Introduction to Mobile Broadband (iMB)

Teaching By
Asst.Prof.Dr. Suwat Pattaramalai
suwat.pat@kmutt.ac.th
Tel. 02-470-9079

Material:
http://webstaff.kmutt.ac.th/~suwat.pat/
Part III Application of IP-OFDMA

• Long-Term Evolution of 3GPP
Part III Application of IP-OFDMA

• Long-Term Evolution of 3GPP
  – EPS: Evolved Packet System
    • MME: Mobility Management Entity, SGW: Serving Gateway, PDN GW: Packet Data Network Gateway
  – E-UTRAN
    • eNB: Evolved NodeB
  – UE: User Equipment
    • Reference Points
  – System Aspects
    • QoS, Security
  – LTE Higher Protocol Layers
    • Communication Channel Structure, NAS Layer, RRC Layer, PDCP Layer, RLC Layer
  – LTE MAC Layer
    • Scheduling, HARQ, Cell Search, Power Control, Intercell Interference Mitigation, Internode B Synchronization, Physical Layer Measurements, Evolved-Multicast Broadcast Multimedia Services, Self Configuration
  – LTE PHY Layer
    • LTE Frame, Channel Coding, OFDMA Downlink, MIMO for OFDMA Downlink, SC-FDMA Uplink, MIMO for SC-FDMA Uplink
  – Summary
Part III Application of IP-OFDMA

- Long-Term Evolution of 3GPP

LTE has set aggressive performance requirements and enhances its IP-based OFDMA access with MIMO and smart antennas. Although the specification has not been finalized yet, significant details are emerging.

LTE is being designed to address higher throughput, increased base station capacity, reduced latency, and full mobility. UTRA & UTRAN Long-Term Evolution has started in December 2004 and first commercial deployments are expected in 2010.²

"3GPP has approved the functional freeze of LTE as part of Release 8 in December 2008."³

LTE’s objectives include a radio-interface physical layer to support transmission bandwidth up to 20 MHz together with new transmission schemes and advanced multiantenna technologies. LTE performance requirements are presented in Table 11.1. LTE’s perspective for mobility considers optimum performance for mobile speeds 0–15 km/h. LTE is being designed to ensure high performance between 15 and 120 km/h and still expected to maintain mobility at speeds between 120 and 350 km/h even up to 500 km/h for some frequency bands. At over entire speed range, LTE is expected to support voice and real-time service quality without interruption. As one can see, mobile speeds above 350 km/h are mainly for trains. Typical performance criterion is uninterrupted operation below 120 km/h for vehicular and pedestrian speeds.
Part III Application of IP-OFDMA

- Long-Term Evolution of 3GPP

Table 11.1 LTE performance metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak data rate</td>
<td>DL/UL: 100/50 Mbps for 20 MHz</td>
</tr>
<tr>
<td>Full mobility</td>
<td>Up to 500 km/h</td>
</tr>
<tr>
<td>Latency in control/user plane</td>
<td>&lt;100 ms (idle to active)/&lt;5 ms</td>
</tr>
<tr>
<td>Capacity</td>
<td>&gt;200 users per cell (5 MHz)</td>
</tr>
<tr>
<td>Cell sizes</td>
<td>5–100 km</td>
</tr>
<tr>
<td>Spectrum</td>
<td>1.25, 2.5, 5, 10, 15, and 20 MHz</td>
</tr>
</tbody>
</table>

![LTE architecture diagram](image)

Fig. 11.1 LTE architecture
Part III Application of IP-OFDMA

- Long-Term Evolution of 3GPP
  - EPS: Evolved Packet System

The EPS (aka SAE) is a “flat”, all-IP based core network with a simplified architecture and open interfaces. The EPS is based on TCP/IP protocols to enable PC-like services including voice, video, rich media, and messaging. This migration also enables improved interworking with other fixed and wireless communication networks as seen in Fig. 11.2. The EPS architecture is similar to WiMAX architecture in terms of set of functionalities. The EPS introduces the following entities: MME, SGW, and PDN GW. The control plane functionality in ASN-GW of WiMAX is assigned to MME and data plane functionality is preserved in SGW. The reasoning behind that is stated as an optimization of each entity according to its functionality; MME can be optimized for signaling and SGW can be optimized for high bandwidth packet processing. It may give operator to implement those two entities topologically separated or colocated depending on the considered bandwidth latencies and congestion.
Part III Application of IP-OFDMA

- Long-Term Evolution of 3GPP
  - EPS: Evolved Packet System

Fig. 11.2 LTE integration
Part III Application of IP-OFDMA

• Long-Term Evolution of 3GPP
  – EPS: Evolved Packet System
    • MME: Mobility Management Entity

  In brief, the MME hosts the following functions:
  • Selecting SAE GW for a UE at the network entry
  • Performing intra-LTE handover
  • Paging – distribution of messages to eNBs
  • Handling security key management
  • Providing mobility in idle state
  • Controlling SAE bearer – de/activation
  • Ciphering and integrity protection of NAS signaling
  • Allocating temporary IDs to UEs
  • Handling mobility to other 3GPP or non-3GPP access networks
  • Terminating the S6a interface toward the home HSS when UE roams
  • Supporting Lawful intercept
Part III Application of IP-OFDMA

- Long-Term Evolution of 3GPP
  - EPS: Evolved Packet System
    - SGW: Serving Gateway

SGW (aka SAE Gateway) is responsible to provide routing and forwarding of user data packets with S1-U interface. SGW connects to PDN GW with S5 interface and gets instruction from MME through S11 interface. SGW is responsible for data paths and handles IP header compression, encryption of user data streams, termination of U-plane packets for paging reasons, and switching of U-plane to support UE mobility as seen in Fig. 11.3. It provides handover function when handover is between LTE and other 3GPP/2 technologies through S4/S103 interface. SGW terminates the data path and triggers paging when UE enters idle mode. SGW is responsible to store the context of UEs. In case of lawful interception, it also performs replication of the user traffic.
Part III Application of IP-OFDMA

- Long-Term Evolution of 3GPP
  - EPS: Evolved Packet System
    - SGW: Serving Gateway
Part III Application of IP-OFDMA

- Long-Term Evolution of 3GPP
  - EPS: Evolved Packet System
  - PDN GW: Packet Data Network Gateway

The Packet Data Network Gateway (PDN GW) provides connectivity to external packet data networks and operates as the main mobility point. PDN GW (aka P-GW) is connected to Policy and Charging Rules Function (PCRF) with S7 interface to retrieve policy information. UE may connect to multiple PDN GWs, and UE IP address allocation is performed through PDN GW as well. PDN GW is also first interface toward Internet or hosted services such as IMS, PSS (Packet-Switched Streaming Service), etc, with SGi interface. The PDN GW performs deep packet inspection for a user along with lawful interception. To provide QoS, transport level packet marking for MPLS or DiffServ is performed in PDN GW as well. Charging support for uplink and downlink together with rate enforcement are also provided in PDN GW. The PDN GW is an anchor for mobility between 3GPP and non-3GPP technologies such as WiMAX, 3GPP2 (CDMA 1X and EV-DO), and WLAN through various sets of interfaces seen in Fig. 11.2.
Part III Application of IP-OFDMA

- Long-Term Evolution of 3GPP
  - EPS: Evolved Packet System

Fig. 11.2 LTE integration
Part III Application of IP-OFDMA

• Long-Term Evolution of 3GPP
  – E-UTRAN

E-UTRAN (Evolved UMTS Terrestrial Radio Access Network) consists of eNBs, which is the base station of LTE and responsible to provide the E-UTRA user plane and control plane. eNBs function as a base station. eNBs are connected to each other with full mesh in order to provide the following functions:

- Transfer of user data in order to provide user data transfer capability across the E-UTRAN between the S1 and LTE-Uu (air) interfaces.
- Radio channel ciphering and deciphering in order to protect transmitted data over the air against unauthorized third party. The key for ciphering and deciphering is derived through signaling or session-dependent information.
- Integrity protection in order to avoid alteration of the transmitted data by an unauthorized third party.
- Header compression in order to provide a compression for a particular network layer or protocol combination such as TCP/IP and RTP/UDP/IP.
- Mobility control functions:
  – Handover manages the radio interface by radio measurements, and it is used to maintain the Quality of Service requested by EPC. It transfers context during handover to target eNB.
  – Paging provides a mechanism to a UE to contact the E-UTRAN when it is in LTE idle state.
  – Positioning is currently being designed to provide physical location information for UE.
Part III Application of IP-OFDMA

• Long-Term Evolution of 3GPP

  • Intercell interference coordination in order to reduce the intercell interference with coordination. This is part of multicell RRM function that considers all information from multiple cells.
  • Connection setup and release in order to participate in processing of the end-to-end connection setup and release; maintains and manages the end-to-end connection.
  • Load balancing in order to distribute the uneven load distribution to keep the call dropping probabilities minimum. Load balancing may result in handover or cell reselection.
  • Distribution function for NAS messages in order to transfer the messages transparently for RRC and S1-AP protocol.
  • NAS node selection function in order to select the MME/S-GW for UE.
  • Synchronization in order to maintain the timing between different nodes within the network.
  • Radio access network sharing in order to provide sharing of radio access network by multiple PLMNs (Public Land Mobile Network). This mechanism directs the UE to appropriate PLMN. E-UTRAN broadcasts the PLMN-ids in the air link (up to 6). The UE selects one of the PLMN-id and notifies E-UTRAN in random access procedure.
  • MBMS function in order to ensure the transmission of the same data to multiple recipients.
  • Subscriber and equipment trace in order to provide trace of the subscriber equipment. Traces are initiated by core network and a trace setup is transferred on X2 or S1 interface during handover.
Part III Application of IP-OFDMA

- Long-Term Evolution of 3GPP
  - E-UTRAN
    - eNB: Evolved NodeB

Evolved NodeB (eNB) is the only entity in the evolved-RAN (E-UTRAN) that interfaces with User Equipment (UE) through LTE-UE interface. eNB hosts the PHY, MAC, Radio Link Control (RLC), and Packet Data Control Protocol (PDCP) layers. eNB can support FDD mode, TDD mode, or dual-mode operation with the protocol model depicted in Fig. 11.4.

![Diagram of Protocol model of E-UTRAN](image-url)
Part III Application of IP-OFDMA

- Long-Term Evolution of 3GPP
  - E-UTRAN
    - eNB: Evolved NodeB
Part III Application of IP-OFDMA

- Long-Term Evolution of 3GPP
  - UE: User Equipment

User Equipment (UE) consists of user-plane and control-plane protocol stack. User-plane protocol stack consists of PDCP, RLC, MAC, and PHY layers, which communicates with eNB through LTE wireless link. Control-plane protocol stack contains NAS and RRC in addition to user-plane protocol stack. NAS in UE communicates directly with NAS in MME, and RRC in UE communicates with RRC in eNB as seen in Fig. 11.3.

NAS control-plane protocol is responsible for SAE bearer management, authentication, idle mode mobility/paging handling, and security control.

RRC control-plane protocol is responsible for paging/broadcast, RRC connection management, Radio Bearer (RB) control, mobility functions, and UE measurement and reporting.

E-UTRAN provides two identities for UE: C-RNTI,\textsuperscript{7} which is a unique UE identification at cell level to identify RRC connection, and Random value for contention resolution, which is for a transient condition to resolve a contention.

Network level identities include MME identity, which UE presents to the eNB in the idle state, eNB or cell identity, which is given to new eNB in order to have it retrieve UE context, and tracking area id, which describes the paging region. eNB broadcasts cell id, tracking area id, and one or more PLMN ids (identifying each operator).
Long-Term Evolution of 3GPP

- **UE**: User Equipment

UE cycles among **LTE_DETACHED**, **LTE_ACTIVE**, and **LTE_IDLE** as seen in Fig. 11.6. During detached mode, UE looks for attachment point to register and it shifts to active mode after registration. In the active mode, it performs its normal operation and initiates handover if needed. During handover, data integrity of packets is satisfied either by buffering in eNB and forwarding to target eNB or unicasting from SAE GW to candidate eNBs. Packet level ordering can be addressed with PDCP sequence numbers. During idle mode, UE is tracked by MME in tracking...
3GPP System Architecture Evolution (SAE) has an objective to migrate the current system to a better technology. Interoperability provides coexistence and colocation with GERAN/UTRAN on adjacent channels. E-UTRAN terminals should support measurements, handover to/from UTRAN or GERAN. The interruption time between E-UTRAN and UTRAN/GERAN should be less than 300ms. Figure 11.2 shows a system architecture possibly relying on different access technologies where WiMAX falls into trusted non-3GPP IP Access.

LTE-Uu: Reference point of the radio interface between UE and eNB.
S1-MME: Reference point for control plane between E-UTRAN and MME. S1-MME uses SCTP as the transport protocol.
S1-U: Reference point between E-UTRAN and SGW for the per-bearer user plane tunneling and inter-eNB path switching during handover with GTP-U as transport protocol.
S2a: Reference point for user plane with related control and mobility support between trusted non-3GPP IP access and the gateway based on Proxy Mobile IP. S2a also supports Client Mobile IPv4 FA mode if PMIP is not available.
Part III Application of IP-OFDMA

- Long-Term Evolution of 3GPP
  - Reference Points

S2b: Reference point to provide the user plane with related control and mobility support between evolved Packet Data Gateway (ePDG) and the PDN GW over PMIP.

S2c: Reference point to provide the user plane with related control and mobility support between UE and the PDN GW. This reference point is implemented over trusted and/or untrusted non-3GPP access and/or 3GPP access over CMIP collocated mode.

S3: Reference point between SGSN and MME to enable user and bearer information exchange for inter-3GPP access network mobility in idle and/or active state over GTP and Gn reference point as defined between SGSN and GGSN.

S4: Reference point to provide the user plane with related control and mobility support between SGSN and the SGW over GTP and Gn reference point as defined between SGSN and GGSN.

S5: Reference point to provide user plane tunneling and tunnel management between SGW and PDN GW when SGW relocation is needed due to UE mobility and if the SGW needs to connect to a noncollocated PDN GW for the required PDN connectivity. GTP and the IETF-based PMIP are possible solutions.
Part III Application of IP-OFDMA

- Long-Term Evolution of 3GPP
  - Reference Points

S6a: Reference point to enable transfer of subscription and authentication data for authenticating/authorizing user access to the evolved system (AAA interface) between MME and HSS.

S6c: Reference point between PDN GW, Home PLMN\(^8\) (HPLMN), and 3GPP AAA server for mobility-related authentication if needed.

S6d: Reference point between SGW, Visited PLMN\(^9\) (VPLMN), and 3GPP AAA Proxy for mobility-related authentication if needed.

S7: Reference point to provide transfer of QoS policy and charging rules from PCRF to Policy and Charging Enforcement Function (PCEF) in the PDN GW over Gx interface.

S8a: Reference point based on GTP protocol and the Gp interface defined between SGSN and GGSN. It is for home-routed traffic in order to provide user plane with related control between the SGW in VPLMN and the PDN GW in HPLMN. S8a is a variant of S5 for roaming and S8b is available that supports PMIP.
Part III Application of IP-OFDMA

- Long-Term Evolution of 3GPP
  - Reference Points

S9: Reference point between hPCRF and vPCRF used in roaming to enforce in the VPLMN of dynamic control policies from the HPLMN.

S10: Reference point between MMEs for MME relocation and MME to MME information transfer.

S11: Reference point between MME and SGW to instruct the decisions for enforcement point.

SGi: Reference point between the PDN GW and the packet data network. Packet data network may be an operator-external public or private packet data network or an intraoperator packet data network. This reference point corresponds to Gi for 2G/3G accesses.

Rx+: Reference point between the Application Function and the PCRF defined in the 3GPP TS 23.203.

Wn*: Reference point between the untrusted non-3GPP IP access and the ePDG. Traffic on this interface has to be forwarded toward ePDG.
Part III Application of IP-OFDMA

- Long-Term Evolution of 3GPP
  - Reference Points

The interfaces between the SGSN in 2G/3G Core Network and EPC will be based on the GPRS Tunneling Protocol (GTP). The GTP protocol consists of two parts: the GTP-C and the GTP-U. The GTP-C is for control purpose in order to create, modify, and delete the GTP tunnels. Unlike GRE, tunnel creation in GTP is with explicit signaling. The GTP-U transports the user data and some control information. The GTP header is illustrated in Fig. 11.7.

![GTP header diagram](image)
Part III Application of IP-OFDMA

• Long-Term Evolution of 3GPP
  – System Aspects
    • QoS, Security

EPS bearers are defined as an aggregate point of one or more IP flows. The GTP bearers exist between UE and the PDN GW as seen in Fig. 11.8. Aggregation is
Part III Application of IP-OFDMA

- Long-Term Evolution of 3GPP
  - System Aspects
    - QoS, Security

SAE/LTE security defines a new architecture with extended key hierarchy. It prohibits SIM (Subscriber Identity Module) access but uses USIM (Universal Subscriber Identity Module) from Rel-99. This is the master key (128 bits) and there is possibility to add 256-bit keys later.

The subscriber authentication is through AKA procedure between the UE and the MME. Additional Access Security Management Entity (ASME), collocated with MME, is introduced to protect the NAS signaling (encryption and integrity via AES and SNOW 3G as the selected crypto-algorithms).

The keys used for NAS protection are separate in eNB and EPC. This makes it impossible to use the eNB key in order to extract the EPC key. CK/IK keys are confined to home network and ASME receives the derived key ($K_{ASME}$) for authentication with the UE as seen in Fig. 11.9. ASME passes this key to MME and also sends keys to eNB derived from $K_{ASME}$. MME retains the keys when UE goes to idle state.

When UE enters the connected state, eNB keys are sent to eNB from EPC. If keys are detected to be corrupted, UE restarts the radio attachment procedure. $NAS$ and $K_{eNB}$ keys are derived from $K_{ASME}$, which never leaves the EPC. From $K_{eNB}$, eNB and UE derive the $UP$ and $RRC$ keys. These three keys are deleted when UE goes to idle or null state. NAS keys are used for the protection of NAS traffic, $UP$ is used for the protection of U-Plane traffic, and $RRC$ key is used only for protection of $RRC$ traffic.
Part III Application of IP-OFDMA

- Long-Term Evolution of 3GPP
  - System Aspects
    - QoS, Security

![Key hierarchy diagram](image)

*Fig. 11.9 Key hierarchy; USIM: Universal Subscriber Identity Module, AuC: Authentication Center*
Part III Application of IP-OFDMA

• Long-Term Evolution of 3GPP
  – LTE Higher Protocol Layers

  Protocol layer architecture for LTE system is shown Fig. 11.3. There are control plane and user plane protocol stacks in eNB and UE.
  Protocol layers in UE are as follows:
  
  • NAS: Nonaccess Stratum
  • RRC: Radio Resource Control
  • PDCP: Packet Data Convergence Protocol
  • RLC: Radio Link Control
  • MAC: Medium Access Control
  • PHY: Physical Layer

  Protocol layers in eNB are as follows:
  
  • RRC: Radio Resource Control
  • PDCP: Packet Data Control Protocol
  • RLC: Radio Link Control
  • MAC: Medium Access Layer
  • PHY: Physical Layer

  Communication between these layers is established via channels as seen in Fig. 11.10. First, let us look at the channel structure and then delve into protocol layers.
Part III Application of IP-OFDMA

- Long-Term Evolution of 3GPP
  - LTE Higher Protocol Layers
    - Communication Channel Structure

Protocol layers in eNB are as follows:

- RRC: Radio Resource Control
- PDCP: Packet Data Control Protocol
- RLC: Radio Link Control
- MAC: Medium Access Layer
- PHY: Physical Layer

Communication between these layers is established via channels as seen in Fig. 11.10. First, let us look at the channel structure and then delve into protocol layers.
Long-Term Evolution of 3GPP

- LTE Higher Protocol Layers

There are two types of logical channels: control and traffic channels. Control channels are as follows:

- **BCCH**: Broadcast Control Channel is to transmit broadcasting system control information.
- **PCCH**: Paging Control Channel is to transmit paging information when UE is unlocated.
- **CCCH**: Common Control Channel is used by UE when UE has no RRC connection.
- **MCCH**: Multicast Control Channel is used to transmit MBMS control information, which is point-to-multipoint (eNB to UEs) and only UEs that receive MBMS use it.
- **DCCH**: Dedicated Control Channel is a point-to-point bidirectional channel used by UE for RRC connection.

Traffic channels are as follows:

- **DTCH**: Dedicated Traffic Channel is a point-to-point bidirectional channel dedicated to one UE to transfer user information.
- **MTCH**: Multicast Traffic Channel is a point-to-multipoint channel for transmitting traffic data from the network to the UE.
Part III Application of IP-OFDMA

- Long-Term Evolution of 3GPP
  - LTE Higher Protocol Layers

Transport channels provide structure passing data to/from higher layers, mechanism to configure PHY, status indicators to higher layers (CQI, error, etc.) and higher-layer peer-to-peer signaling. Transport channels for downlink are as follows:

- **BCH**: Broadcast Channel transmits entire cell area with fixed transport format.
- **DL-SCH**: Downlink Shared Channel is used for HARQ, dynamic link adaptation, UE DRX (discontinuous receive) for power save, dynamic and semistatic allocation, and beamforming.
- **PCH**: Paging Channel is used for UE DRX, broadcast over cell coverage.
- **MCH**: Multicast Channel provides support for Multicast Broadcast -Single Frequency Network (MB-SFN) with semi-static resource allocation.

Transport channels for uplink are as follows:

- **UL-SCH**: Uplink Shared Channel is for HARQ, dynamic link adaptation, support for UE DRX, and dynamic and semistatic resource allocation with 1/3 turbo coding.
- **RACH**: Random Access Channel is for limited control information, which has collision risk.
Long-Term Evolution of 3GPP

- LTE Higher Protocol Layers

Transport channels are connected to physical channels. LTE downlink physical channels are as follows:

- **PDSCH**: Physical Downlink Shared Channel is utilized for data and multimedia transport. It is designed for high data rates with QPSK, 16QAM, and 64QAM modulation with 1/3 turbo coding and spatial multiplexing.

- **PDCCH**: Physical Downlink Control Channel conveys UE-specific information with QPSK-only modulation for robustness. Up to first three OFDM symbols in the first slot of a subframe are used for PDCCH.

- **CCPCH**: Common Control Physical Channel conveys cell information with QPSK-only modulation and convolutional coding. CCPCH is sent close to center frequency.

LTE uplink physical channels are the following:

- **PUSCH**: Physical Uplink Shared Channel is allocated subframe basis by the UL scheduler with QPSK, 16QAM, or 64QAM modulation.

- **PUCCH**: Physical Uplink Control Channel carries uplink control information including CQI, ACK/NACK, HARQ, and uplink scheduling requests.

Each physical channel has a defined algorithm for bit scrambling, modulation, layer mapping, precoding, and scheduling. Also, note that layer mapping and precoding are applicable when MIMO mode is present.
Part III Application of IP-OFDMA

- Long-Term Evolution of 3GPP
  - LTE Higher Protocol Layers
    - Communication Channel Structure

![Diagram of communication channel structure](image)

*Fig. 11.11 Downlink and uplink channel mapping: dotted lines are still being studied by 3GPP*
Part III Application of IP-OFDMA

• Long-Term Evolution of 3GPP
  – LTE Higher Protocol Layers
    • NAS Layer

  NAS layer is used between UE and MME for establishing control signaling. This communication is used for the following:

  • Network entry (attach)
  • Authentication
  • Data bearers setup
  • Mobility management

  The NAS signalling security is provided by ciphering and integrity protection. Transfer of NAS messages from/to UE is handled by RRC layer.

• PDCP Layer

  Figure 11.13 illustrates the PDCP, RLC, and MAC layers in detail for both eNB and UE. The PDCP layer provides ROHC header compression and decompression for efficient air bandwidth usage. It transfers the PDCP SDU received from NAS to RLC layer and vice versa. It supports ciphering of user plane and control plane data. PDCP PDU comprises PDCP header and PDCP SDU.
Part III Application of IP-OFDMA

• Long-Term Evolution of 3GPP
  – LTE Higher Protocol Layers
    • RRC Layer

The Number of RRC states in LTE is reduced to 2 as compared to that in predecessors. Two states of RRC are RRC_IDLE and RRC_CONNECTED. RRC may perform one of the listed functions in Fig. 11.12 according to these states.

The RRC layer of eNB is responsible to broadcast system information, perform paging, and establish an RRC connection with UEs to allocate temporary identifiers (RA-RNTI). The RRC layer also configures the signaling radio bearer for RRC connection and is responsible for integrity of RRC messages.

RRC plays a key role in mobility. UE measurement and reporting, intra-LTE handover, UE cell re/selection, and context transfer are handled by the RRC layer. RRC also facilitates MBMS services.

Fig. 11.12 UE states
Part III Application of IP-OFDMA

• Long-Term Evolution of 3GPP
  – LTE Higher Protocol Layers
    • RLC Layer

The RLC layer is responsible to transfer traffic PDUs between UE and eNB with segmentation if needed and applies error correction through ARQ for received data. It applies concatenation, in-sequence delivery, and duplicate detection. RLC PDU comprises RLC header and RLC SDU. RLC layer provides three different reliability modes:

**AM:** Acknowledge Mode requires acknowledgement and is good for unreal time services such as file download.

**UM:** Unacknowledge Mode does not require an acknowledgement and is suitable for real time services such as video streaming.

**TM:** Transparent Mode implement implicits acknowledgement and is used when file sizes are known as in broadcasting.
Part III Application of IP-OFDMA

- Long-Term Evolution of 3GPP
  - LTE Higher Protocol Layers
    - RLC Layer

![Layer and channel structure for UE and eNB](image_url)