3G Long-Term Evolution (LTE) and System Architecture Evolution (SAE)

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Outline

• Introduction
• Requirements
• Evolved Packet System Architecture
• LTE Radio Interface and OFDMA
• Protocol Architecture
• Self-Organization in LTE
• Conclusions
• Control Questions
• References
• Abbreviations
From GSM to LTE

GSM Core (Circuit switched)
- MSC
- GMSC
- HLR
- AuC
- EIR

E-UTRAN
- e-node B
- +HSPA

GSM RAN
- Base station
- Base station controller

EPC GPRS Core (Packet Switched)
- S-GW
- P-GW
- GGSN

Internet

PSTN
3GPP Evolution – Background (1/2)

Discussion started in December 2004
State of the art then:

• The combination of HSDPA and E-DCH provides very efficient packet data transmission capabilities, but UMTS should continue to be evolved to meet the ever increasing demand of new applications and user expectations

• 10 years have passed since the initiation of the 3G program and it is time to initiate a new program to evolve 3G which will lead to a 4G technology

• From the application/user perspectives, the UMTS evolution should target at significantly higher data rates and throughput, lower network latency, and support of always-on connectivity
3GPP Evolution – Background (2/2)

• From the operator perspectives, an evolved UMTS will make business sense if it:
  – Provide significantly improved power and bandwidth efficiencies
  – Facilitate the convergence with other networks/technologies
  – Reduce transport network cost
  – Limit additional complexity

• Evolved-UTRA is a packet only network - there is no support of circuit switched services (no MSC)

• Evolved-UTRA starts on a clean state - everything is up for discussion including the system architecture and the split of functionality between RAN and CN

• Led to 3GPP Study Item (Study Phase: 2005-4Q2006) „3G Long-term Evolution (LTE)” for new Radio Access and “System Architecture Evolution” (SAE) for Evolved Network
Economic Drivers for Network Evolution

- Traffic volume
- Network cost (existing technologies)
- Revenue
- Profitability

Voice dominated

Data dominated

Network cost (LTE)

Time

Voice dominated

Data dominated
LTE Requirements and Performance Targets

- **High Peak Data Rates**
  - 100 Mbps DL (20 MHz, 2x2 MIMO)
  - 50 Mbps UL (20 MHz, 1x2)

- **Support Scalable BW**
  - 1.4, 3, 5, 10, 15, 20 MHz

- **Low Latency**
  - < 5ms user plane (UE to RAN edge)
  - < 100ms camped to active
  - < 50ms dormant to active

- **Improved Spectrum Efficiency**
  - 3-4x HSPA Rel’6 in DL*
  - 2-3x HSPA Rel’6 in UL
  - 1 bps/Hz broadcast

- **Improved Cell Edge Rates**
  - 2-3x HSPA Rel’6 in DL*
  - 2-3x HSPA Rel’6 in UL
  - Full broadband coverage

- **Packet Domain Only**
  - High VoIP capacity
  - Simplified network architecture

* Assumes 2x2 in DL for LTE, but 1x2 for HSPA Rel’6
Key Features of LTE to Meet Requirements

• Selection of Orthogonal Frequency Division Multiplexing (OFDM) for the air interface
  – Less receiver complexity
  – Robust to frequency selective fading and inter-symbol interference (ISI)
  – Access to both time and frequency domain allows additional flexibility in scheduling (including interference coordination)
  – Scalable OFDM makes it straightforward to extend to different transmission bandwidths

• Integration of Multiple-Input Multiple-Output (MIMO) techniques
  – Pilot structure to support 1, 2, or 4 Tx antennas in the Downlink (DL) and Multi-user MIMO (MU-MIMO) in the Uplink (UL)

• Simplified network architecture
  – Reduction in number of logical nodes \(\rightarrow\) flatter architecture
  – Clean separation of user and control plane
Terminology: LTE + SAE = EPS

• From the set of requirements it was clear that evolution work would be required for both, the radio access network as well as the core network
  – LTE would not be backward compatible with UMTS/HSPA!
  – RAN working groups would focus on the air interface and radio access network aspects
  – System Architecture (SA) working groups would develop the Evolved Packet Core (EPC)

• Note on terminology
  – In the RAN working groups term Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) and Long Term Evolution (LTE) are used interchangeably
  – In the SA working groups the term System Architecture Evolution (SAE) was used to signify the broad framework for the architecture
  – For some time the term LTE/SAE was used to describe the new evolved system, but now this has become known as the Evolved Packet System (EPS)
Network Simplification: From 3GPP to 3GPP LTE

- **3GPP architecture**
  - 4 functional entities on the control plane and user plane
  - 3 standardized user plane and control plane interfaces

- **3GPP LTE architecture**
  - 2 functional entities on the user plane: eNodeB and S-GW
  - SGSN control plane functions \(\Rightarrow\) S-GW & MME
  - Less interfaces, some functions will disappear

- **4 layers into 2 layers**
  - Evolve GGSN \(\Rightarrow\) integrated S-GW
  - Moving SGSN functionalities to S-GW
  - RNC evolutions to RRM on a IP distributed network for enhancing mobility management
  - Part of RNC mobility function being moved to S-GW & eNodeB
Evolved Packet System (EPS) Architecture

Key elements of network architecture

- No more RNC
- RNC layers/functionalities moves in eNB
- X2 interface for seamless mobility (i.e. data/context forwarding) and interference management

Note: Standard only defines logical structure!
EPS Architecture - Functional Description of the Nodes

**eNodeB** contains all radio access functions
- Admission Control
- Scheduling of UL & DL data
- Scheduling and transmission of paging and system broadcast
- IP header compression
- Outer ARQ (RLC)

**MME control plane functions**
- Idle mode UE reachability
- Tracking area list management
- S-GW/P-GW selection
- Inter core network node signaling for mobility bw. 2G/3G and LTE
- NAS signaling
- Authentication
- Bearer management functions

**Serving Gateway**
- Local mobility anchor for inter-eNB handovers
- Mobility anchor for inter-3GPP handovers
- Idle mode DL packet buffering
- Lawful interception
- Packet routing and forwarding

**PDN Gateway**
- UE IP address allocation
- Mobility anchor between 3GPP and non-3GPP access
- Connectivity to Packet Data Network
EPS Architecture - Control Plane Layout over S1

NAS sub-layer performs:
- Authentication
- Security control
- Idle mode mobility handling
- Idle mode paging origination

RRC sub-layer performs:
- Broadcasting
- Paging
- Connection Mgt
- Radio bearer control
- Mobility functions
- UE measurement reporting & control

PDCP sub-layer performs:
- Integrity protection & ciphering

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- Paging
- Connection Mgt
- Radio bearer control
- Mobility functions
- UE measurement reporting & control

PDCP sub-layer performs:
- Integrity protection & ciphering
EPS Architecture - User Plane Layout over S1

Physical sub-layer performs:
- DL: OFDMA, UL: SC-FDMA
- Forward Error Correction (FEC)
- UL power control
- Multi-stream transmission & reception (i.e. MIMO)

RLC sub-layer performs:
- Transferring upper layer PDUs
- In-sequence delivery of PDUs
- Error correction through ARQ
- Duplicate detection
- Flow control
- Concatenation/Concatenation of SDUs

MAC sub-layer performs:
- Scheduling
- Error correction through HARQ
- Priority handling across UEs & logical channels
- Multiplexing/de-multiplexing of RLC radio bearers into/from PhCHs on TrCHs

PDCP sub-layer performs:
- Header compression
- Ciphering

S-Gateway

UE

<table>
<thead>
<tr>
<th>PDCP</th>
<th>RLC</th>
<th>MAC</th>
<th>PHY</th>
</tr>
</thead>
</table>

eNode-B

<table>
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<tr>
<th>PDCP</th>
<th>RLC</th>
<th>MAC</th>
<th>PHY</th>
</tr>
</thead>
</table>

MME

UE eNode-B
EPS Architecture - Interworking for 3GPP and Non-3GPP Access

- Serving GW anchors mobility for intra-LTE handover between eNBs as well as mobility between 3GPP access systems → HSPA/EDGE uses EPS core for access to packet data networks

- PDN GW is the mobility anchor between 3GPP and non-3GPP access systems (SAE anchor function); handles IP address allocation

- S3 interface connects MME directly to SGSN for signaling to support mobility across LTE and UTRAN/GERAN; S4 allows direction of user plane between LTE and GERAN/ UTRAN (uses GTP)
LTE Key Features (Release 8)

- **Multiple access scheme**
  - DL: OFDMA with Cyclic Prefix (CP)
  - UL: Single Carrier FDMA (SC-FDMA) with CP

- **Adaptive modulation and coding**
  - DL modulations: QPSK, 16QAM, and 64QAM
  - UL modulations: QPSK and 16QAM (optional for UE)
  - Rel. 6 Turbo code: Coding rate of 1/3, two 8-state constituent encoders, and a contention-free internal interleaver

- **ARQ within RLC sublayer and Hybrid ARQ within MAC sublayer**

- **Advanced MIMO spatial multiplexing techniques**
  - (2 or 4) x (2 or 4) downlink and uplink supported
  - Multi-layer transmission with up to four streams
  - Multi-user MIMO also supported

- **Implicit support for interference coordination**
- **Support for both FDD and TDD**
Multi-antenna Solutions

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)
Interference Coordination

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*
OFDM Basics – Overlapping Orthogonal

- **OFDM**: Orthogonal Frequency Division Multiplexing
- **OFDMA**: Orthogonal Frequency Division Multiple-Access
- FDM/FDMA is nothing new: carriers are separated sufficiently in frequency so that there is minimal overlap to prevent cross-talk

\[
\text{conventional FDM}
\]

- OFDM: still FDM but carriers can actually be **orthogonal** (no cross-talk) while actually overlapping, if specially designed \(\rightarrow\) saved bandwidth!

\[
\text{OFDM}
\]
OFDM Basics – Waveforms

• **Frequency domain**: overlapping sinc ($= \sin(x)/x$) functions
  – Referred to as subcarriers
  – Typically quite narrow, e.g. 15 kHz

• **Time domain**: simple gated sinusoid functions
  – For orthogonality: each symbol has an integer number of cycles over the symbol time
  – Fundamental frequency $f_0 = 1/T$
  – Other sinusoids with $f_k = k \cdot f_0$
Modulating the symbols onto subcarriers can be done very efficiently in baseband using the FFT algorithm.

### OFDM Transmitter

- Encoding + Interleaving + Modulation
- Serial to Parallel
- IFFT
- Parallel to Serial
- Add CP
- D/A
- RF Tx

### OFDM Receiver

- Demod + de-interleave + decode
- Parallel to Serial
- FFT
- Serial to Parallel
- Remove CP
- A/D
- RF Rx

Cyclic Prefix (CP) is needed to ensure orthogonality in multipath channels.

Channel estimation and compensation.
Comparison with CDMA – Principle

- **OFDM**: particular modulation symbol is carried over a relatively long symbol time and narrow bandwidth
  - LTE: 66.6 $\mu$sec symbol time and 15 kHz bandwidth
  - For higher data rates send more symbols by using more sub-carriers \( \rightarrow \) increases bandwidth occupancy

- **CDMA**: particular modulation symbol is carried over a relatively short symbol time and a wide bandwidth
  - UMTS HSPA: 4.17 $\mu$sec symbol time and 3.84 Mhz bandwidth
  - To get higher data rates use more spreading codes
Comparison with CDMA – Time Domain Perspective

- Short symbol times in CDMA lead to ISI in the presence of multipath

  ![CDMA symbols diagram]

  Multipath reflections from one symbol significantly overlap subsequent symbols → ISI

- Long symbol times in OFDM together with CP prevent ISI from multipath

  ![OFDM symbols diagram]

  Little to no overlap in symbols from multipath
• In CDMA each symbol is spread over a large bandwidth, hence it will experience both good and bad parts of the channel response in frequency domain

• In OFDM each symbol is carried by a subcarrier over a narrow part of the band \( \rightarrow \) can avoid send symbols where channel frequency response is poor based on frequency selective channel knowledge \( \rightarrow \) frequency selective scheduling gain in OFDM systems
Scalable OFDM for Different Operating Bandwidths

• With Scalable OFDM, the subcarrier spacing stays fixed at 15 kHz (hence symbol time is fixed to 66.6 μs) regardless of the operating bandwidth (1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz, 20 MHz)

• The total number of subcarriers is varied in order to operate in different bandwidths
  – This is done by specifying different FFT sizes (i.e. 512 point FFT for 5 MHz, 2048 point FFT for 20 MHz)

• Influence of delay spread, Doppler due to user mobility, timing accuracy, etc. remain the same as the system bandwidth is changed → robust design
# LTE Downlink Frame Structure

<table>
<thead>
<tr>
<th>Spectrum allocation</th>
<th>1.4 MHz</th>
<th>3 MHz</th>
<th>5 MHz</th>
<th>10 MHz</th>
<th>15 MHz</th>
<th>20 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slot duration</td>
<td>0.5 ms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub-frame duration</td>
<td>1.0 ms ( = 2 slots)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub-carrier spacing</td>
<td>15 kHz (7.5 kHz for MBMS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sampling frequency</td>
<td>1.92 MHz (1/2 x 3.84)</td>
<td>3.84 MHz</td>
<td>7.68 MHz (2 x 3.84)</td>
<td>15.36 MHz (4 x 3.84)</td>
<td>23.04 MHz (6 x 3.84)</td>
<td>30.72 MHz (8 x 3.84)</td>
</tr>
<tr>
<td>FFT size</td>
<td>128</td>
<td>256</td>
<td>512</td>
<td>1024</td>
<td>1536</td>
<td>2048</td>
</tr>
<tr>
<td>Number of sub-carriers</td>
<td>75</td>
<td>150</td>
<td>300</td>
<td>600</td>
<td>900</td>
<td>1200</td>
</tr>
<tr>
<td>OFDM symbols per slot</td>
<td>7 (short CP), 6 (long CP)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP length</td>
<td>Short</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.69 μs x 6</td>
<td>5.21 μs x 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Long</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>16.67 μs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Subframe length relevant to the latency requirement**
- **Sampling rates are multiples of UMTS chip rate, to ease implementation of dual mode UMTS/LTE terminals**
- **FFT size scales to support larger bandwidth**
- **Scalable OFDM**
LTE Half-Duplex FDD

- In addition to FDD & TDD, LTE supports also Half-Duplex FDD (HD-FDD)

- HD-FDD is like FDD, only the UE cannot transmit and receive at the same time

- Note, that the eNodeB can still transmit and receive at the same time to different UEs; half-duplex is enforced by the eNodeB scheduler

- Reasons for HD-FDD
  - Handsets are cheaper, as no duplexer is required
  - More commonality between TDD and HD-FDD than compared to full duplex FDD
  - Certain FDD spectrum allocations have small duplex space; HD-FDD leads to duplex desense in UE
## Downlink Peak Rates

<table>
<thead>
<tr>
<th>Bandwidth</th>
<th># of parallel streams supported</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>1.4 MHz</td>
<td>5.4 MBps</td>
</tr>
<tr>
<td>3 MHz</td>
<td>13.5 MBps</td>
</tr>
<tr>
<td>5 MHz</td>
<td>22.5 MBps</td>
</tr>
<tr>
<td>10 MHz</td>
<td>45 MBps</td>
</tr>
<tr>
<td>15 MHz</td>
<td>67.5 MBps</td>
</tr>
<tr>
<td>20 MHz</td>
<td>90 MBps</td>
</tr>
</tbody>
</table>

Assumptions: 64QAM, code rate =1, 1OFDM symbol for L1/L2, ignores subframes with P-BCH, SCH
## Uplink Peak Rates

<table>
<thead>
<tr>
<th>Bandwidth (MHz)</th>
<th>16 QAM</th>
<th>64QAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4</td>
<td>2.9 MBps</td>
<td>4.3 MBps</td>
</tr>
<tr>
<td>3</td>
<td>6.9 MBps</td>
<td>10.4 MBps</td>
</tr>
<tr>
<td>5</td>
<td>11.5 MBps</td>
<td>17.3 MBps</td>
</tr>
<tr>
<td>10</td>
<td>27.6 MBps</td>
<td>41.5 MBps</td>
</tr>
<tr>
<td>15</td>
<td>41.5 MBps</td>
<td>62.2 MBps</td>
</tr>
<tr>
<td>20</td>
<td>55.3 MBps</td>
<td>82.9 MBps</td>
</tr>
</tbody>
</table>

Assumptions: code rate = 1, 2 PRBs reserved for PUCCH (1 for 1.4 MHz), no SRS, ignores subframes with PRACH, takes into account highest prime-factor restriction
Scheduling and Resource Allocation (1/2)

• LTE uses a scheduled, shared channel on both the uplink (UL-SCH) and the downlink (DL-SCH)

• Normally, there is no concept of an autonomous transmission; all transmissions in both uplink and downlink must be explicitly scheduled

•LTE allows "semi-persistent" (periodical) allocation of resources, e.g. for VoIP
Scheduling and Resource Allocation (2/2)

- Basic unit of allocation is called a Resource Block (RB)
  - 12 subcarriers in frequency (\(= 180 \text{ kHz}\))
  - 1 sub-frame in time (\(= 1 \text{ ms}, = 14 \text{ OFDM symbols}\))
  - Multiple resource blocks can be allocated to a user in a given subframe

- The total number of RBs available depends on the operating bandwidth

<table>
<thead>
<tr>
<th>Bandwidth (MHz)</th>
<th>1.4</th>
<th>3.0</th>
<th>5.0</th>
<th>10.0</th>
<th>15.0</th>
<th>20.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of available resource blocks</td>
<td>6</td>
<td>15</td>
<td>25</td>
<td>50</td>
<td>75</td>
<td>100</td>
</tr>
</tbody>
</table>
Random Access (RA) Procedure

- RACH only used for Random Access Preamble
  - Response/Data are sent over SCH

- Non-contention based RA to improve access time, e.g. for HO
LTE Handover (1/2)

- LTE uses UE-assisted network controlled handover
  - UE reports measurements; network decides when to handover and to which cell
  - Relies on UE to detect neighbor cells → no need to maintain and broadcast neighbor lists
    - Allows "plug-and-play" capability; saves BCH resources
  - For search and measurement of inter-frequency neighboring cells only carrier frequency need to be indicated

- X2 interface used for handover preparation and forwarding of user data
  - Target eNB prepares handover by sending required information to UE transparently through source eNB as part of the Handover Request Acknowledge message
    - New configuration information needed from system broadcast
    - Accelerates handover as UE does not need to read BCH on target cell
  - Buffered and new data is transferred from source to target eNB until path switch → prevents data loss
  - UE uses contention-free random access to accelerate handover
LTE Handover (2/2)

Characteristics
- No soft handover
- Handover latency (2. –11.) ~ 55 msec
- Handover Interruption (7. –11.) ~ 35 msec
- Synchronization (9.) on RACH
Tracking Area

Tracking Area Identifier (TAI) sent over Broadcast Channel BCH
Tracking Areas can be shared by multiple MMEs
EPS Bearer Service Architecture

- E-UTRAN
- EPC
- Internet

- UE
- eNB
- S-GW
- P-GW

- Peer Entity

- End-to-end Service
- EPS Bearer
- External Bearer

- Radio Bearer
- S1 Bearer
- S5/S8 Bearer

- Radio
- S1
- S5/S8
- Gi

Long-Term Evolution (LTE) and System Architecture Evolution (SAE)
**LTE RRC States**

- **RRC_IDLE**
  - No RRC connection, no context in eNodeB (but EPS bearers are retained)
  - UE controls mobility through cell selection
  - UE-specific paging DRX cycle controlled by upper layers
  - UE acquires system information from BCH
  - UE monitors paging channel to detect incoming calls

- **RRC_Connected**
  - RRC connection and context in eNodeB
  - Network controlled mobility
  - Transfer of unicast and broadcast data to and from UE
  - UE monitors control channels associated with the shared data channels
  - UE provides channel quality and feedback information
  - Connected mode DRX can be configured by eNodeB according to UE activity level

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*Long-Term Evolution (LTE) and System Architecture Evolution (SAE)*
EPS Connection Management States

- No signaling connection between UE and core network (no S1-U/S1-MME)
- No RRC connection (i.e. RRC_IDLE)
- UE performs cell selection and tracking area updates (TAU)

- Signaling connection established between UE and MME, consists of two components
  - RRC connection
  - S1-MME connection
- UE location is known to accuracy of Cell-ID
EPS Mobility Management States

- EMM context holds no valid location or routing information for UE
- UE is not reachable by MME as UE location is not known
- UE successfully registers with MME with Attach procedure or Tracking Area Update (TAU)
- UE location known within tracking area
- MME can page to UE
- UE always has at least one PDN connection
Broadcast/Multicast Support

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
LTE vs. WiMax vs. 3GPP2

**WiMAX**
- AAA
- HA
- CAP-C
- FA/Router
- Access Point
- Authenticator
- Paging Controller
- Page buffering
- Handover Control
- Radio Resource Management
- ARQ/MAC PHY
- L2 Ciphertexting
- Classification/ROHC

**3GPP/LTE**
- PCRF
- HSS
- MME
- E-Node B
- IMS
- PDN GW
- Serv GW
- Authenticator
- Paging Controller
- Session setup
- Handover Control
- Radio Resource Management
- ARQ/MAC PHY
- L2 Ciphertexting
- L2 Ciphering
- ROHC
- Local mobility
- Session setup
- Bearer mapping

**3GPP2/UMB**
- PCRF
- AAA
- HA
- SRNC
- eBTS
- Access GW
- IMS
- Authenticator
- Paging Controller
- Session setup
- Handover Control
- Radio Resource Management
- ARQ/MAC PHY
- L2 Ciphertexting
- L2 Ciphering
- ROHC
- Local mobility
- Session setup
- Bearer mapping

IETF-centric architecture

IETF-friendly, but still some flavor of UMTS/GPRS – GTP, etc

Long-Term Evolution (LTE) and System Architecture Evolution (SAE)
Self-organization – General Definitions

Yates et al. (1987)

“Technological systems become organized by commands from outside, as when human intentions lead to the building of structures or machines. But many natural systems become structured by their own internal processes: these are the self-organizing systems, and the emergence of order within them is a complex phenomenon that intrigues scientists from all disciplines.”

Camazine et al. (2003)

“Self-organization is a process in which pattern at the global level of a system emerges solely from numerous interactions among the lower-level components of a system. Moreover, the rules specifying interactions among the systems’ components are executed using only local information, without reference to the global pattern.”
Self-Organizing Systems – General Definitions

Local system control

Local interactions (environment, neighborhood)

Simple local behavior
## Self-Organizing Systems – General Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Description</th>
</tr>
</thead>
</table>
| No central control     | No global control system  
                          | No global information  
                          | Subsystems perform completely autonomous                                                |
| Emerging structures    | Global behavior or functioning of the system emerges in form of observable pattern or structures                                          |
| Resulting complexity   | Even if the individual subsystems can be simple as well as their basic rules, the resulting overall system becomes complex and often unpredictable |
| High scalability       | No performance degradation if more subsystems are added to the system  
                          | System performs as requested regardless of the number of subsystems                      |
Self-organization in LTE

Motivation and drivers

• Multitude of re-configurable parameters e.g. transmit powers, control channel powers, handover parameters etc.

• Huge number of eNBs expected with the introduction of Home eNB concept

• Home eNB
  – Small Coverage Area
  – Small number of users per cell
  – May be switched off by user
  – Not physically accessible for operators

• Self-organization (SO) is driven by operators to reduce Operational Expenses (OPEX)

• Main push of Self-Optimizing Networks (SON) by NGMN alliance (www.ngmn.org)
SO Functionality in LTE (1/5)

SO functionality includes

• Self-configuration
• Self-optimization
• Self-healing and self-repair
Self-Configuration

- Objective is to have plug-n-play enabled nodes
- Works in pre-operational state, which starts when the node is powered up and has backbone connectivity until the RF transmitter is switched on
- Automatic installation procedures for newly deployed nodes
- Automatic creation of the logical associations (interfaces) with the network and establishment of the necessary security contexts
- Download of configuration files from a configuration server
- Performing a self-test to determine that everything is working as intended
- Finally, switching to active service
SO Functionality in LTE (3/5)

Self-optimization

- Uses UE & eNB measurements and performance statistics to auto-tune the network
- Works in operational state, which starts when the RF interface is switched on
SO Functionality in LTE (4/5)

Self-optimization process includes

- **Neighbor list optimization**
  - Reconfigures the neighbor list to have the minimum set of cells necessary for handover

- **Coverage and capacity optimization**
  - Maximizes the system capacity while ensuring an appropriate overlapping area between the adjacent cells

- **Mobility robustness optimization**
  - Adjusts the handover thresholds to avoid unnecessary handovers

- **Mobility load balancing optimization**
  - Automatically handover some UEs in the edge of a congested cell to neighboring less congested cells

- **Energy Saving**
  - Autonomously switching off some of the resources or the complete node during the times of low network demand
Self-healing and self-repair

- Detects equipment faults, identifies the root causes and takes recovery actions such as
  - Reducing transmit power in case of temperature alarm
  - Fallback to the previous software version
  - Switching to the backup units
- If the fault can not be resolved by the above measures, the affected cell and the neighboring cells take cooperative actions to minimize QoS degradation
- Results in a reduced failure recovery time and a more efficient allocation of maintenance personnel
SON Architecture (1/4)

• Based on the location of SO functionality three architectural approaches are possible
  – Centralized
  – Distributed
  – Hybrid
Centralized Architecture

- SO functionality resides in the OAM system at higher level of network architecture
- Easy to deploy due to fewer number of installation sites
- OAM is vendor specific, so no support for multi-vendor optimization
- Existing interface N (Itf-N) between Network Manager (NM) and Element Manager (EM) or Network Element (NE) needs to be extended
SON Architecture (3/4)

Distributed Architecture
- SO functionality resides in the eNB at the lower level of network architecture
- Difficult to deploy because of large number of installation sites
- Difficult to perform complex optimizations involving large number of eNBs
- Better performance for less complex optimizations involving a small number of eNBs
- X2 interface between the eNBs needs to be extended
Hybrid Architecture

- SO functionality resides both at the OAM and eNB level
- Difficult to deploy because of large number of installation sites involved
- Optimization problems can be categorized depending upon their complexity level and can be performed either locally at eNB or at OAM center
- Requires multiple interfaces extension
Conclusions

• LTE is a new air interface with no backward compatibility to WCDMA
  – Combination of OFDM, MIMO and Higher-Order Modulation
• SAE/EPS realizes a flatter IP-based network architecture with less complexity
  – eNodeB, S-GW, P-GW
• Some procedures/protocols are being reused from UMTS
  – Protocol stack
  – Concept of Logical, Transport and Physical Channels
• Complexity is significantly reduced
  – Reduced UE state space
  – Most transmission uses shared channels
• LTE standard (Rel. 8) is stable
  – Enhancements are discussed for Rel. 10 under LTE+
    – Support of wider spectrum bandwidth (up to 100 MHz)
    – Spatial multiplexing in UL and DL
    – Beamforming and Higher-order MIMO in DL
    – Coordinated multipoint transmission and reception
    – Repeater (L1) and relaying (L3) functionality
Control Questions

• What are main goals of upcoming LTE/SAE networks?
• How does the architecture of LTE/SAE networks look like? What are the main tasks of each component?
• Which media access scheme is employed in LTE/SAE networks? What are the benefits of using multiple access schemes, one for downlink and one for uplink?
• Compare OFDM with CDMA?
• How many RRC states do we have in LTE/SAE networks? What are the tasks of each state?
• Explain the handover procedure in LTE/SAE networks?
• How many mobility management states do we have in LTE/SAE networks? What are the tasks of each state?
• What are the drivers and the benefits of self-organization in LTE/SAE and in mobile communications in general? Discuss challenges arising and possible solutions?
• Assume you want to provide a mobile service in an urban environment. Which technology would you use? 802.11 or UMTS/LTE? What are the criteria for the decision?
References

**LTE/SAE**

- Special Issue on LTE/ WIMAX, Nachrichtentechnische Zeitung, pp. 12–24, 1/2007
- 3rd Generation Partnership Project Long Term Evolution (LTE), official website: [http://www.3gpp.org/Highlights/LTE/LTE.htm](http://www.3gpp.org/Highlights/LTE/LTE.htm)

**Standards**

- TS 36.xxx series, RAN Aspects
- TS 36.300, “E-UTRAN; Overall description; Stage 2”
- TR 25.814, “Physical layer aspect for evolved UTRA”

**Self-organizing networks and LTE**

## Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tbody>
<tr>
<td>CP</td>
<td>Cyclic Prefix</td>
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<tr>
<td>DFT</td>
<td>Discrete Fourier Transformation</td>
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<tr>
<td>DRX</td>
<td>Discontinuous Reception</td>
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<tr>
<td>ECMEPS</td>
<td>Connection Management</td>
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<tr>
<td>EMM</td>
<td>EPS Mobility Management</td>
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<tr>
<td>eNodeB</td>
<td>Evolved NodeB</td>
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<tr>
<td>eNB</td>
<td>Evolved NodeB</td>
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<td>EPC</td>
<td>Evolved Packet Core</td>
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<td>EPS</td>
<td>Evolved Packet System</td>
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<td>E-UTRAN</td>
<td>Evolved UTRAN</td>
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<tr>
<td>FDD</td>
<td>Frequency-Division Duplex</td>
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<td>FDM</td>
<td>Frequency-Division Multiplexing</td>
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<td>FFT</td>
<td>Fast Fourier Transformation</td>
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<td>HD-FDD</td>
<td>Half-Duplex FDD</td>
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<td>HO</td>
<td>Handover</td>
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<td>HOM</td>
<td>Higher Order Modulation</td>
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<td>IFFT</td>
<td>Inverse FFT</td>
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<td>ISI</td>
<td>Inter-Symbol Interference</td>
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<tr>
<td>LTE</td>
<td>Long Term Evolution</td>
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<tr>
<td>MIMO</td>
<td>Multiple-Input Multiple-Output</td>
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<tr>
<td>MME</td>
<td>Mobility Management Entity</td>
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<tr>
<td>OAM</td>
<td>Operation, Administration and Management</td>
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<tr>
<td>OFDM</td>
<td>Orthogonal Frequency-Division Multiplexing</td>
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<tr>
<td>OFDMA</td>
<td>Orthogonal Frequency-Division Multiple-Access</td>
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<tr>
<td>PDN</td>
<td>Packet Data Network</td>
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<td>P-GW</td>
<td>PDN Gateway</td>
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<tr>
<td>RA</td>
<td>Random Access</td>
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<tr>
<td>RB</td>
<td>Resource Block</td>
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<tr>
<td>RRC</td>
<td>Radio Resource Control</td>
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<td>SAE</td>
<td>System Architecture Evolution</td>
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<td>SCH</td>
<td>Shared Channel</td>
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<td>S-GW</td>
<td>Serving Gateway</td>
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<td>SC-FDMA</td>
<td>Single Carrier FDMA</td>
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<tr>
<td>TDD</td>
<td>Time-Division Duplex</td>
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<tr>
<td>TA</td>
<td>Timing Advance/ Tracking Area</td>
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<td>TAI</td>
<td>Tracking Area Indicator</td>
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<td>TAU</td>
<td>Tracking Area Update</td>
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<tr>
<td>UE</td>
<td>User Equipment</td>
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