# Power Management
# and
# Mobility Management
# in LTE

*Irfan Ali*

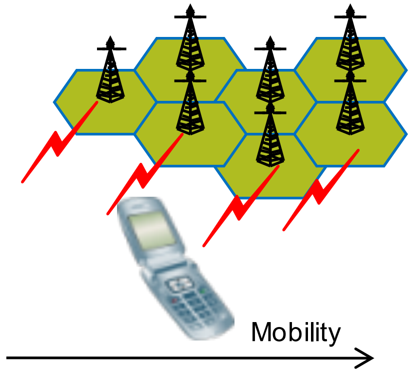
# Overview

- **Power Conservation in UE**
  - High Power: “Connected Mode” when UE has both its transmitter and receiver always on.
  - Low Power: “Idle Mode” when UE turns off it transmitter. It turns on its receiver periodically
- **Transition between the states**
- **Mobility in Idle Mode**
  - Cell Selection and Re-selection
  - Tracking Area Update
- **Mobility in Connected Mode: Handovers**

# Power Management in LTE

## High Power Mode
*Connected Mode*

- Network controls UE's movement through handover.
- Location of the UE is known to the network at granularity of a cell.

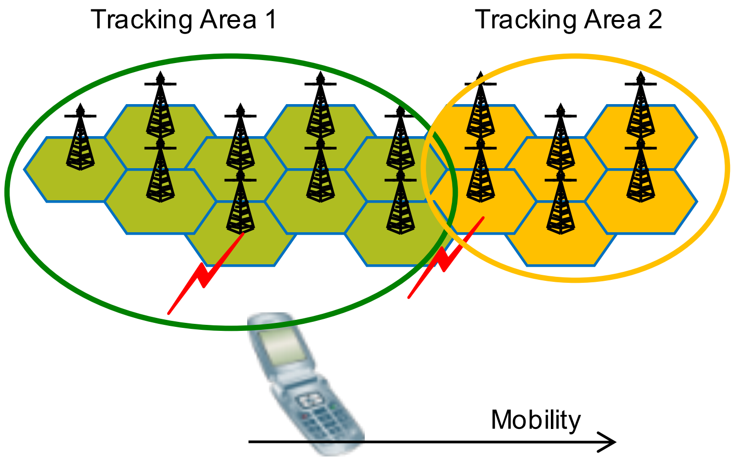



- UE's radio is in ON state.
- UE is constantly communicating with the network.

***UE is like a dog on a leash ☺***

## Low Power Mode
*Idle Mode*

- Network does not control UE's movement. UE autonomously selects new cell as it moves.
- Network only knows the location of the UE to the granularity of a tracking-area.

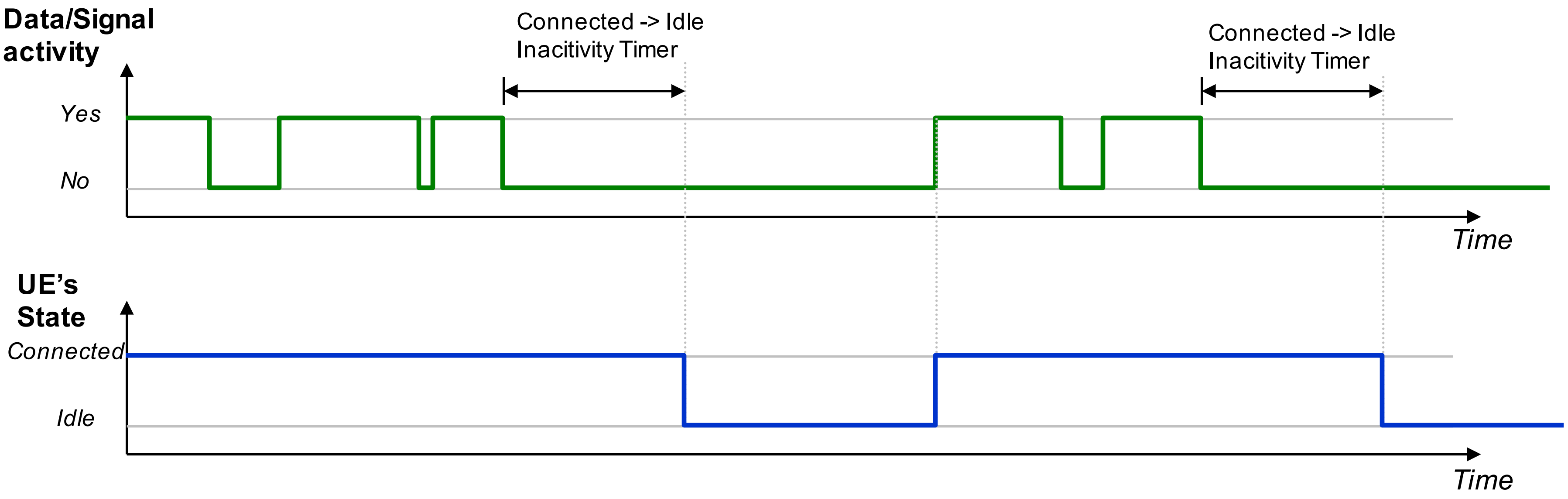



- UE's radio is in low-power state. UE's transmitter is off.
- UE only listens periodically to control channel. If UE enters a new location area, based on hearing information from base-station, the UE informs the network of the new tracking area it has entered.

***UE is like a dog without a leash enclosed in an electronic fence***

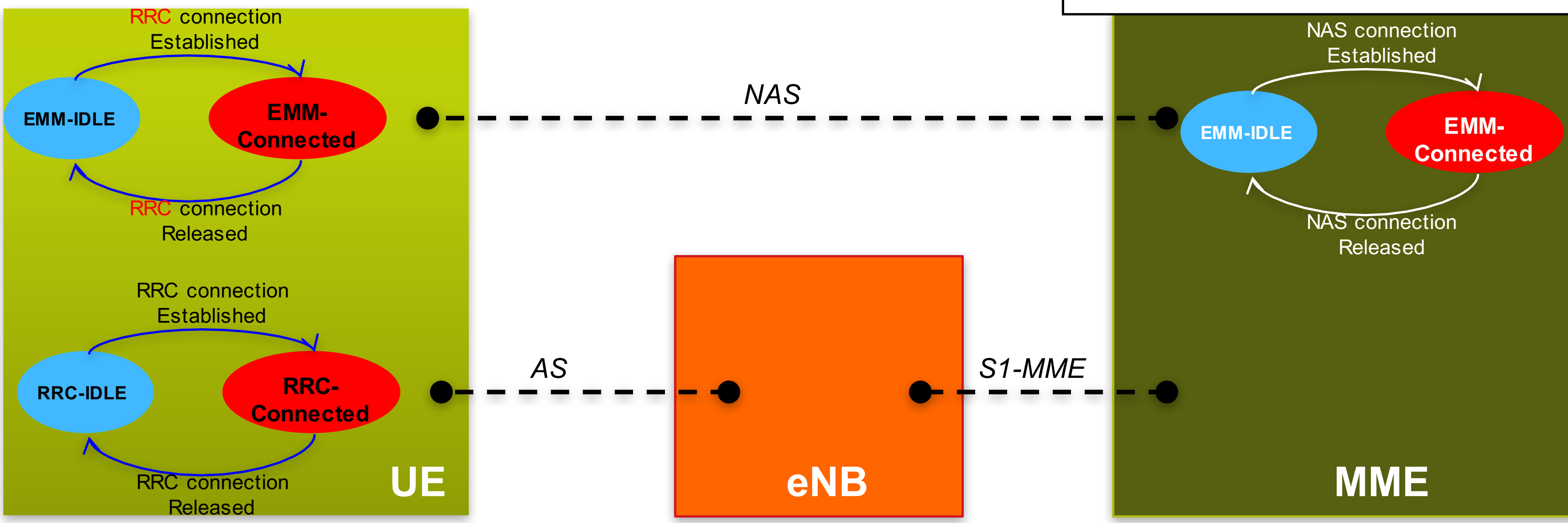
# Activity State Management

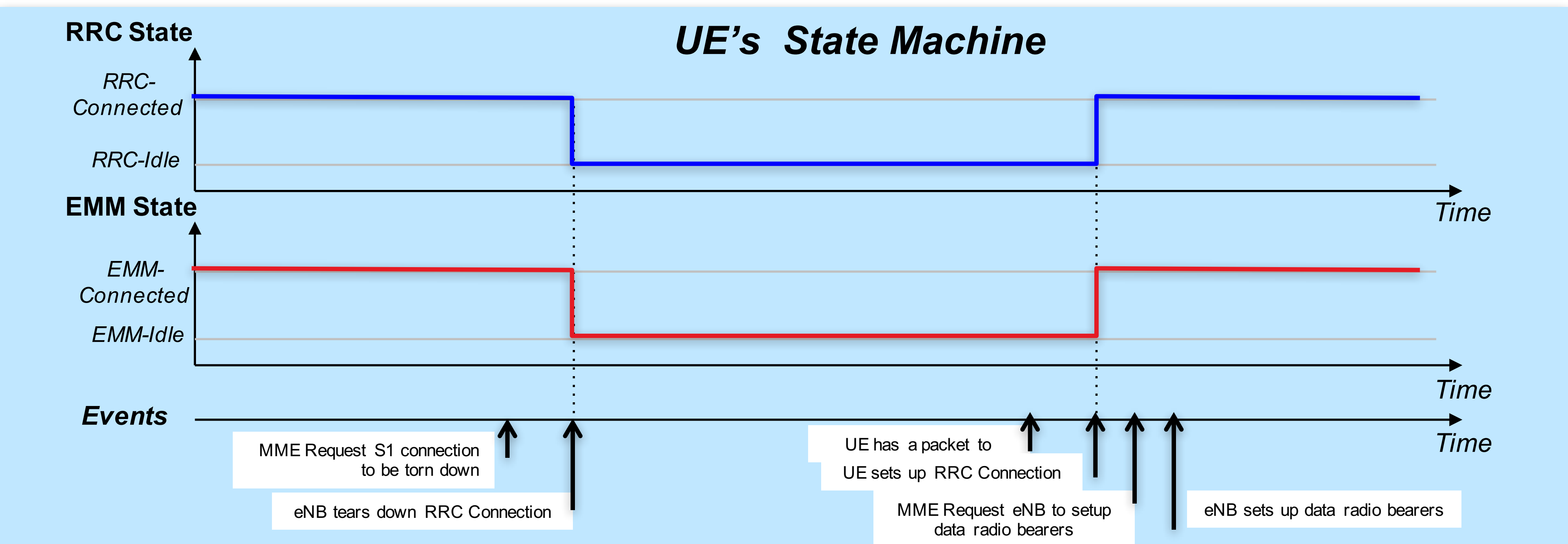
- **A UE in LTE can be in two states:**
  - **Connected Mode**: The UE is transmitting and receiving data from the network.
  - **Idle Mode**: The UE is only monitoring the paging and broadcast channel.
- **After the UE stops transmitting/receiving data/signal for a period of time, called inactivity period, the network moves the UE's state to idle-state**



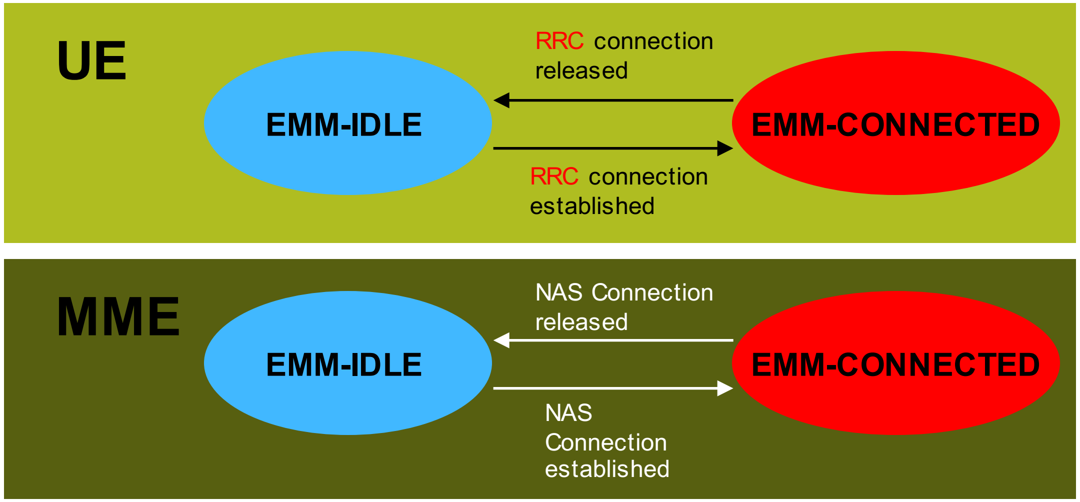
# UE's Activity States for AS and NAS

| | |
|---|---|
| EMM | Enhanced Mobility Management |
| NAS | Non Access Stratum |
| AS | Access Stratum |
| RRC | Radio Resource Control |



# Activity States of UE




*Both the UE and MME keep track of the state of the UE*

*Idle Mode*

- *UE monitors paging channels periodically (DRX cycle) and some System Information channel*
- *No NAS signalling connection between UE and MME*
- *UE (independently) performs cell selection/re-selection based on broadcast information*
- *No UE information in the eNB*
- *Location of UE is known to the MME at granularity of Tracking Area.*
- *UE performs TAU when UE enters a new TAI or when the periodic TAU timer expires.*
- *UE enters connected mode when RRC signaling connection is established.*
  - *For MME there is no clear indication when the UE's state transitions to EMM-Connected. Typically this happens when the S1-MME connection is established for the UE.*

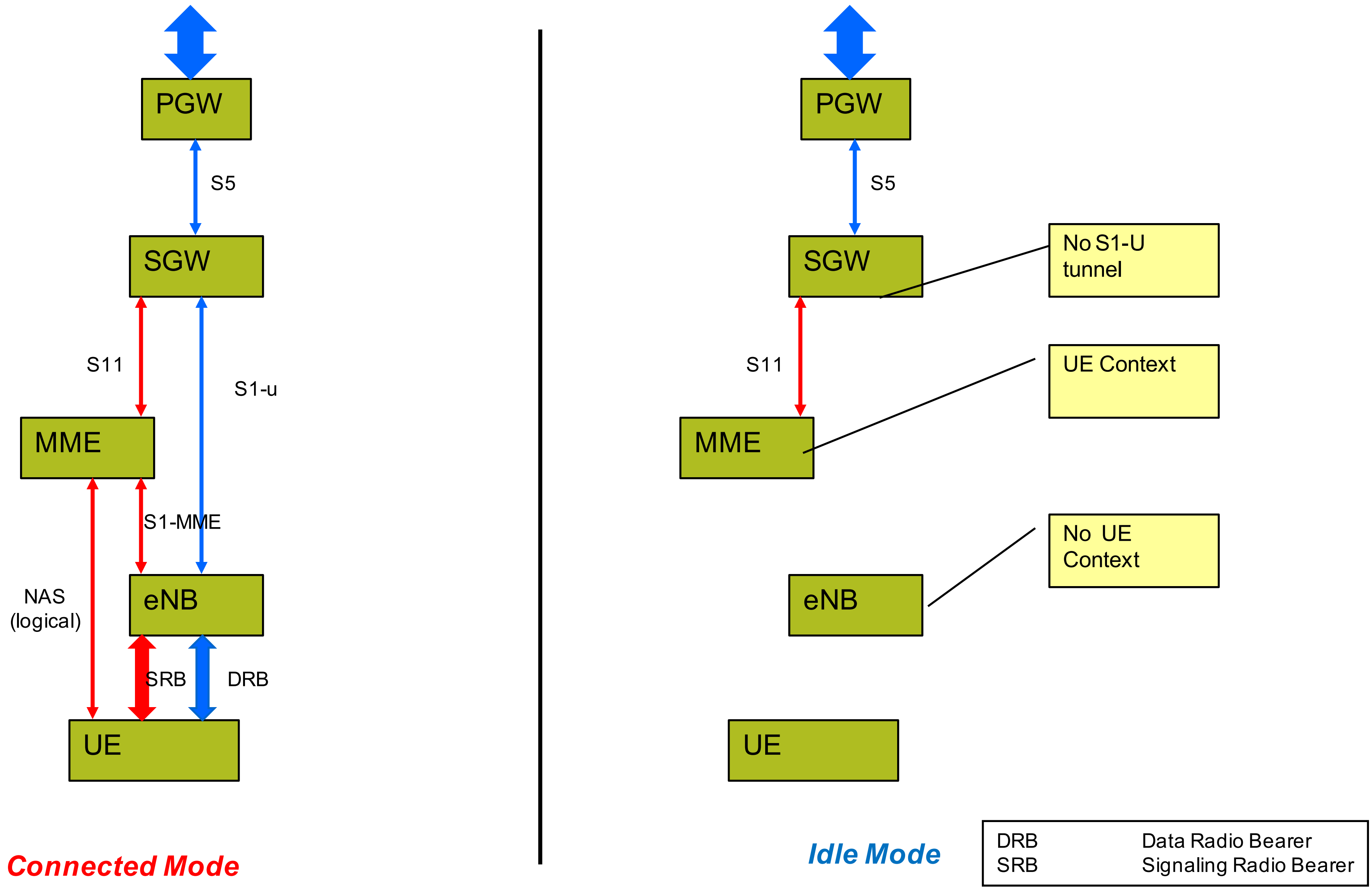
*Connect Mode*

- *UE monitors System Information channel and control channels associated with shared data channels.*
- *NAS signalling connection between UE and MME*
- *Network (eNB) controls UE's movement through handover.*
- *UE context in the eNB*
- *Location of the UE is known to the MME at granularity of eNB.*
- *UE performs TAU when UE enters a new TAI broadcast*
- *UE enters idle mode when RRC connection is released.*
  - *For MME there is no clear indication when the UE's state transitions to EMM-Idle. Typically this happens when the S1-MME connection is released for the UE.*

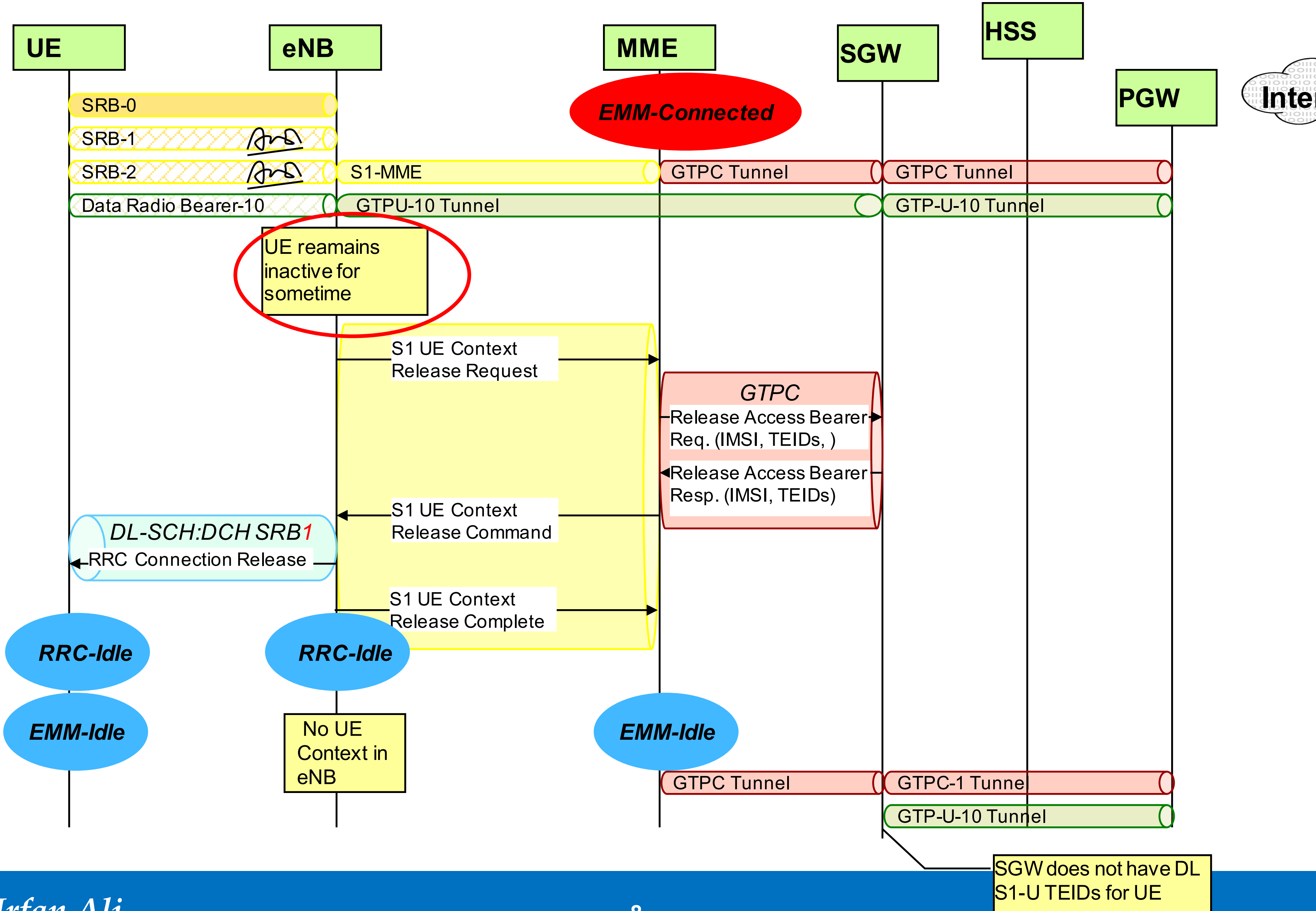


| | |
|---|---|
| EMM | Enhanced Mobility Management |
| NAS | Non Access Stratum |
| RRC | Radio Resource Control |

# State in Network for Connected and Idle mode



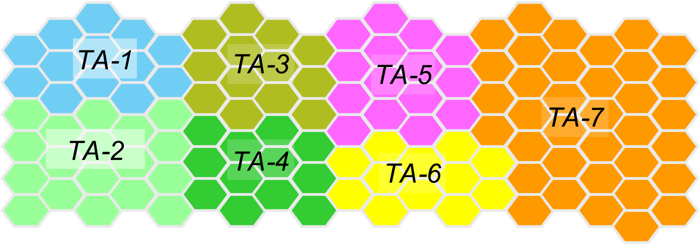
# Transition from Connected to Idle State – S1 Release Procedure



Packet arrives at Serving GW for idle UE: **Where** to page the UE?

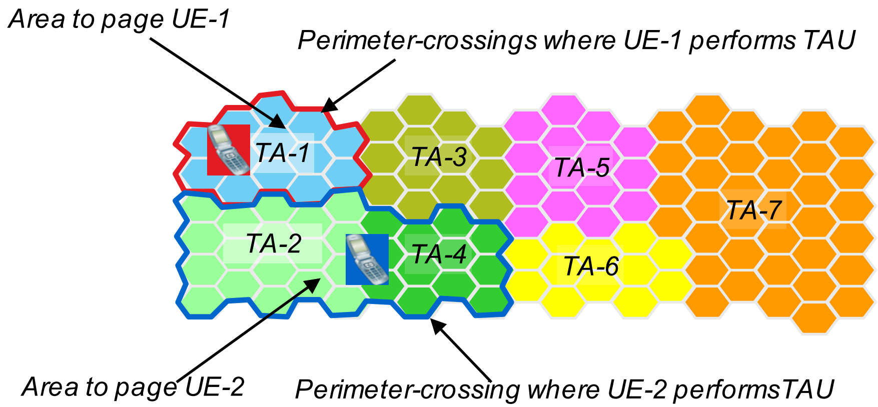
# Concept of Tracking Area-1

- Tracking Area consists of a set of eNBs.
- The concept of tracking area is introduced to reduce the amount of location reporting (Tracking Area Update TAU) signaling that a UE does when in idle-state
  - ➢ The UE only signals to the network (MME) when the UE enters a TA to which it is not admitted.
  - ➢ The MME knows the location of the UE to the granularity of TAs.
- Tracking areas are non-overlapping in LTE.
- The identity of each tracking area is called Tracking Area Identity (TAI).
- Each cell in a eNB can belong to only one TAI.
- Each cell advertises in broadcast message the TAI to which it belongs.
- The MME tells the UE which Tracking areas the UE is registered in.
  - ➢ This is done in EMM-Connected mode.



# Concept of Tracking Area-2

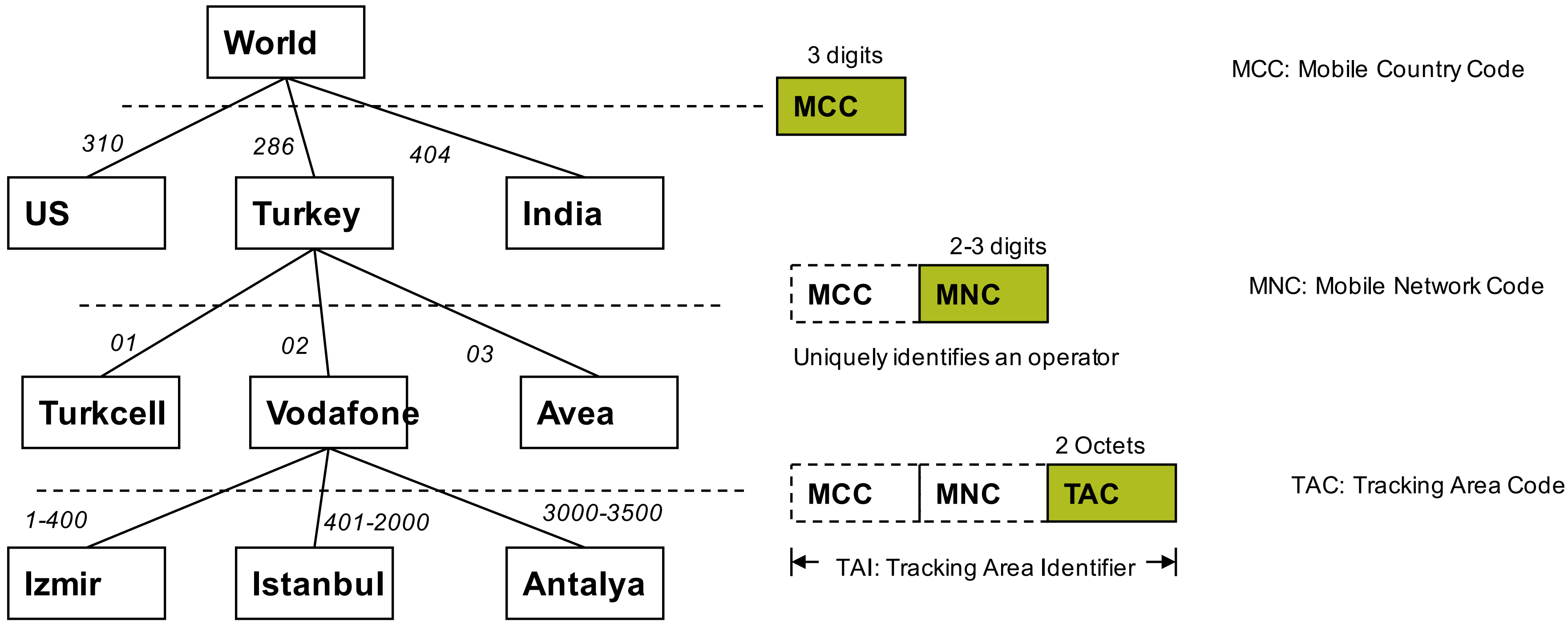
- A UE in LTE can be admitted to multiple tracking areas. The list of tracking areas to which the UE is admitted is called the tracking area list (TAI List) is provided to the UE.
- When a UE is idle and the MME needs to locate the UE, the MME pages the UEs in the set of eNB which belong to the TAI that the UE is registered in.
  - Larger the tracking area, less frequent will be the UE's need to signal to the network; however larger the number of eNBs that the UE will need to be paged in.




*UE-1 is admitted to TAI-1*

*UE-2 is admitted to {TAI-2, TAI-4}*

# Tracking Area Identity (TAI)

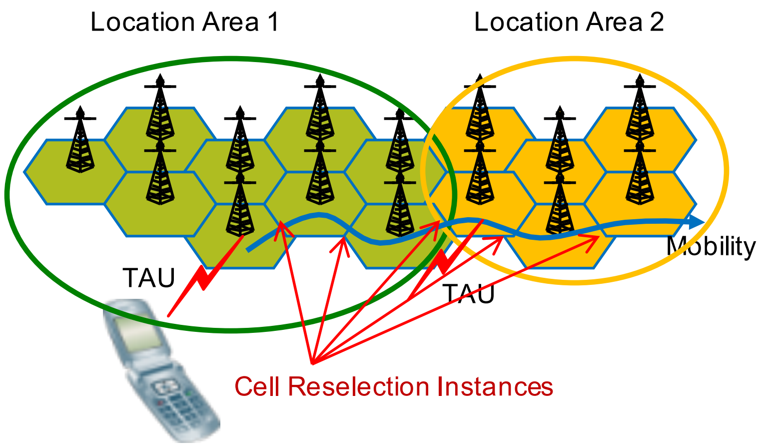



Source for MCC and MNC codes: www.wikipedia.org

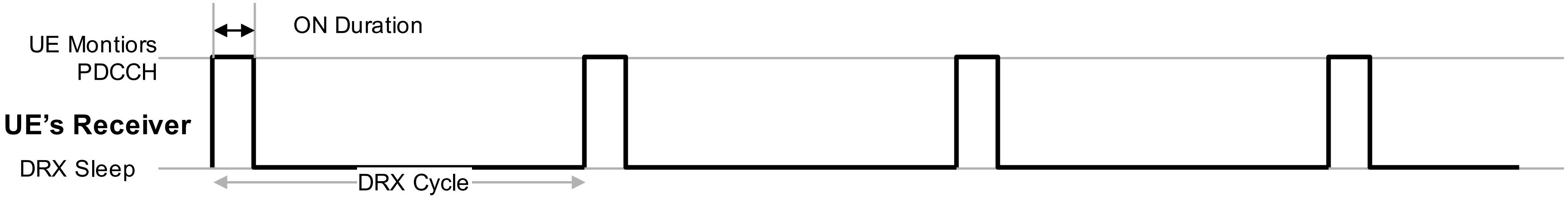
# Cell-Selection and Cell-Reselection in Idle-mode: Which cell should UE "camp" on?

# Low Power (Idle Mode)

- ***Network does not control UE's movement. UE autonomously selects new cell as it moves.***
- ***Network only knows the location of the UE to the granularity of a location-area.***

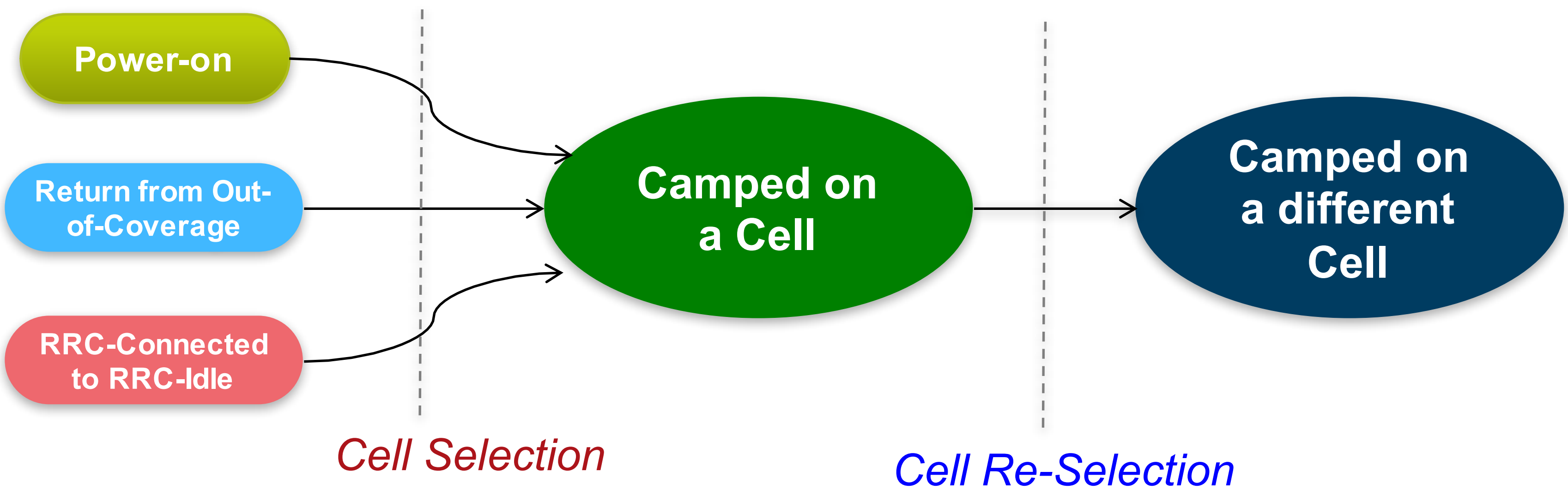



- ***UE's radio is in low-power state. UE's transmitter is off.***
- ***UE only listens periodically to control channel. If UE enters a new location area, based on hearing information (SIB) from base-station, the UE informs the network of the new location area it has entered.***



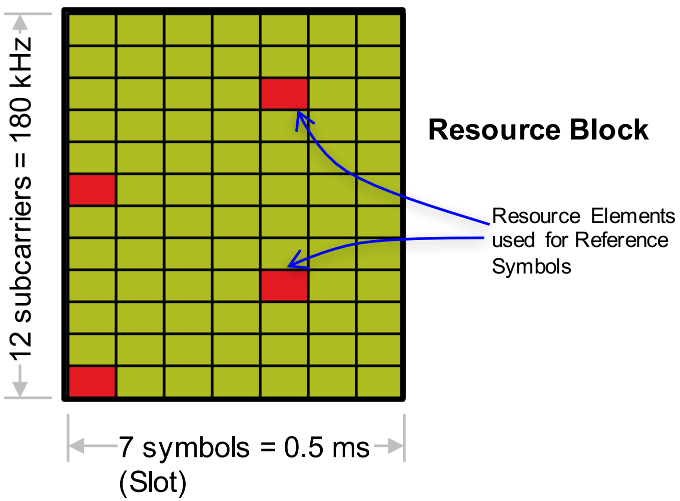
# Cell Selection vs Cell Reselection

- **Cell selection or cell-reselection is the process of UE choosing a cell.**
- **Camped on a cell: UE has completed the cell selection/reselection process and has chosen a cell. The UE monitors system information and (in most cases) paging information.**



# What does the UE measure to determine if it can camp on a cell? (1 of 3)

- **Reference Symbols**
  - In order for receiver to estimate the channel, known reference symbols also referred to as pilot symbols are inserted at regular intervals within the OFDM time-frequency grid.
  - Using knowledge of the reference symbols the receiver can estimate the frequency-domain channel around the location of the reference symbol
  - The reference symbols should have sufficient high density in time and frequency to provide estimates of the entire time/frequency grid.
  - There are four resource elements per resource block that are dedicated to Reference Symbols.
  - The location of Reference Symbols depends on the Physical layer cell identity of the cell.
  - Once the UE has decoded the Primary and Secondary Synchronization Signals and consequently identified the Physical Layer Cell Identity, the UE is able to deduce the resource elements allocated to the Reference Signal.

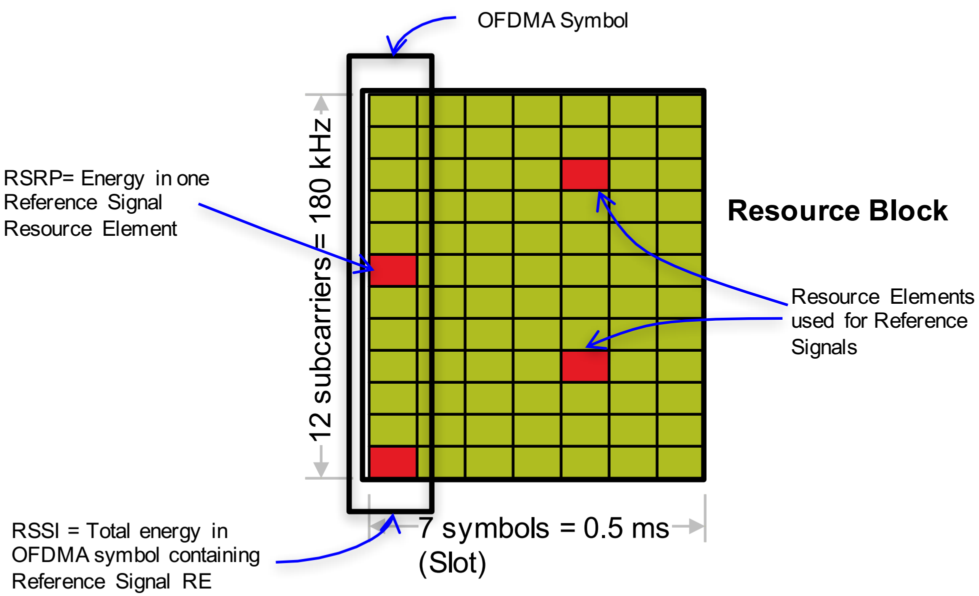


# What does the UE measure to determine if it can camp on a cell? (2 of 3)

- **Reference Signal Received Power (RSRP)**
  - The RSRP is the average power (in watts) received from a single Reference Signal resource element
    - **The power measurement is based upon the energy received during the useful part of the OFDMA symbol and excludes the energy of the cyclic prefix.**
  - Knowledge of absolute RSRP provides the UE with essential information about the strength of cells from which path loss can be calculated for power-control calculations.
- **Reference Signal Received Quality (RSRQ)**
  - RSRP on its own it gives no indication of signal quality.
  - The Received Signal Strength Indicator RSSI parameter represents the <u>entire received power</u> including the wanted power from the serving cell as well as all co-channel power and other sources of noise.

$$RSRQ = \frac{RSRP}{RSSI / N}$$

- where *N* is the number of Resource blocks over which the RSSI is measured
- RSRQ is always less than 1 (< 0 dB, actually < -3dB)



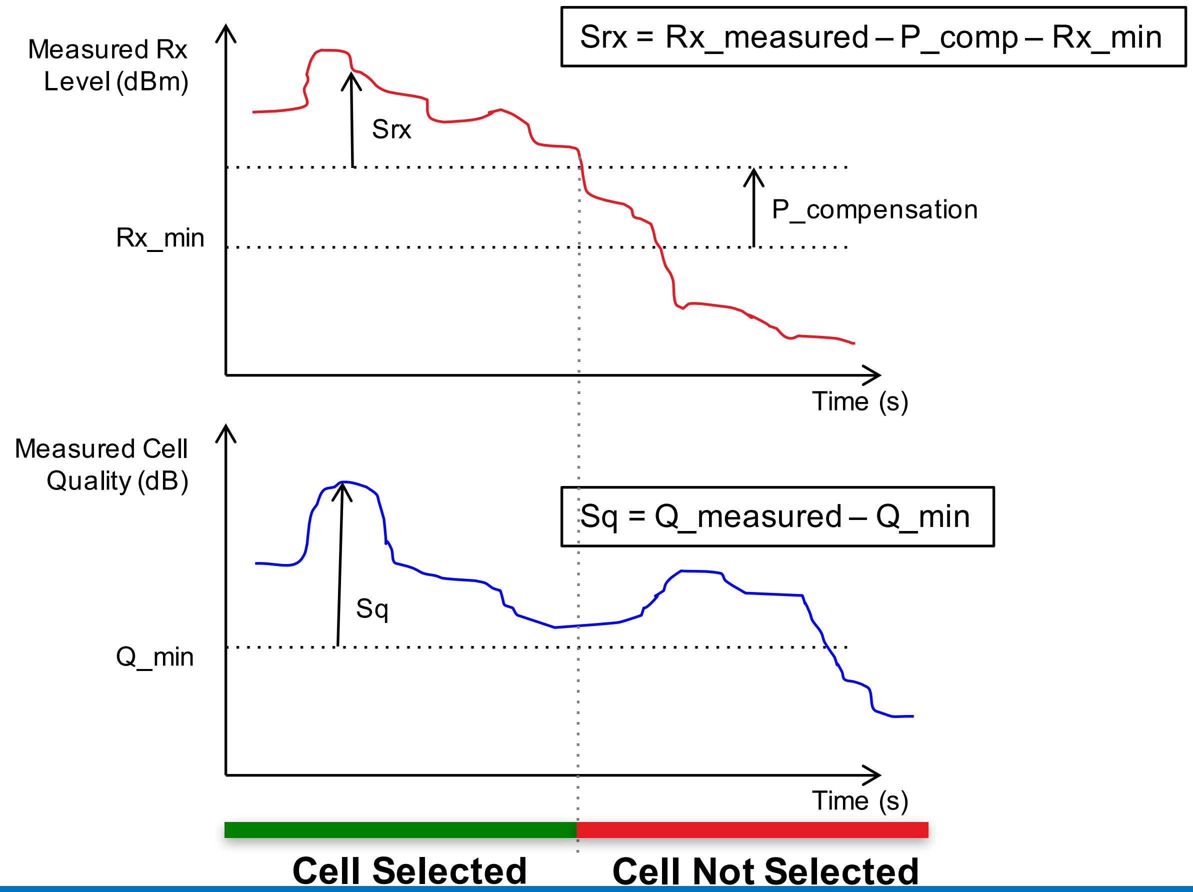
# What does the UE measure to determine if it can camp on a cell? (3 of 3)

- **Cell Selection Criteria**

Cell is selected if:

Srx > 0, and

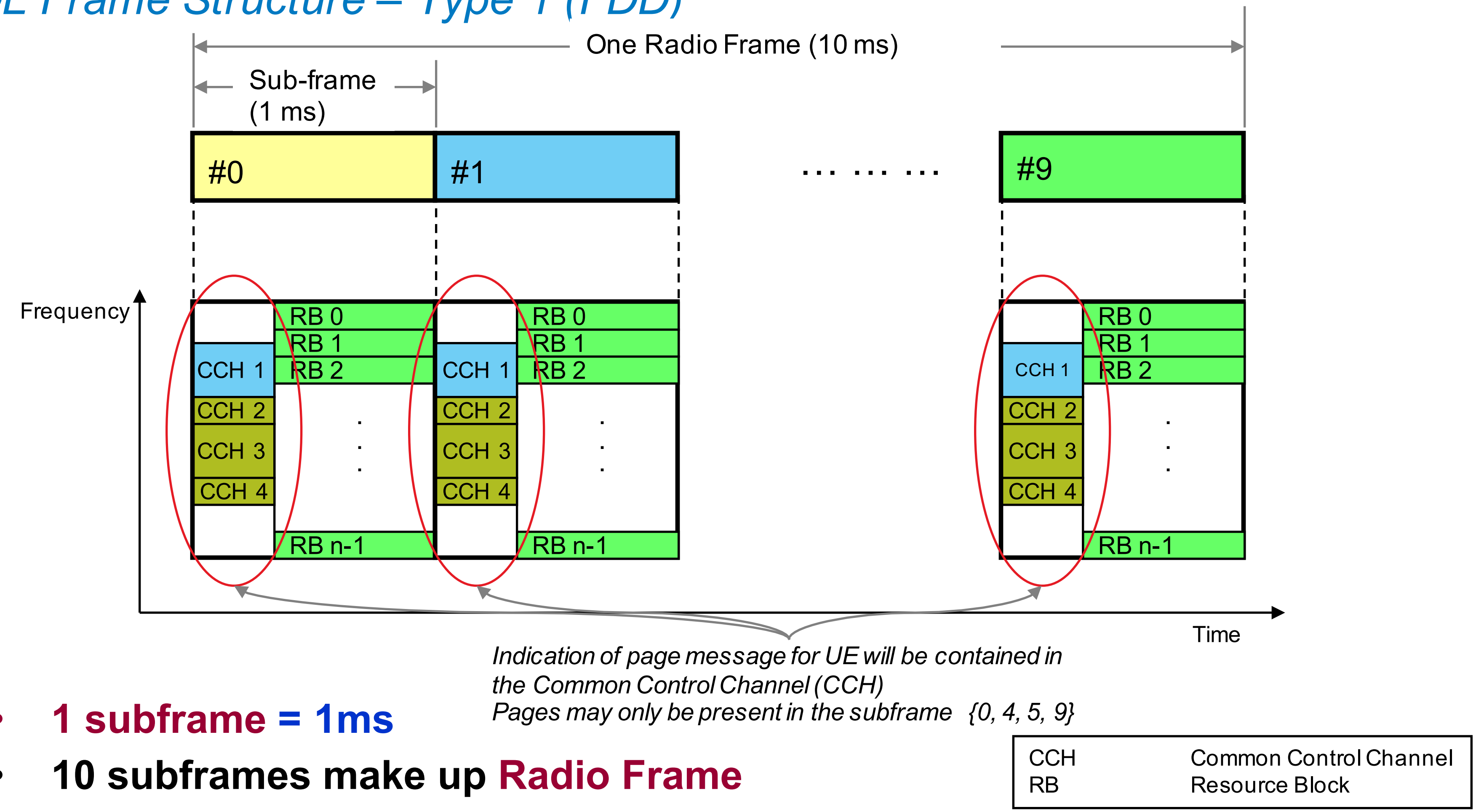
Sq > 0



# Idle-mode: **When** to page the UE?

In the next few set of slides we figure out when the UE turns on its receiver to figure out if the network is paging the UE.

# DL Frame Structure – Type 1 (FDD)




- **1 subframe = 1ms**
- **10 subframes make up Radio Frame**
- **Each subframe consists of 14 symbols**
- **DL control signalling is in the first 1-3 symbols**
  - The rest of the symbols (11-13) are used for data and dedicated control channels.

# UEs DRX cycle in idle mode: Paging DRX

- **The UE's paging DRX cycle period is one of the following:**
  - {32, 64, 128, 256} frames (each frame is 10 msec), i.e
  - {0.32, 0.64,1.28, 2.56} seconds

- **The UE determines its idle-mode DRX paging cycle either**
  - From the information in System Information Block (SIB)
  - Or is provided to the UE via dedicated signal before UE goes idle.

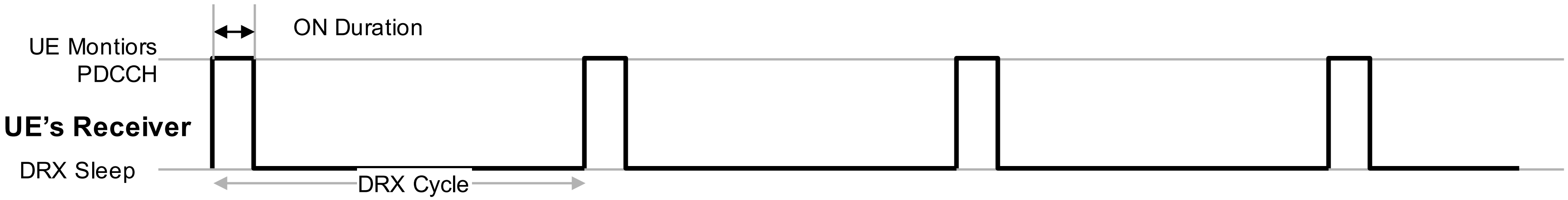
- **Not all radio frames contain page messages.**
  - Paging Occasion (PO) is a subframe that contains paging message
  - Paging Frame (PF) is a radio frame that contains one or more paging occasions.

- **The UE needs to monitor only one paging occasion per DRX cycle.**
- **Changes in the system information are indicated by the network using a Paging message.**
  - Hence UE only monitors PDCCH.
  - If there is a page message, the ID in the PDCCH is P-RNTI. All UEs share the same P-RNTI (FFFE).
  - Once the UE finds PRNTI, it looks at the appropriate Resource Block in the PDSCH pointed to by the PDCCH message. If it finds its P-TMSI in the PDSCH, then page is destined for the UE.
  - When the Paging message indicates system information changes then UE shall re-acquire all system information.

| | |
|---|---|
| PDCCH | Physical Downlink Common Control Channel |
| DRX | Discontinuous Reception |
| P-RNTI | Paging Radio Network Temporary Identity |
| S-TMSI | S Temporary Mobile Service Identity |

# Low Power (Idle Mode)

- *UE's radio is in low-power state. UE's transmitter is off.*
- *UE listens periodically to control channel.*
  - *To receive pages from the network.*



# Formula to determine which radio frame number (SFN) and which subframe within the SFN for UE to monitor for page message

$$SFN \bmod T = (T/N) \times (UE\_ID \bmod N)$$

$$i\_s = \text{floor}(UE\_ID/N) \bmod Ns$$

$$T = \min (Tc, Tue)$$

$$N = \min (T, \text{number of paging subframes per frame} \times T)$$

$$Ns = \max (1, \text{number of paging subframes per frame}(Nf))$$

where,

| | |
|---|---|
| Tc | cell specific paging cycle {32,64,128,256} radio frames |
| Tue | UE specific paging cycle {32,64,128,256} radio frames |
| N | number of paging frames within the paging cycle of the UE |
| UE_ID | IMSI mod 1024 |
| i_s | index to a table containing the subframes with a radio frame used for paging |
| N_f | number of paging subframes in a radio frame that is used for paging. {4, 2, 1, 1/2, 1/4, 1/8, 1/16,1/32} |

**Table to determine the subframe within a radio frame that is used for paging**

| Ns | PO when i_s=0 | PO when i_s=1 | PO when i_s=2 | PO when i_s=3 |
|---|---|---|---|---|
| 1 | 9 | N/A | N/A | N/A |
| 2 | 4 | 9 | N/A | N/A |
| 4 | 0 | 4 | 5 | 9 |

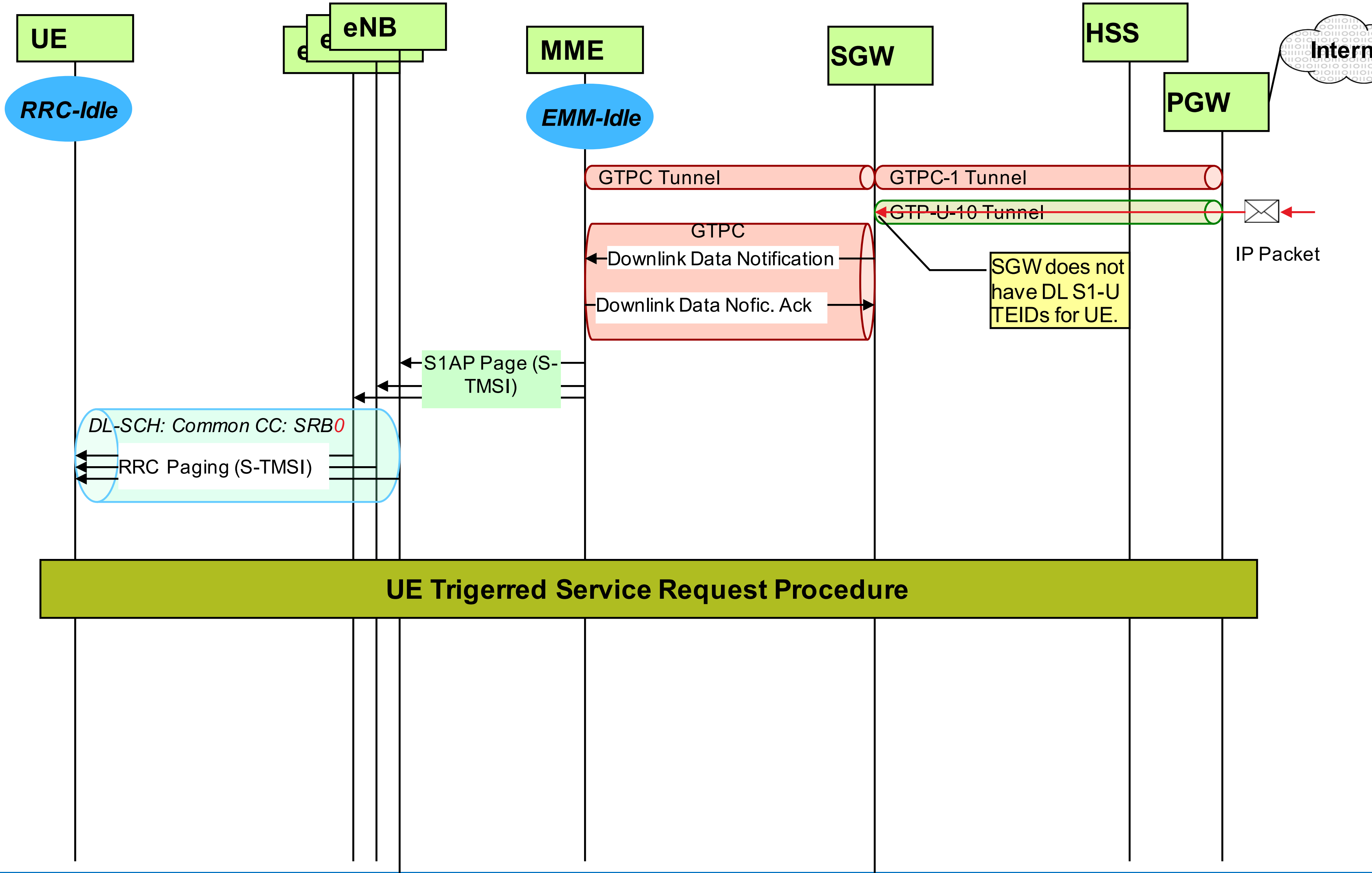


SFN System Frame Number

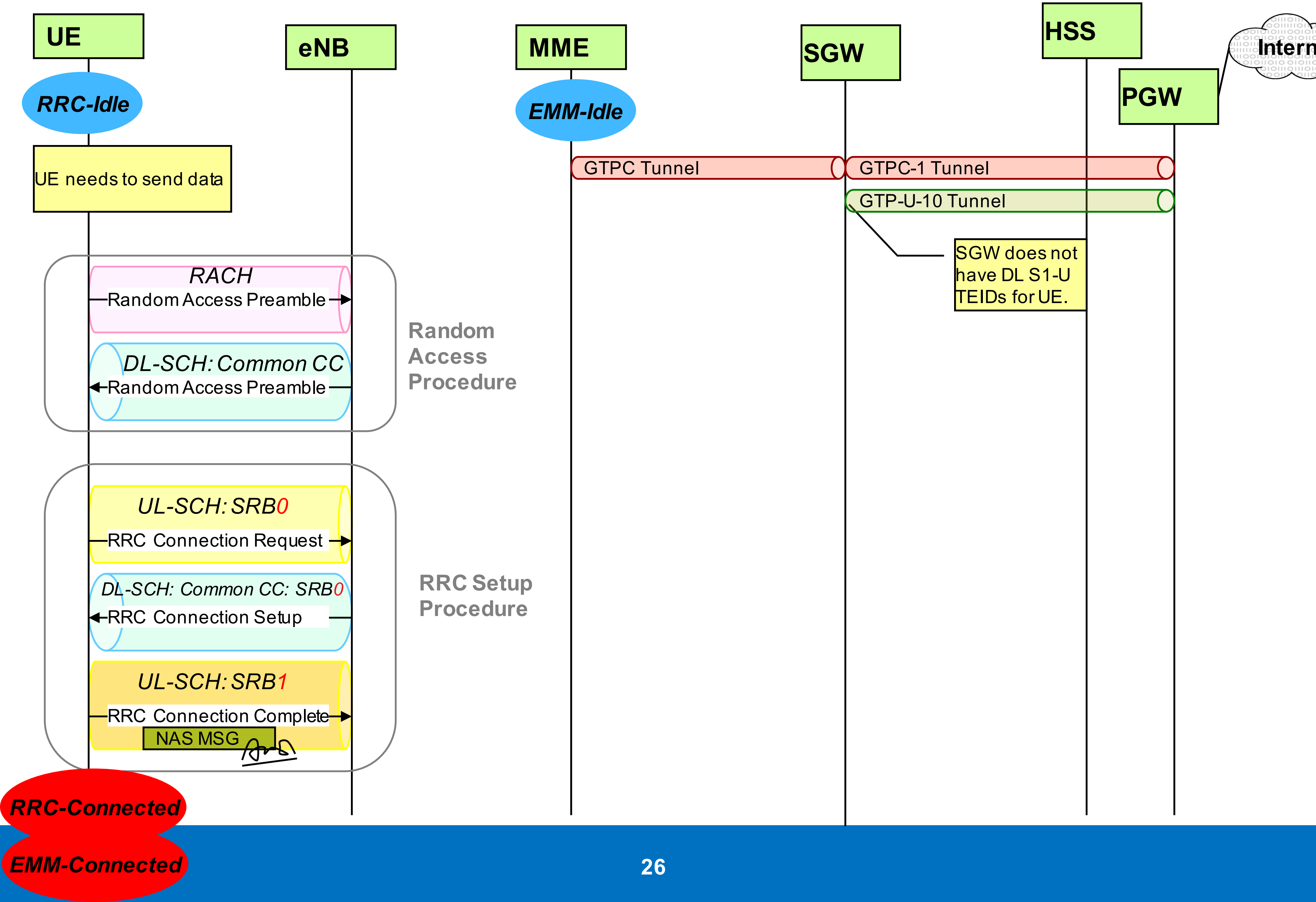
Source: 36.304 Section 7.1

# Idle to Connected Mode Transition Flows

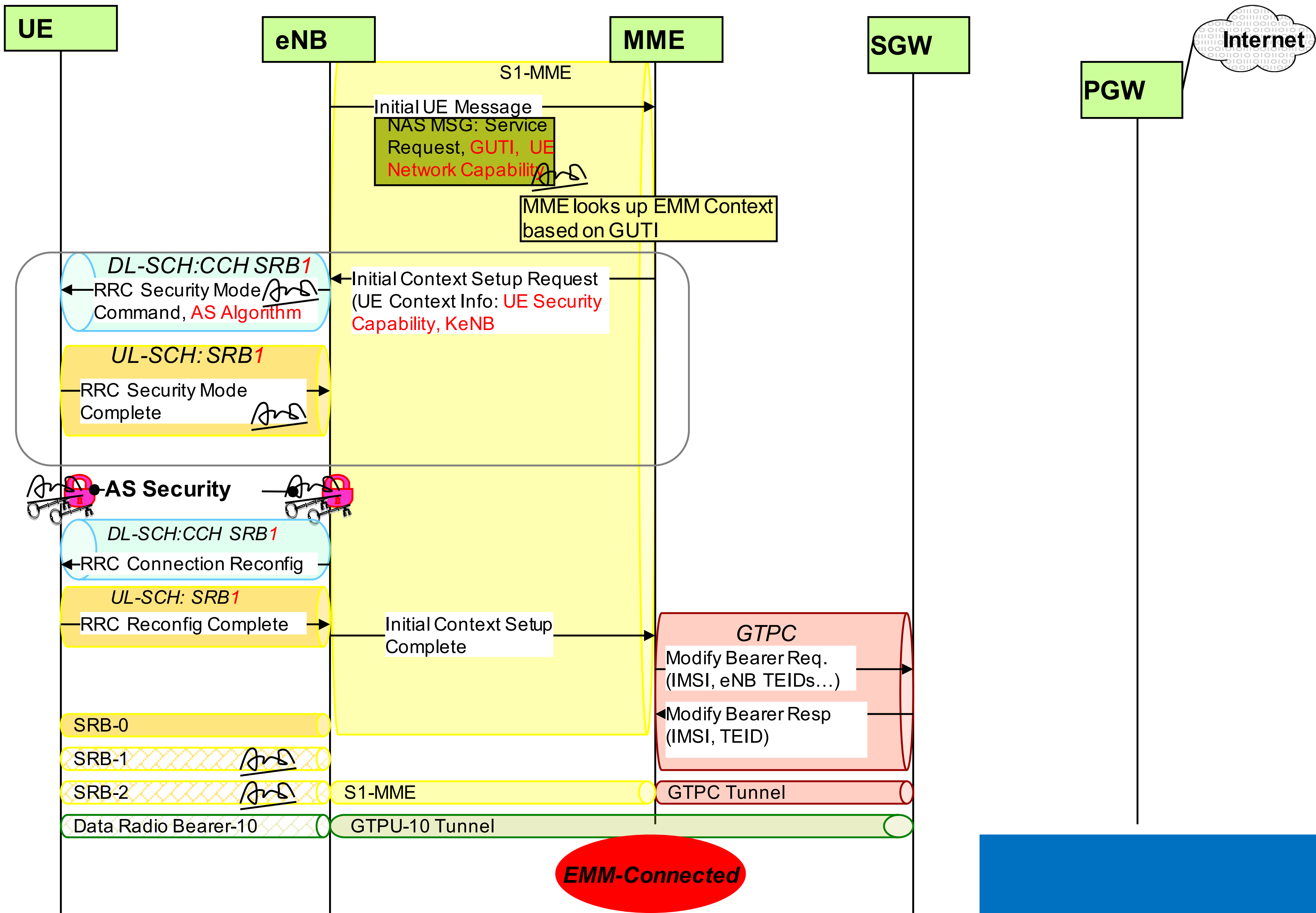
# Transition from Idle to Active: Network Triggered – Part 1 of 1



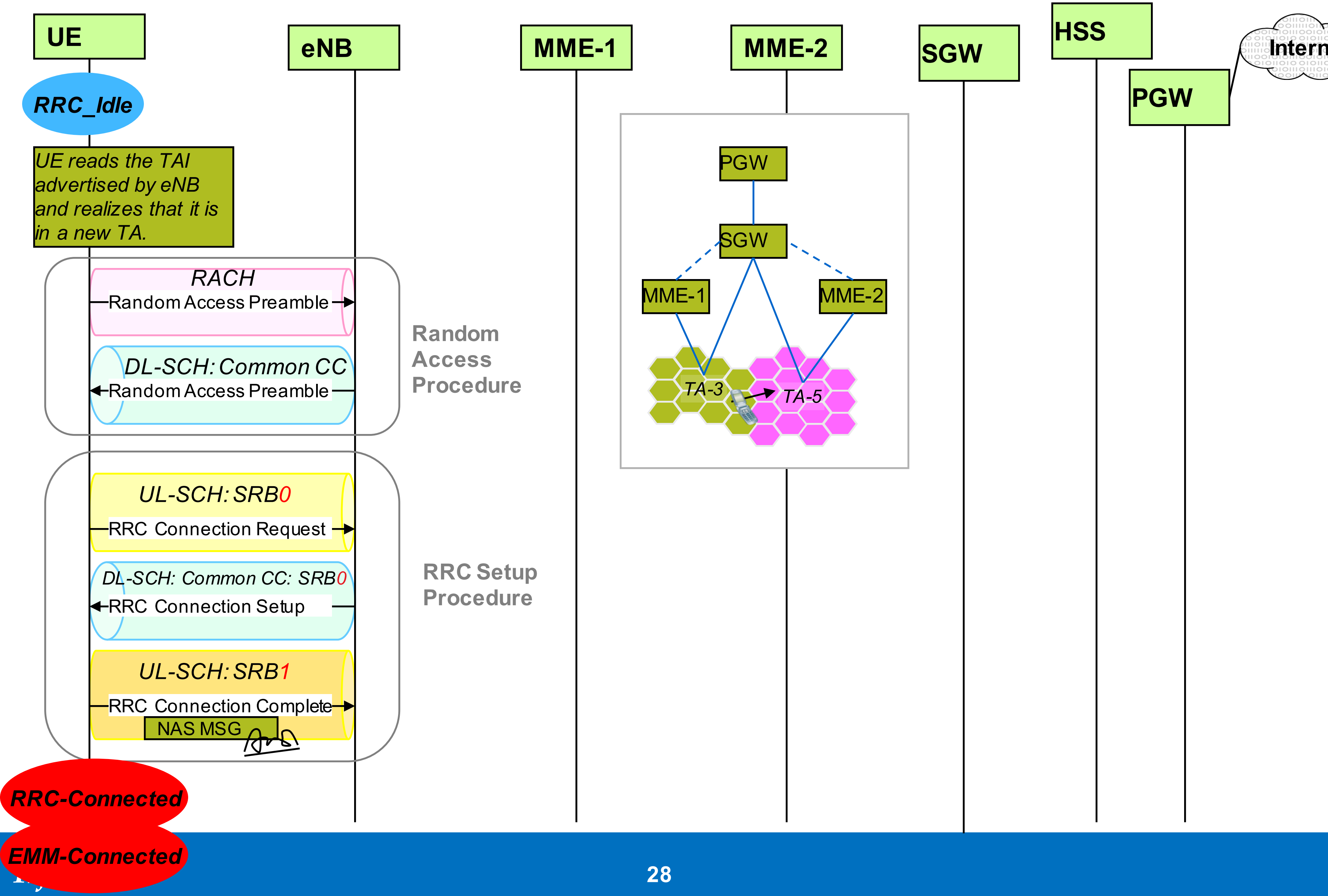
# Transition from Idle to Active: UE Triggered (1 of 2)



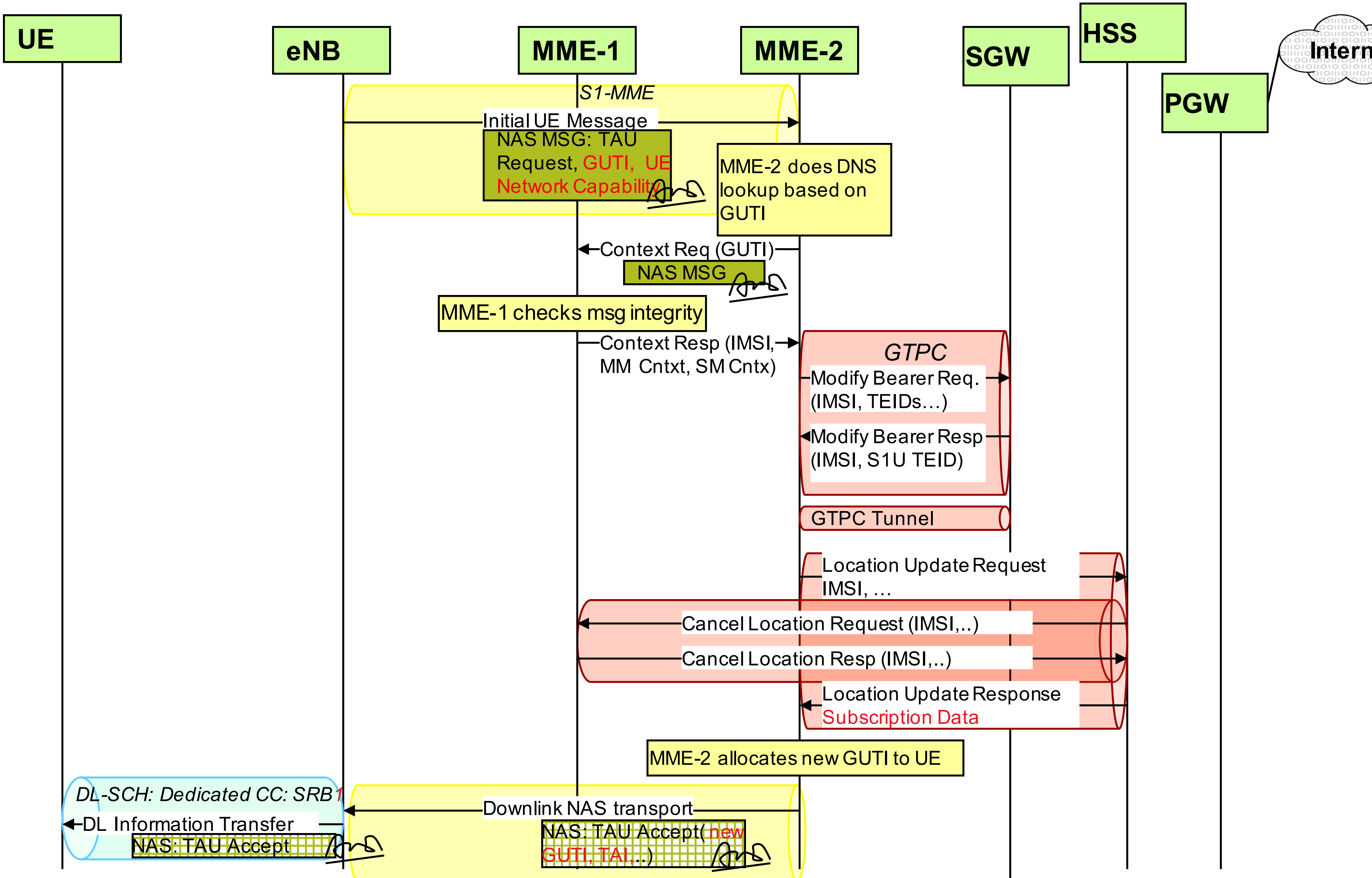
# Transition from Idle to Active – UE Triggered (2 of 2)



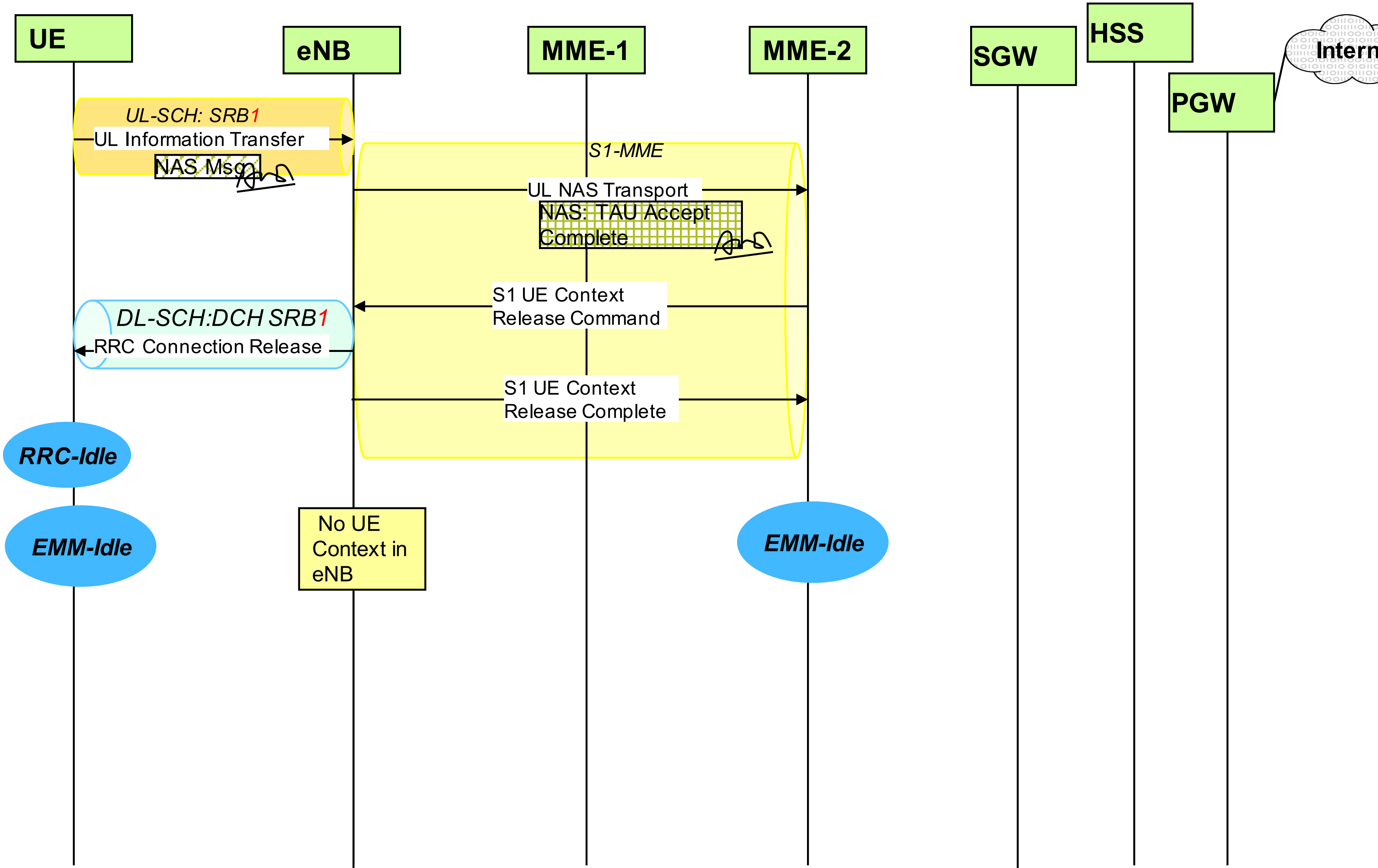
# Tracking Area Update, Inter-MME – Part 1 of 3



# Tracking Area Update, Inter-MME – Part 2 of 3



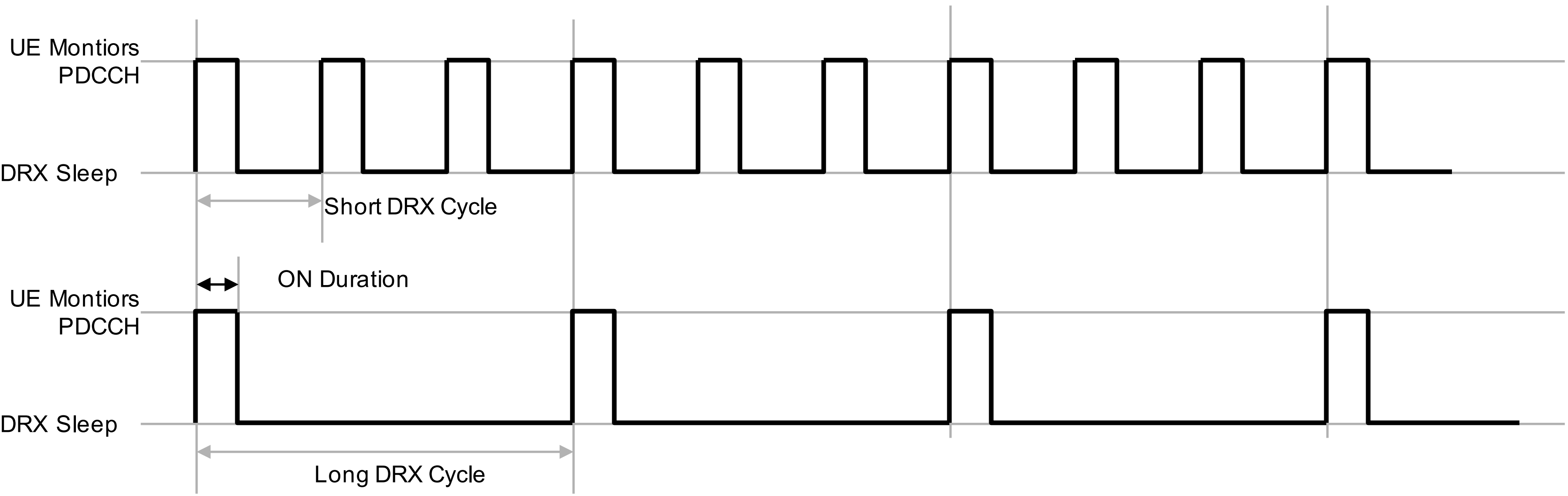
# Tracking Area Update, Inter-MME – Part 3 of 3



# Power savings in active state: DRX in connected mode in LTE

# Overveiw

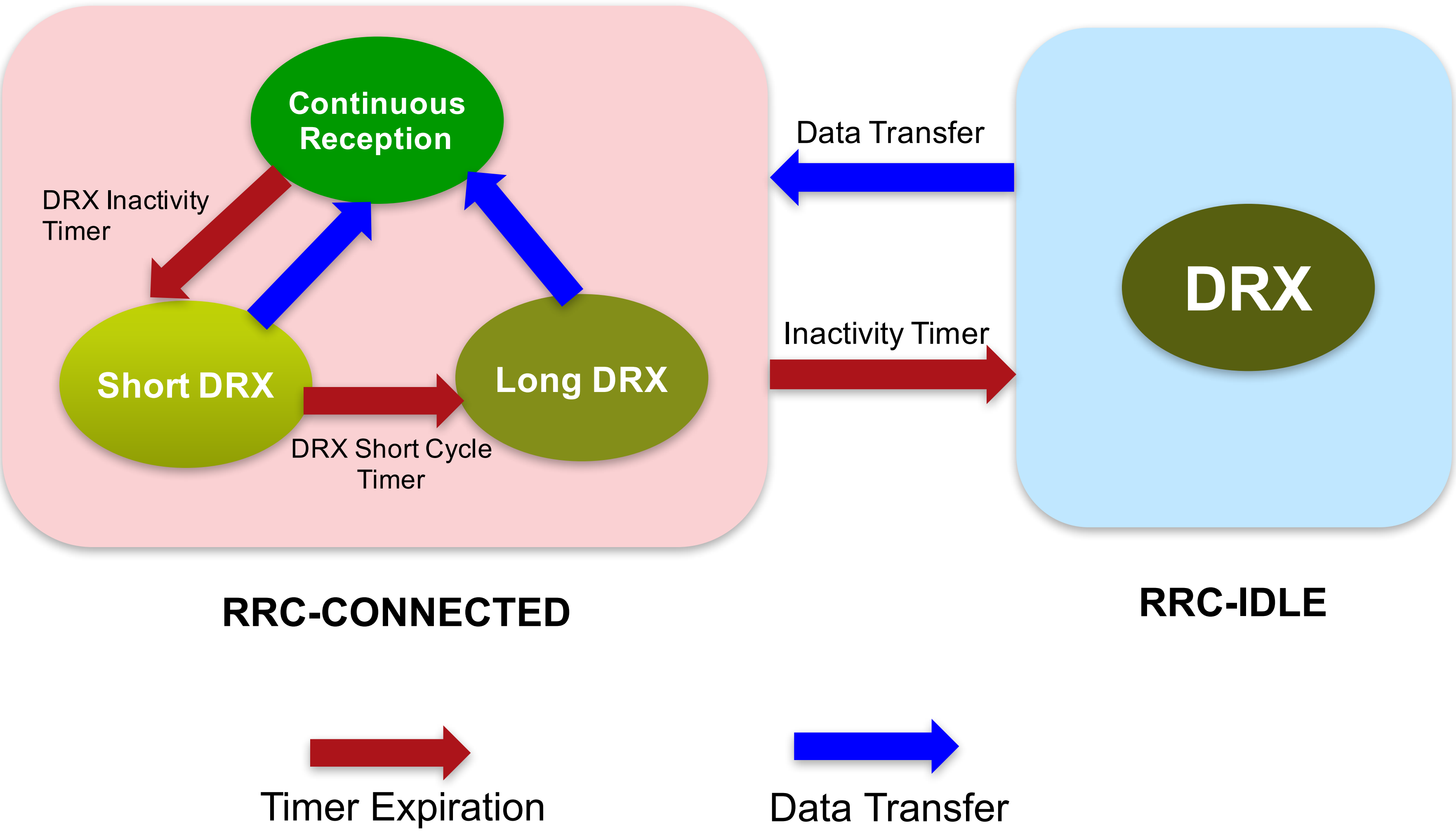
- DRX allows UE to not continuously monitor the PDCCH
  - Leads to power-savings for UE in active state.
  - Configured using RRC signaling by the eNB
  - Per UE mechanism
  - The eNB keep track of UE's DRX cycle, so that it transmits DL data to the UE only during the subframe when the UE is listening to PDCCH.
- DRX Cycle: Specifies the periodic repetition of the On Duration followed by a period of sleep
  - Two types of DRX cycles: Long DRX cycle, and (optional) Short DRX cycle. The Long DRX cycle is a multiple of short DRX cycle.
- On Duration Timer: Specifies the number of consecutive PDCCH-subframe(s) at the beginning of a DRX Cycle




Source: 36.300 (Section 12), 36.321 (Section 5.7)

| | |
|---|---|
| PDCCH | Physical Downlink Common CHannel |

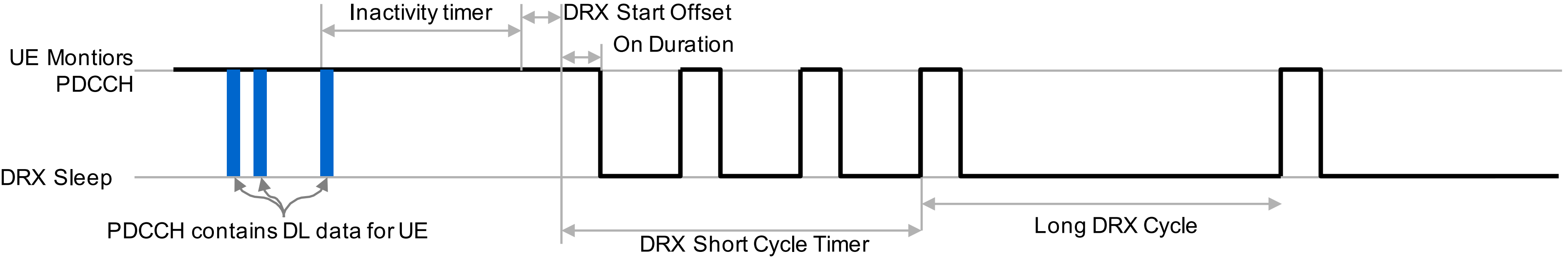
# RRC State Transition in LTE with Connected Mode DRX






*Source: A Close Examination of Performance and Power Characteristics of 4G LTE Networks, Junxian Huang, et al, 2012*

# Entering DRX operation

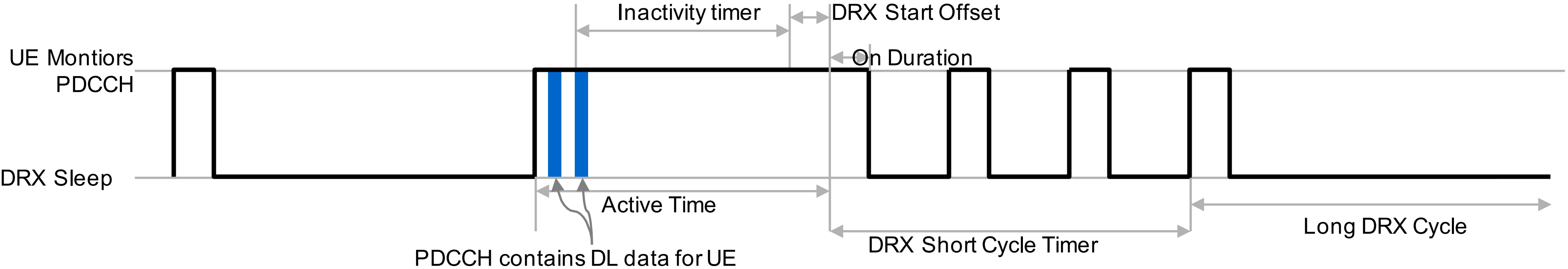



- Inactivity Timer: Duration in downlink subframes that the UE waits from the last successful decoding of a PDCCH which contained data for UE, till entering DRX.
- On-duration: Duration in downlink subframes that the UE waits for, after waking up from DRX, to receive PDCCHs. If the UE receives PDCCH with data for UE, the UE stays awake and starts the inactivity timer.

- **DRX Start Offset**: Number of subframes.
- **Short DRX Cycle**: Value in number of subframes. 2,5, 8, 10,…, 320,512,640
- **DRX Short Cycle Timer**: Number of short cycles before the UE enters Long DRX Cycle
- **Long DRX Cycle**: Value in number of subrame.10, 20, .. 2560 (2.56s)

- ***All DRX parameters are signalled by eNB during RRC Connection Setup message.***
- ***The frame-number, $x$, and the subframe number, $y$, to start the On-duration is computed as follows:***
  - [x * 10 + y] mod (Short_DRX_Cycle) = DRX_Start_Offset mod (Short_DRX_Cycle), *for Short DRX cycle*
  - [x * 10 + y] mod (Long_DRX_Cycle) = DRX_Start_Offset, *for Long DRX Cycle*

# Exiting and re-entering DRX operation

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- **DRX Short Cycle Timer**: Number of short cycles before the UE enters Long DRX Cycle
- **Short DRX Cycle**: Value in number of subframes. 2,5, 8, 10,…, 320,512,640
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  - [x * 10 + y] mod (Long_DRX_Cycle) = DRX_Start_Offset, *for Long DRX Cycle*

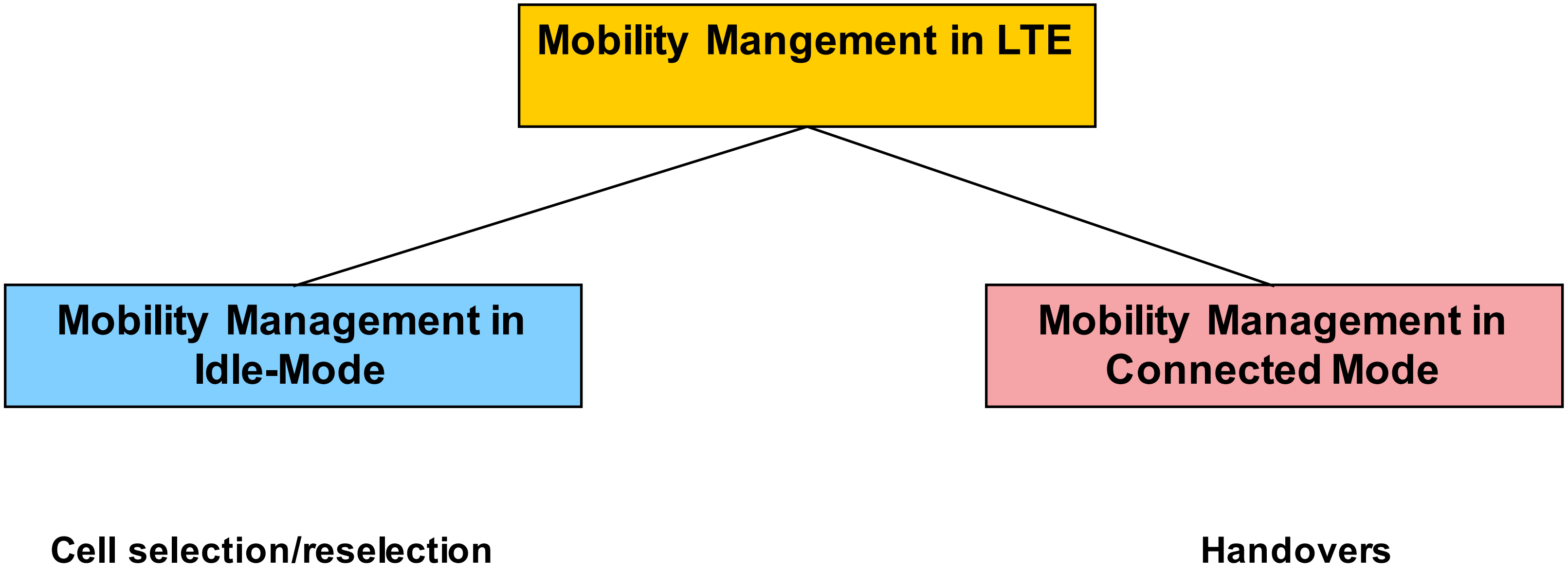
# Difference between Connected mode DRX and Idle mode DRX

- **Typically the DRX period of connected mode DRX is shorter than that of idle mode DRX**
  - In connected mode, there is a higher probability of data activity from UE. Longer connected mode DRX would mean higher delay in sending the first packet to the UE.
- **Power consumption for UE in connected-mode DRX is typically greater than that during idle-mode DRX.**
  - For more details, please refer to: A Close Examination of Performance and Power Characteristics of 4G LTE Networks, Junxian Huang, et al, 2012
- **Since smart phones generate constant dribble of traffic, with several background processes doing keep-alives, and there is too much signaling overhead in transitioning the UE to idle and then back to connected state, operators keep smartphones in connected mode for long duration of time using connected mode DRX in LTE.**

# Mobility Management in LTE

Irfan Ali

# Overview



Mobility Mangement in LTE
Mobility Management in Idle-Mode
Mobility Management in Connected Mode
Cell selection/reselection
Handovers