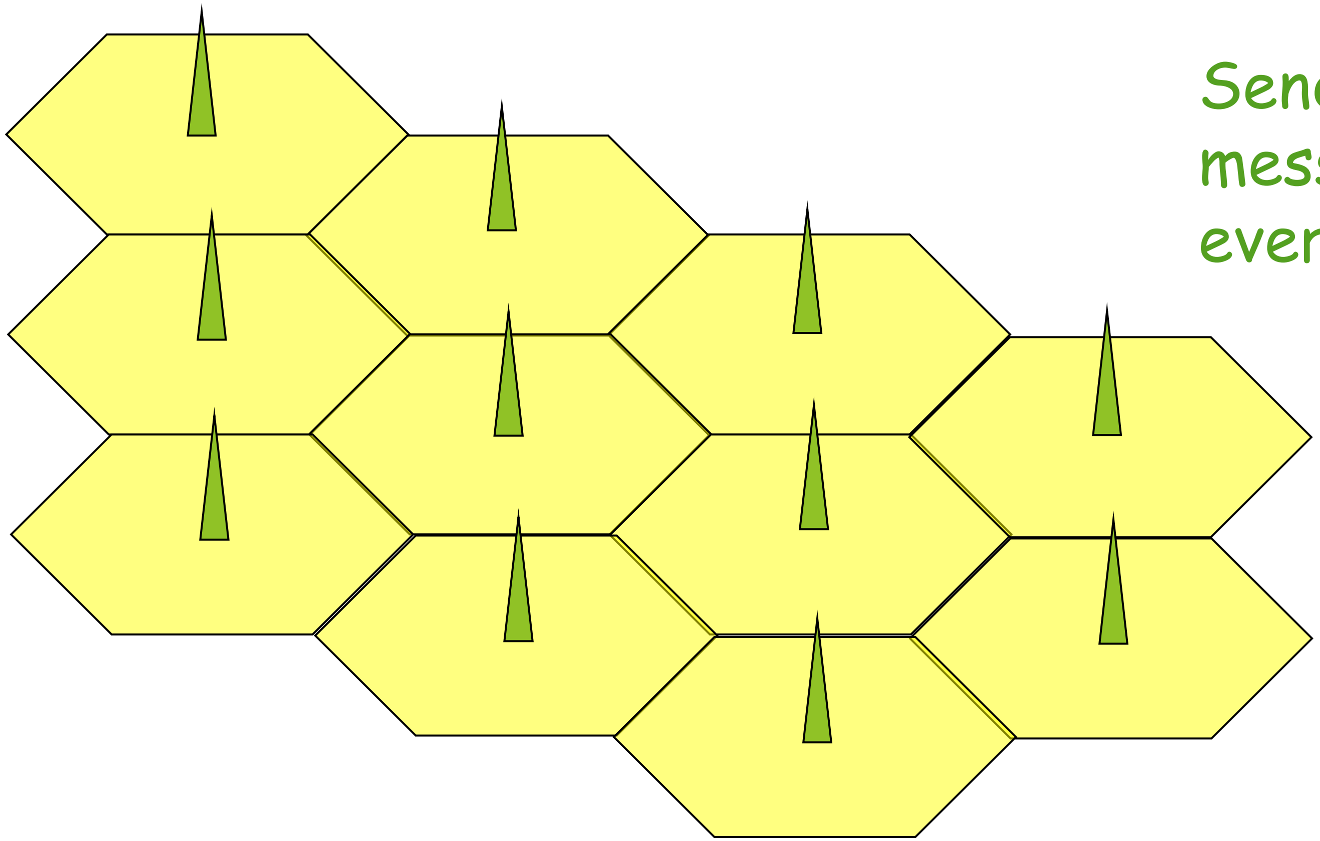
Location Management for Mobile Cellular Systems

Cellular Systems

Where is 97532468?



Send broadcast messages from every base station?

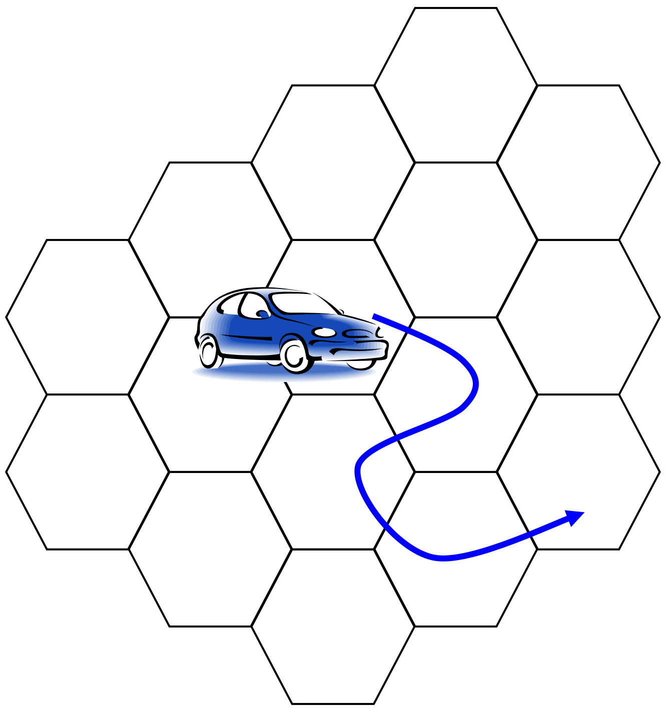
Two Major Components

- Location Update
  - The mobile terminal informs the system its current location.
- Paging
  - The system sends messages (from one or more base stations) to find a particular user.

Two Extreme Cases

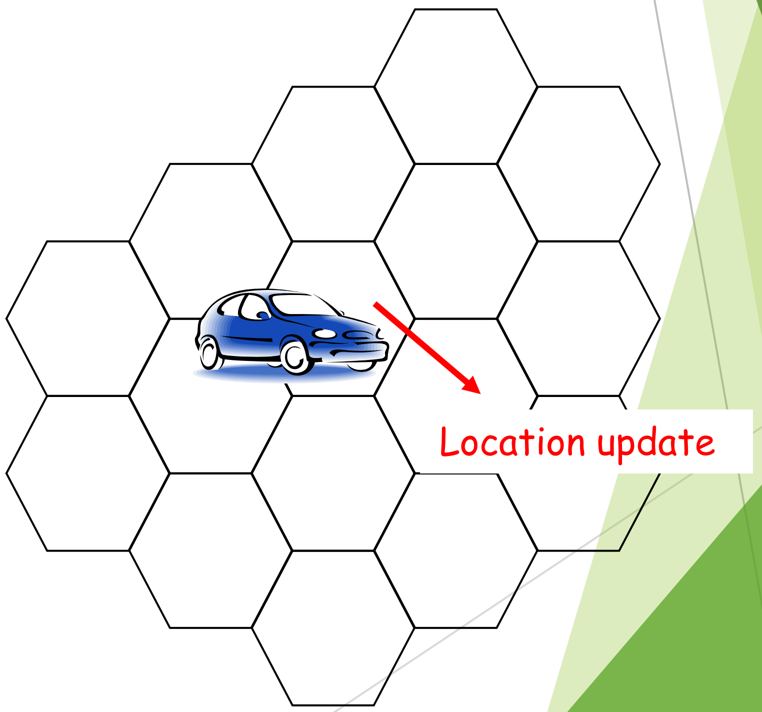
Location never update (no cost).

Need to page every cells (high cost).



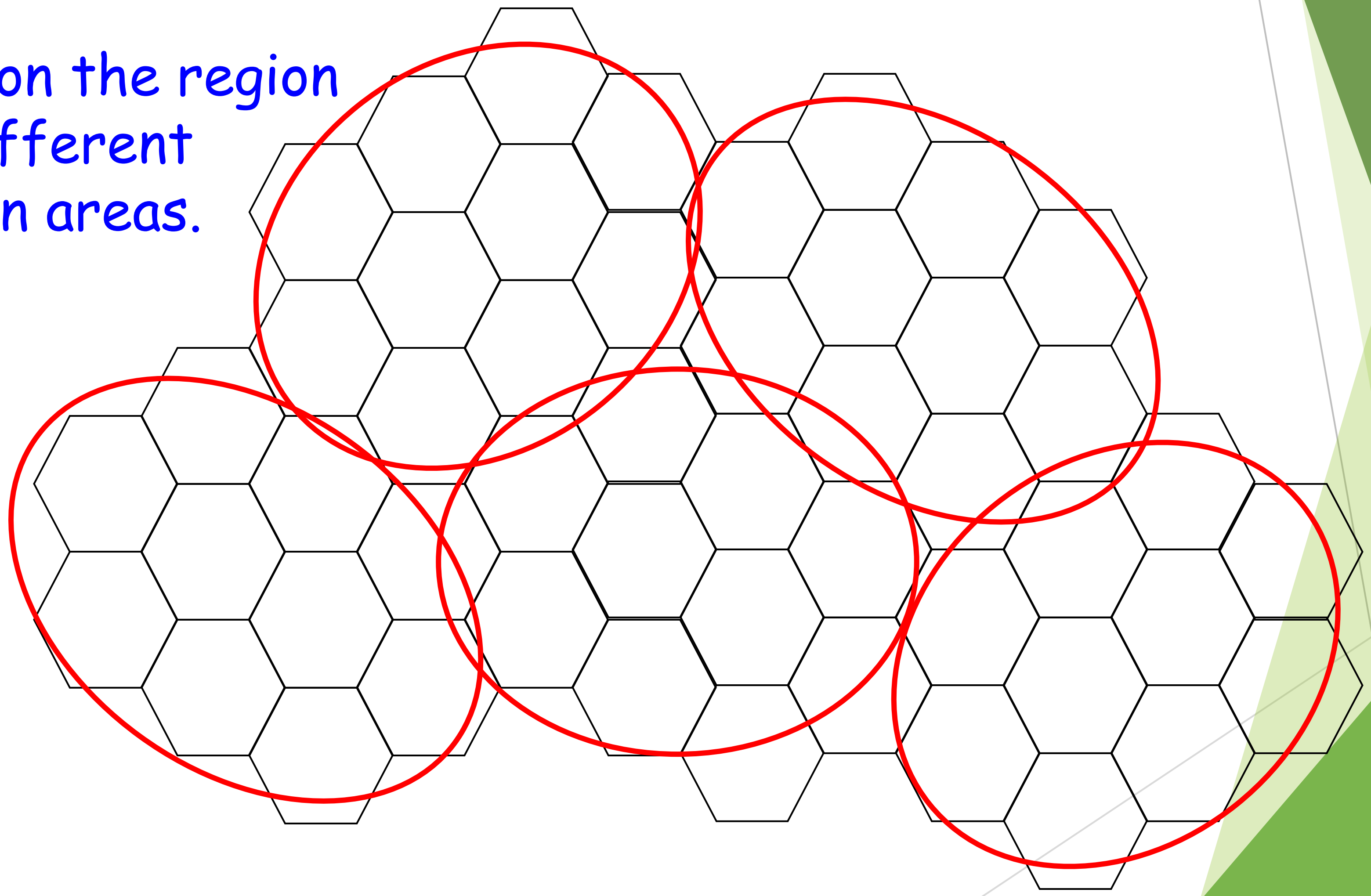
Location updates for every cell crossing (high cost).

Need to page only one cell (low cost).

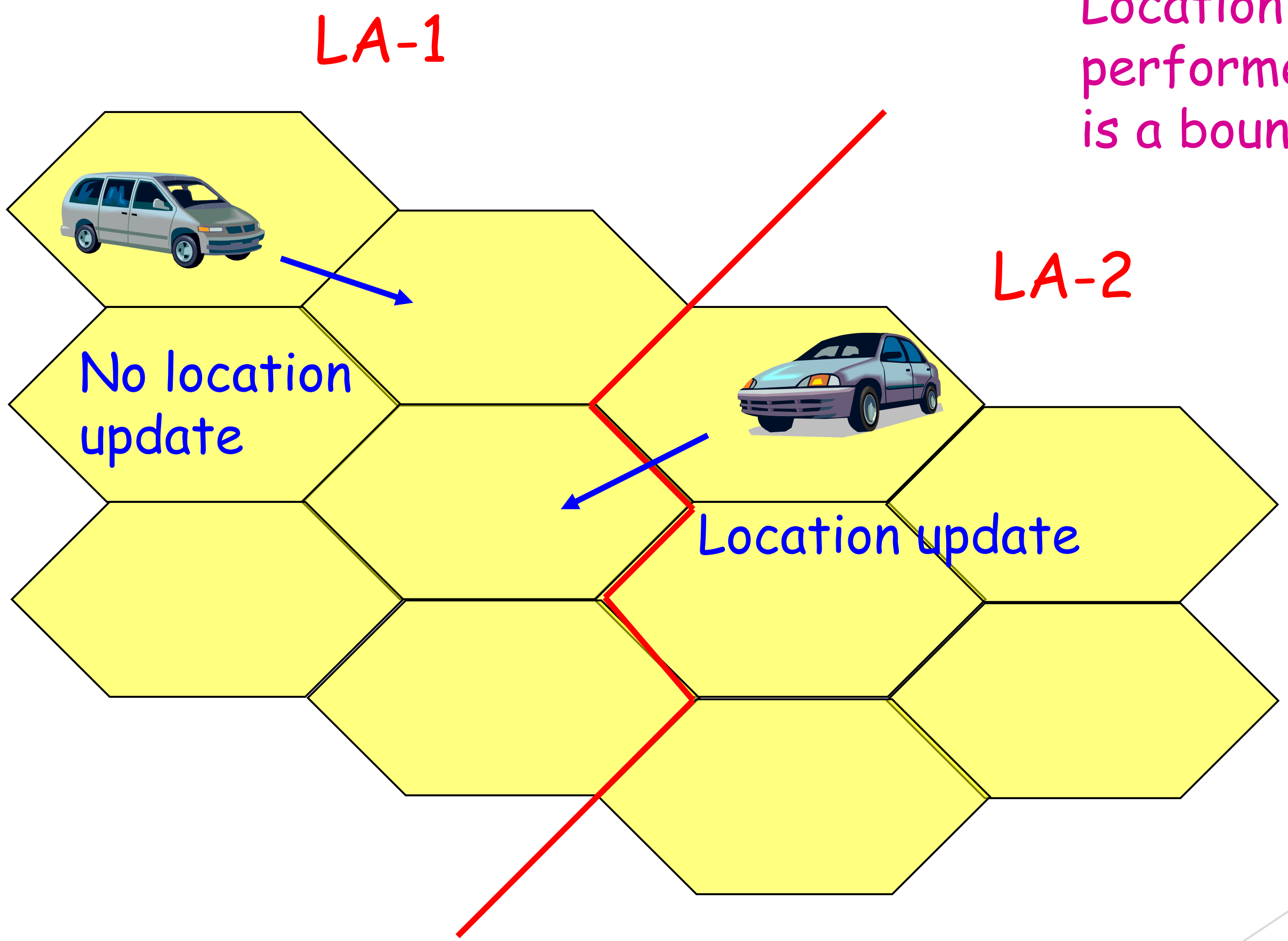


Location Area

Partition the region into different location areas.



Location Update



Location update is performed when there is a boundary crossing.

How to determine the size of a LA?

Location Databases

These two databases communicate with each other to authenticate and update each other about the location of an MS.

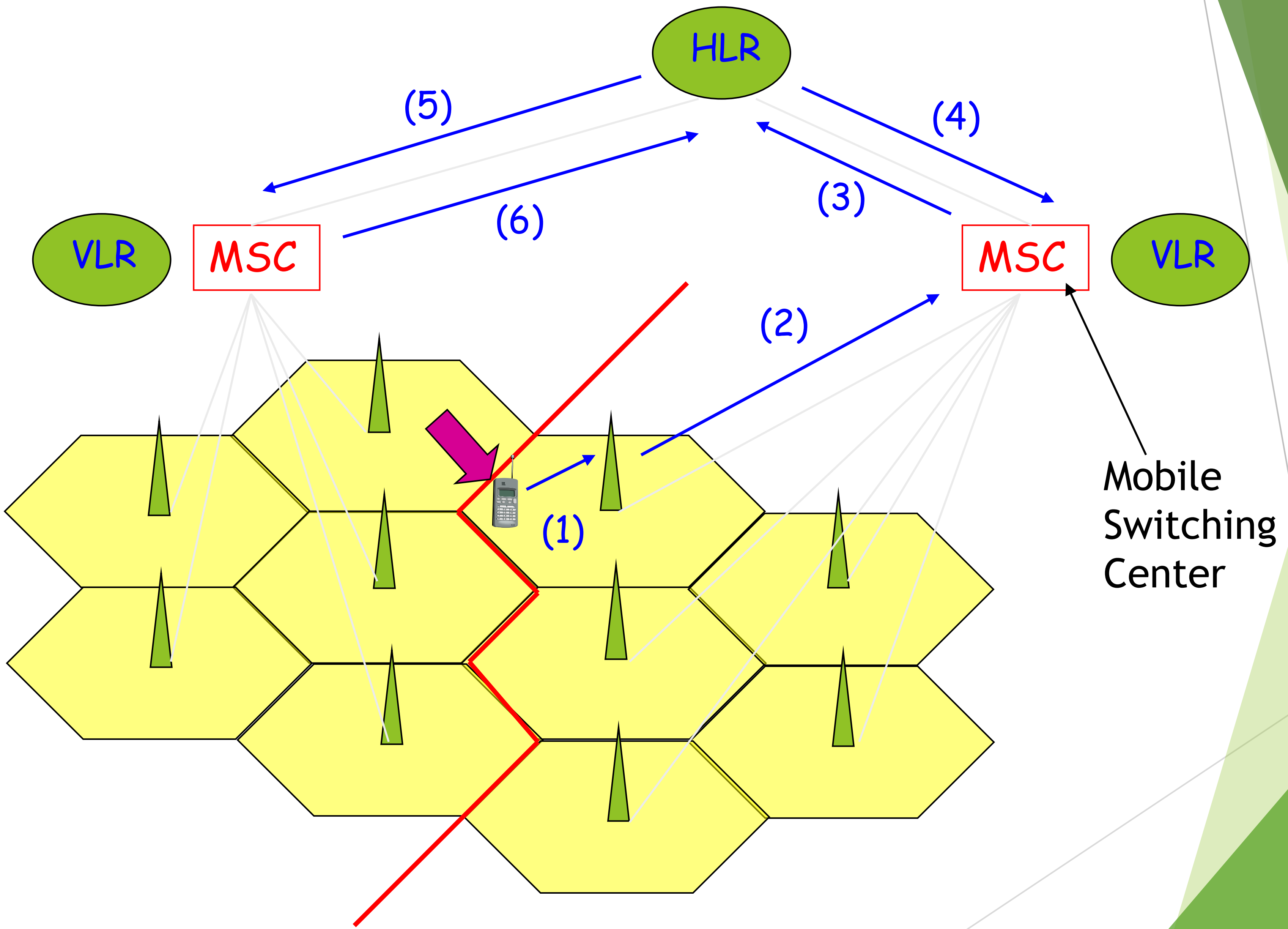
GSM Terminology:

Home Location Register (HLR)

Visitor Location Register (VLR)

- Home Database
  - Every MS is permanently associated with a home database
  - Keep track of the profile of the MS
    - Mobile ID, authentication keys, location, etc.
- Visiting Database
  - Keeps track of the MSs in its service area.

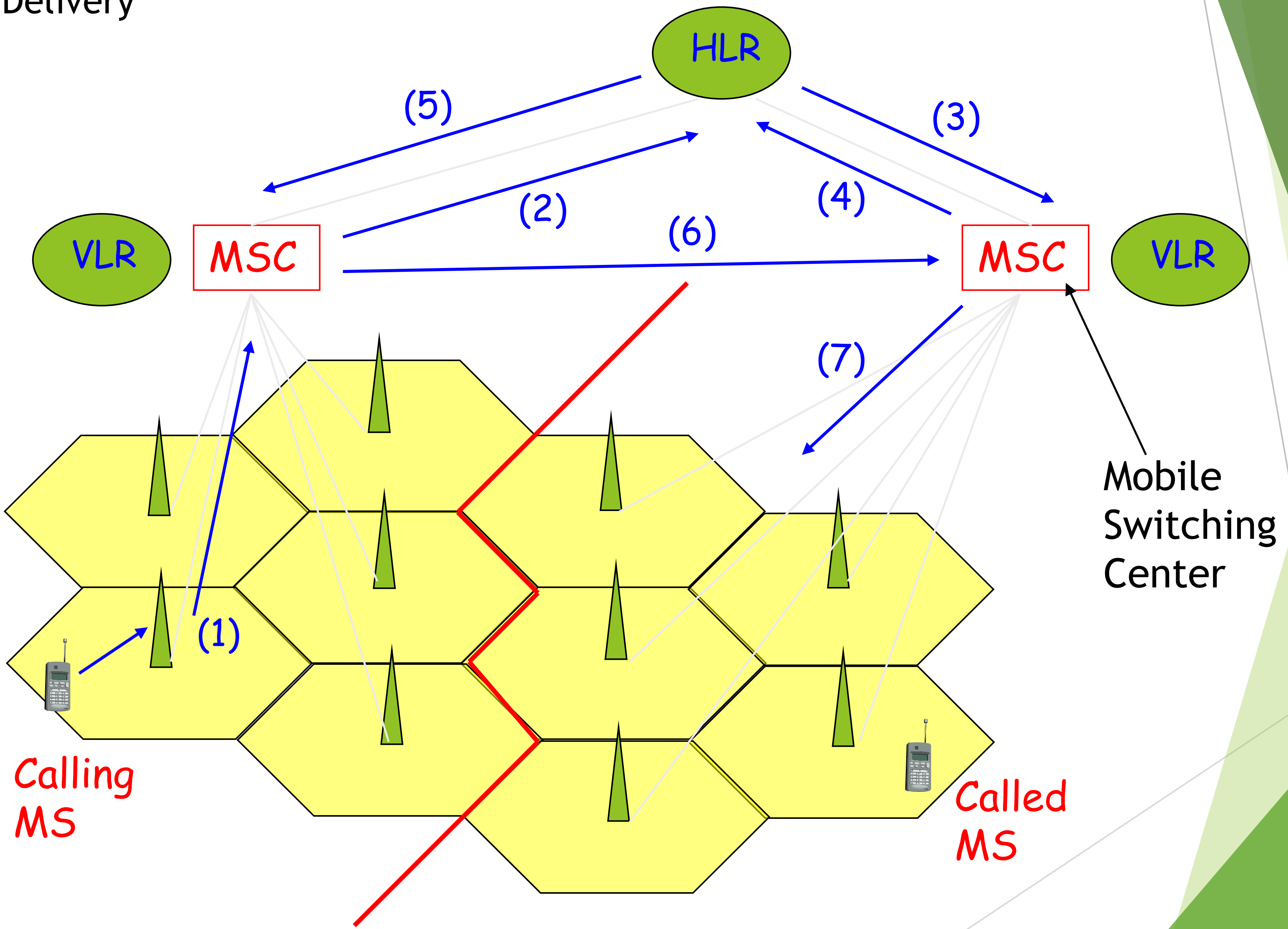
GSM Example: Location Update



Location Update Procedures

1. MS transmits a LU to the new BS
2. The BS forwards the LU to the MSC
3. MSC sends LU to the HLR and updates VLR
4. HLR does the following:
   - authenticate the MS
   - record the ID of the new VLR
   - send an ACK to the new VLR
5. HLR sends a registration cancellation message to the old VLR
6. The old VLR removes the record of the MS and returns an ACK to HLR

GSM Example: Call Delivery

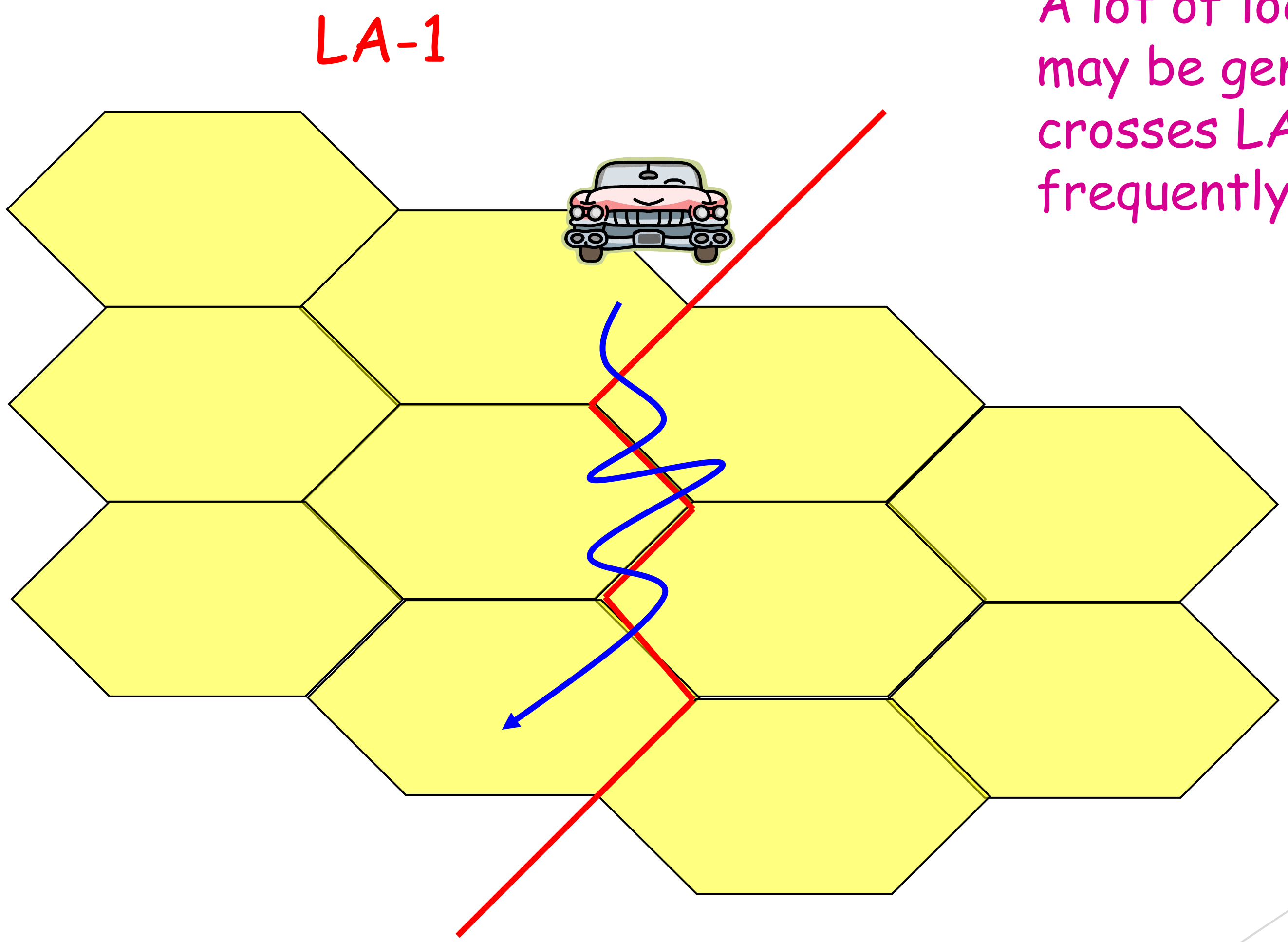


Call Delivery Procedure

1. Calling MS sends a call initiation signal to MSC through BS.
2. MSC sends a location request to HLR of the called MS
3. HLR determines serving VLR of called MS and sends a route request message to it.
4. MSC allocates a temporary ID to MS and sends this ID to HLR
5. HLR forwards the ID to MSC of the calling MS
6. Calling MSC requests a call set up to the called MSC
7. Paging messages are sent to cells within the LA.

Other Location Management Strategies

Ping-Pong Effect



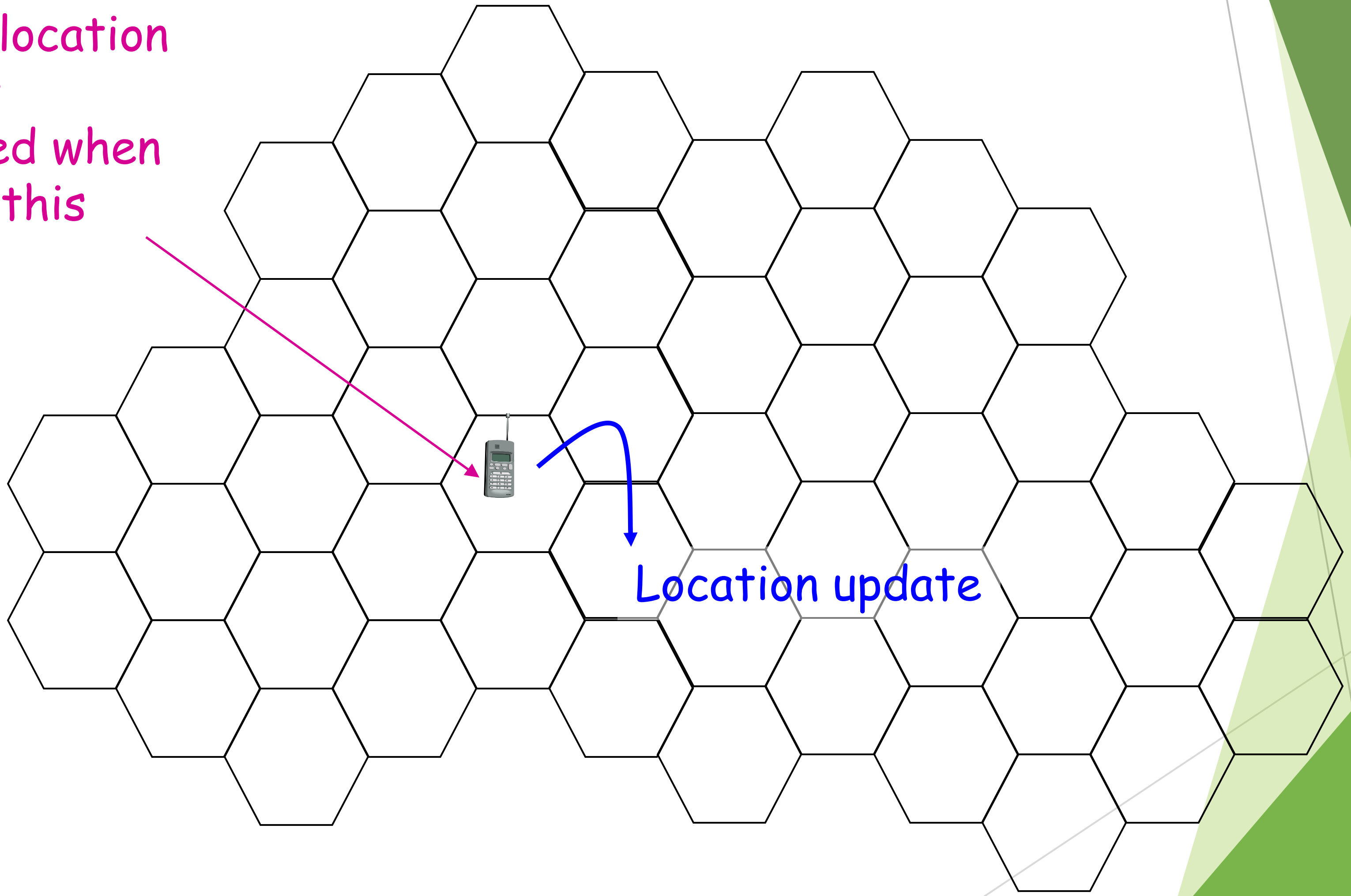
A lot of location updates may be generated if a user crosses LA boundary frequently.

Other Location Update Algorithms

- Time Based
  - Each user periodically updates his location (e.g. every hour)
- Movement Based
  - Each user counts the number of boundary crossings between cells.
  - Updates his location when this number reaches a predefined value, *N*.
- Distance Based
  - Each user tracks the distance he has moved (in number of cells) since the last update.
  - Updates his location when the distance reaches a predefined value, *N*.

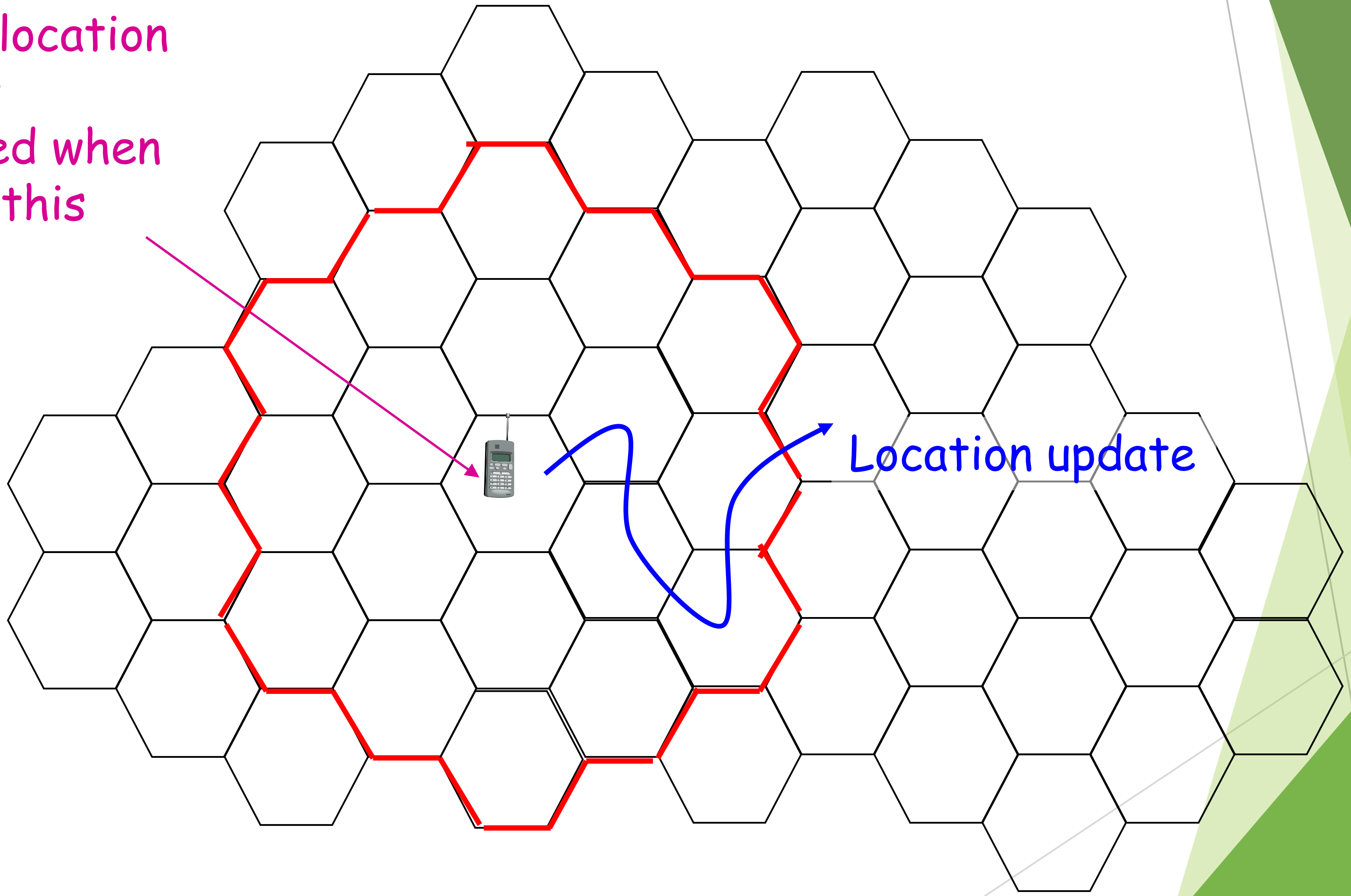
Movement Based (N = 2)

Suppose location update is performed when entering this cell.

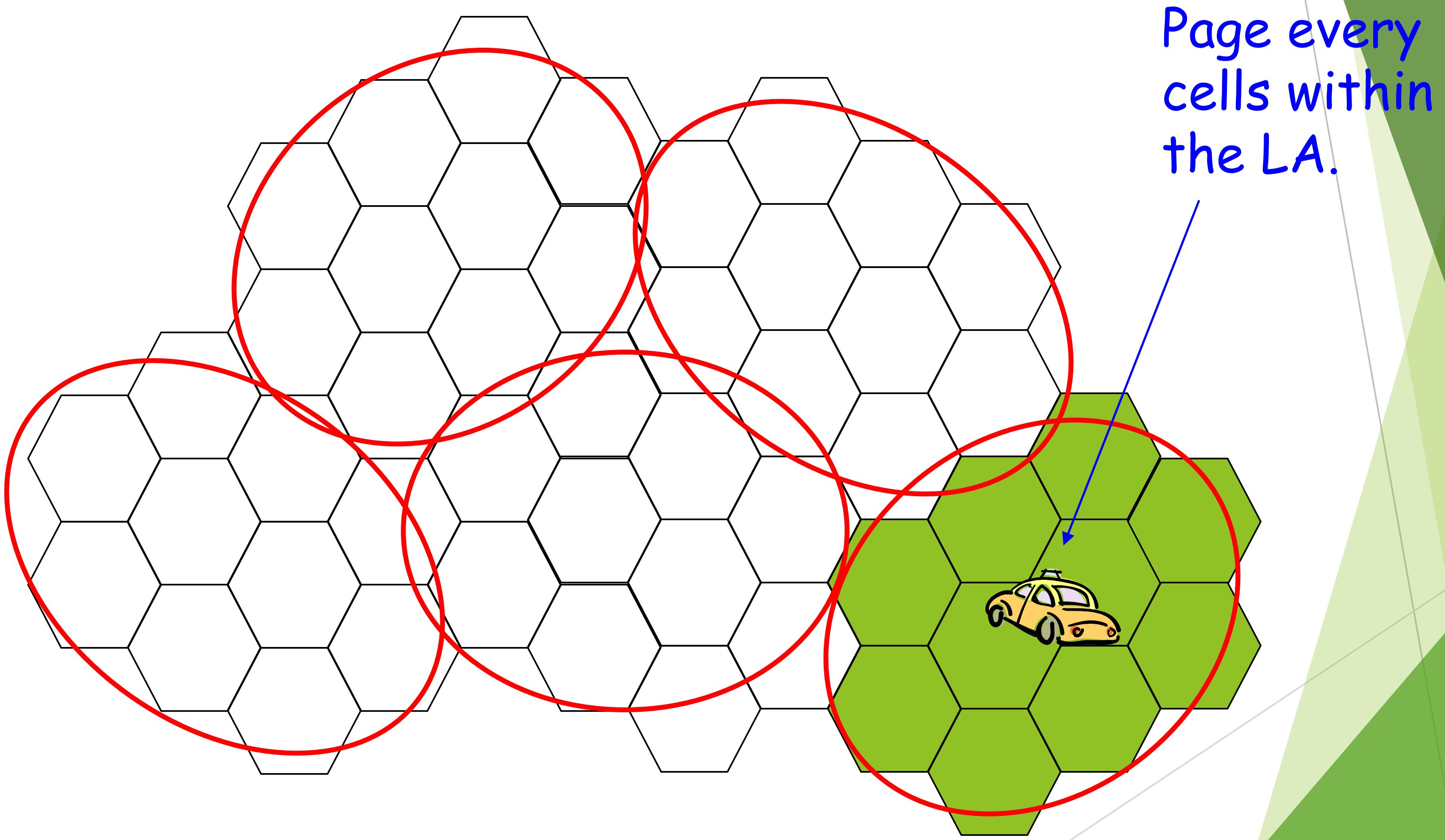


Distance Based (N = 2)

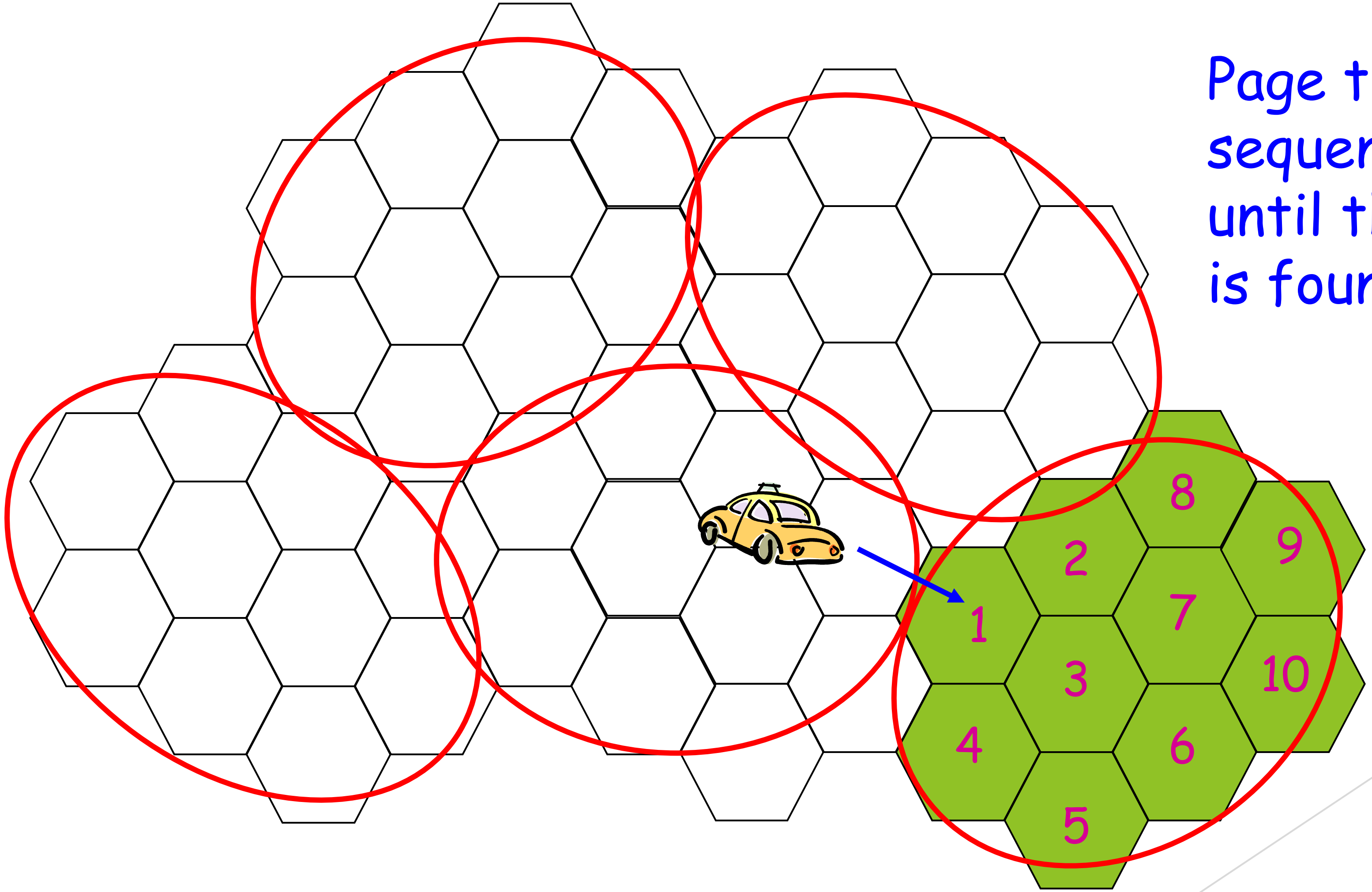
Suppose location update is performed when entering this cell.



Blanket Paging



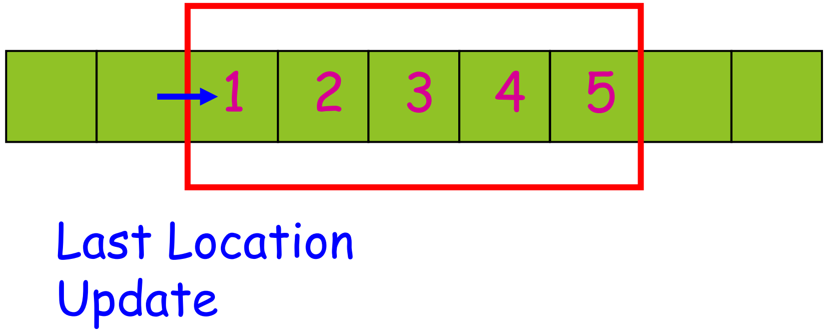
Sequential Paging



Page the cells sequentially until the user is found.

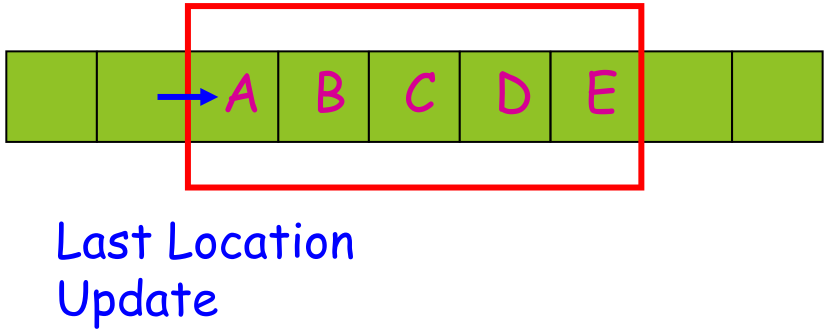
How to determine paging order?

- Method 1: Shortest Distance First
  - Pages the user starting from the cell where he last updated his location.
  - Move outward in a shortest-distance-first order.
  - Ties are broken arbitrarily.
- Example: (in a highway)



How to determine paging order?

- Method 2: Based on Location Probability
  - Estimate the probability that a user is located in each cell within the current LA.
  - Page the cells in decreasing order of probability.
- Example: (in a highway)



Suppose Prob. Distribution is:

{0.05, 0.2, 0.4, 0.25, 0.1}

Paging order: C, D, B, E, A

Paging Delay

- In our previous example, the expected delay is

$E[D] = 0.4 \times 1 + 0.25 \times 2 + 0.2 \times 3 + 0.1 \times 4 + 0.05 \times 1$

$= 1.95$ (paging cycles)

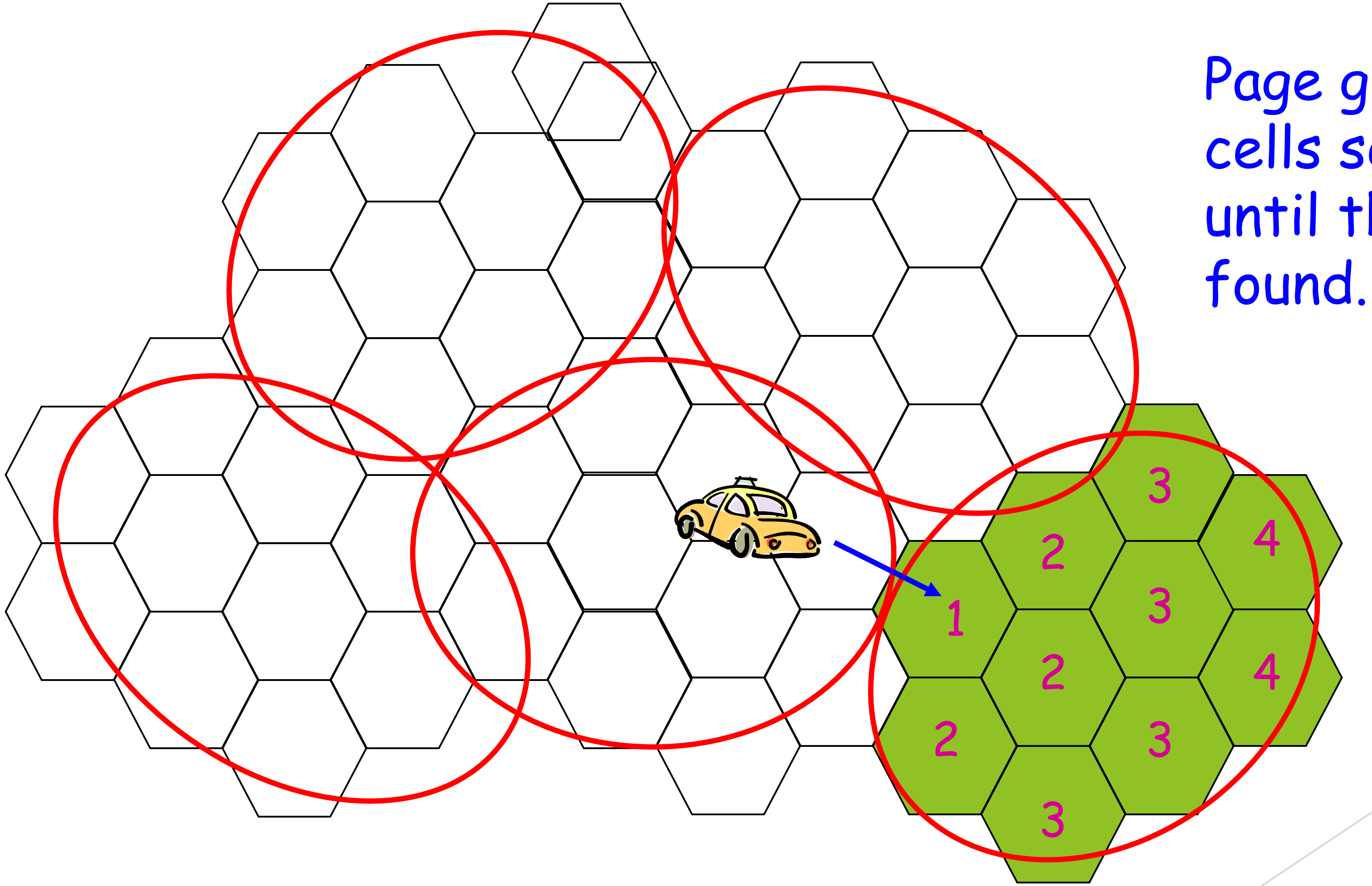
- Worst-case delay is 5 paging cycles.
- The expected number of cells to be paged is also 1.95.
- Worst-case: 5 cells.

Blanket Paging vs. Sequential Paging

	Blanket	Sequential
Paging cost	Large	Small
Paging delay	Small	Large

Sequential group paging may be used if there is a constraint on paging delay

Sequential Group Paging



Page groups of cells sequentially until the user is found.

Worst case delay is 4 cycles.

Database Management

- Location Update
  - Involves the updating of location databases
- Call Delivery
  - Involves the querying of location databases
- The cost is very high if the MS is located far away from its HLR.
  - e.g. if the MS is roaming in Europe and its HLR is in HK.

Database Management

Three Enhancement Methods:

- Per User Location Caching
- User Profile Replication
- Forwarding Pointers

Per-User Location Caching

- Every time user *x* is called, *x*'s locaton is cached at the VLR in the caller's LA.
- Any subsequent call to *x* originated from that LA can reuse this information.
  - No need to contact user *x*'s HLR.

Cache Invalidation

- Eager Caching
  - Whenever a user moves to a new LA, all cache entries for this user’s location are updated.
  - Location update cost increases if a user moves frequently.
- Lazy Caching
  - Cache update is not performed.
  - Two cases can occur: a hit or a miss
  - In case of a miss,
    - contact the HLR
    - there is an additional cost, since the cached VLR must be visited first.

User Profile Replication

- Observation:
  - Each user usually communicates frequently with a small number of sources.
- How can we make use of this observation?
- User profiles are replicated at selected databases to reduce the cost of querying the HLR.

User Profile Replication

- When a call is initiated from a certain LA, the corresponding MSC determines if a replication of the called MS's user profile is available locally.
  - If available, no HLR query is needed.
- When the MS moves to another location, the network updates all replications.

Pointer Forwarding

- Each time a user moves to a new LA, a forwarding pointer is set up to its pervious VLR to point to the new VLR.
- Calls to the user will first query the HLR to determine the first VLR and then follow the chain to reach the current VLR.
- The length of the pointer chain is limited to a maximum value *N*.
- This method can reduce the cost of updating the HLR.

Call-to-Mobility Ratio (CMR)

- In this lecture, we compare the performances of lazy caching and eager caching, and how they will be affected by the call-to-mobility ratio:

- For simplicity, consider a caller and only one callee.

$$\mathrm{CMR} \equiv \frac{\text{Call Arrival Rate}}{\text{LA Crossing Rate}} = \frac{\lambda}{\mu}$$

System Model

- Let C be the location updating cost of the callee whenever he moves to a new LA.
- Let c_v be the cost of updating/querying the cache in the caller's VLR.
- Let c_h be the cost of querying the HLR of the callee.
- Assume $c_h > c_v$. Otherwise, caching should not be used.

Eager Caching

- Updating Cost = $\mu\ (C + c_v)$
- Paging Cost = $\lambda\ c_v$

Lazy Caching

- Updating Cost = $\mu\, C$

- Paging Cost = $\lambda\, [p\, c_v + (1\text{-}p)\, (c_h + c_v)]$

  = $\lambda\, [c_v + (1\text{-}p) c_h]$

  where p is the prob. of a hit, and

$$p = \frac{\lambda}{\lambda + \mu}$$

according to queueing theory.

Comparison: Total Cost

- Eager caching:

  $$C_e = \mu\,(C + c_v) + \lambda\, c_v$$

- Lazy caching:

  $$C_l = \mu\, C + \lambda\, [c_v + (1\text{-}p)c_h]$$

- *Which one is larger?*

$$
\begin{aligned}
C_e - C_l &= \mu c_v - \lambda(1-p)c_h \\
&= \mu c_v - \frac{\lambda\mu}{\lambda+\mu}c_h \\
&= \mu\left(c_v - \frac{\lambda}{\lambda+\mu}c_h\right) \\
&= \mu\left(c_v - \frac{CMR}{CMR+1}c_h\right)
\end{aligned}
$$

$$C_e - C_l = \mu\left(c_v - \frac{CMR}{CMR+1}c_h\right)$$

$$= \begin{cases} \mu c_v & \text{if } CMR \to 0 \\ \mu(c_v - c_h) & \text{if } CMR \to \infty \end{cases}$$

If CMR is small, lazy caching has a lower cost.

If CMR is large, eager caching has a lower cost.

General Packet Radio Service (GPRS)

GPRS vs. GSM

- GPRS reuses the existing GSM infrastructure to provide end-to-end **packet-switched services**.

- GSM is based on circuit-switched services.

Comparison of GSM & GPRS

	GSM	GPRS
Data Rates	9.6 Kbps	14.4 to 115.2 Kbps
Modulation Technique	GMSK	GMSK
Billing	Duration of connection	Amount of data transferred
Type of Connection	Circuit – Switched Technology	Packet - Switched Technology

What is GPRS ?

- General Packet Radio Service (GPRS) is a new bearer service for GSM that greatly improves and simplifies wireless access to packet data networks
- GPRS applies packet radio principal to transfer user data packets in an efficient way b/w MS & external packet data network

GPRS Mobile Stations

- New Mobile Station are required to use GPRS services because existing GSM phones do not handle the enhanced air interface or packet data.

GPRS Base Station Subsystem

- Each BSC requires the installation of one or more Packet Control Units (PCUs) and a software upgrade. The PCU provides a physical and logical data interface to the base station subsystem (BSS) for packet data traffic. The BTS can also require a software upgrade but typically does not require hardware enhancements.
- When either voice or data traffic is originated at the subscriber mobile, it is transported over the air interface to the BTS, and from the BTS to the BSC in the same way as a standard GSM call. However, at the output of the BSC, the traffic is separated; voice is sent to the mobile switching center (MSC) per standard GSM, and data is sent to a new device called the SGSN.

GPRS Nodes

- **GPRS Support Nodes**

  Following two new components, called GPRS support nodes (GSNs), are added:

- **Gateway GPRS support node (GGSN)**

  The Gateway GPRS Support Node acts as an interface and a router to external networks. The GGSN contains routing information for GPRS mobiles, which is used to tunnel packets through the IP based internal backbone to the correct Serving GPRS Support Node. The GGSN also collects charging information connected to the use of the external data networks and can act as a packet filter for incoming traffic.

- **Serving GPRS support node (SGSN)**

  The Serving GPRS Support Node is responsible for authentication of GPRS mobiles, registration of mobiles in the network, mobility management, and collecting information for charging for the use of the air interface.

Routing Area

- GPRS introduces the concept of a routing area. This is much the same as a Location Area in GSM, except that it will generally contain fewer cells. Because routing areas are smaller than Location Areas, less radio resources are used when a paging message is broadcast.
-

Benefits of GPRS

- New Data Services
- High Speed (Data Rate 14.4 – 115 kbps)
- Efficient use of radio bandwith (Statistical Multiplexing)
- Circuit switching & Packet Switching can be used in parallel
- Constant connectivity

Salient Features of GPRS

- Important step on the path to 3G
- Standardized by ETSI
- GPRS is an overlay network over the GSM
- Provides Data Packet delivery service
- Support for leading internet communication protocols
- Billing based on volume of data transferred
- Utilizes existing GSM authentication and privacy procedures.

High Data Rate

- GPRS uses radio channel i.e. 200 kHz wide
- Radio channel carries digital data stream of 271 kbps
- This rate is divided into 8 time slots each carrying 34 kbps per time slot
- Data rate 14 kbps per time slot achieved after corrections
- GPRS can combine upto 8 time slots giving data rate of 114 kbps

GPRS Terminals

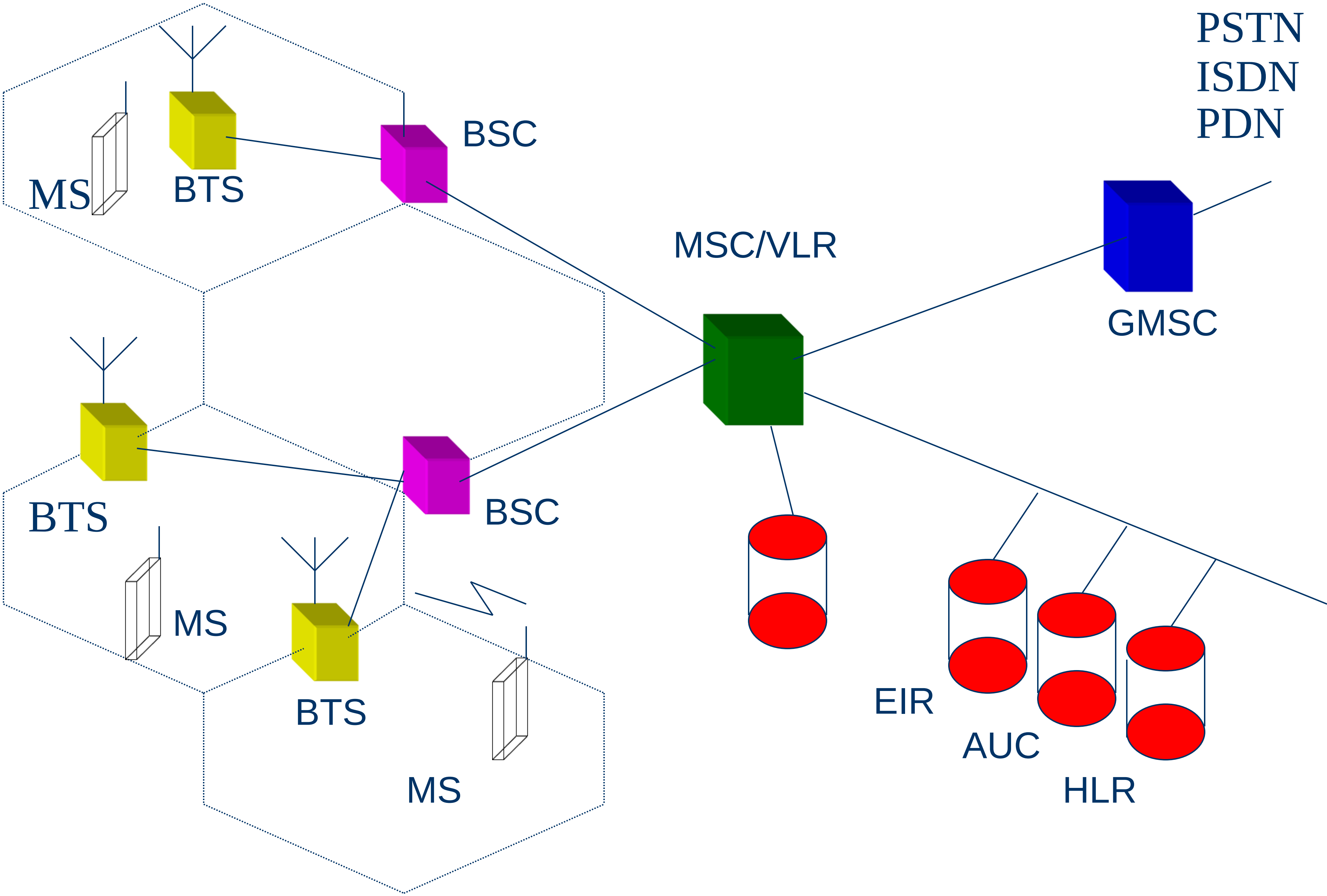
- **Class A**
  - MS supports simultaneous operation of GPRS and GSM services
- **Class B**
  - MS able to register with the n/w for both GPRS & GSM services simultaneously. It can only use one of the two services at a given time.
- **Class C**
  - MS can attach for either GPRS or GSM services

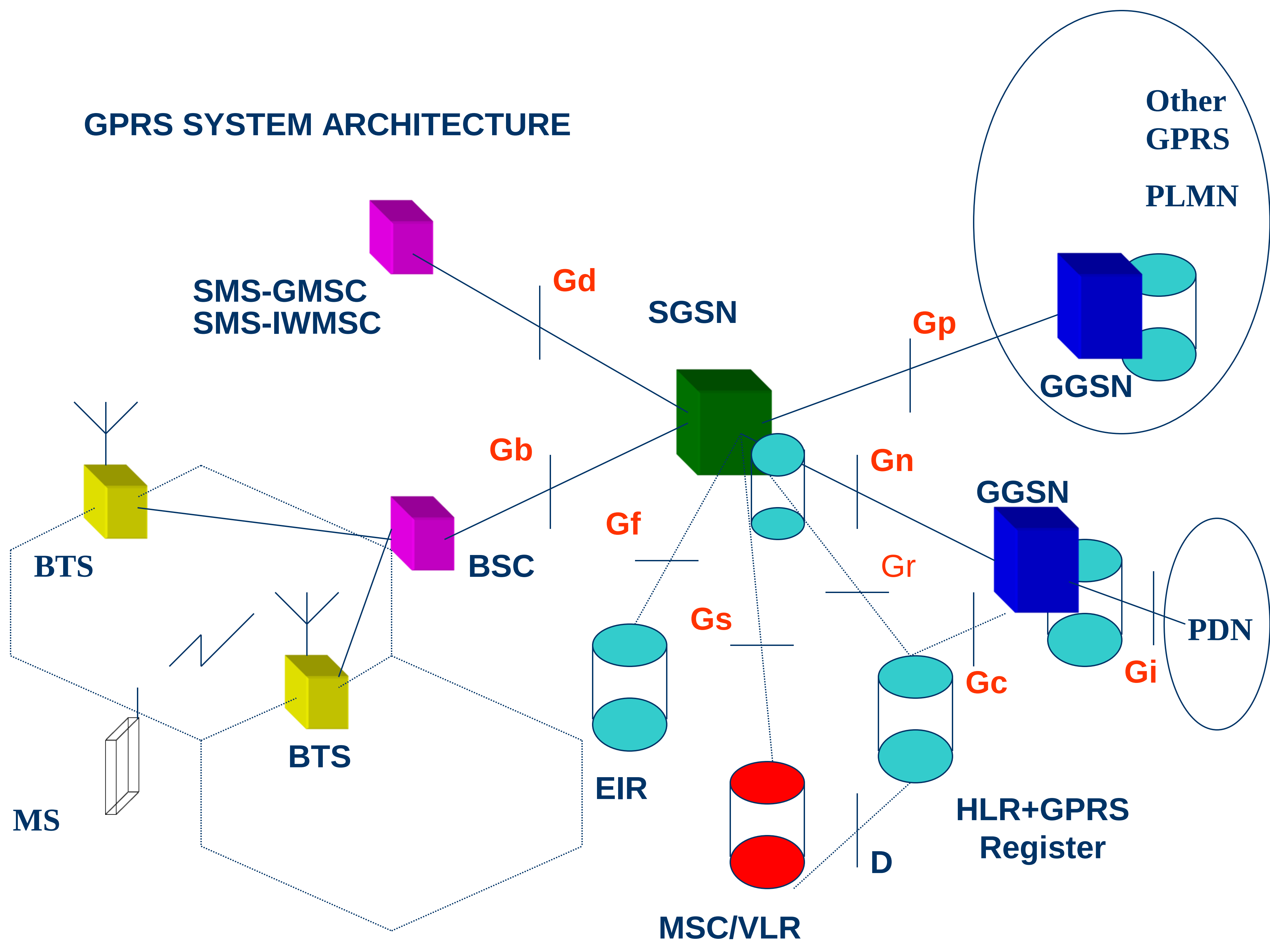
GPRS Network Elements

GPRS Architecture is same as GSM except few hardware modifications :

- GPRS includes GSNs
  - SGSN : Serving GPRS Support Node
  - GGSN : Gateway GPRS Support Node
- GPRS Register

GSM SYSTEM ARCHITECTURE




GPRS SYSTEM ARCHITECTURE
Other
GPRS
PLMN
SMS-GMSC
SMS-IWMSC
Gd
SGSN
Gp
GGSN
Gb
Gn
GGSN
Gf
BTS
BSC
Gr
Gs
PDN
Gc
Gi
BTS
EIR
MS
HLR+GPRS
Register
D
MSC/VLR

Interfaces

- Gb – Connects BSC with SGSN
- Gn – SGSN – SGSN/GGSN (in the same network)
- Gp – SGSN –GGSN (in different networks)
- Gf – For equipment querying at registering time
- Gi – Connects PLMN with external Packet Data Networks (PDNs)
- Gr – To exchange User profile between HLR & SGSN
- Gs – To exchange Database between SGSN & MSC
- Gd – Interface between SMS & GPRS
- Gc - Used by the GGSN to retrieve information about the location and supported services for the MS,to be able to activate a packet data network address ;this is optional interface

SGSN – Serving GPRS Support Node

- Delivers data packets to mobile stations & vice-versa
- Detect and Register new GPRS MS in its serving area
- Packet Routing, Transfer & Mobility Management
- Authentication, Maintaining user profiles
- Its location register stores location info. & user profiles

GGSN – Gateway GPRS Support Node

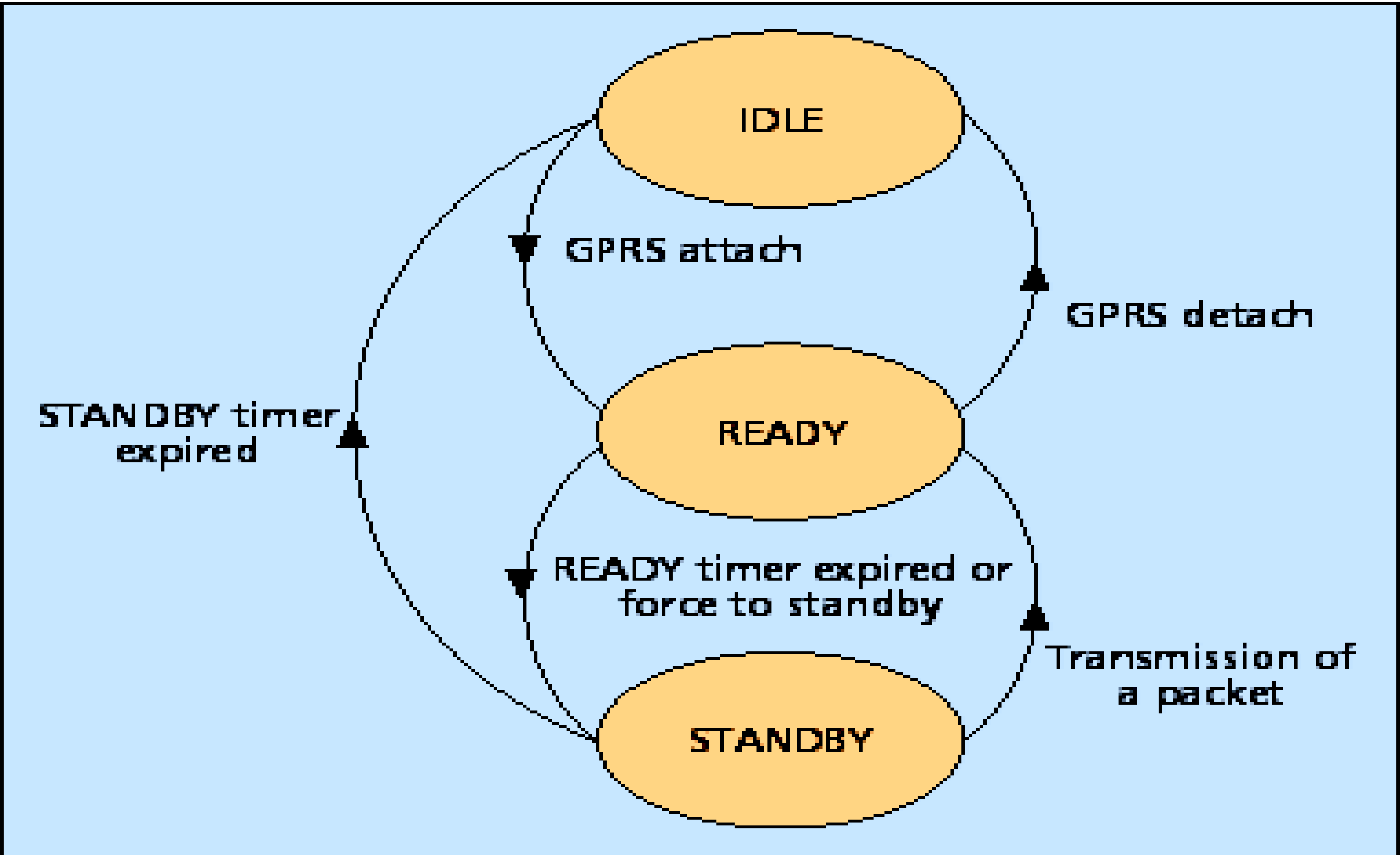
- Interfaces GPRS backbone network & external packet data networks
- Converts the GPRS packets from SGSN to the PDP format
- Converts PDP addresses change to GSM addresses of the destination user
- Stores the current SGSN address and profile of the user in its location register
- Performs authentication

GPRS Register

- GPRS Register is integrated with GSM-HLR.
- Maintains the GPRS subscriber data and Routing information.
- Stores current SGSN address

LOCATION MANAGEMENT IN GPRS

State Model of GPRS MS



Location Management

Mobile station can be in 1 of the 3 states depending on traffic amount

– **Idle** In the idle state, the MS does not have a logical GPRS context activated or any packet-switched public data network (PSPDN) addresses allocated. MS is not using GPRS service.

- **Ready (Active state)** Data is transmitted between an MS and the GPRS network only when the MS is in the active state. In the active state, the SGSN knows the cell location of the MS.

Location Management

- **Standby** In the standby state, only the routing area of the MS is known. When MS does not send any packets for longer period of time, Ready timer Expires

Routing Area Update

- GSM Location Area(LA) is divided into several Routing Areas(RA)
- RA consists of several cells
- SGSN is informed when MS moves to a new RA
- MS sends a “Routing Area Update Request” to its assigned SGSN

  When an MS that is in an active or a standby state moves from one routing area to another within the service area of one SGSN, it must perform a routing update. The routing area information in the SGSN is updated, and the success of the procedure is indicated in the response message.

Mobility Management

Consists of two levels

- Micro mobility management

  Tracks the current RA or cell of MS. It is performed by SGSN

- Macro mobility management
  - Keep tracks of MS’s current SGSN
  - Stores it in HLR, VLR, and GGSN

characteristics GPRS

- **Mobility** The ability to maintain constant voice and data communications while on the move
- **Immediacy** Allows subscribers to obtain connectivity when needed, regardless of location and without a lengthy login session.
- **Localization** Allows subscribers to obtain information relevant to their current location.

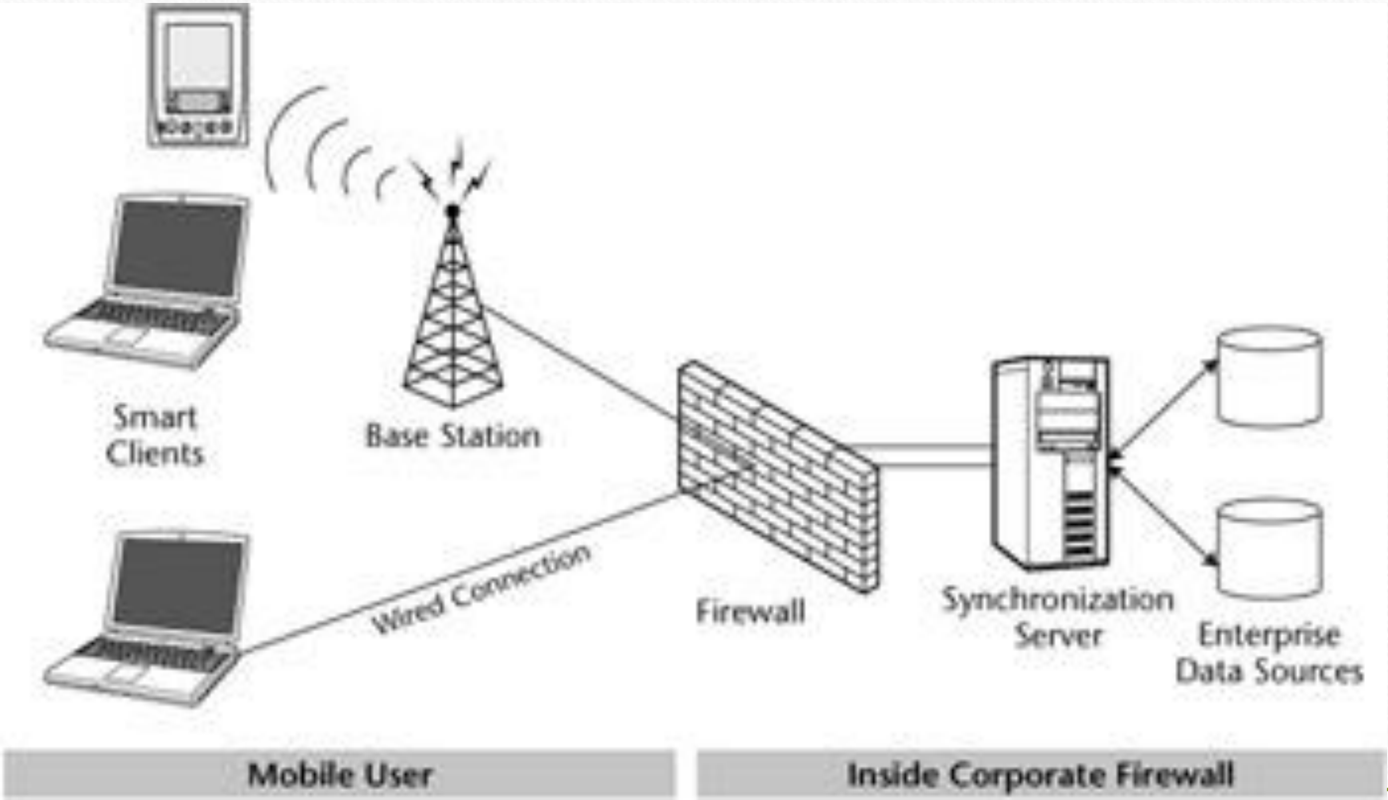
Applications of GPRS

- Web browsing
- Corporate & Internet Email
- Vehicle Positioning
- Remote LAN Access
- Home Automation
- Document Sharing/Collaborative working

Smart Client

- Smart client applications are a powerful alternative to wireless Internet applications.
- Instead of using a microbrowser on the client, custom software is developed.
- This software typically contains a persistent data storage mechanism as well as business logic. This means that smart client applications can be executed at any time, even when a wireless connection is unavailable

Smart Client



Smart Client Architecture Components

- **Smart Client**
- The smart client application is where client-side business logic is executed. The application itself is either a native executable or Java application that is deployed to the mobile device. To provide offline data access, mobile data store products are incorporated into the application

Synchronization Server

- Data is sent from the client application to the synchronization server. This can occur over a wireless or wired connection to the server. From there it is then communicated to the enterprise data sources. The synchronization server, with its associated logic, is responsible for ensuring that the minimal amount of data is transferred and that any conflicts are detected and resolved. It also provides the communication layer to enterprise systems.

Enterprise Data Source

- The synchronization server will access the enterprise data source using the preferred access mechanism. The access to the enterprise source may occur during the synchronization process if it is imperative for the smart client to receive feedback from the synchronization. This is a simple process and requires that the client connection to the synchronization server remain active until the enterprise is finished processing the data.

Advantages of Smart Client Applications

- Always-available data
- Rich user interface
- Performance
- Distributed computing
- Security
- Cost

Disadvantages of Smart Client Applications

- Enterprise integration
- Application deployment
- Mobile viruses
- Development complexity
- Multiple development cycles

Messaging

- Messaging applications can take many forms, ranging from email to alerts and notifications to application-to-application messaging. In some cases messaging is used as an enhancement to an existing mobile application; in other situations, it is itself an application architecture.

User-to-user messaging

- Messages can be sent from one user to another using a variety of mechanisms, including email, paging, and wireless text messaging such as the Short Message Service (SMS) or Instant Messaging (IM). Richer messages that include graphics and formatted text can be sent using the Enhanced Message Service (EMS), while multimedia content can be sent using the Multimedia Message Service (MMS). These forms of messaging can also be generated by server-side processes as a means of information dispersal.

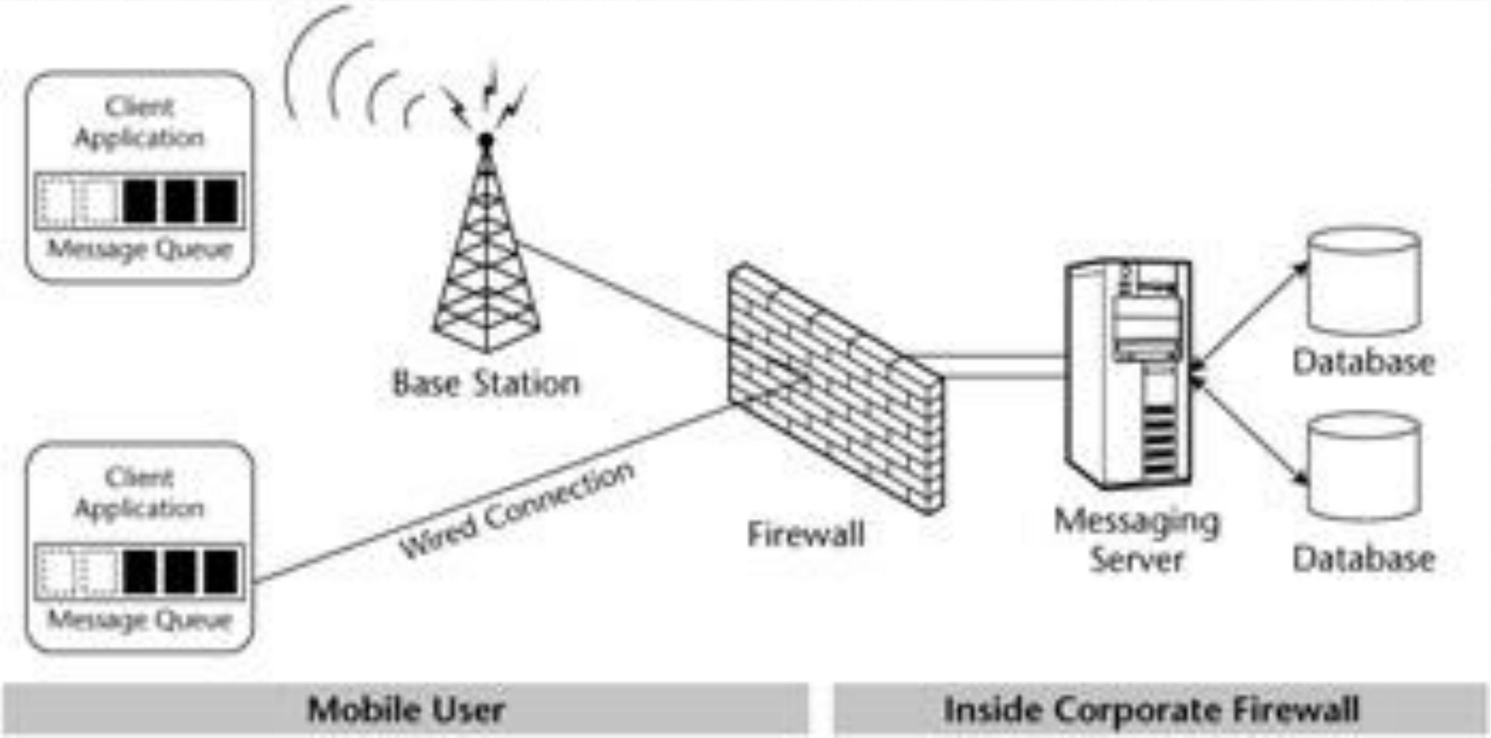
Notifications and alerts

- Messages that are urgent in nature can be pushed to mobile users on their wireless devices. This allows corporations to ensure that information is received in a timely fashion. These messages can contain a URL link to a wireless Internet site where the user can obtain additional information. These types of messages are called actionable alerts, since the recipient performs an action based on the message content. The two leading technologies for notifications and alerts are Handheld Device Markup Language (HDML) alerts and WAP Push.

Application-to-application messaging

- In many cases, user interaction is not required for the message to be successful. Enterprises can communicate data directly from an enterprise server to a client application without user interaction. This can be useful to enhance smart client applications with server-initiated synchronization

Application-to-Application Messaging Architecture



Application-to-Application Messaging Architecture Components

- **Messaging client.** The client application contains message queues as well as clientside logic. The message queues can store incoming and outgoing transactions for future access. For example, if an application attempts to send data to the server when a connection is unavailable, it can be stored in an outgoing queue and be sent automatically when the user establishes a connection to the server. This technique is called store-and-forward messaging. The messaging client can be used either on its own or in conjunction with other smart client features such as a persistent data store. The application itself can usually be programmed in languages specific to the operating system or in Java.

Messaging Server

- The server component is the part of the system that communicates with the messaging client, as well as the enterprise systems. The industry name for messaging servers is Message Oriented Middleware (MOM). Many of these systems are built on the Java Message Service (JMS). JMS provides a reliable and scalable base platform with store-and-forward capabilities. This form of messaging is useful for m-business applications because the sender of the message does not have to wait for the recipient to receive the information, allowing him or her to continue working while the message is routed and acted upon.

Enterprise data source

- The messaging server can interact with a variety of backend systems, including databases, business applications, and other messaging systems. This integration can use the preferred access technique for the enterprise system. The asynchronous nature of messaging systems is well suited for systems that require complex enterprise integration since the user does not have to wait for a response.

Advantages of Messaging

- Push capabilities
- Store-and-forward
- Personalized data delivery
- Wired and wireless communication

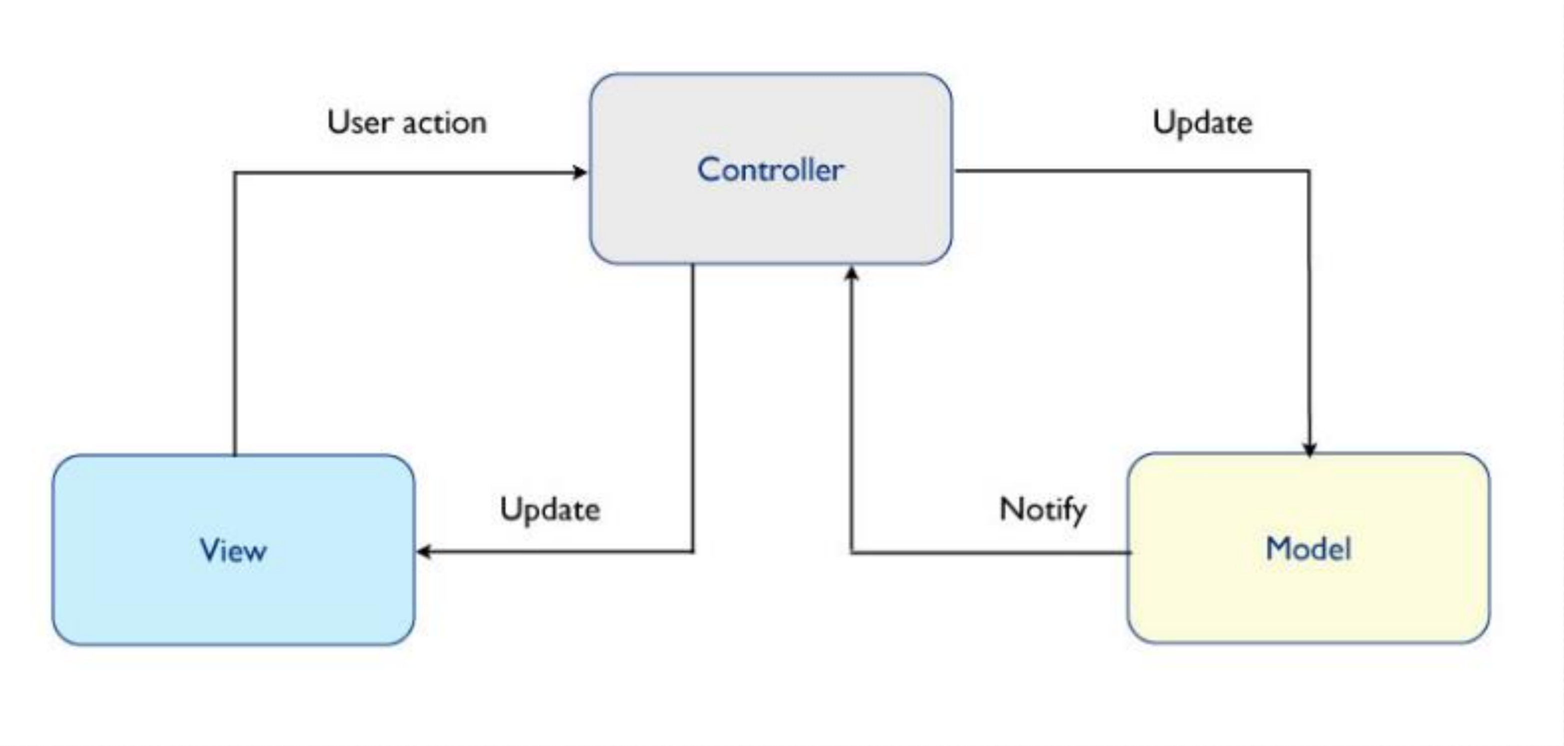
Model View Controller (MVC) Pattern

- A way to separate the code into three functionally independent areas.
- Assigns the objects in an app to one of three roles : model , view , or controller.
- The main purpose for MVC is reusability where you can reuse the same model for different views.

MVC

- Models
- – Keep track of your app's data
- Views
- – Display your user interface and make up the content of an app
- Controllers
  - – Manage your views by responding to user actions and populating views with content from the data model
  - – Serve as a gateway for communication between the model and views

MVC



Model Objects

- Model objects encapsulate the data specific to an application and define the logic and computation that manipulate and process that data.
- For example, a model object might represent a character in a game or a contact in an address book.
- A model object can have to-one and to-many relationships with other model objects, and so sometimes the model layer of an application effectively is one or more object graphs. Much of the data that is part of the persistent state of the application (whether that persistent state is stored in files or databases) should reside in the model objects after the data is loaded into the application.

Communication

- User actions in the view layer that create or modify data are communicated through a controller object and result in the creation or updating of a model object.
- When a model object changes (for example, new data is received over a network connection), it notifies a controller object, which updates the appropriate view objects.

Controller Objects

- A controller object acts as an intermediary between one or more of an application's view objects and one or more of its model objects.
- Controller objects are thus a conduit through which view objects learn about changes in model objects and vice versa.
- Controller objects can also perform setup and coordinating tasks for an application and manage the life cycles of other objects

Delegate Pattern

- A simple and powerful pattern in which one object in an app acts on behalf of/or in coordination with another object.

 - Delegating object

- Keeps a reference to the other object (the delegate)
- The delegating object sends a message to the delegate at appropriate time

Delegating Object

- The message informs the delegate of an event that the delegating object is about to handle/has just handled
- The delegate may respond to the message by updating the appearance/state of itself or of other objects in the app
- In some cases it will return a value that affects how an impending event is handled

Android Development

- Released under the open source Apache License
- Built on Linux kernel version 2.6
- A project of the Open Handset Alliance (OHA)
- Founded by Google

Android Development

- On Windows/Linux/Mac platforms
- No Java Virtual Machine on the platform
- Java classes are recompiled in to Dalvik bytecode and run on a Dalvik virtual machine

ios development

- Advanced OS
- – With iOS SDK and Xcode IDE creates revolutionary mobile apps

Xcode

- Xcode suite includes Interface Builder and Instruments –
  - Interface Builder helps you create user interfaces for your app
  - Instruments provides a thorough analysis of your app's
- Runtime performance
- Memory usage
- Allowing you to efficiently find memory leaks and bottlenecks to help improve the user experience

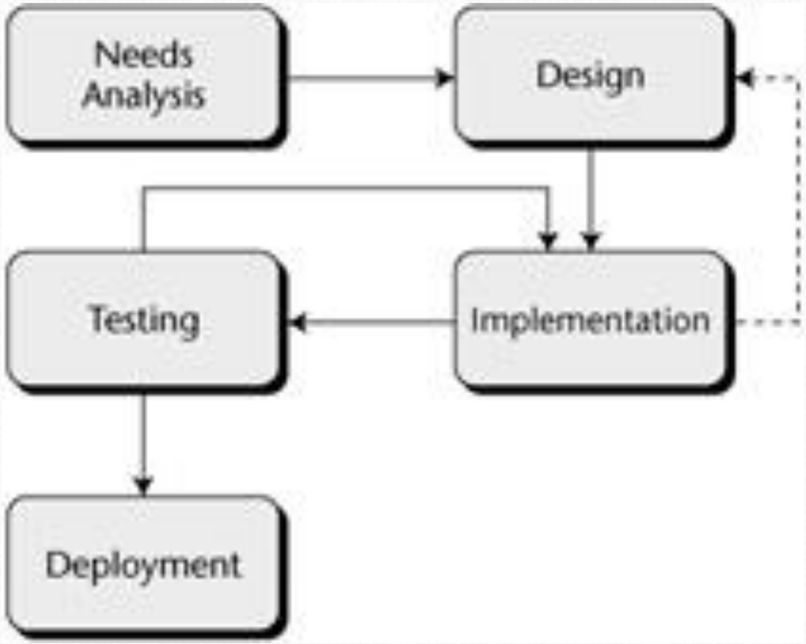
Blackberry development

- A product of Research in Motion (RIM)
- Runs a proprietary multitasking OS

BlackBerry Development

- BlackBerry Web Development
- – The newest offering from RIM using the Widget SDK
- – BlackBerry Widgets are small, discrete, standalone web applications that use HTML/CSS/JavaScript

Smart Client Development



Needs Analysis Phase

- Who are the end users of this application?
- What is their technical skill level?
- What is the overall goal of this application?
- What data integration is required? Does the user require data access at all times?
- Does this application require wireless connectivity? If so, what type of wireless access does it require, and in which geographies?
- What are the primary usage scenarios for this application?

Application Goals

- Across the globe, companies are implementing mobile and wireless applications for a variety of reasons. In some cases, the goal is to increase productivity; in others, it is to reduce costs; while in still others, the reason may be simply that it seemed like the next logical thing to do, regardless of the return on the investment. Whatever the reason, it is important that the final solution satisfy the original purpose of development.

Application goals

- During the needs analysis stage, it is important to determine why the project is being undertaken and to produce a result that is in line with expectations. If, say, the project is being implemented to automate order entry, thereby reducing paperwork, the final application should be well suited for rapid data entry, with integration back into the enterprise system.
- The technical features being implemented should correspond to a business problem that it will solve. By creating a user interface that allows for rapid data entry, we are solving the order entry problem. By having enterprise integration, we are ensuring that the data entered on the mobile device will flow into the back-end system without requiring additional paperwork.

End User

- The end users of the application play a key role in the application design and rollout. Their level of technical ability determines some of the intricacies that may be required. If the user is not comfortable setting up wireless network connection parameters, such details will need to be automated within the application. If the user does not have experience with pen-based input devices, using a device with an alphanumeric keyboard may be more appropriate. Many mobile applications fail to reach their potential because they were not developed with the end user in mind.

Data Access

- Extending corporate data to mobile users is essential to many mobile solutions. If this is the goal of the application being developed, then data integration and client storage options will have to be considered.
- Other factors to consider are how fresh the data must be on the client, how much data should reside on the client, and how often inputted data should be sent back to the server. All of these items will factor into the decision on the data storage and synchronization systems being used.

Wireless Access

- Not all mobile applications require wireless access. In fact, many applications are better off without it since real time data access is rarely a requirement. Updates can be made over wireline connections, forgoing the need for wireless access. Other reasons for avoiding wireless access include: complexity of implementation, unreliability of the networks, cost of deployment, or lack of performance.
- For field services applications, access to updated work orders, inventory analysis, or routing information can be critical to the success of the solution. Determining the level of wireless connectivity will affect both the implementation criteria and the cost of any given solution.

Usage Scenarios

- Predicting how an application will be used is not easy. Nevertheless, it should be attempted, because having some idea of possible use can prove helpful for the application design phase. If, for example, an application is going to be used constantly and is critical to the success of the user's job, then battery life of the chosen device must be considered. It would not make sense to choose a device that has a short battery life that requires constant recharging for such an application. On the other hand, if the application is used infrequently but must perform some complex logic, it might be sufficient to choose a device with better processing power but with perhaps a shorter battery life.

Design Phase

- **Client Data Access**
- Enterprise data sources will contain much more data than you can hope to store on the mobile device. This is true for enterprise databases such as Oracle, Sybase, or IBM; for ERP systems such as SAP or PeopleSoft; and for CRM systems such as Siebel. The amount of data stored on the device will depend on the mobile data store solution being used, device performance characteristics, and physical limitations of the device.
- When designing a smart client application, start by examining the subset of data that is required for the mobile user. This subset can be determined by looking at many factors, often depending on the type of application being developed. The subset of data that is required can have various levels of granularity. You can partition the data by its structure in the enterprise source—taking only specific tables from an enterprise database. Another approach is to base the partition on specific data, such as a userid, geography, or price range.

Client Data Access

- Let's look at an example sales force automation (SFA) application. For such a system, the enterprise database may contain customer contact information, order history, product information, inventory levels, and supplier information. We do not need all of this data on the mobile device, so we can take a subset of it. In this case, only the contact information, order history, and inventory level tables provide a benefit on the device, so we can limit the data to those tables. To go even further, we can say that we only want data for a particular sales representative, perhaps based on a userid, to be sent down to the device. The result is that we will have a subset of the enterprise data that contains everything relevant to the mobile user, and nothing that is not.

Enterprise Integration

- Enterprise integration is a term used to describe any communication to systems not on the device. It encapsulates integration with enterprise databases, business applications, XML data, Web content, and legacy data, among other things. For the purpose of designing your mobile solution, you will need to determine to which enterprise systems you require access. This should be based upon the data access requirements that you have already set forth in the client data access stage of the design process. There are two levels of integration that you may require: basic integration and complex integration.

Enterprise Integration

- Basic levels of enterprise integration include the ability to access enterprise databases using defined communication protocols. These capabilities may include the following:
- Device communication using the standard synchronization software such as HotSync for Palm devices or ActiveSync for Pocket PC devices
- Communication over IP-based networks
- Direct integration with a relational database or flat-file system
- Limited support for transactions

Enterprise Integration

- Support for a variety of mobile clients including laptops, handheld PCs, and PDAs
- Communication over networks that may not be IP-based
- Support for synchronizing multiple users simultaneously to a central back-end data store
- Communicating with systems that do not have well-defined interfaces, often requiring custom adapters
- Synchronization of complex data models
- Support for very large amounts of data with many transactions
- Conflict detection and resolution
- Administration tools to manage the entire process

User Interface

- The user interface can account for as much as 80 percent of the total code in a mobile solution. When you have one part of the application accounting for such a large portion of the development effort, it has to be designed correctly to avoid costly changes later in the development cycle.

Screen Size

- One of the most dramatic differences between desktop applications and those developed for mobile devices is the screen "real estate." When targeting mobile applications, you will have a one-half VGA, one-quarter VGA, or even smaller screen to work with. Using the screen to its maximum benefit is crucial for successful applications. There are many different ways to accomplish this goal, depending on the operating system you are using. Windows CE, for example, supports a tab-based interface, allowing easy navigation to multiple forms with the click of a button.

Human Interaction

- Studying human interaction with your application will prove to be invaluable in determining its overall usability. History has shown that people always interact with the system in unexpected ways. There is no way that these ways can be predicted, so testing is critical.
- Before you get to the stage where you can study human interaction, there are application-specific requirements that can lead the direction of the user interface. If the application focuses on data input, then the main input screens should be easy to navigate using the input properties of the device. For example, if the device offers keyboard support, make it possible for the user to quickly tab between entry fields, rather than having to use a scroll-wheel to get there. If the only means of input is a stylus with character recognition, then including radio buttons and drop-down lists are effective ways to improve the efficiency of data input.

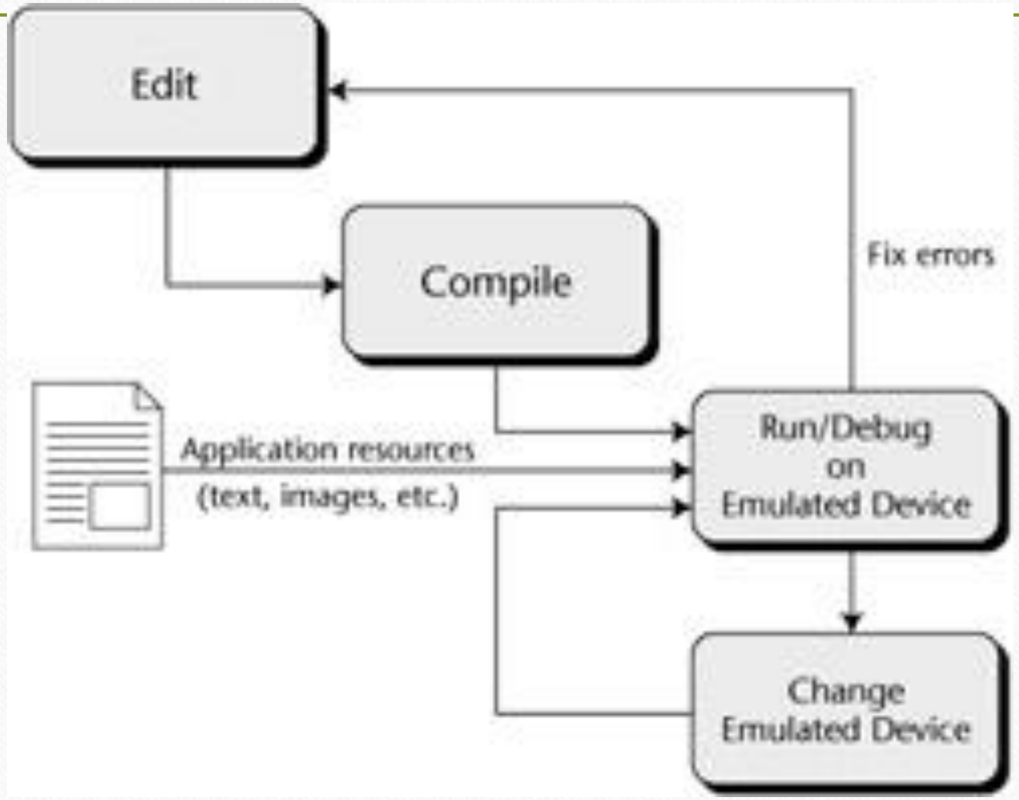
Wireless Connectivity

- *Wireless coverage is not guaranteed*. In fact, many areas do not have adequate coverage for data communication. This situation applies even in countries that have excellent overall wireless coverage.
- *Network penetration issues can arise even in areas that do have coverage*. Network penetration can be problematical not only in obvious places like subways and tunnels but also in many corporate buildings.
- *Wireless networks operate over a variety of protocols*. Some of these are not IP-based, so if your application requires IP for data communication, you may have to add an additional IP layer for connectivity. Many software vendors can provide this layer for you, if required.

Wireless Connectivity

- *Limit the frequency of wireless data transfer*. Because there are potential problems with the reliability of wireless networks, this consideration will make the application more effective. Having suitable persistent data storage within the application will make it possible to limit the frequency of network connectivity within the application. Infrequent wireless data transfer also has a positive effect on battery life, as wireless communications require more battery power than local access.
- *Limit the amount of data transferred*. This limitation is urged, once again because of the nature of the wireless networks.

Implementation and Testing Phase



Prototypes

- Which device and related operating system is most suitable for my application?
- Which wireless network is appropriate for my application, and does it perform as expected?
- Does the user interface provide the most efficient way for the user to operate the application? Does it match the device characteristics?
- Is the appropriate data available in the application? Can the client data store handle the amount of data required on the client device?

Prototypes

- Does the enterprise integration layer work? Is it scalable, to meet the needs for my application?
- Have security concerns been addressed? Are there holes where corporate data is left unprotected?
- Does the application provide an upgrade path for new features? Will it be adaptable for new wireless networks as they arrive?

Development Tools

- Choosing which development tool to use is not a decision to take lightly. Many development tools are available for smart client applications, each with benefits and drawbacks. You need to consider many factors when making your development tool choice. Some of the more important ones include the target mobile operating system, the preferred programming language, the tool's feature set, and the tool's layout. In addition, you should also take into consideration your personal preferences.

Deployment Phase

- **Wide range of devices that need to be supported.** These can range from two-way pagers to PDAs to laptops. Ideally, a way can be found to manage all of these devices in the same manner.
- **Deployment of applications to these devices.** This includes the original application as well as updates as they occur.
- **Management of mobile assets.** This includes keeping an inventory of the devices in the field, as well the software on these devices.
- **Backup and recovery.** Because the primary functions of many of the mobile applications are to retrieve data and to make sure the data is safe in the event of a system crash.

Deployment Phase

- **Working with wireless networks.** In most cases, the rules that were developed for LAN-based applications do not apply to wireless deployment and management. The bandwidth of the wireless networks makes the efficiency of the solution a top priority.
- **End users have little access to technical assistance.** Very often remote workers do not have direct access to technical support, making troubleshooting and repair difficult.
- **Participating in business analysis to determine application effectiveness.** In today's economic environment, businesses need ways to determine if their mobile applications are meeting their goals of improving employee productivity and cost savings.

INTRODUCTION

- LTE stands for *Long Term Evolution* and it was started as a project in 2004 by telecommunication body known as the Third Generation Partnership Project (3GPP).
- SAE (System Architecture Evolution) is the corresponding evolution of the GPRS/3G packet core network evolution. The term LTE is typically used to represent both LTE and SAE.
- LTE evolved from an earlier 3GPP system known as the Universal Mobile Telecommunication System (UMTS), which in turn evolved from the Global System for Mobile Communications (GSM).

GOALS OF LTE

- A rapid increase of mobile data usage and emergence of new applications such as MMOG (Multimedia Online Gaming), mobile TV, Web 2.0, streaming contents have motivated the 3rd Generation Partnership Project (3GPP) to work on the Long-Term Evolution (LTE) on the way towards fourth-generation mobile.
- The main goal of LTE is to provide a high data rate, low latency and packet optimized radio access technology supporting flexible bandwidth deployments.
- Same time its network architecture has been designed with the goal to support packet-switched traffic with seamless mobility and great quality of service.

LTE history and development

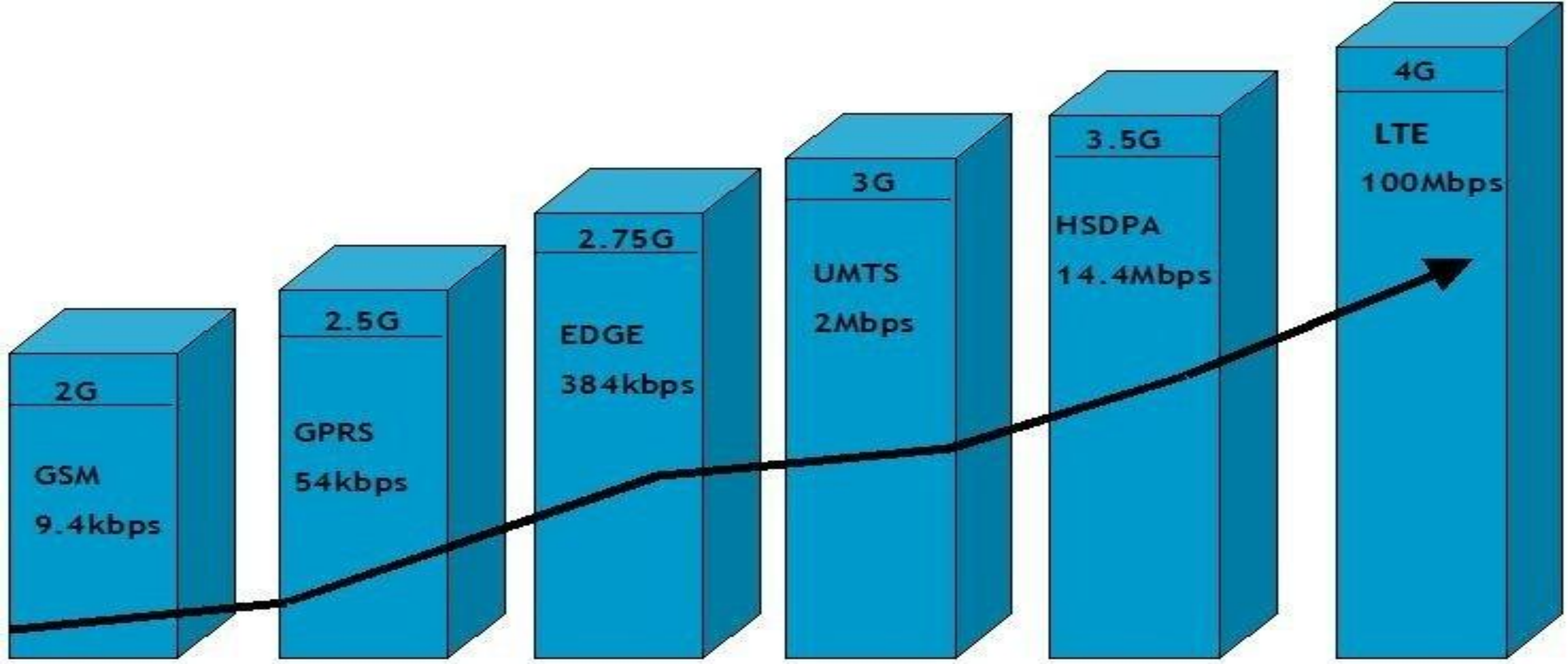
- There was no global standard for wireless broadband until the advent of LTE.
- Major milestones in LTE's development include the following:
  - **2004.** NTT DoCoMo, a Japanese mobile phone operator, proposed making LTE the next international standard for wireless broadband, and work on the LTE standard started.
  - **2006.** During a live demonstration, Nokia Networks simultaneously downloaded HD video and uploaded a game via LTE.
  - **2007.** Ericsson, a Swedish telecommunications company, demonstrated LTE with a bit rate of 144 Mbps.

LTE history and development

- Major milestones in LTE's development include the following:
  - **2008.** Ericsson demonstrated the first LTE end-to-end phone call, and LTE was finalized.
  - **2009.** TeliaSonera, a Swedish mobile network operator, made LTE available in Oslo and Stockholm.
  - **2011.** LTE-Advanced was finalized in 3GPP Release 10.
  - **2016.** 3GPP engineers began developing the 5G standard that will eventually succeed LTE.
  - **2017.** The first NSA 5G specification was released, becoming widely available in 2018-2019.
  - **2021.** 5G specification work is ongoing.

Facts about LTE

- LTE is important because it will bring up to 50 times performance improvement and much better spectral efficiency to cellular networks.
- LTE introduced to get higher data rates, 300Mbps peak downlink and 75 Mbps peak uplink. In a 20MHz carrier, data rates beyond 300Mbps can be achieved under very good signal conditions.
- LTE is an ideal technology to support high date rates for the services such as voice over IP (VOIP), streaming multimedia, videoconferencing or even a high-speed cellular modem.
- LTE uses both Time Division Duplex (TDD) and Frequency Division Duplex (FDD) mode. In FDD uplink and downlink transmission used different frequency, while in TDD both uplink and downlink use the same carrier and are separated in Time.



GSM - Global System for Mobile communication

GPRS - General Packet Radio Service

EDGE - Enhanced Data rate for GSM Evolution

UMTS - Universal Mobile Telecommunication Systems

HSDPA - High Speed Downlink Packet Access

LTE - Long Term Evolution

Facts about LTE

- LTE supports flexible carrier bandwidths, from 1.4 MHz up to 20 MHz as well as both FDD and TDD.
- All LTE devices have to support (MIMO) Multiple Input Multiple Output transmissions, which allow the base station to transmit several data streams over the same carrier simultaneously.
- All interfaces between network nodes in LTE are now IP based, including the backhaul connection to the radio base stations.
- This is great simplification compared to earlier technologies that were initially based on E1/T1, ATM and frame relay links, with most of them being narrowband and expensive.

Facts about LTE

- Quality of Service (QoS) mechanism have been standardized on all interfaces to ensure that the requirement of voice calls for a constant delay and bandwidth, can still be met when capacity limits are reached.
- Works with GSM/EDGE/UMTS systems utilizing existing 2G and 3G spectrum and new spectrum. Supports hand-over and roaming to existing mobile networks.

	LTE	LTE Advanced	LTE Advanced Pro
DL Modulation Schemes	QPSK, 16 QAM, 64 QAM	QPSK, 16 QAM, 64 QAM, 256 QAM	QPSK, 16 QAM, 64 QAM, 256 QAM
UL Modulation Schemes	QPSK, 16 QAM, 64 QAM	QPSK, 16 QAM, 64 QAM	QPSK, 16 QAM, 64 QAM, 256 QAM
DL Peak Data Rate	150 mbps / 300 Mpbs	1 Gbps	3 Gbps
UL Peak Data Rate	50 Mbps / 75 mbps	500 mbps	-
Carrier Aggregation	Not supported	Support	Support
Max Aggregated Carrier	0	5	32
3GPP Standard	Release 8, 9	Release 10, 11, 12	Release 13 and beyond
Latency	10 ms	10 ms	2 ms
Total Carrier Bandwidth	20 MHz	100 MHz	640 MHz
Spectrum Resources	700 MHz – 2.6 GHz	450 MHz – 3.8 GHz	450 MHz – 3.8 GHz, 5.1GHz – 5.9 GHz

Advantages of LTE

- High throughput: High data rates can be achieved in both downlink as well as uplink. This causes high throughput.
- Low latency: Time required to connect to the network is in range of a few hundred milliseconds and power saving states can now be entered and exited very quickly.
- FDD and TDD in the same platform: Frequency Division Duplex (FDD) and Time Division Duplex (TDD), both schemes can be used on same platform.
- Superior end-user experience: Optimized signaling for connection establishment and other air interface and mobility management procedures have further improved the user experience. Reduced latency (to 10 ms) for better user experience.

Advantages of LTE

- Seamless Connection: LTE will also support seamless connection to existing networks such as GSM, CDMA and WCDMA.
- Plug and play: The user does not have to manually install drivers for the device. Instead system automatically recognizes the device, loads new drivers for the hardware if needed, and begins to work with the newly connected device.
- Simple architecture: Because of Simple architecture low operating expenditure (OPEX).

FUTURE OF CELLULAR NETWORK

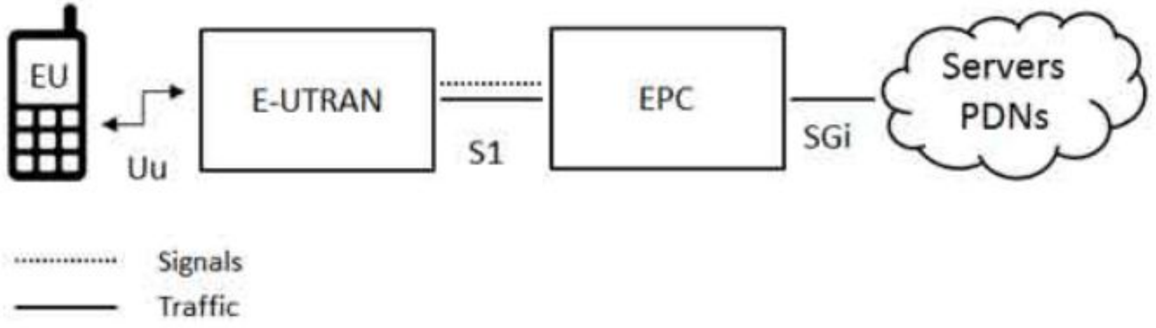
- The majority of 5G networks use the NSA spec that requires a 4G LTE core network to facilitate 5G data sessions.
- 4G LTE is still the major mobile network standard across the world.
- It will not be replaced by 5G for at least a decade and will probably hang on for years after that.

4G vs. 5G: What's the difference?

	4G	5G
LATENCY	60 to 98 ms	Less than 1 ms
POTENTIAL DOWNLOAD SPEED	1 Gbps	10 Gbps
BASE STATIONS	Cell towers	Small cells
OFDM ENCODING	20 MHz channels	100 to 800 MHz channels
GOAL FOR CELL DENSITY	200 to 400 users per cell	100 times greater than 4G

NETWORK ARCHITECTURE

- The network architecture of LTE comprises of the following 3 main components:
  - User Equipment (UE)
  - Evolved UMTS Terrestrial Radio Access Network (E-UTRAN)
  - Evolved Packet Core (EPC)



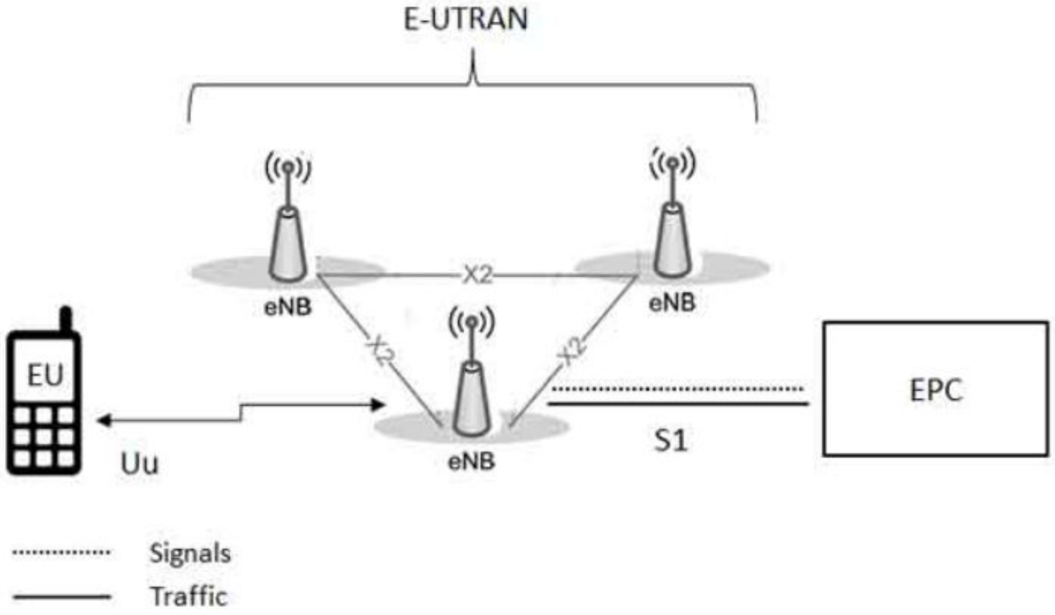
USER EQUIPMENT (UE)

- The internal architecture of UE is identical to that of MS in GSM.
- It comprises of the following important modules:
  - Mobile Termination (MT)
    - This handles all communication functions.
  - Terminal Equipment (TE)
    - This terminates the data streams.
  - Universal Integrated Circuit Card (UICC)
    - This is also known as SIM card for LTE equipments. It runs a application known as the Universal Subscriber Identity Module (USIM) which stores user-specific data like phone number, home network identity,etc.

E-UTRAN (Access Network)

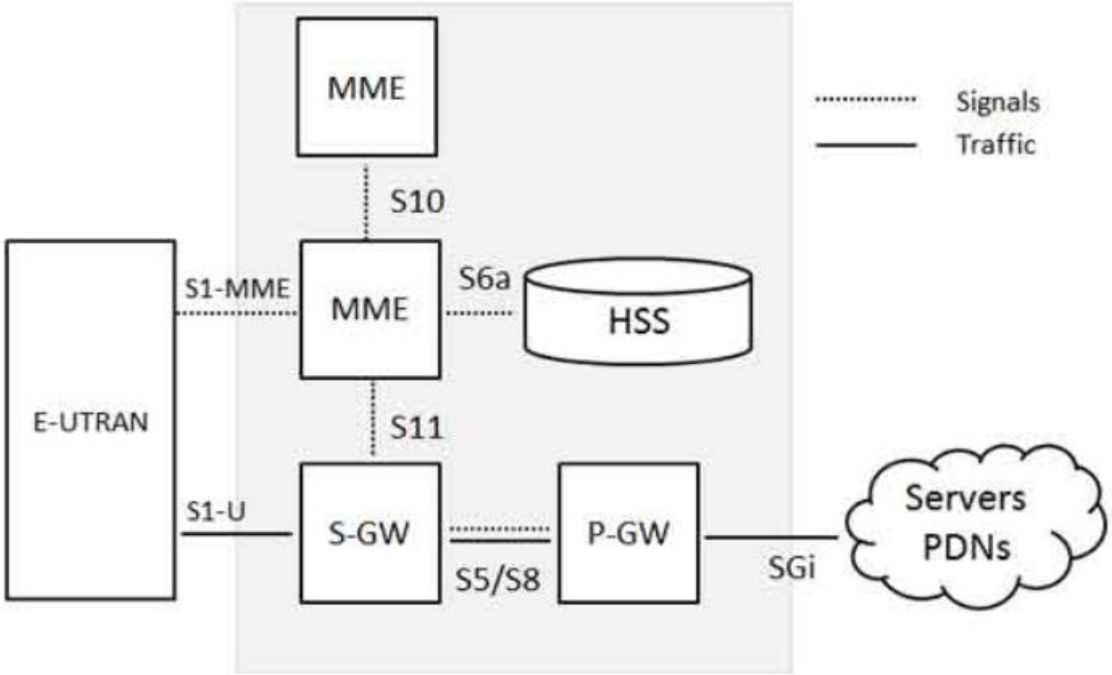
- The E-UTRAN handles radio communications between the UE and EPC.
- It has just one component, the evolved Base Station (eNodeB or eNB) which controls the mobiles in one or more cells.
- LTE mobile communicates with just one BS and one cell at a time.
- Two main functions of eNB:
    - It sends and receives radio transmissions to all the mobiles using analogue and digital signal processing functions.
    - It controls the low-level operation of all its mobiles, by sending them signalling messages such as handover commands.

- Each eNB connects with EPC by means of the S1 interface and it can also be connected nearby BS by X2 interface, which is mainly used for signalling and packet forwarding during handover.



EPC (Core Network)

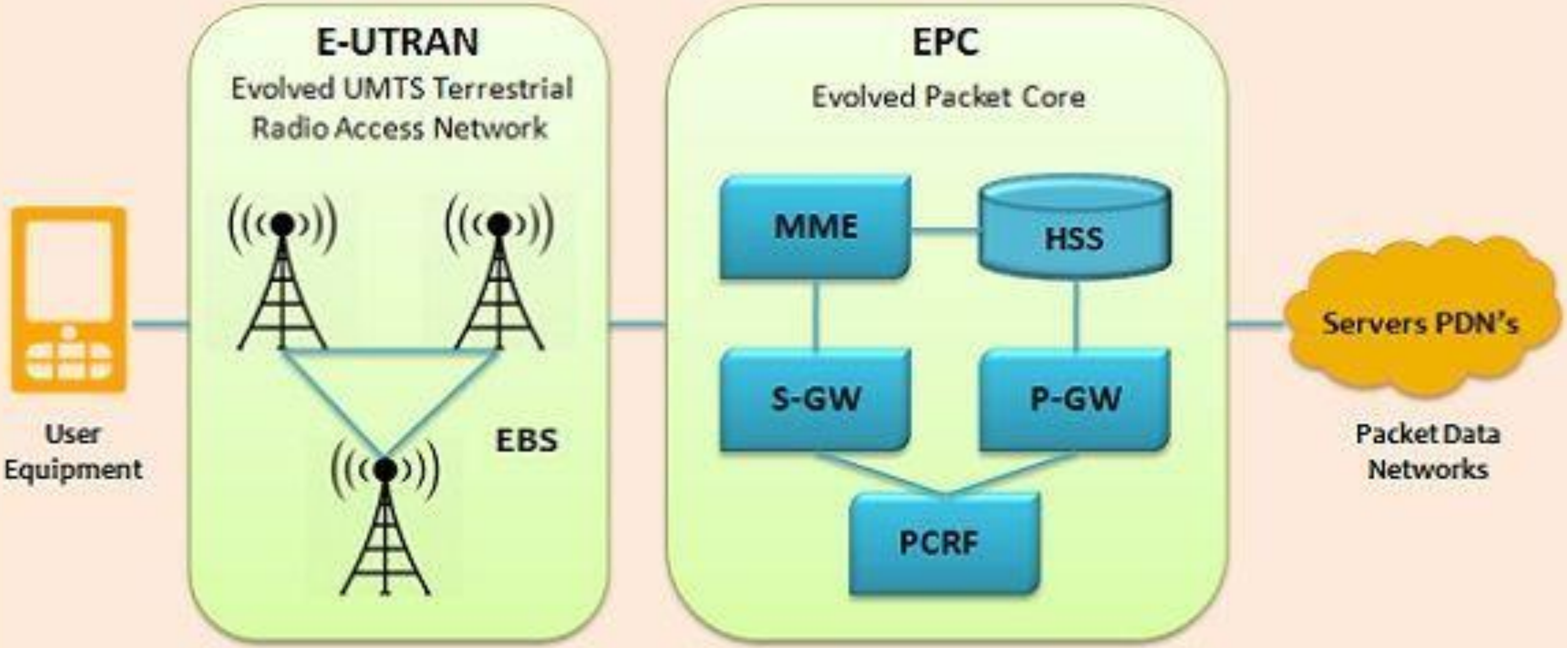
The architecture of EPC:



- Home Subscriber Server (HSS) component has been carried forward from GSM and is a central database that contains information about all the network operator’s subscribers.
- Packet Data Network (PDN) Gateway (P-GW) communicates with the outside world ie. packet data networks PDN, using SGi interface. Each packet data network is identified by an access point name (APN). The PDN gateway has the same role as the GPRS support node (GGSN) and the serving GPRS support node (SGSN) with UMTS and GSM.
- The serving gateway (S-GW) acts as a router, and forwards data between the base station and the PDN gateway.
- The mobility management entity (MME) controls the high-level operation of the mobile by means of signalling messages and Home Subscriber Server (HSS).

- The Policy Control and Charging Rules Function (PCRF) is a component which is not shown in the above diagram but it is responsible for policy control decision-making, as well as for controlling the flow-based charging functionalities in the Policy Control Enforcement Function (PCEF), which resides in the P-GW.
- There are few more components which have not been shown in the diagram to keep it simple. These components are like the Earthquake and Tsunami Warning System (ETWS), the Equipment Identity Register (EIR) and Policy Control and Charging Rules Function (PCRF).
- The interface between the serving and PDN gateways is known as S5/S8. This has two slightly different implementations, namely S5 if the two devices are in the same network, and S8 if they are in different networks.

4G LTE Network Architecture Model



EBS - Evolved Base Stations

MME - Mobility Management Entity

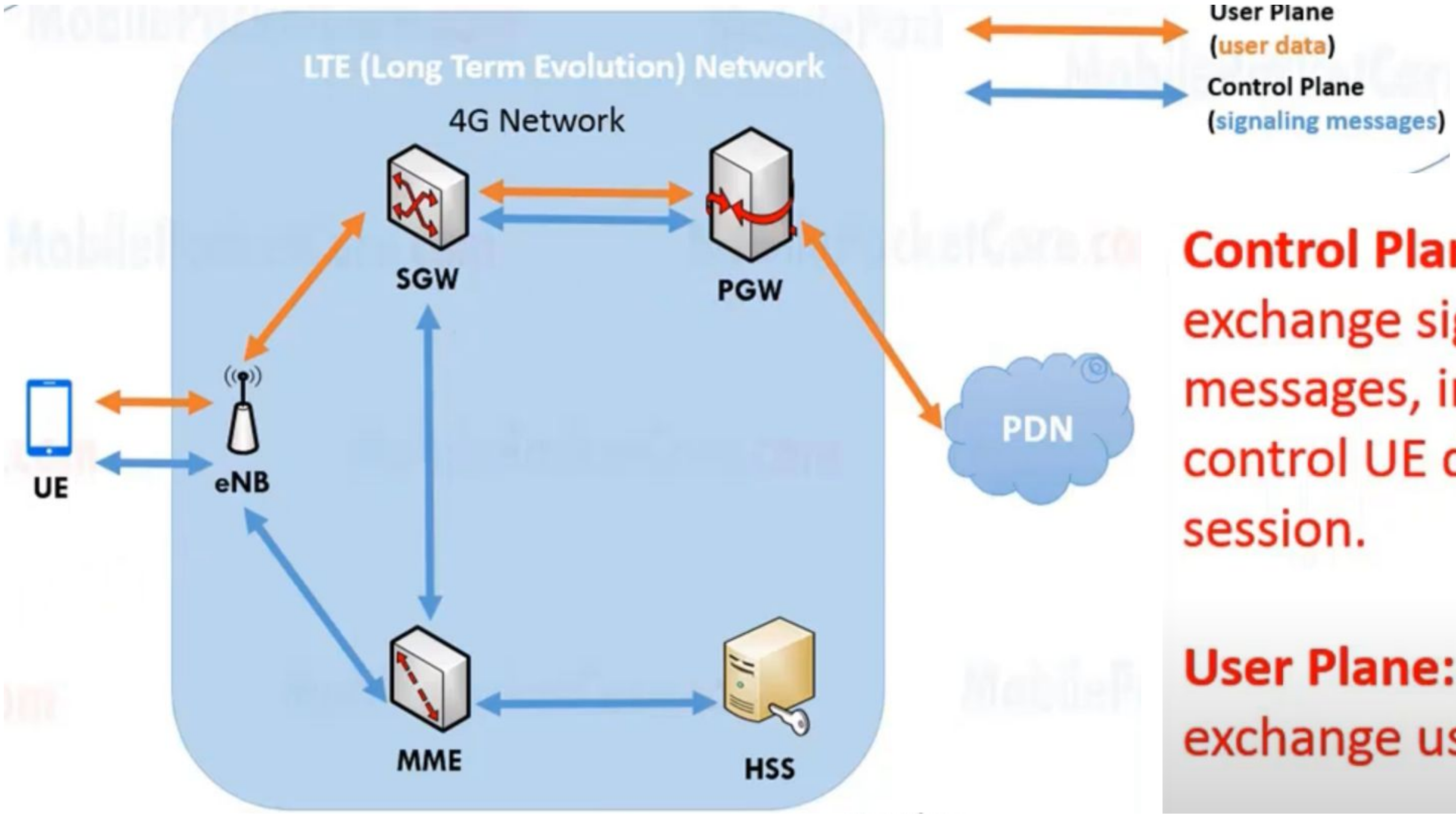
HSS - Home Subscriber Server

S-GW - Serving Gateway

P-GW - Packet Data Network Gateway

PCRF - Policy Control and Charging Rules Functions

NETWORK FLOW



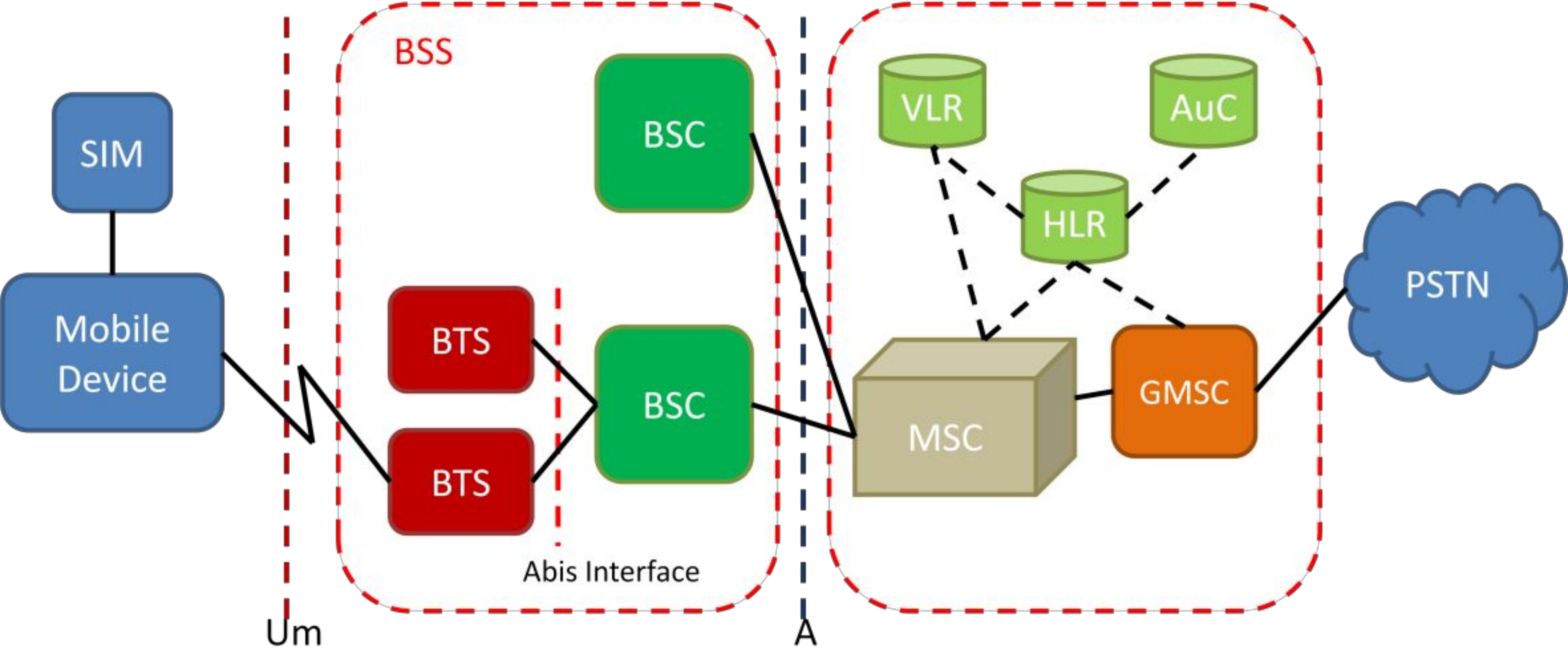
Control Plane: Used to exchange signaling messages, in order to control UE data session.

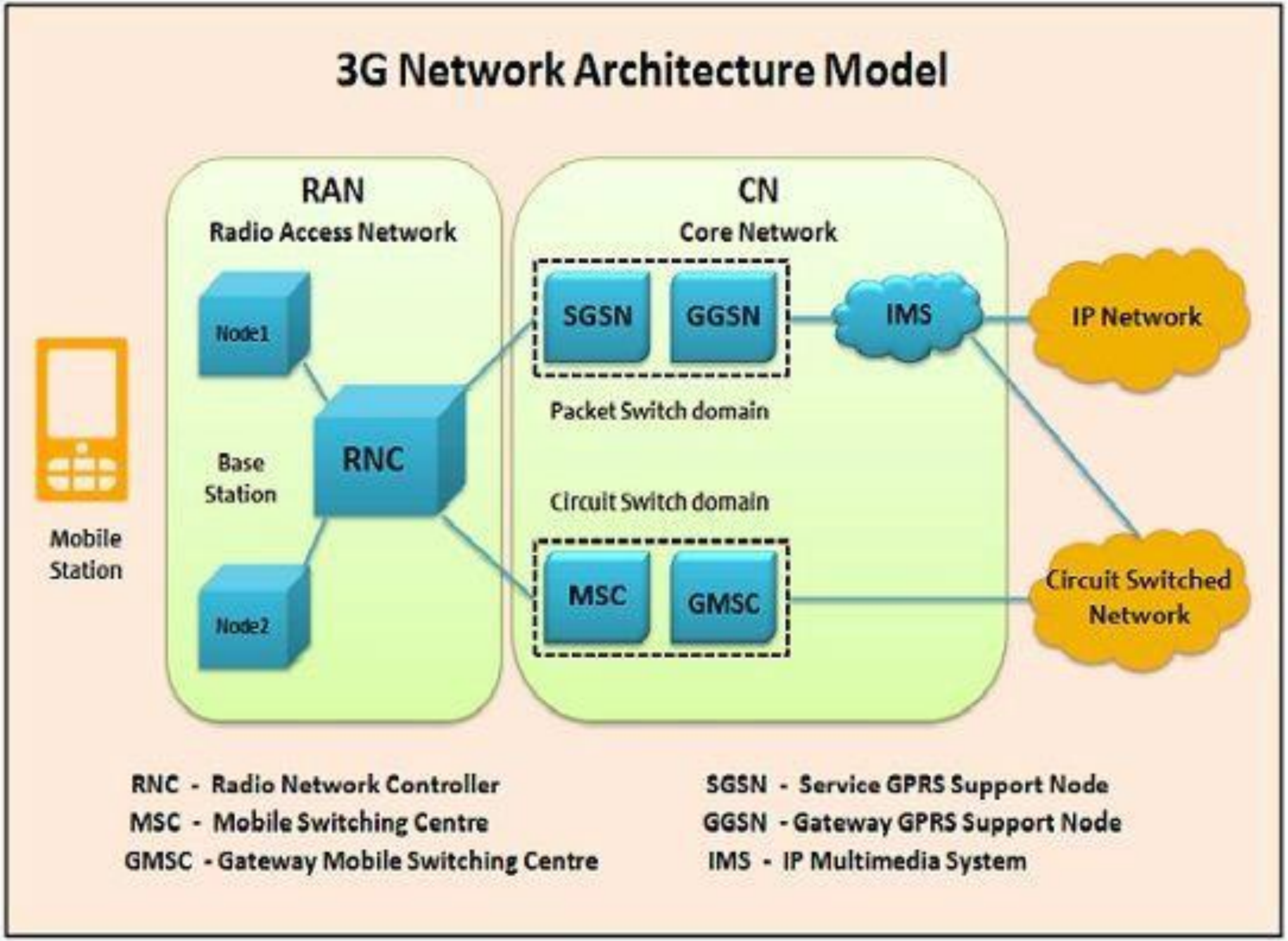
User Plane: Used to exchange user data.

COMPARISION B/W 2G,3G & 4G

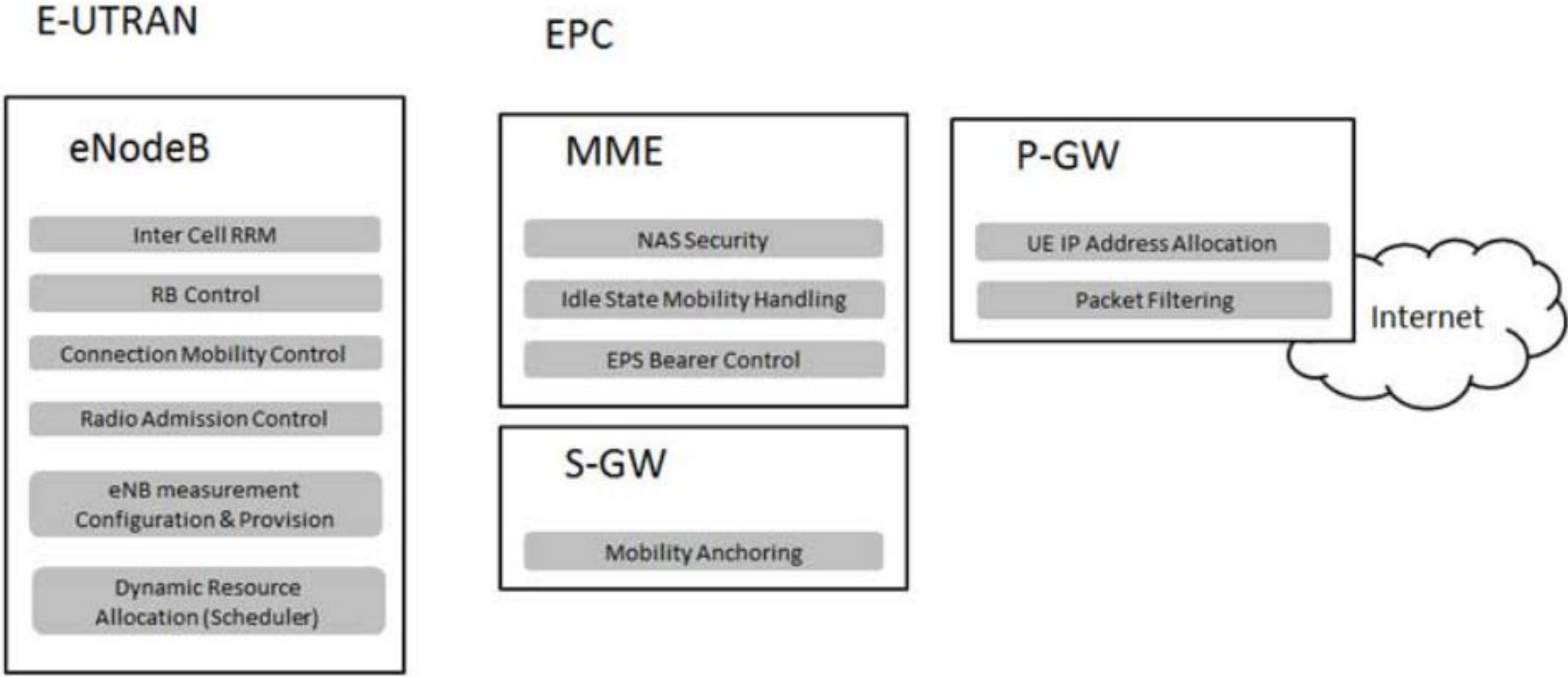
- In order to attain high mobility and larger data rates, the complexity of the network should be reduced.
- This is achieved by reducing number of nodes in the network.
- In 2G & 3G , there are 4 intermediate nodes between MS/UE and PDN.
- In both 2G & 3G, core network is the same ie SGSN & GGSN and only the radio network is different.
- In 4G, RNC is removed and eNB is directly attached to core network.
- This led to a new architecture with new components and higher efficiency. This new evolved architecture was called System Architecture Evolution (SAE).

2G Architecture Model




3G Network Architecture Model
RAN
Radio Access Network
CN
Core Network
Node1
Base Station
RNC
Node2
Mobile Station
SGSN
GGSN
Packet Switch domain
IMS
IP Network
Circuit Switch domain
MSC
GMSC
Circuit Switched Network
RNC - Radio Network Controller
MSC - Mobile Switching Centre
GMSC - Gateway Mobile Switching Centre
SGSN - Service GPRS Support Node
GGSN - Gateway GPRS Support Node
IMS - IP Multimedia System

FUNCTIONAL SPLIT



DIVISION OF LTE NETWORK AREA

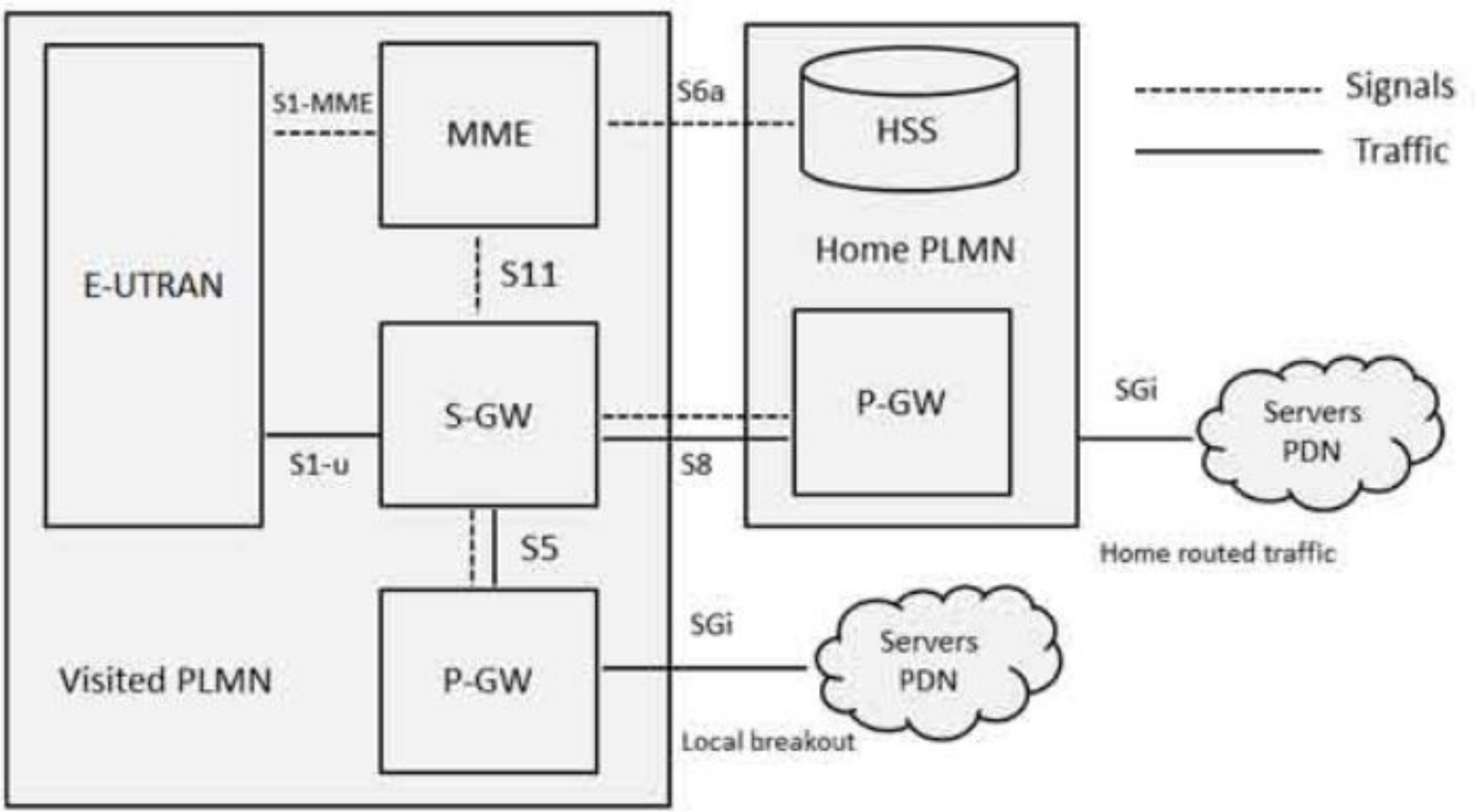
- MME pool areas:
  - This is an area through which the mobile can move without a change of serving MME. Every MME pool area is controlled by one or more MMEs on the network.
- S-GW service areas:
  - This is an area served by one or more serving gateways S-GW, through which the mobile can move without a change of serving gateway.
- Tracking areas:
  - The MME pool areas and the S-GW service areas are both made from smaller, non-overlapping units known as tracking areas (TAs). They are similar to the location and routing areas from UMTS and GSM and will be used to track the locations of mobiles that are on standby mode.

ROAMING ARCHITECTURE

- A network run by one operator in one country is known as a Public Land Mobile Network (PLMN) and when a subscribed user uses his operator's PLMN then it is said Home-PLMN but roaming allows users to move outside their home network and using the resources from other operator's network. This other network is called Visited-PLMN.
- A roaming user is connected to the E-UTRAN, MME and S-GW of the visited LTE network. However, LTE/SAE allows the P-GW of either the visited or the home network to be used.
- The home network's P-GW allows the user to access the home operator's services even while in a visited network. A P-GW in the visited network allows a "local breakout" to the Internet in the visited network.

- The interface between the serving and PDN gateways is known as S5/S8. This has two slightly different implementations, namely S5 if the two devices are in the same network, and S8 if they are in different networks. For mobiles that are not roaming, the serving and PDN gateways can be integrated into a single device, so that the S5/S8 interface vanishes altogether.

ROAMING ARCHITECTURE MODEL



SYSTEM ARCHITECTURE

- SAE is a study within 3GPP ,targeting at the evolution of the overall system architecture
- Objective is to develop a framework for an evolution or migration of the 3GPP system to a higher-data-rate, lower-latency,packet optimized system that supports multiple radio access technologies.
- The focus of this work is on the PS(Packet Service) domain with the assumption that voice services are supported in this domain. This study included the vision of an all-IP network.

WHY LTE/SAE?

- Packet Switched data is more and more dominant.
- VoIP is the most efficient method to transfer voice data.
- Amount of data is continuously growing.
- Need for higher data rates at low cost.
- Users demand better quality to accept new services.
- Alternative solution for non 3GPP technologies (WiMax) needed.
- LTE must enhance the system to satisfy these requirements.

LTE TECHNICAL OBJECTIVES AND ARCHITECTURE`

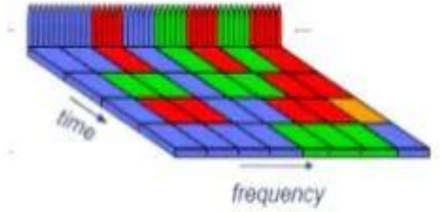
- **User throughput[MHz]:**
  - Downlink: 3 to 4 times Release 6 HSDPA
  - Uplink: 2 to 3 times Release 6 Enhanced Uplink
- **Downlink Capacity:**Peak Data Rate of 100 Mbps in 20 MHz maximum bandwidth.
- **Uplink Capacity:** Peak Data Rate of 50 Mbps in 20 MHz maximum bandwidth.
- **Latency:** Transition time less than 5 ms in ideal conditions (user plane), 100ms for Control plane (fast connection setup)

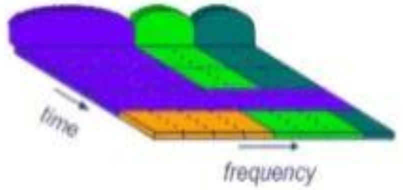
LTE TECHNICAL OBJECTIVES AND ARCHITECTURE`

- **Mobility:** Optimized for low speed but supporting 120 km/h.
  - Most data users are less mobile
- **Simplified Architecture:** Simpler E-UTRAN architecture: no RNC, no CS domain.
- **Scalable Bandwidth:** 1.25 MHz to 20 MHz. Deployment possible in GSM bands.

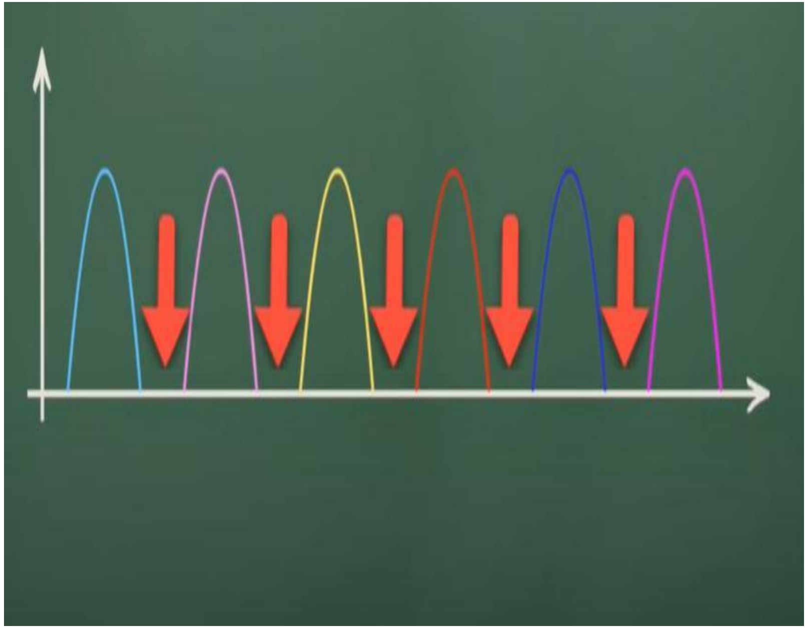
LTE RADIO INTERFACE

- New radio interfaces modulation: SC-FDMA UL and OFDMA DL
    - Frequency Division, TTI 1 ms.
    - Scalable Bandwidth 1.25-20 MHz
    - TDD and FDD modes
        - UL/DL in either in same or in another frequency
    - OFDMA has multiple orthogonal subcarriers that can be shared between users.
        - Quickly adjustable bandwidth per user.
    - SC-FDMA is technically similar to OFDMA but is better suited for uplink hand held devices

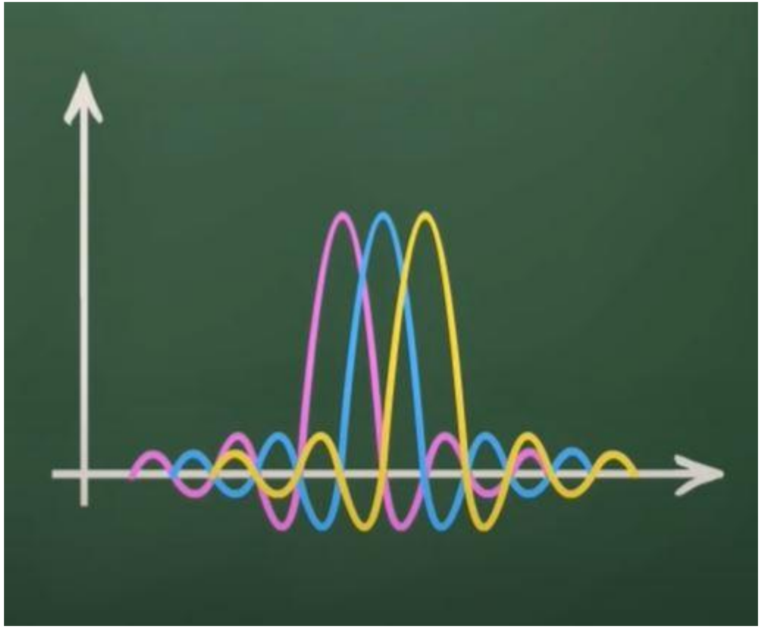




OFDMA



FDMA

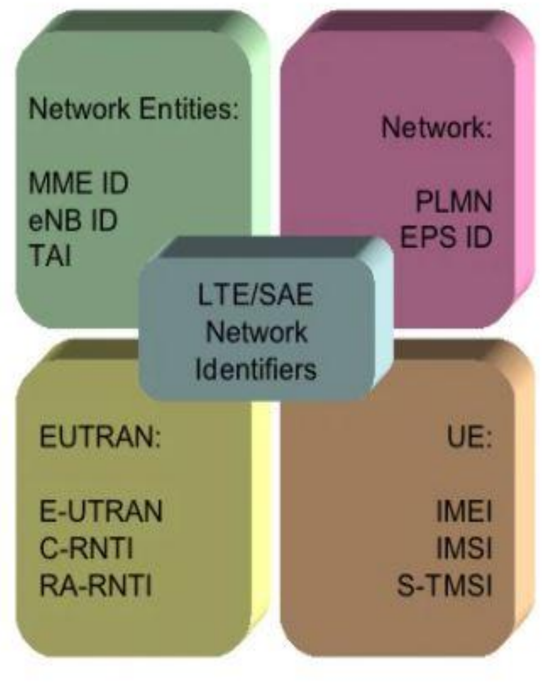


OFDMA

LTE/SAE KEYWORDS

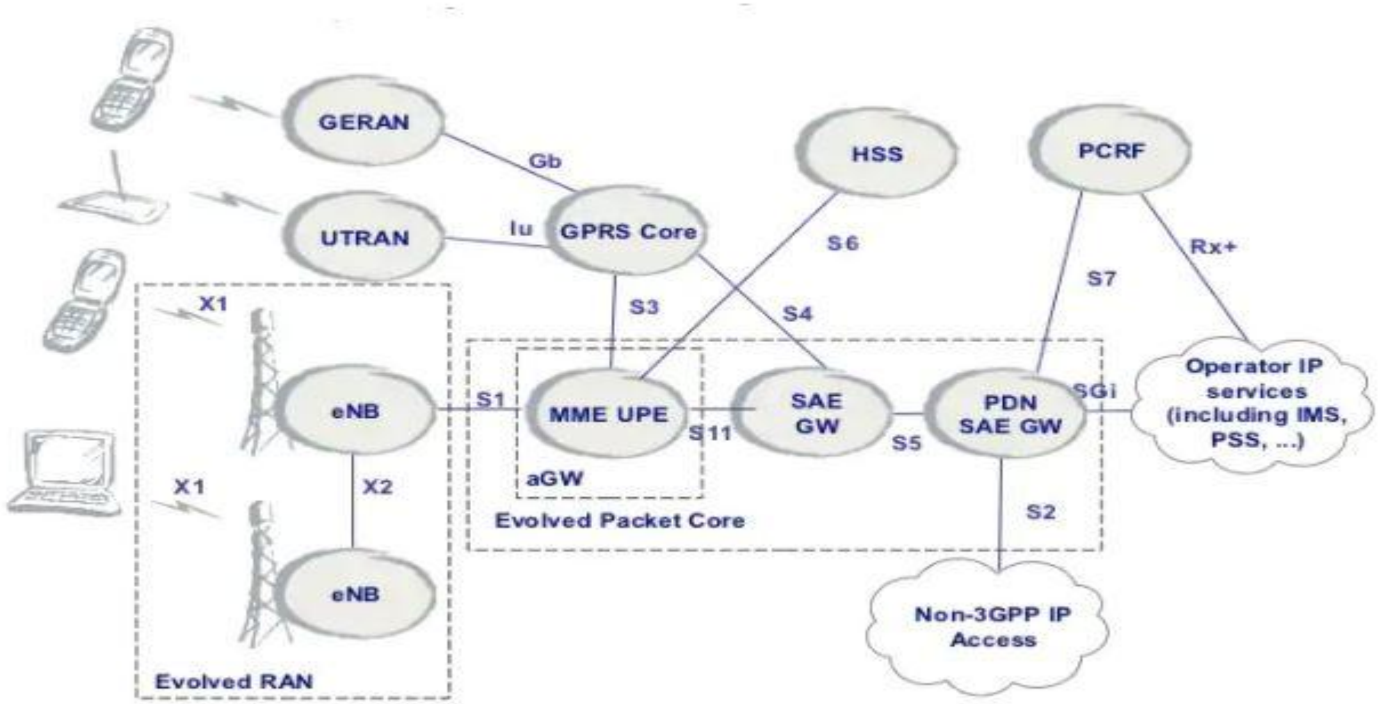
- aGW : Access Gateway
- eNB : Evolved NodeB
- EPC : Evolved Packet Core
- E-UTRAN : Evolved UTRAN
- LTE : Long Term Evolution of UTRAN
- MME : Mobility Management Entity
- OFDMA : Orthogonal Frequency Division Multiple Access
- SC-FDMA :Single Carrier Frequency Division Multiple Access.
- SAE : System Architecture Evolution
- UPE : User Plane Entity

3GPP TR 23.401/25.813



- PLMN - Public Land Mobile Network
- EPS - Evolved Packet System
- MME- Mobile Management Entity
- eNB - E UTRAN NodeB
- TAI - Tracking Area ID
- E-UTRAN - Evolved Universal Radio Access Network
- C-RNTI - Cell Radio Network Temporary Identifier.
- RA-RNTI - Random Access RNTI
- UE - User Equipment
- IMEI - International Mobile Equipment Identity
- IMSI - International Mobile Subscriber Identity
- S-TMSI - SAE Temporary Mobile Subscriber Identity

SAE ARCHITECTURE



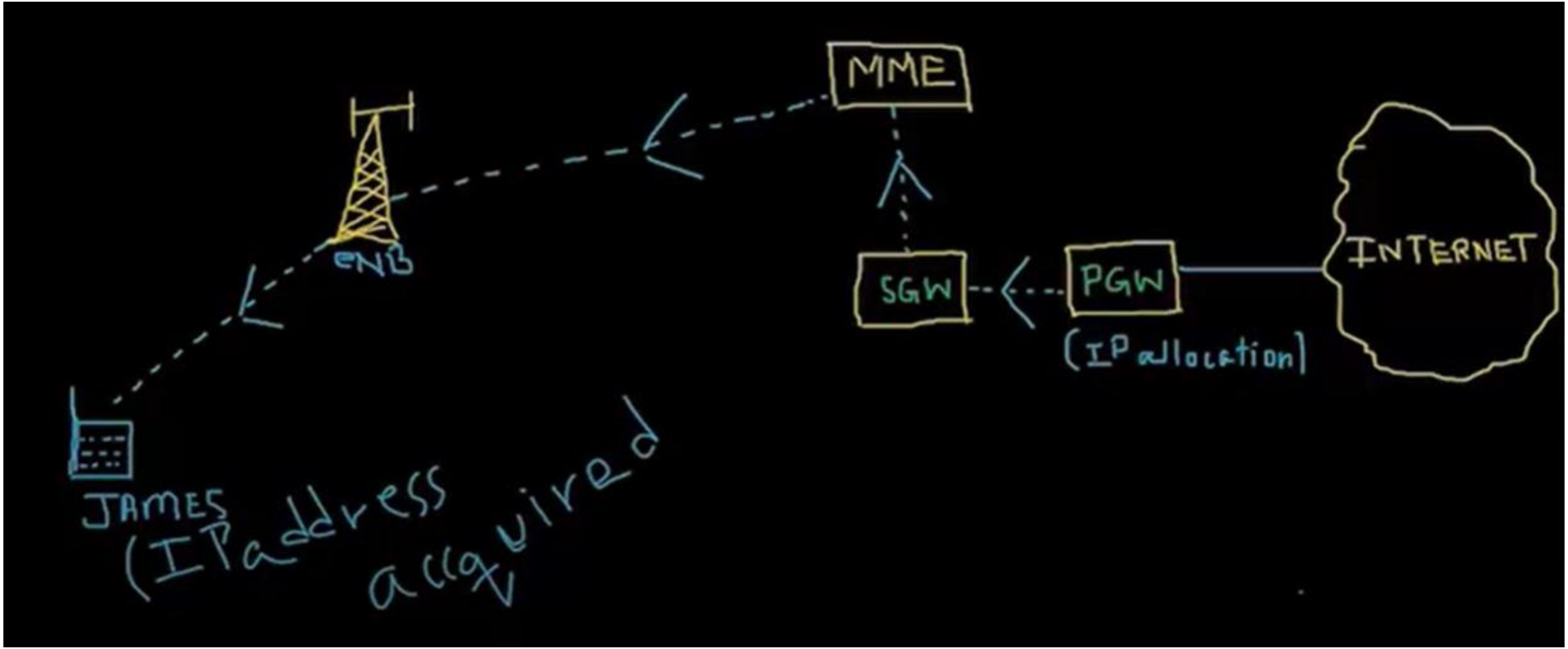
FUNCTIONS OF eNB

- Terminates RRC,RLC and MAC protocols and takes care of Radio Resource Management Functions.
    - Controls radio bearers.
    - Controls radio admissions
    - Controls mobility connections.
    - Allocates radio resources dynamically
    - Receives measurement reports from UE
- Selects MME at UE attachment
- Schedules and transmits broadcast information coming from MME
- Schedules and transmits broadcast information coming from MME & O&M
- Decides measurement reports configuration for mobility and scheduling.
- Does IP header compression and encryption of user data streams.

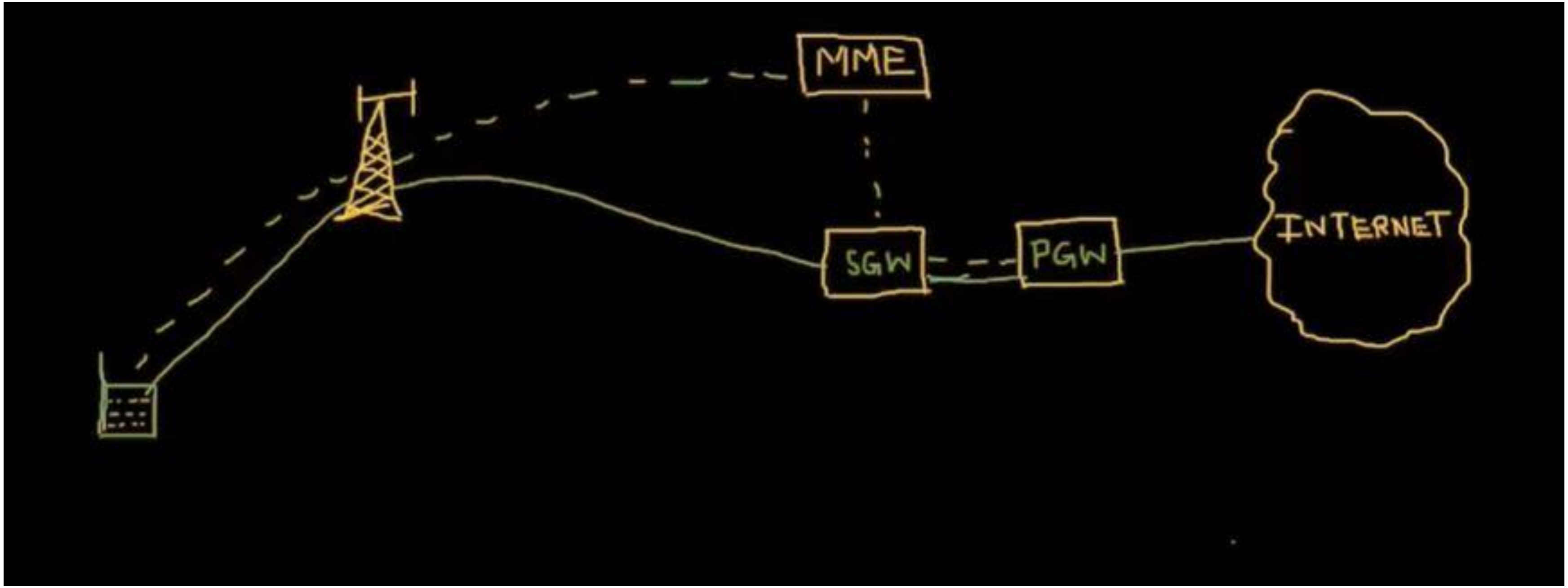
FUNCTIONS OF aGW

- Takes care of Mobility Management Entity(MME) functions
  - Manages and stores UE content
  - Generates temporary identifiers and allocates them to UEs
  - Check authorization
  - Distributes paging messages to eNBs
  - Takes care of security protocol
  - Controls idle state mobility
  - Control SAE bearers
  - Ciphers & Integrity protects NAS signaling

LTE CONTROL PLANE



LTE USER PLANE



LTE PHYSICAL LAYER

- Exchange of data & control info between eNB and UE and also transport of data to and from higher layers.
- Functions performed include error detection, FEC, MIMO antenna processing,synchronization,etc.
- It consists of Physical Signals and Physical Channels
- Physical Signals are used for system synchronisation, cell identification and channel estimation.
- Physical Channels for transporting control, scheduling and user payload from the higher layers.
- OFDMA in DL, SC-FDMA in th UL
- LTE supports FDD and TDD modes of operation.