



FLEXIBLE SPECTRUM USAGE - HOW LTE CAN MEET FUTURE CAPACITY DEMANDS

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BACKGROUND

- › ITU IMT-Advanced requirements on 4G
 - high peak data rates
(>100 Mb/s high mobility; >1Gb/s low mobility)
 - high spectral efficiency (peak and cell edge)
→ high cell capacity
 - flexibility for different bandwidth allocations
 - › single or multiple RF carriers
 - › scalable bandwidth up to 40 MHz
 - bandwidths up to 100 MHz encouraged

Sufficient radio spectrum is the basis for achieving peak data rates and sufficient system capacity

SYSTEM PERFORMANCE

› Link capacity

$$C = B \cdot M \cdot \log_2 \left(1 + \frac{P_{Tx} \cdot G}{N + I} \right)$$



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› System capacity

$$C_{\Sigma} \propto B_i \cdot M_i \cdot \log_2 \left(1 + \frac{P_{Tx,i} \cdot G_i}{N + I_i} \right)$$



LTE CAPACITY EVOLUTION (1)

› Increasing system capacity

- Relaying
- Heterogeneous network deployment

$$C_{\Sigma} \propto B_i \cdot M_i \cdot \log_2 \left(1 + \frac{P_{Tx,i} \cdot G_i}{N + I_i} \right)$$



[Better path gain between transmitters and receivers]

LTE CAPACITY EVOLUTION (2)

› Increasing system capacity

$$C_{\Sigma} \propto B_i \cdot M_i \cdot \log_2 \left(1 + \frac{P_{Tx,i} \cdot G_i}{N + I_i} \right)$$



Avoid interference between multiple simultaneous transmissions

- Inter-cell interference coordination (ICIC)

LTE CAPACITY EVOLUTION (3)

› Increasing system capacity

- Multi-antenna transmission
- Coordinated multipoint transmission (CoMP)

$$C_{\Sigma} \propto B_i \cdot M_i \cdot \log_2 \left(1 + \frac{P_{Tx,i} \cdot G_i}{N + I_i} \right)$$



[MIMO transmission for spatial multiplexing and beam forming]

LTE CAPACITY EVOLUTION (4)

› Increasing system capacity

- Carrier aggregation

$$C_{\Sigma} \propto B_i \cdot M_i \cdot \log_2 \left(1 + \frac{P_{Tx,i} \cdot G_i}{N + I_i} \right)$$

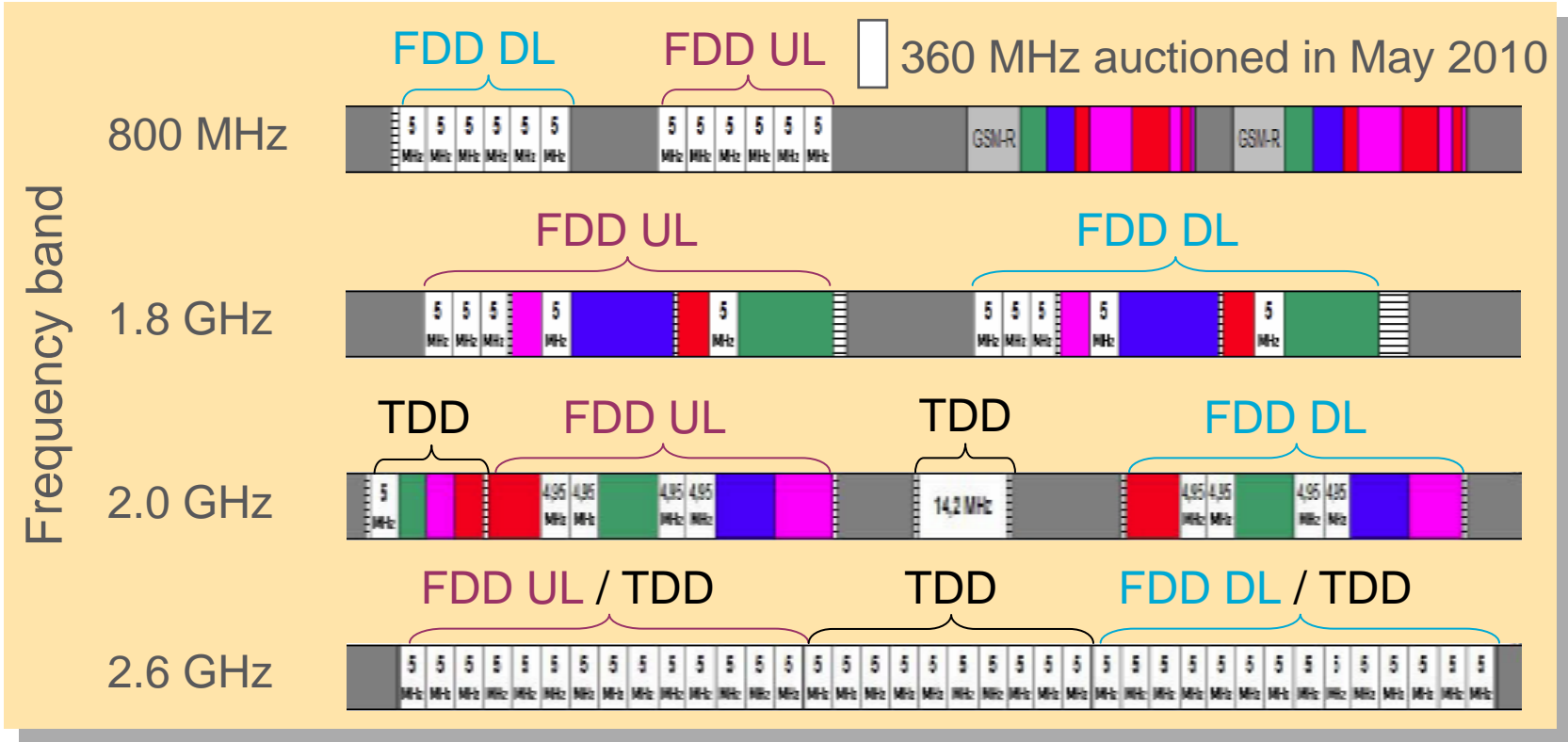


Increasing the amount of spectrum
that can be used for transmission

FOCUS OF THIS TALK

SPECTRUM FOR MOBILE COMMUNICATIONS - GERMANY

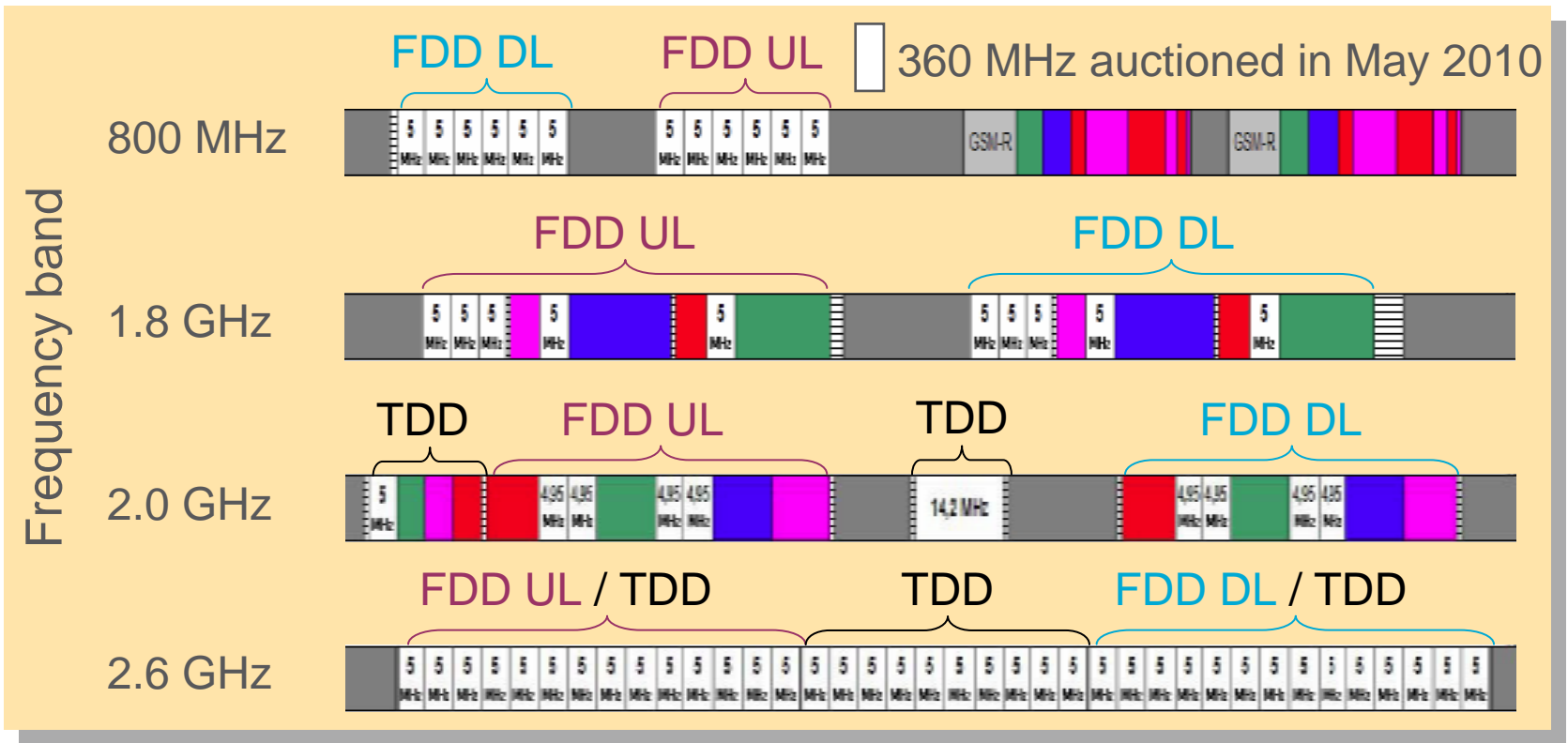
› LTE goal: 1 Gb/s in downlink → ~100 MHz



- Total spectrum increased from 252 to 612 MHz in 2010
- **Fragmented spectrum allocation**

SPECTRUM FOR MOBILE COMMUNICATIONS - GERMANY

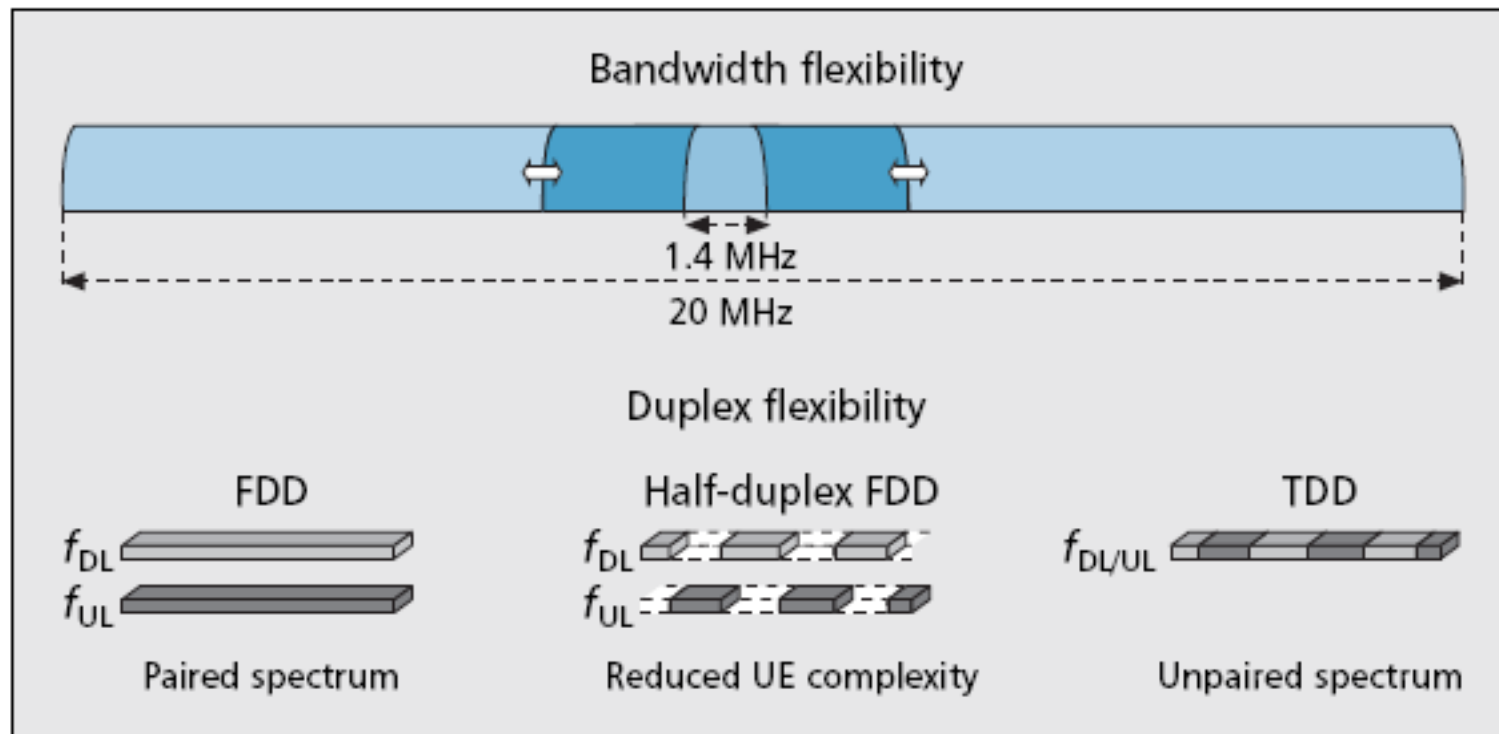
› LTE goal: 1 Gb/s in downlink → ~100 MHz ?



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FLEXIBLE SPECTRUM OPTIONS IN LTE

- › Flexible bandwidth from 1.4 – 20 MHz
- › Paired (FDD) and unpaired (TDD) spectrum

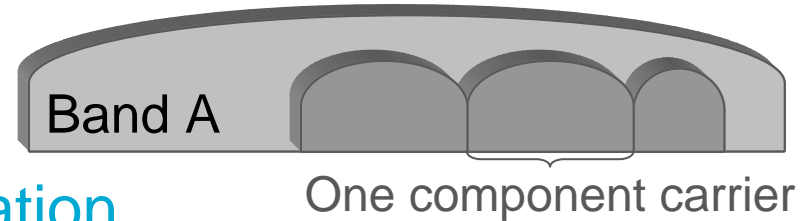


- › Carrier aggregation added in release 10 (LTE-A)

LTE CARRIER AGGREGATION MODES IN THE FREQUENCY DOMAIN

› Contiguous carrier aggregation

- + Possibly only one FFT module and one radio frontend
- + Similar propagation characteristics



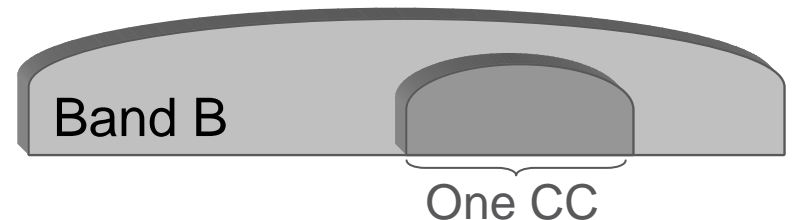
› Non-contiguous carrier aggregation

- + Aggregation of fragmented spectrum

› Intra- or single-band

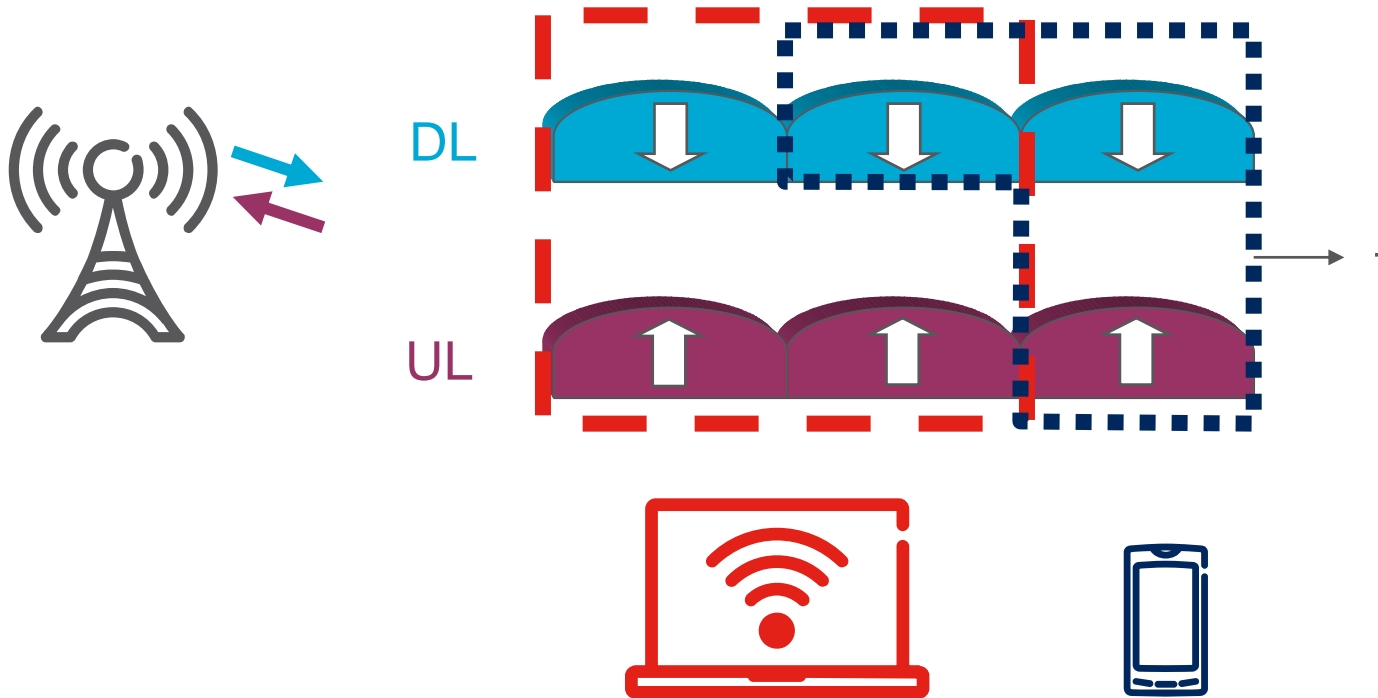


› Inter- or multi-band



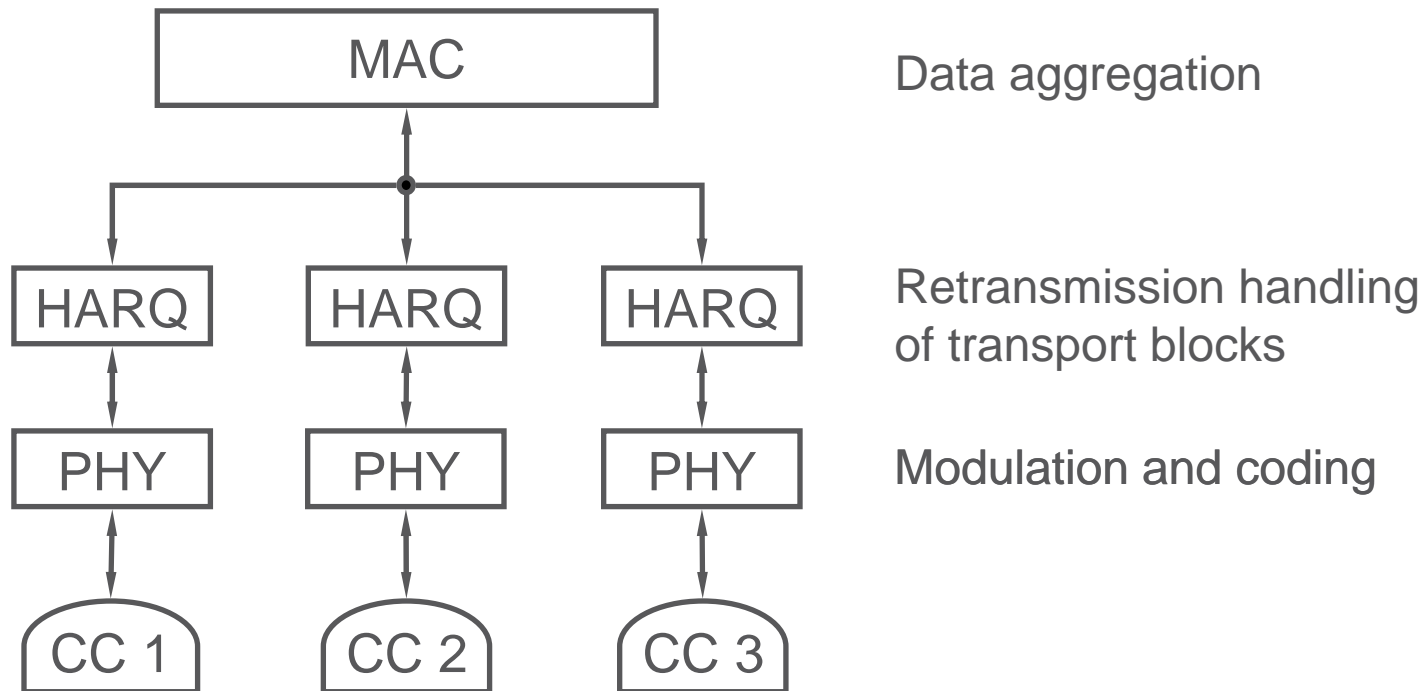
UPLINK-DOWNLINK SYMMETRY

- › Carrier aggregation can be asymmetric or symmetric
 - # DL CC \geq # UL CC
- › Independent configuration for different UE



DATA AGGREGATION IN REL-10

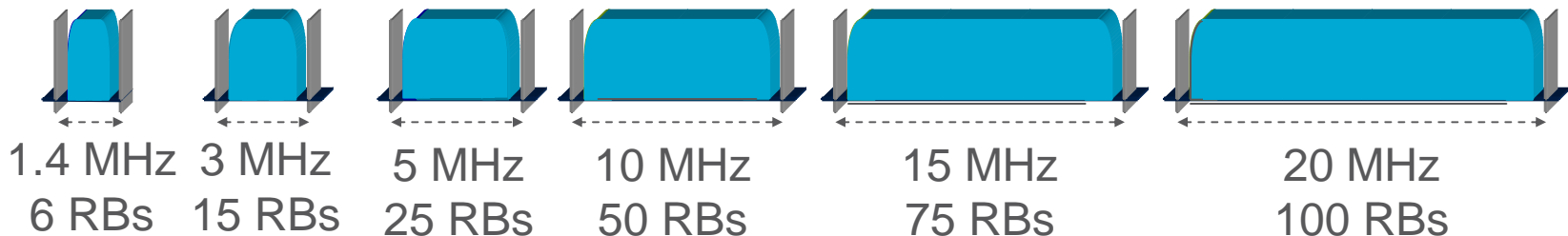
- › Data aggregation in MAC layer
- › Separate HARQ processes and feedback
- › Individual transmission modes (modulation and coding)



COMPONENT CARRIER (CC) TYPES

BACKWARDS COMPATIBLE CARRIERS

- › Part of for LTE Rel-10 (LTE-A)
- › Maximum reuse of Rel-8 → limited complexity
 - Each CC appears as a Rel-8 serving cell to Rel-8 UEs
 - › Synchronization and reference signals
 - › System Information
 - › Backwards compatible bandwidths
- › Signaling extensions for Rel-10 transparent to Rel-8 UEs
- › LTE Rel-8 carrier bandwidths = Rel-10 CC bandwidths:
 - more flexible bandwidths discussed for Rel-11 (e.g. carrier segments)

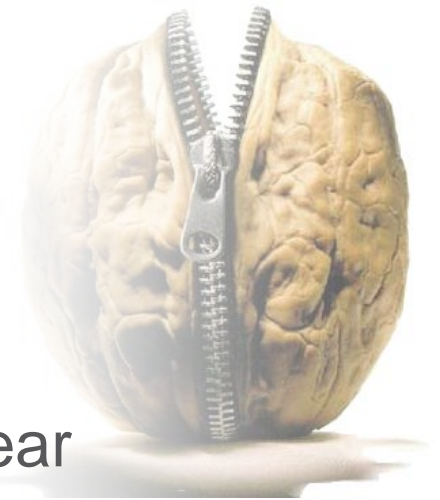


LTE CARRIER AGGREGATION -- IN A NUTSHELL

› Flexible spectrum usage

- Aggregation of “narrow” CCs to obtain large overall bandwidth
- Backwards compatibility for LTE release 8 UEs for release 10

› Good progress in 3GPP to complete WI this year



[End of the story ?]

SPECTRUM REQUIREMENTS

› ITU study (2006) on spectrum requirements for mobile communications

- Required spectrum until 2020

1280–1720 MHz

- Available as of May 2010
(Germany)

612 MHz



[Tremendous amount of additional spectrum
is needed for mobile communications]

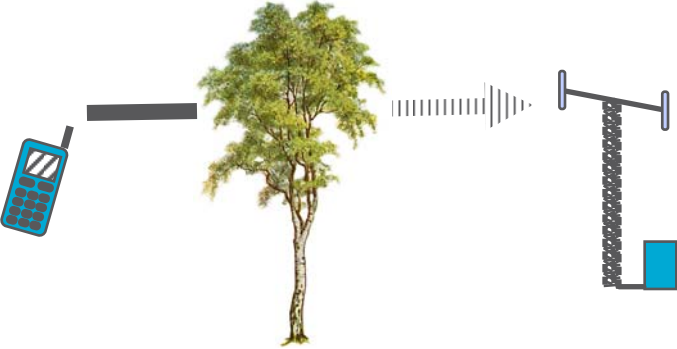
GOOD SPECTRUM



Big equipment



Poor propagation



SPECTRUM IN EUROPE

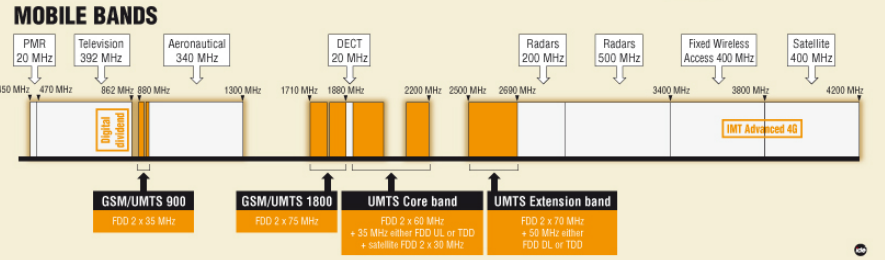
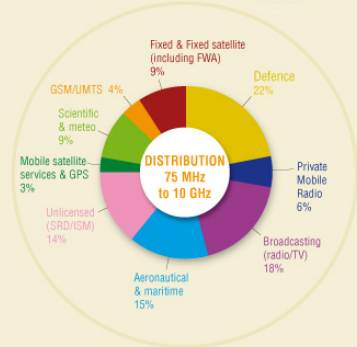
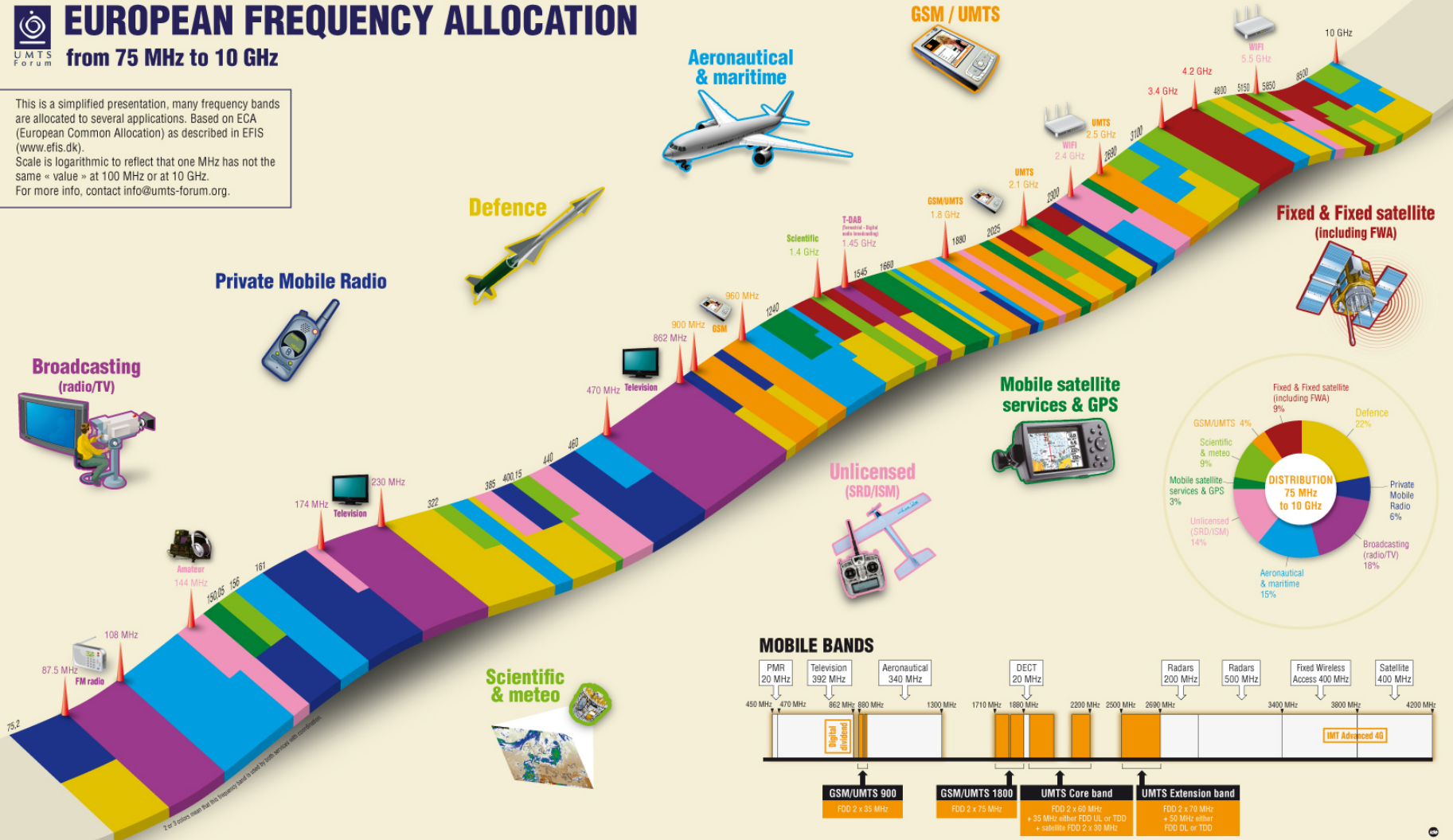
~0 MHz free !



EUROPEAN FREQUENCY ALLOCATION

from 75 MHz to 10 GHz

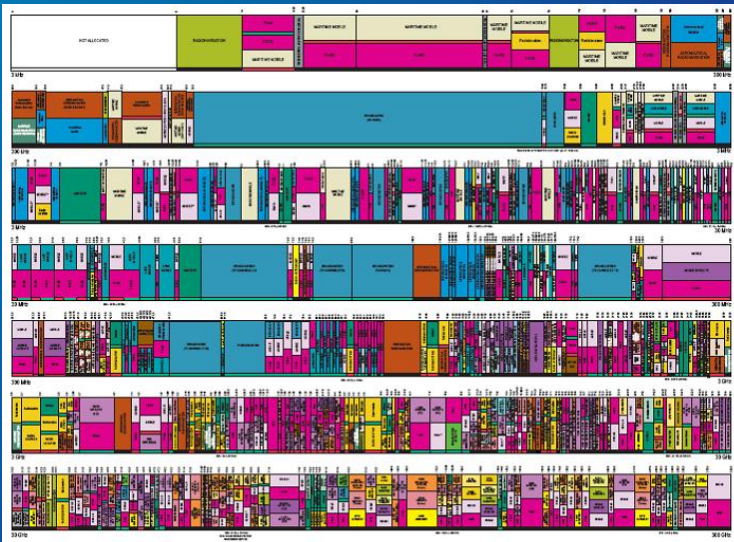
This is a simplified presentation, many frequency bands are allocated to several applications. Based on ECA (European Common Allocation) as described in EFIS (www.efis.dk). Scale is logarithmic to reflect that one MHz has not the same « value » at 100 MHz or at 10 GHz. For more info, contact info@umts-forum.org.



2 or 3 colors mean that the frequency band is used by both, but not with simultaneous

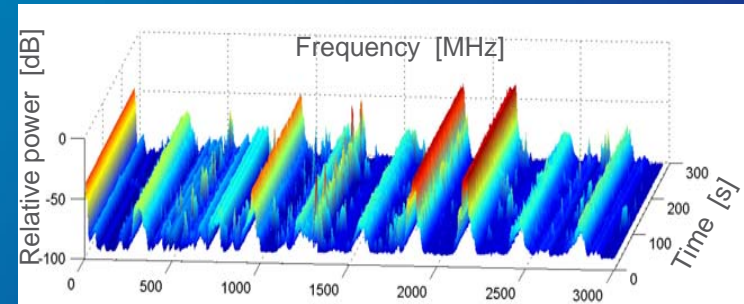
WHITE SPACE?

Tight space...



...or not so tight?

Ericsson Research measurements in Kista



Ericsson Research
White Space
availability analysis

NEW SPECTRUM FOR MOBILE COMMUNICATIONS

- › **Re-allocation** of spectrum from other industries
 - internationally harmonized spectrum assignments
 - › global economy of scale
 - uncertain if sufficient spectrum bands can be found
 - uncertain success of “hostile” lobbying / take-over

- › **Secondary usage** of “other” spectrum
 - investigated as *dynamic spectrum access* or *cognitive radio systems*
 - flexible usage of spectrum
 - uncertain feasibility



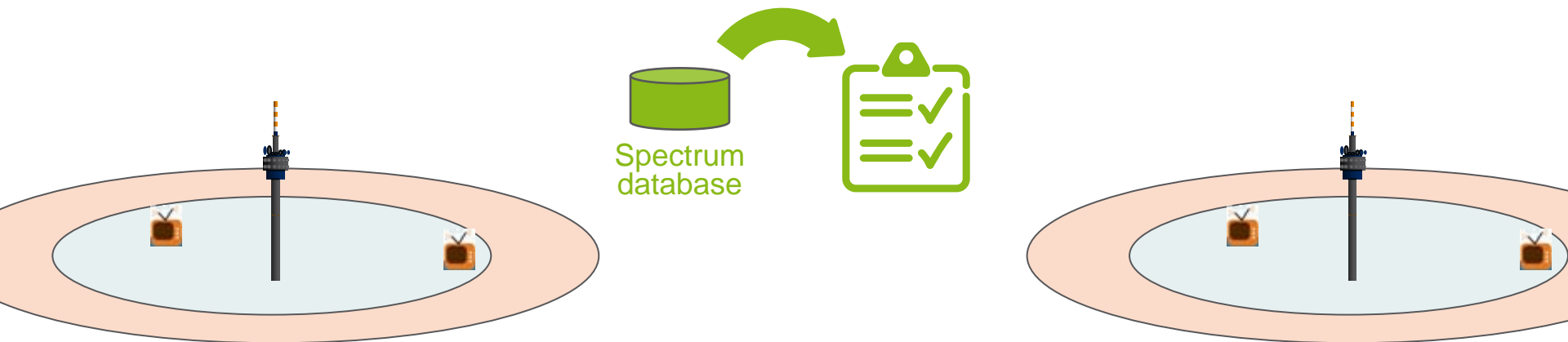
REGULATORY SITUATION

› Regulators

- FCC has allowed secondary usage of TV spectrum (Nov. 2008)
- CEPT SE 43 investigates secondary usage of TV spectrum

› Approach

- regulated database for availability of regionally useable TV channels
- geo-location can be determined for secondary transmitters
- protection of TV reception within service areas



LTE SECONDARY SPECTRUM USAGE

› LTE carrier aggregation

- **secondary spectrum channels** as additional (**opportunistic**) *LTE component carriers*
- flexibility of bandwidth for extension carriers

› New challenges

- **dynamic configuration** of channels in mobile infrastructure
- (dynamic) interaction with **spectrum database** provider
- sufficient flexibility of **mobile devices**
- **co-existence** with other secondary users
 - › secondary licenses?
 - › dynamic spectrum sharing?

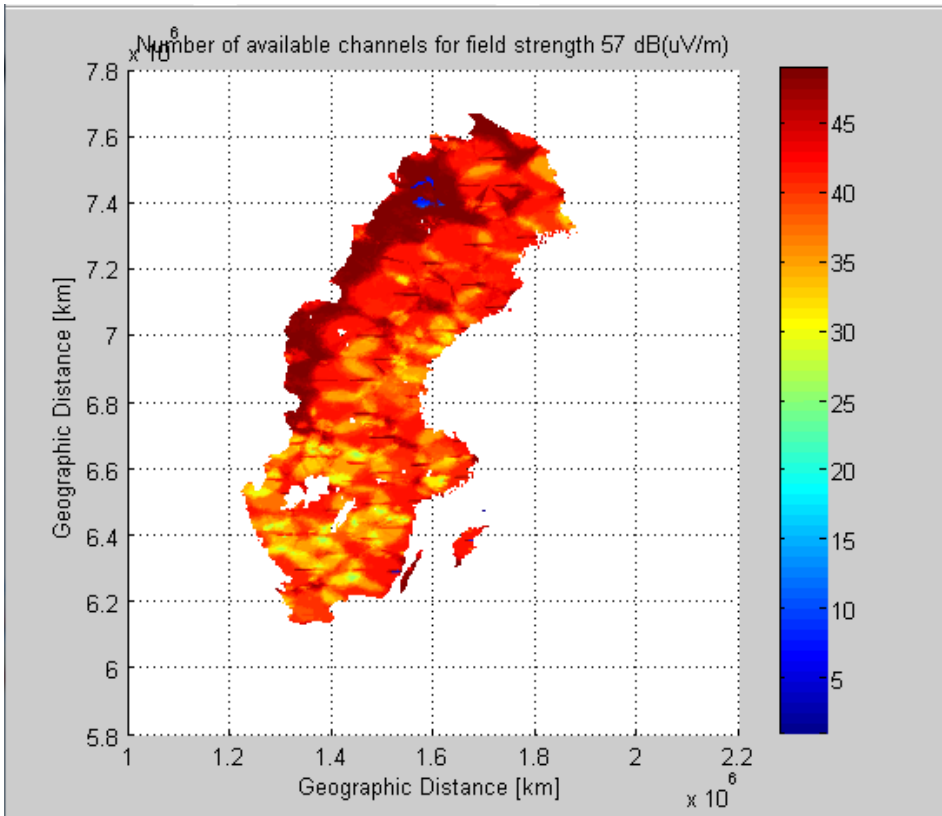
FEASIBILITY OF SECONDARY SPECTRUM USAGE

- › **Business feasibility** of dynamic spectrum access
 - higher cost due to increased complexity (terminals !?)
 - regional differences / economy of scale (terminals !?)
 - uncertainty of spectrum availability / capacity
 - › return on infrastructure investment?

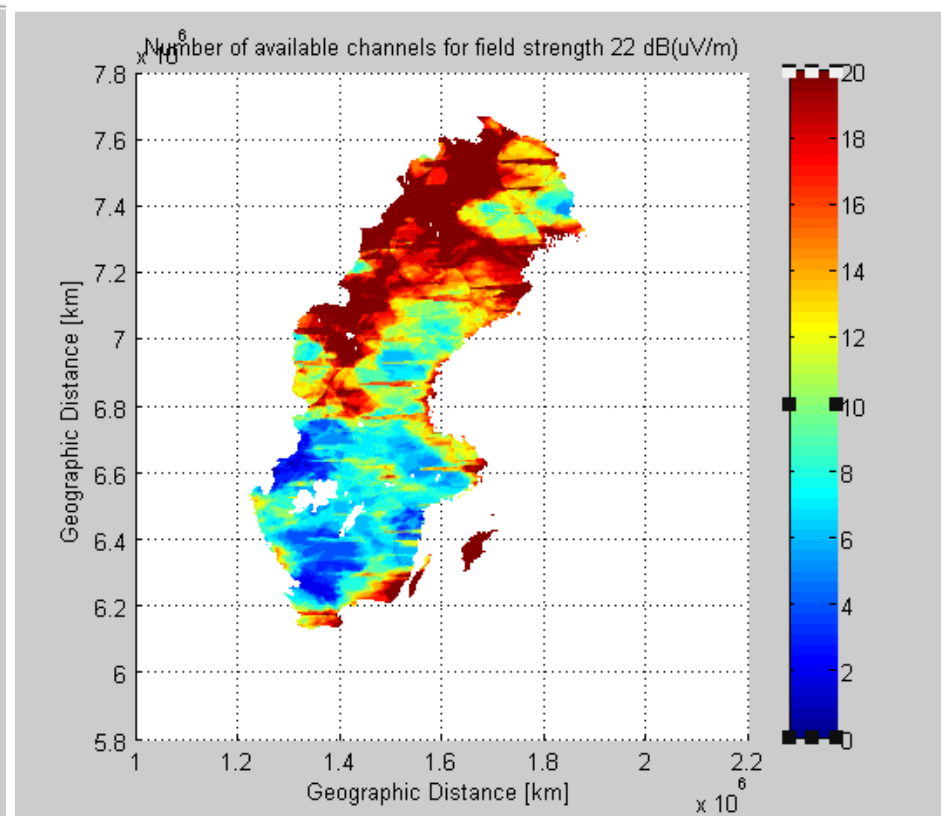
- › **Technical feasibility**
 - what capacity can realistically be achieved in secondary spectrum?

WHITE SPACE SWEDEN

Optimistic



Realistic?



- › Ideal WS availability in Sweden. All areas outside 57 dB(uV/m) (no BC coverage)

- › Realistic WS availability in Sweden. All areas outside 22 dB(uV/m) (spectrum sensing with 35 dB hidden node margin)

FEASIBILITY OF SECONDARY SPECTRUM USAGE

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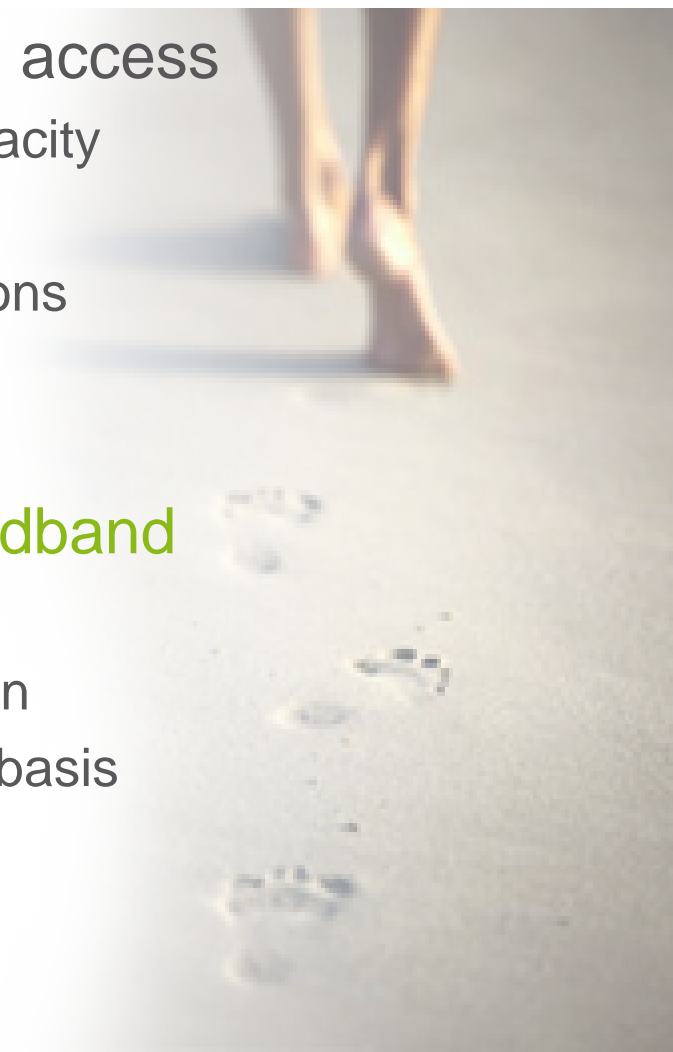
- › **Technical feasibility**
 - what capacity can realistically be achieved in secondary spectrum?
 - e.g. addressed in EU FP7 QUASAR
 - <http://www.quasarspectrum.eu/>

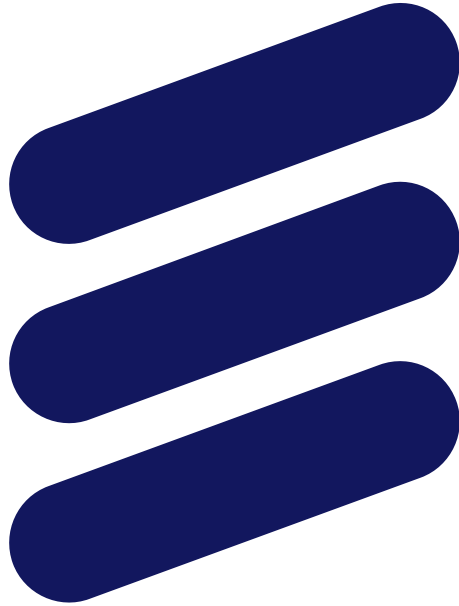
SUMMARY

- › LTE will provide “4G” mobile broadband access
 - targeting very high peak data rates and capacity
 - carrier aggregation one way to
 - › aggregate fragmented spectrum allocations
 - › provide spectrum flexibility

- › In future more spectrum for mobile broadband is required
 - secondary spectrum usage may be an option
 - › carrier aggregation provides technology basis
 - feasibility needs to be evaluated

- › Spectrum allocations take long time
 - research is required now





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