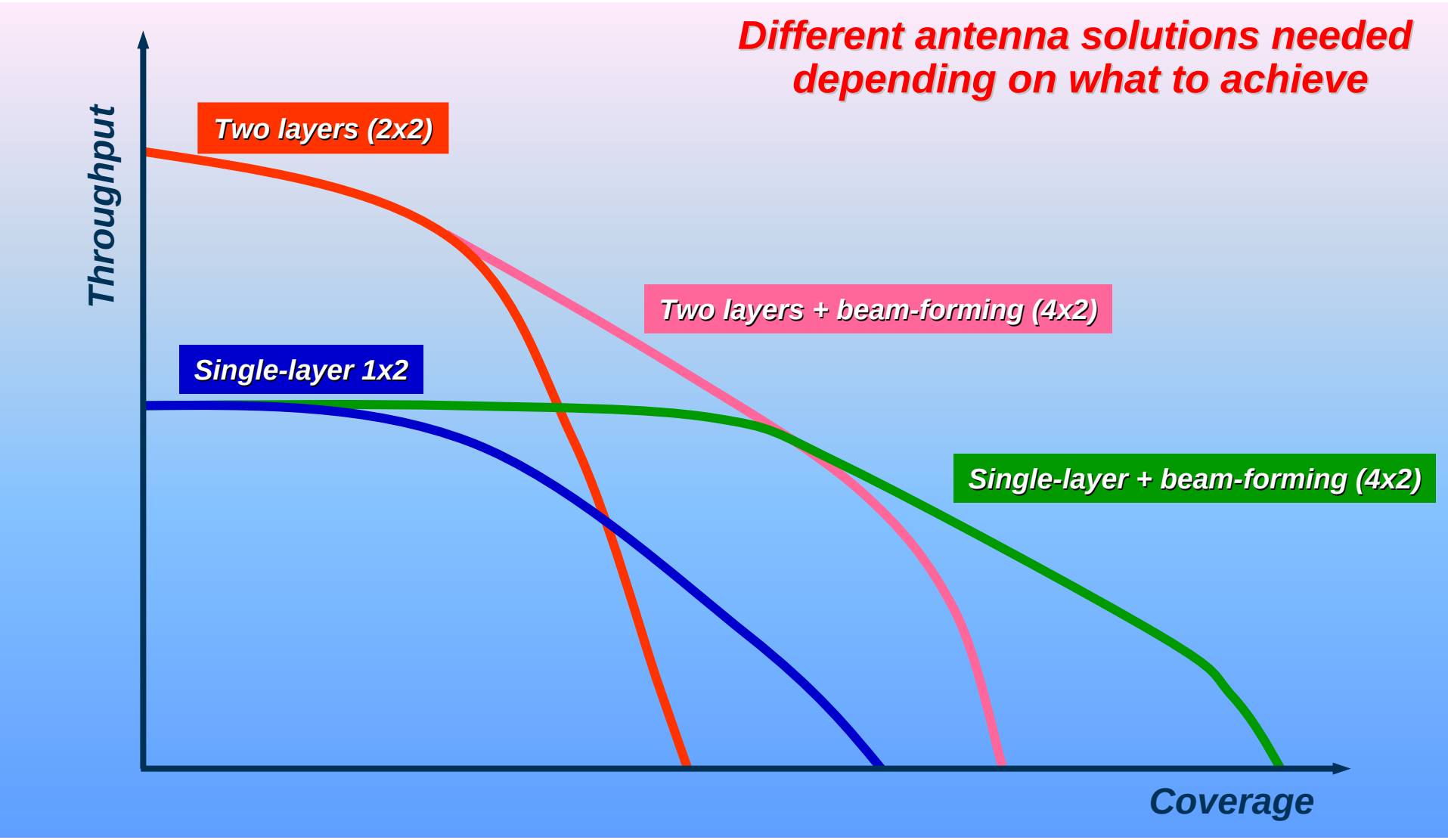


Beam-forming



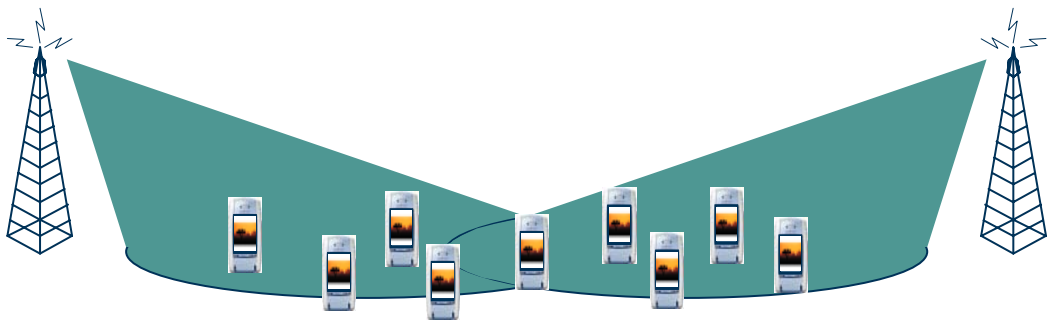
Multi-layer transmission ("MIMO")

3GPP LTE – *Advanced antenna solutions*

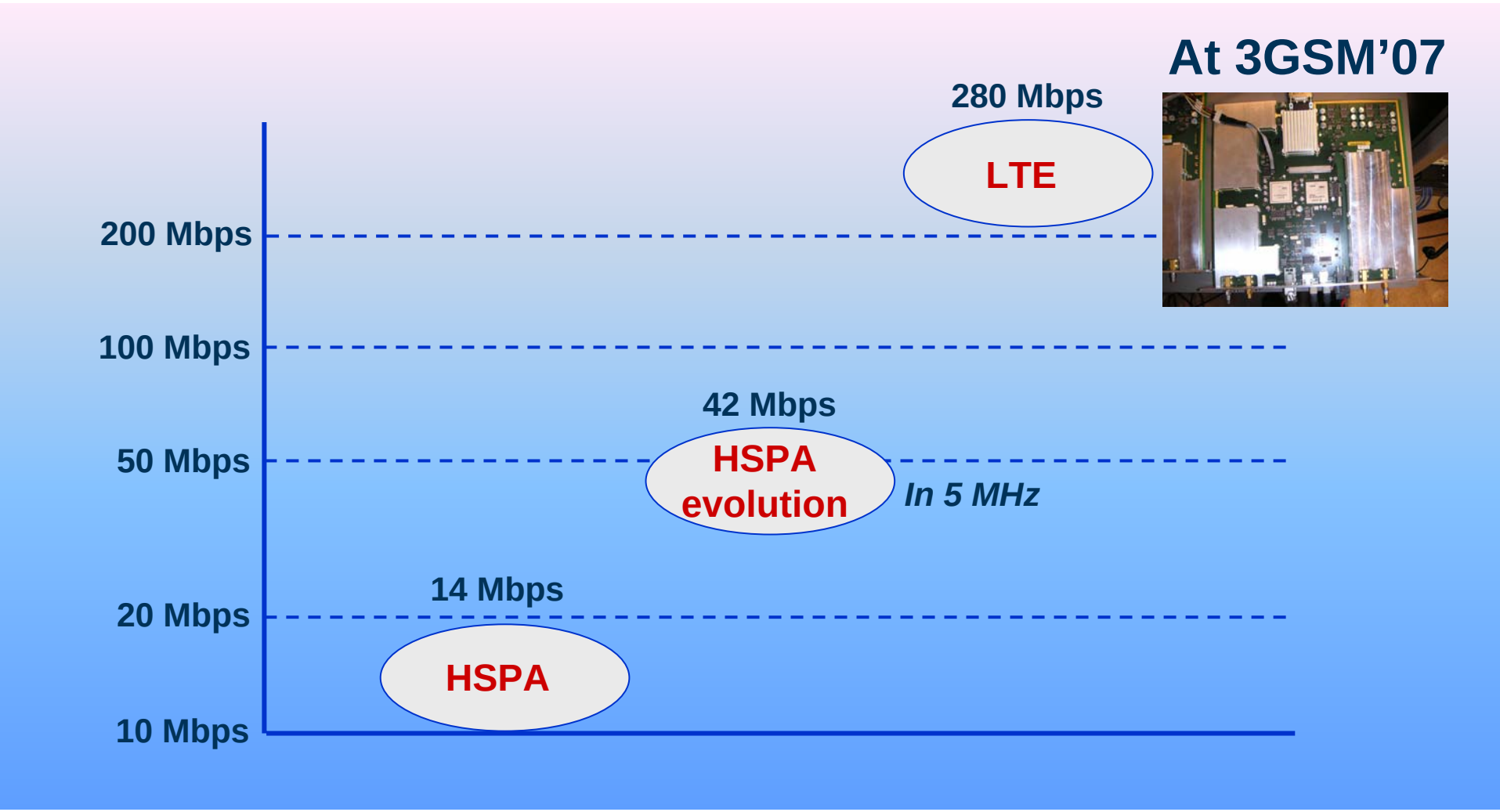


3G LTE – *Multicast/Broadcast*

- MBMS – Multimedia Broadcast/Multicast Service
- OFDM allows for high-efficient MBSFN operation
  - *Multicast/Broadcast Single-Frequency Networking*
  - *Identical transmissions from tightly synchronized neighbour 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



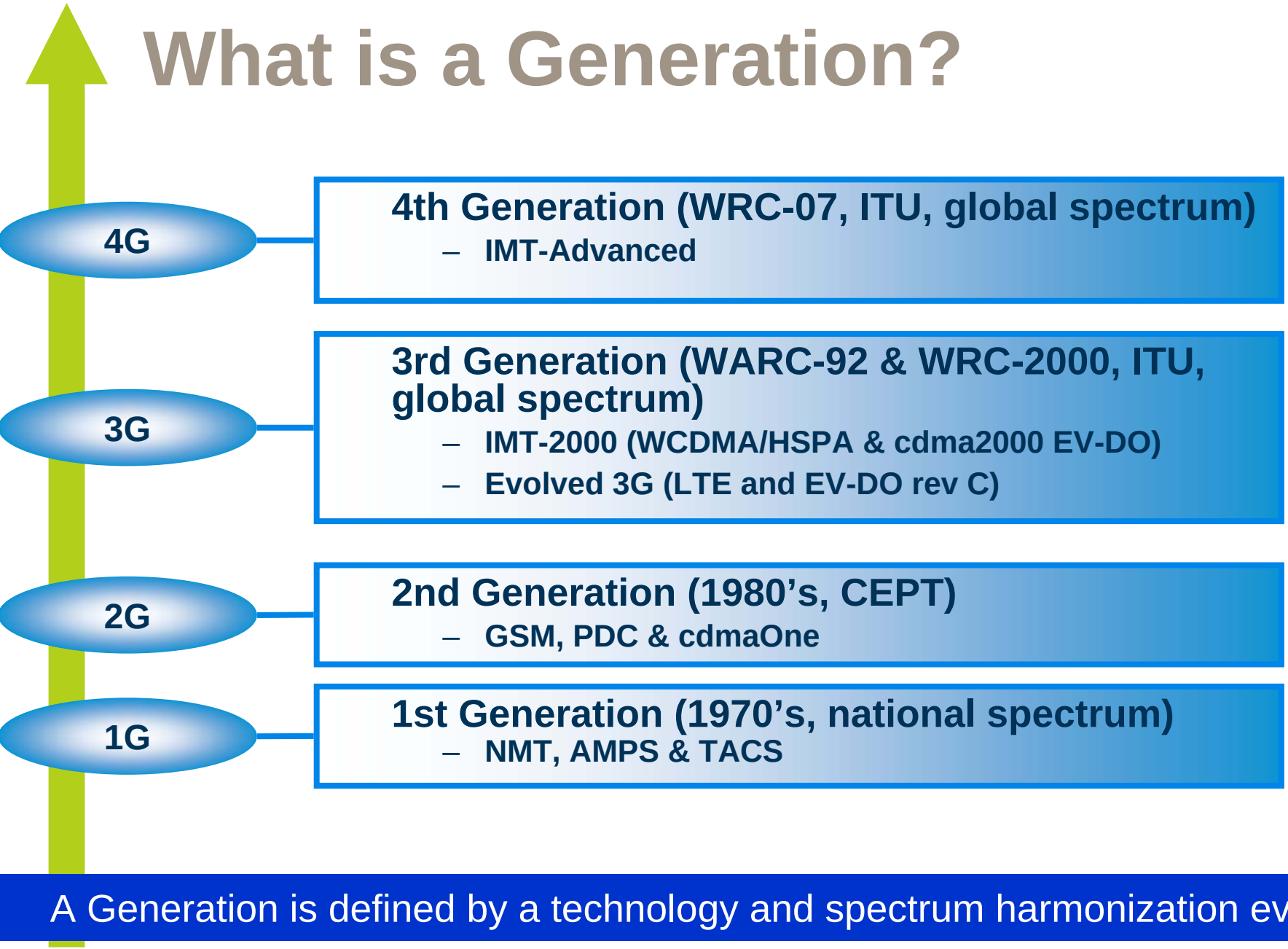
HSPA and LTE – *Data rate capabilites*



Which technologies are 4G?

- The most accepted definition of 4G is the ITU definition of IMT Advanced, which states among other things a capability of above 100 Mbps for wide area coverage
- Ericsson is demonstrating 3G LTE above 100 Mbps in full mobility, thereby meeting these 4G requirements, and in this respect making LTE a 4G technology
- This is not the case for existing 3G technologies such as HSPA. WiMAX will also be on par with HSPA.

What is a Generation?



A Generation is defined by a technology and spectrum harmonization event

Harmonization

- essential to a mass-market industry

international harmonization of spectrum is exceptionally important:

- provides the necessary **clarity** and **confidence** to the industry to **invest**;
- awards a **transparent** regulatory approach:
- provides adaptable and flexible usage **on a national level**, as spectrum allocations are **sovereign decisions**;

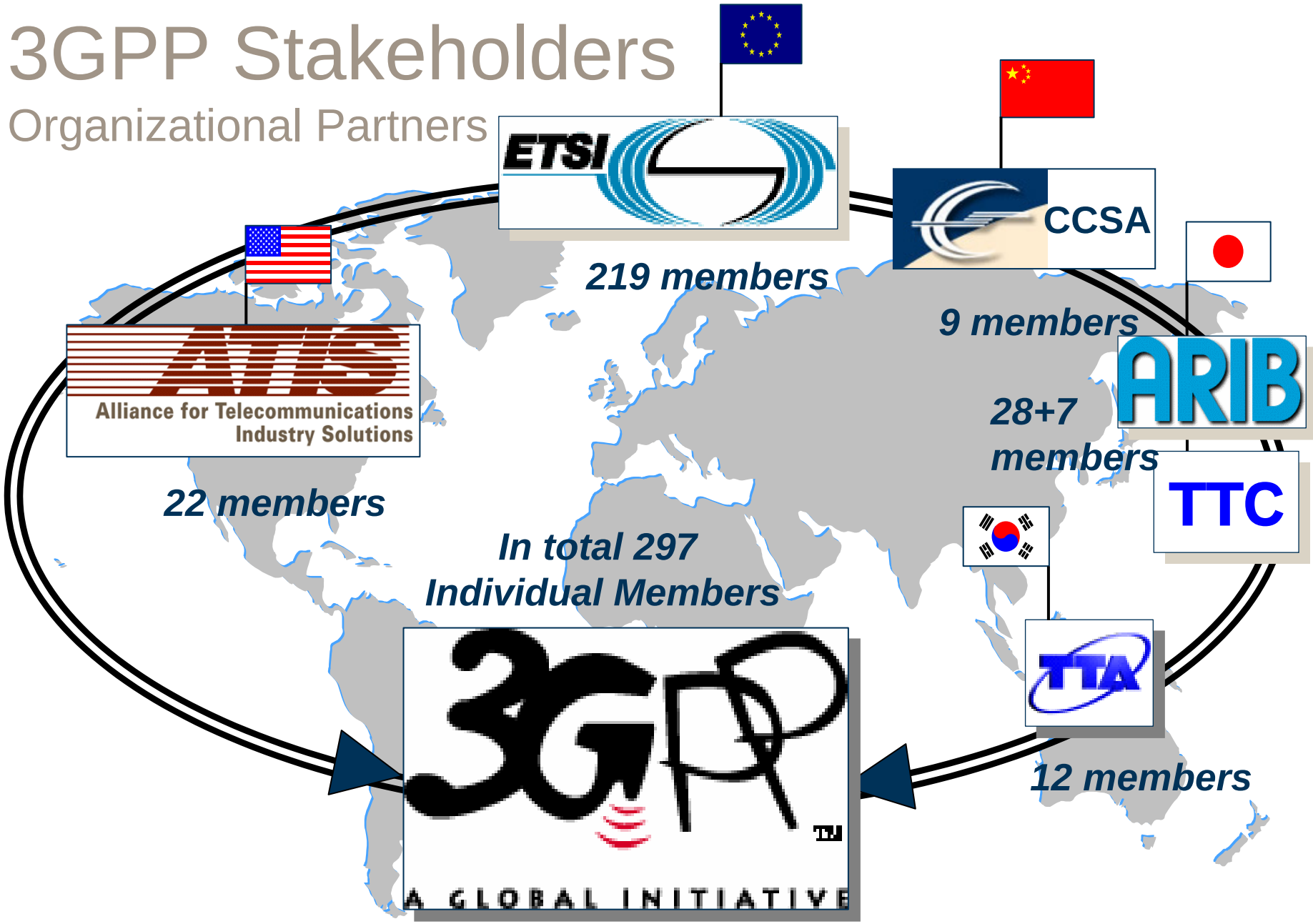
international harmonization of radio systems are providing for:

- economies of scale;
- innovations;
- enhancements, and
- evolution paths towards new technologies / standards

The phenomenal success of GSM and 3G is largely related to both spectrum and technology harmonization

3GPP Stakeholders

Organizational Partners



LTE Spectrum Requirements

- Data rates
  - Higher than 100 Mbps in downlink and 50 Mbps in uplink
- High spectral efficiency
  - Providing for both coverage and capacity
- Spectrum
  - The need for 2x10 and 2x20 MHz contiguous allocations
  - Flexibility, supporting operation in a wide-range (current and future 3GPP bands) of spectrum allocations and a wide range of bandwidths (FDD and TDD)
- Migration
  - Cost-effective migration from current usage to LTE

Target frequency bands and bandwidths for LTE

- To fullfill the LTE Spectrum Requirements and develop specifications available in a timely manner it is suggested that the following bands should be regarded as ”target frequency bands and bandwidths” for LTE;

- LTE FDD;
  - 2.6 GHz band (Band VII) with 2x20 MHz and 2x10 MHz bandwidths
  - 1800 MHz bands and the 1710 MHz paired with 2110 MHz band with 2x10 MHz bandwidth (Bands III, IV, VII, and IX)
  - 700 MHz bands (work started in 3GPP)
- LTE TDD
  - 2.6 GHz band with 2x20 MHz, 2x10 MHz, 2x5 MHz, and below 2x5 MHz bandwidths (Band d)

Estimated future spectrum needs

- WRC-07 agenda item 1.4 (IMT-Advanced)

The process in ITU-R:

- The need for 1280 - 1720 MHz of spectrum has been identified (including already used by IMT-2000) by years 2015 – 2020:
  - the needed amount of spectrum is subject to environments, countries and scenario;
- the draft CPM Report contains the most relevant candidate bands:
  - Bands identified include 410-862 MHz, 2300-2400 MHz, 2700-2900 MHz, 3400-4200 MHz, 4400-4900 MHz
  - Further spectrum fragmentation is a concern

implying a need for around 700 - 1200 MHz (rough estimation) of additional spectrum to be identified at WRC-07 for some regions

3G Mobile Broadband Summary

- HSPA – *Mobile Broadband is already here*
  - *More than 100 commercial networks in more than 50 countries*
  - *7.2 Mbps downlink, 1.4 Mbps uplink commercially available*
  - *More than 100 different devices available*
- HSPA evolution
  - *To ensure long-term HSPA competitiveness*
  - *42 Mbps downlink, 12 Mbps uplink*
  - *Demonstrated at CTIA'06*
- 3G Long Term Evolution – 3G LTE
  - *Wider bandwidth, paired and unpaired spectrum, new radio access*
  - *Peak data rates beyond 250 Mbps in 20 MHz*
  - *Demonstrated at 3GSM'07*
  - *Smooth transition to 4G radio access (IMT-Advanced)*
- IMT-Advanced
  - *Much wider bandwidth of around 2x50 – 2x100 MHz with pairings using both contiguous bands, as well as aggregated spectrum channels / blocks*
  - *An additional required spectrum in the amount of 700 – 1300 MHz has been identified by ITU for the timeframe 2015 – 2020*
  - *Public mobile communication systems will also in the future require well defined radio environments*
  - *Spectrum fragmentation remains a concern*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