UNIT-2
MOBILE NETWORK LAYER

Motivation for Mobile IP

Routing

- based on IP destination address,
- network prefix (e.g. 129.13.42) determines physical subnet
- change of physical subnet => change of IP address to have a topological correct address (standard IP)

Solution: Temporarily change routing table entries for mobile host

- Problem: does not scale if many mobile hosts or frequent location changes

Solution: Change mobile host IP-address

- adjust the host IP address depending on the current location
- DNS updates take to long time
- Old TCP connections break

Requirements to Mobile IP (RFC 3344, was: 3220, was: 2002)

Transparency

- mobile end-systems keep IP address
- Continuous service after link interruption
- point of connection to the fixed network can be changed

Compatibility

- No changes to current hosts, OS, routers
- mobile end-systems can communicate with fixed systems

Security

- authentication of all registration messages

Efficiency and scalability

- only few additional messages to mobile system (low bandwidth)
- Global support for large number of mobile systems

Terminology

Mobile Node (MN)

- Laptop, PDA, etc.. that may move about

Home Agent (HA)

- Router in home network of the MN, helps in forwarding
- registers current MN location, tunnels IP datagrams to COA

Foreign Agent (FA)

- Router in current foreign network of MN
- forwards tunneled datagrams to the MN

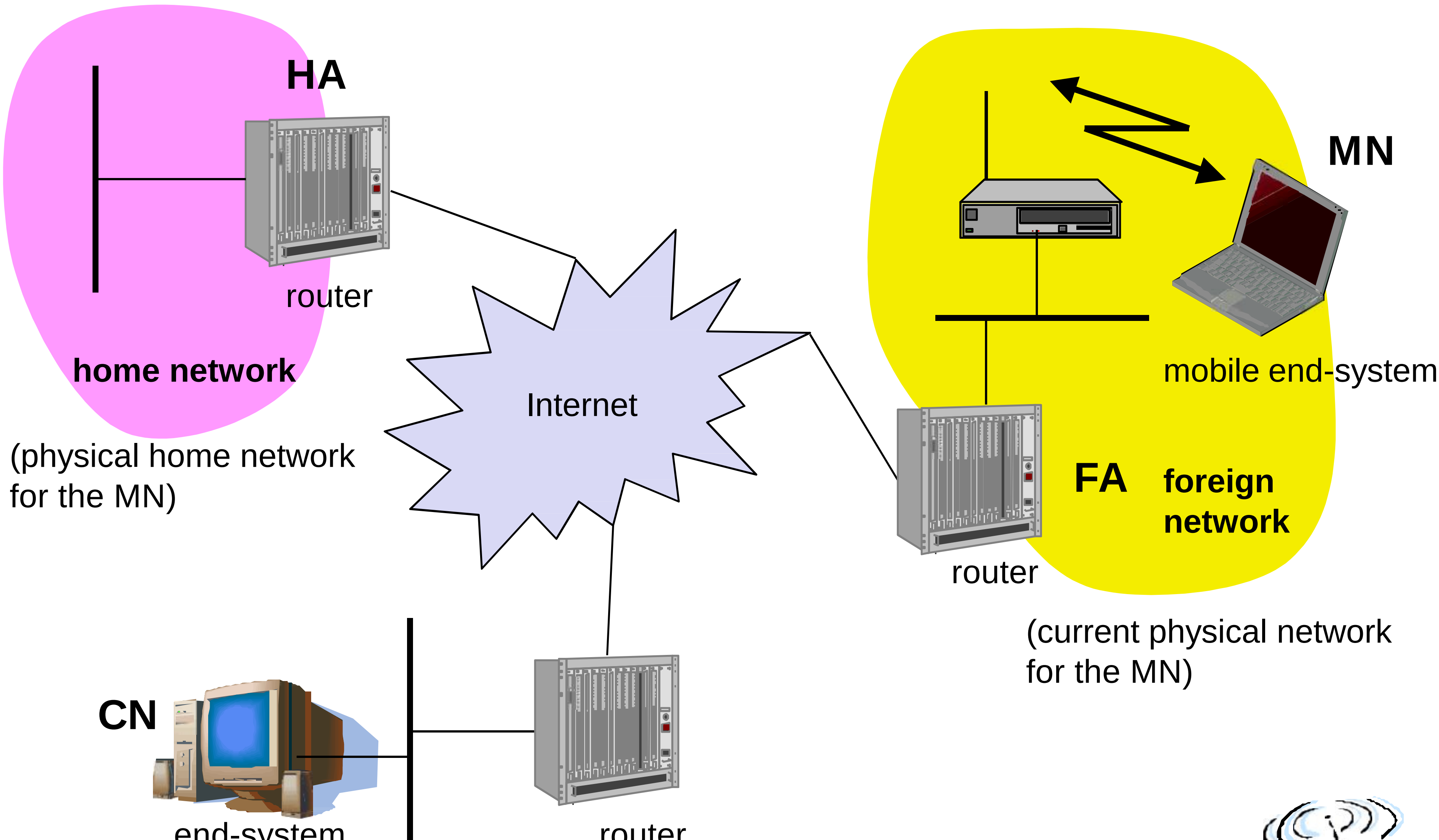
Care-of Address (COA)

- address of the current tunnel end-point for the MN (at FA or MN)
- can be chosen, e.g., via DHCP

Correspondent Node (CN)

- Node that wants to communicate with MN

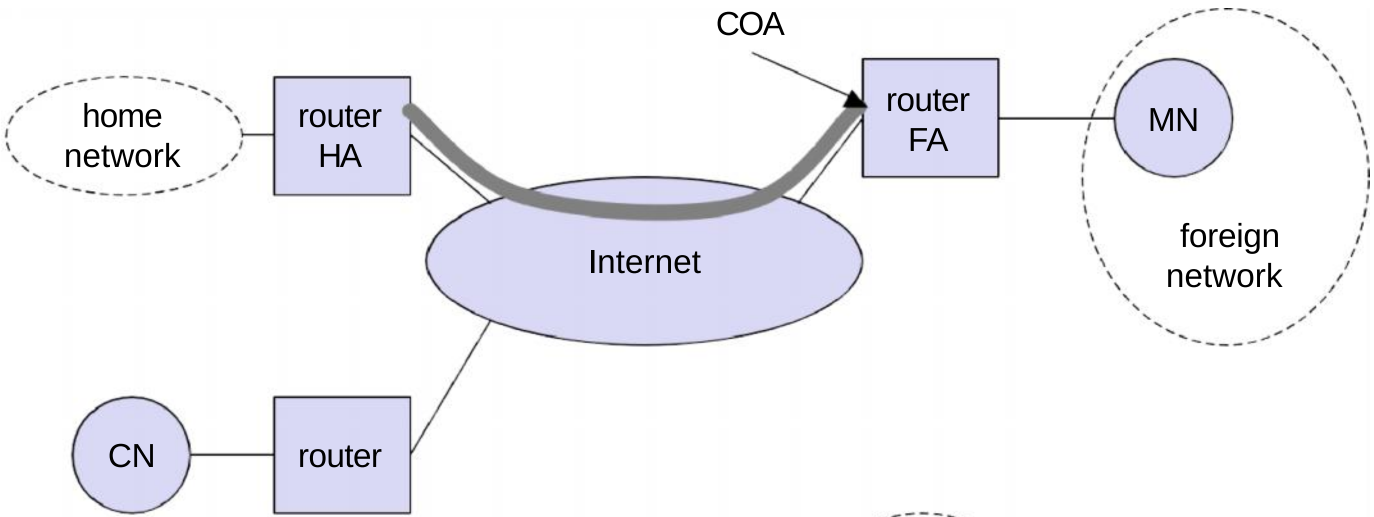
Example network

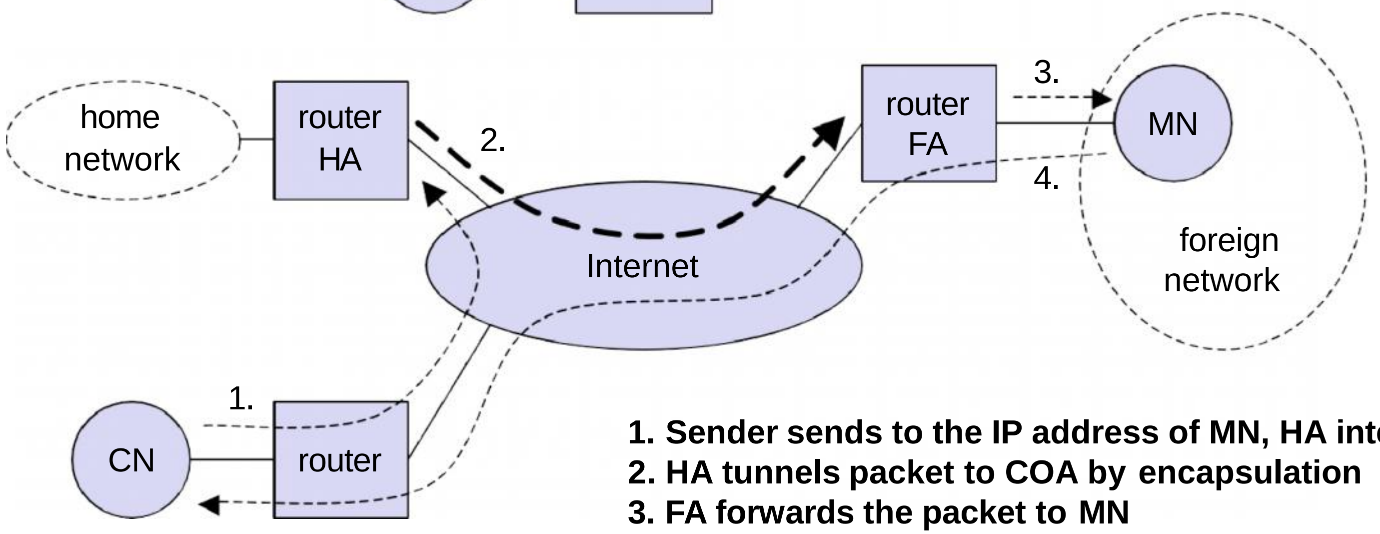


(physical home network for the MN)

(current physical network for the MN)

Overview





1. Sender sends to the IP address of MN, HA intercepts packet
2. HA tunnels packet to COA by encapsulation
3. FA forwards the packet to MN
4. Reverse: Sender sends to IP address of receiver, FA is default router

Network integration

Agent Advertisement

- HA and FA periodically send advertisement messages into their subnets
- MN reads a COA from the FA advertisement messages

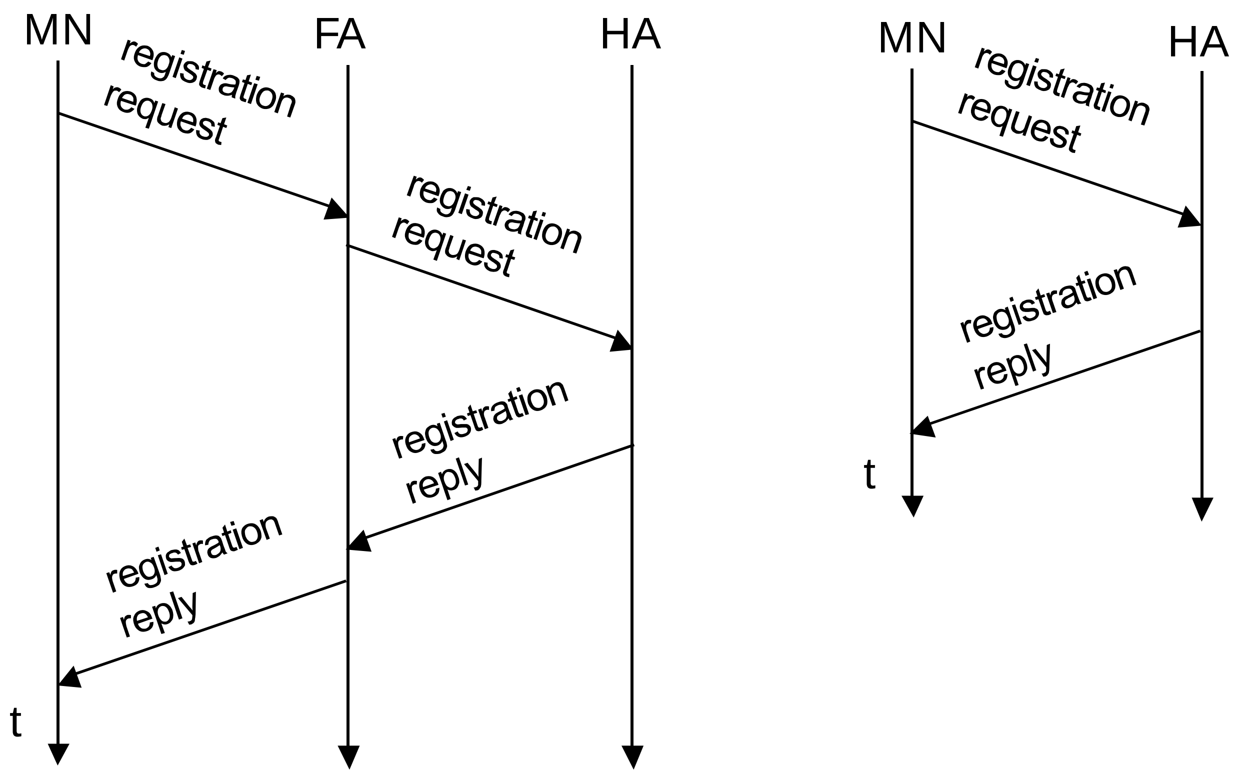
Registration (always limited lifetime!)

- MN signals COA to the HA via the FA, HA acknowledges
- Messeges need to be secured by authentication

Advertisement

- HA advertises the MN IP address (as for fixed systems)
- routers adjust their entries, (HA responsible for a long time)
- All packets to MN are sent to HA

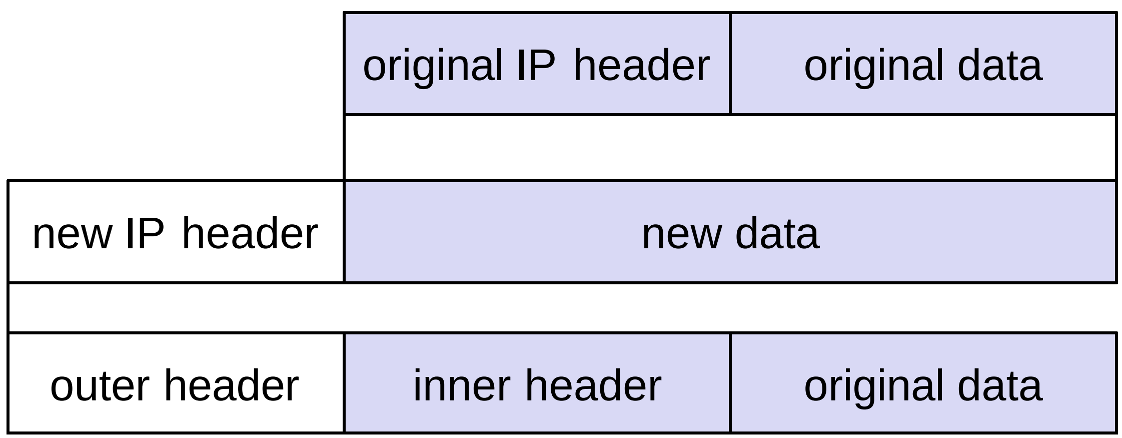
Registration



Encapsulation

Encapsulation of one packet into another as payload

- e.g. IP-in-IP-encapsulation (mandatory, RFC 2003)
- tunnel between HA and COA



Optimization of packet forwarding

Triangular Routing

- sender sends all packets via HA to MN
- Triangular routes longer, higher latency and network load

"Solutions"

- HA informs a sender about the location of MN
- sender learns current location of MN
- direct tunneling to this location
- big security problems!

Change of FA

- packets on-the-fly during the change can be lost
- new FA informs old FA to avoid packet loss
- old FA forwards remaining packets to new FA
- Update also enables old FA to release resources for MN

Mobile IP and IPv6

Mobile IP was developed for IPv4, but IPv6 simplifies the protocols

- security is integrated, not add-on, authentication of registration included
- COA can be assigned via auto-configuration (DHCPv6 is one candidate)
- every node has address autoconfiguration
- no need for a separate FA, **all** routers perform router advertisement
- MN can signal a sender directly the COA, without HA
- „soft“ hand-over, i.e. without packet loss supported
  - MN sends the new COA to its old router
  - old router encapsulates all packets for MN, forwards them to new COA
  - authentication is always granted

Problems with mobile IP

Security

- FA typically belongs to another organization
- authentication with FA problematic
- patent and export restrictions

Firewalls

- Firewalls filter based on IP addresses
- FA encapsulates packets from MN
- Home firewalls rejects packet from MN (unless reverse tunneling)
- MN can no longer send packets back to home network

QoS, etc..

Security, firewalls, QoS etc. are topics of current research and discussions!

IP Micro-mobility support

Micro-mobility support:

- Efficient local handover inside foreign domain without involving a home agent
- Reduces control traffic on backbone
- Especially needed for route optimization

Example approaches:

- Cellular IP
- HAWAII
- Hierarchical Mobile IP (HMIP)

Cellular IP

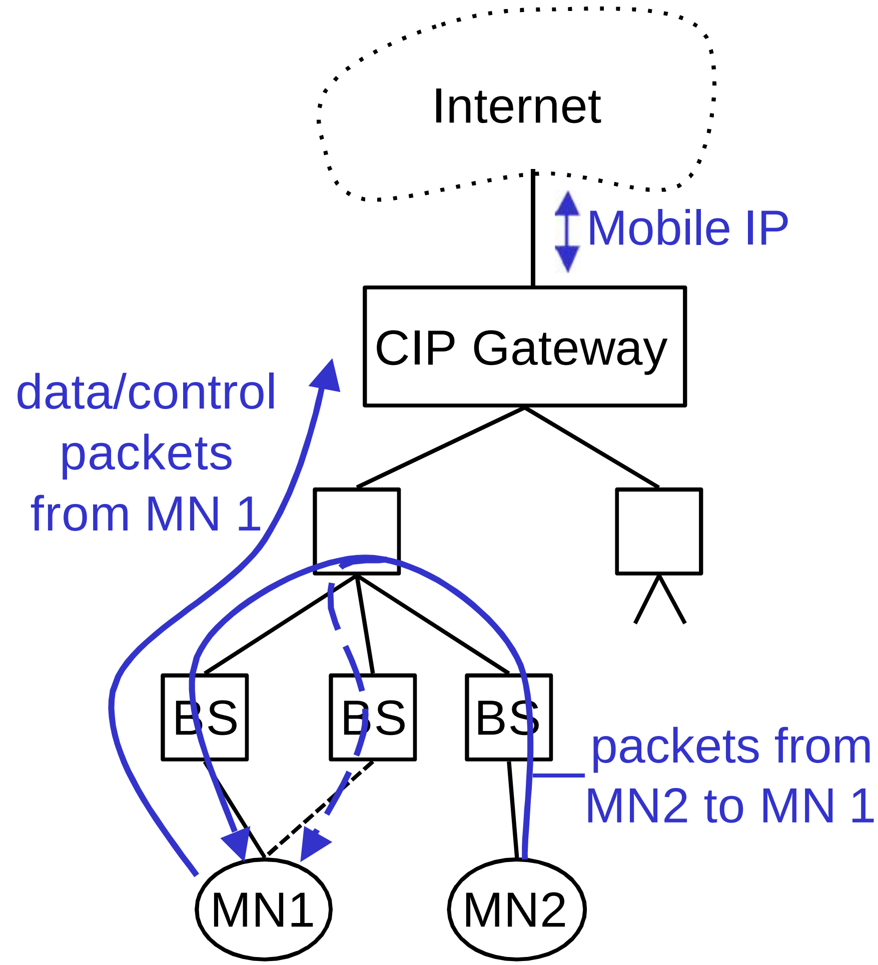
Operation:

- „CIP Nodes“ maintain routing entries (soft state) for MNs
- Multiple entries possible
- Routing entries updated based on update packets sent by MN

CIP Gateway:

- Mobile IP tunnel endpoint
- Initial registration processing

- Other micromobility protocols
  - HAWAII
  - Hierarchical Mobile IPv6 (HMIPv6)



DHCP: Dynamic Host Configuration Protocol

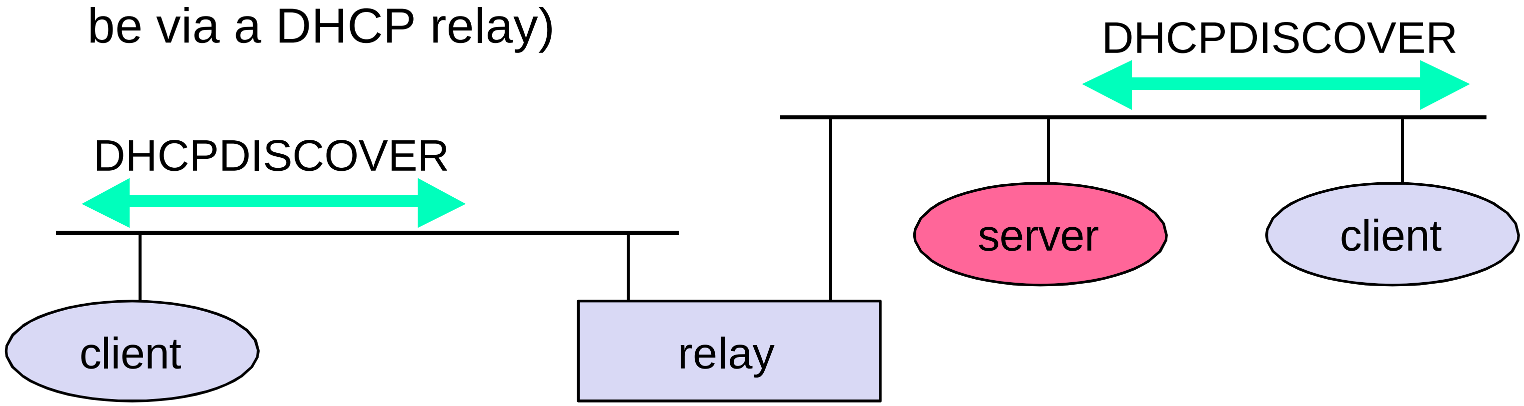
Main idea: E.g WPI has pool of IP addresses it can “lease” to hosts for short term use, claim back when done

Application

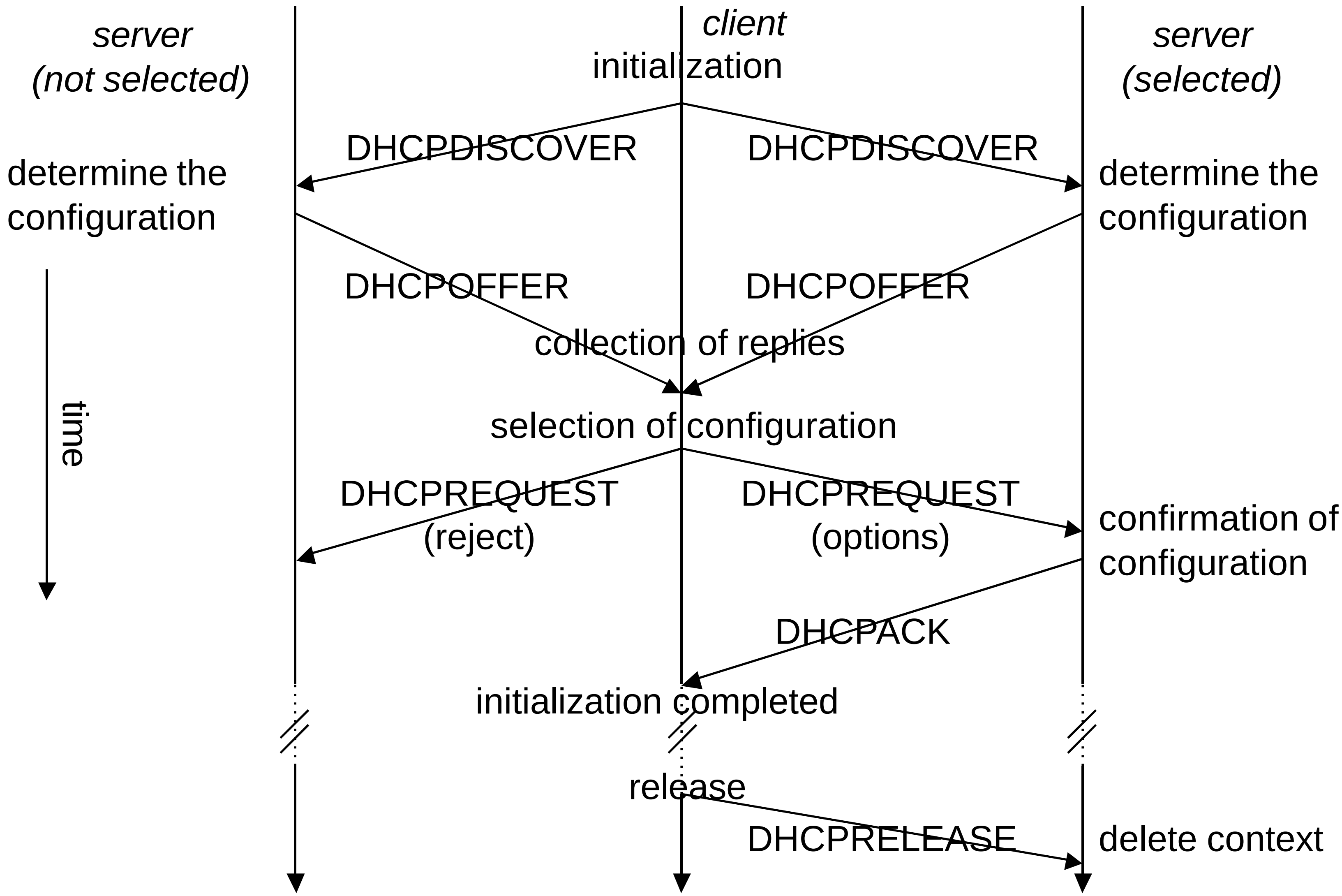
- simplification of installation and maintenance of networked computers
- supplies systems with all necessary information, such as IP address, DNS server address, domain name, subnet mask, default router etc.
- enables automatic integration of systems into an Intranet or the Internet, can be used to acquire a COA for Mobile IP

Client/Server-Model

- the client sends via a MAC broadcast a request to the DHCP server (might be via a DHCP relay)



DHCP - protocol mechanisms



DHCP characteristics

Server

- several servers can be configured for DHCP, coordination not yet standardized (i.e., manual configuration)

Renewal of configurations

- IP addresses have to be requested periodically, simplified protocol

Big security problems!

- no authentication of DHCP information specified

Mobile ad hoc networks

Standard Mobile IP needs an infrastructure

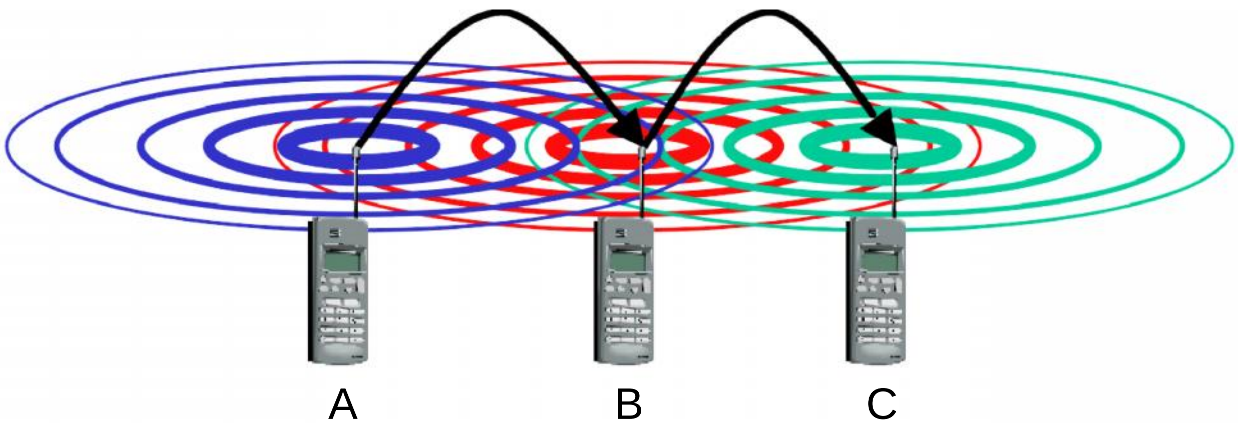
- Home Agent/Foreign Agent in the fixed network
- DNS, routing etc. not designed for mobility

Sometimes there is no infrastructure!

- remote areas, ad-hoc meetings, disaster areas
- cost can also be argument against infrastructure!

Main topic: routing

- no default router available
- every node should be able to forward



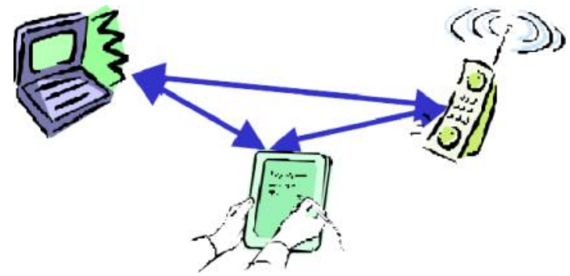
Solution: Wireless ad-hoc networks

Network without infrastructure

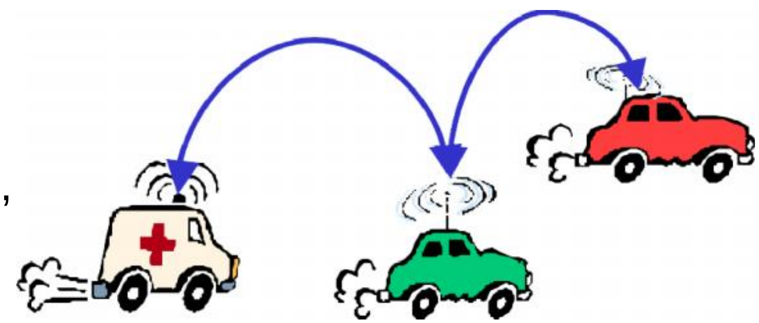
- ❑ Use components of participants for networking

Examples

- ❑ Single-hop: All partners max. one hop apart
  - Bluetooth piconet, PDAs in a room, gaming devices…

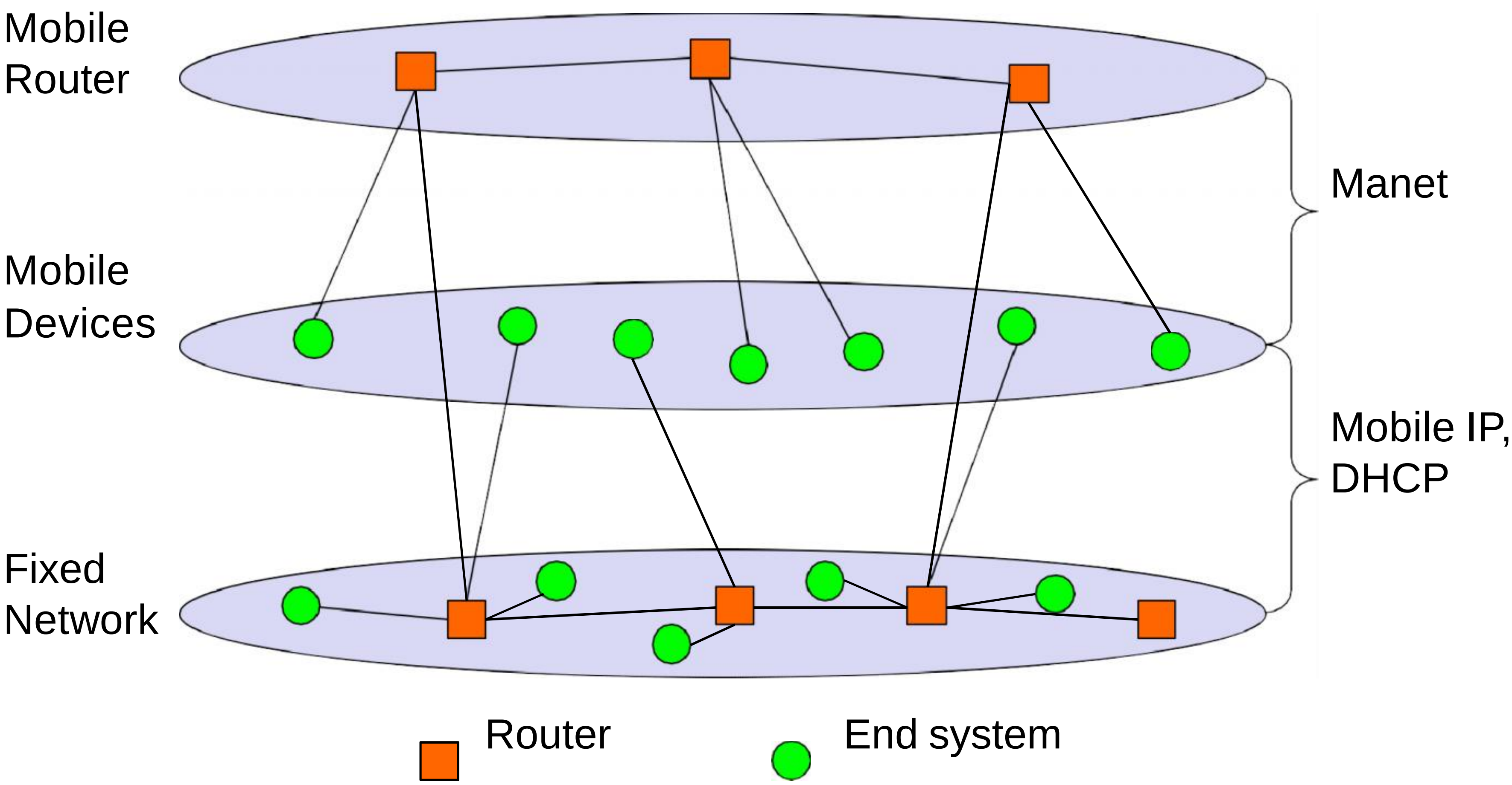


- ❑ Multi-hop: Cover larger distances, circumvent obstacles
  - Bluetooth scatternet, TETRA police network, car-to-car networks…



Internet: MANET (Mobile Ad-hoc Networking) group

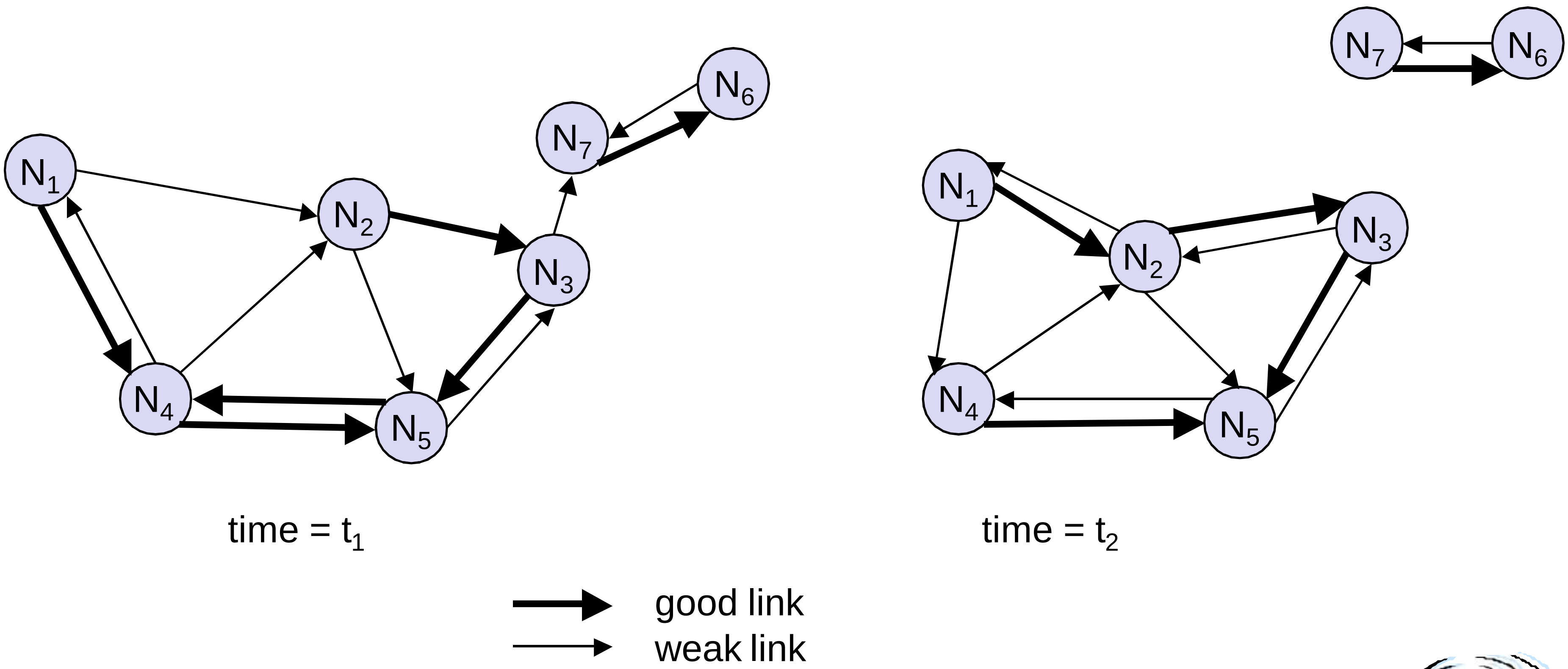
Manet: Mobile Ad-hoc Networking



Problem No. 1: Routing

Highly dynamic network topology

- Device mobility *and* varying channel quality
- Asymmetric connections possible



Traditional routing algorithms

Distance Vector

- periodic exchange of cost to everyone else, with neighbors
- selection of shortest path if several paths available

Link State

- periodic notification of all routers about the current cost to neighbors
- routers get a complete picture of the network, run Djikstra's algorithm

Example

- ARPA packet radio network (1973), DV-Routing
- every 7.5s exchange of routing tables including link quality
- Receive packets, update tables

Routing in ad-hoc networks

THE big topic in many research projects

- Far > 50 different proposals exist
- The most simplest one: Flooding!

Reasons

- Classical approaches from fixed networks fail
  - Fast link quality changes, slow convergence, large overhead
- Highly dynamic, low bandwidth, low computing power

Metrics for routing

- Minimize
  - Number of hops, loss rate, delay, congestion, interference …
- Maximal
  - Stability of logical network, battery run-time, time of connectivity …

Problems of traditional routing algorithms

Dynamic of the topology

- frequent changes of connections, connection quality, participants

Limited performance of mobile systems

- Periodic routing table updates need energy, sleep modes difficult
- limited bandwidth further reduced due to routing info exchange
- links can be asymmetric, directional transmission quality

DSDV (Destination Sequenced Distance Vector)

Early work

- on demand version: AODV

Expansion of distance vector routing

Sequence numbers for all routing updates

- assures in-order execution of all updates
- avoids loops and inconsistencies

Decrease of update frequency

- store time between first and best announcement of a path
- inhibit update if it seems to be unstable (based on the stored time values)

Dynamic source routing I

Split routing into discovering a path and maintaining a path

Discover a path

- only if a path for sending packets to a certain destination is needed and no path is currently available

Maintaining a path

- only while the path is in use one has to make sure that it can be used continuously

No periodic updates needed!

Dynamic source routing II

Path discovery

- broadcast a packet with destination address and unique ID
- if a station receives a broadcast packet
  - if receiver (i.e., has the correct destination address) then return packet to the sender (path was collected in the packet)
  - if the packet already received earlier (identified via ID) then discard the packet
  - otherwise, append own address and broadcast packet
- sender receives packet with the current path (address list)

Optimizations

- limit broadcasting if maximum diameter of the network is known
- caching of address lists (i.e. paths) received
  - stations can use the cached information for path discovery (own paths or paths for other hosts)

Dynamic Source Routing III

Maintaining paths

- after sending a packet
  - wait for a layer 2 acknowledgement (if applicable)
  - listen into the medium to detect if other stations forward the packet (if possible)
  - request an explicit acknowledgement
- if a station encounters problems it can inform the sender of a packet or look-up a new path locally

Examples for interference based routing

Routing based on assumptions about interference between signals

Examples

- Least Interference Routing (LIR)
- Max-Min Residual Capacity Routing (MMRCR)
- Least Resistance Routing (LRR)

A plethora of ad hoc routing protocols

Flat

- proactive
  - FSLS – Fuzzy Sighted Link State
  - FSR – Fisheye State Routing
  - OLSR – Optimised Link State Routing Protocol
  - TBRPF – Topology Broadcast Based on Reverse Path Forwarding
- reactive
  - **AODV** – Ad hoc On demand Distance Vector
  - DSR – Dynamic Source Routing

Hierarchical

- CGSR – Clusterhead-Gateway Switch Routing
- HSR – Hierarchical State Routing
- LANMAR – Landmark Ad Hoc Routing
- ZRP – Zone Routing Protocol

Geographic position assisted

- DREAM – Distance Routing Effect Algorithm for Mobility
- GeoCast – Geographic Addressing and Routing
- GPSR – Greedy Perimeter Stateless Routing
- LAR – Location-Aided Routing

Further difficulties and research areas

Auto-Configuration

- Assignment of addresses,

Service discovery

- Discovery of services and service providers

Multicast

- Transmission to a selected group of receivers

Quality-of-Service

- Maintenance of a certain transmission quality

Power control

- Minimizing interference, energy conservation mechanisms

Security

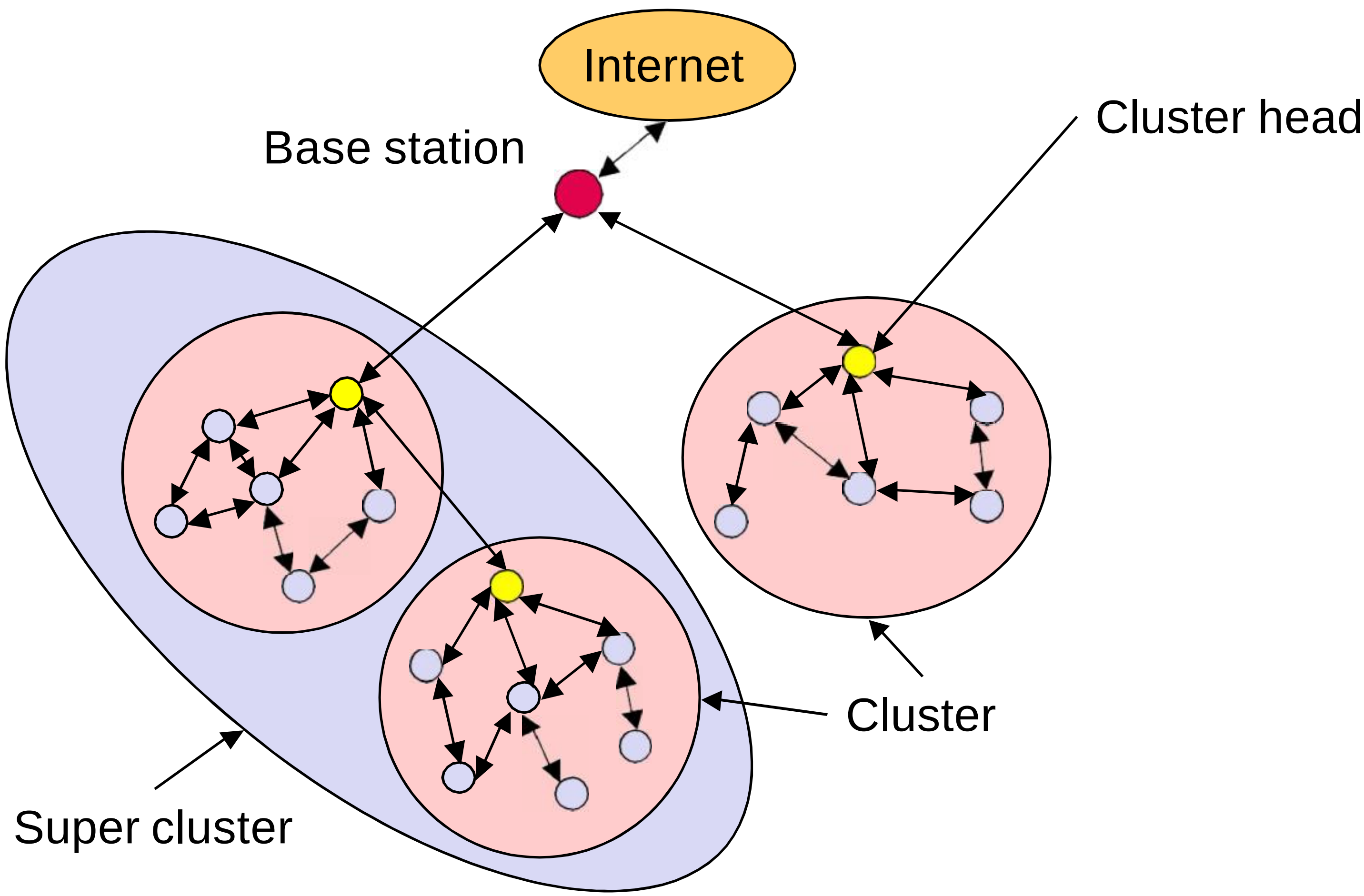
- Data integrity, protection from attacks (e.g. Denial of Service)

Scalability

- 10 nodes? 100 nodes? 1000 nodes? 10000 nodes?

Integration with fixed networks

Clustering of ad-hoc networks



The next step: Wireless Sensor Networks (WSN)

Main idea thousands of networked sensors thrown into phenomenon to be sensed

Example:

Commonalities with MANETs

- Self-organization, multi-hop
- Typically wireless, should be energy efficient

Differences from MANETs

- *Applications:* MANET more powerful, more general
  - ¶ WSN more specific
- *Devices:* MANET more powerful, higher data rates, more resources
  - ¶ WSN rather limited, embedded, interacting with environment
- *Scale:* MANET rather small (some dozen devices)
  - ¶ WSN can be large (thousands)
- *Basic paradigms:* MANET individual node important, ID centric
  - ¶ WSN network important, individual node may be dispensable, data centric
- Mobility patterns, Quality-of-Service, Energy, **Cost per node** …

UNIT-3
MOBILE TRANSPORT LAYER

Transport Layer

g.HTTP (used by web services) typically uses TCP

- Reliable transport between client and server required

TCP

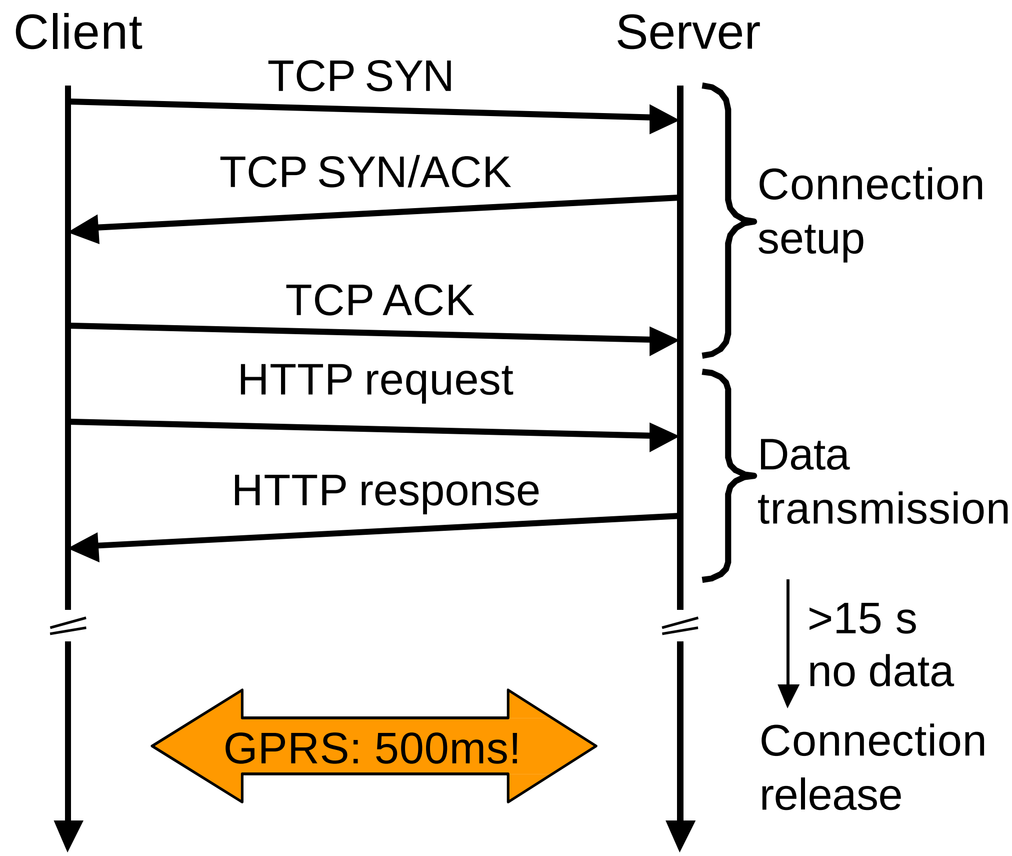
- Steam oriented, not transaction oriented
- Network friendly: time-out
  - congestion
  - slow down transmission

Well known – TCP wrongly assumes congestion in wireless and mobile networks when

- Packet losses due to transmission errors
- Packet loss due to change of network

Result

- Severe ***performance*** degradation



Motivation I

Transport protocols typically designed for

- Fixed end-systems
- Fixed, wired networks

Research activities

- How to improve TCP performance in wireless networks
- Maintain congestion control behavior
- Efficient retransmissions

TCP congestion control in fixed networks

- Timeouts/Packet loss typically due to (temporary) overload
- Routers discard packets when buffers are full
- TCP recognizes congestion only indirectly via missing ACKs, retransmissions unwise, since they increase congestion
- slow-start algorithm as reaction

Motivation II

TCP slow-start algorithm

- sender calculates a congestion window for a receiver
- start with a congestion window size equal to one segment (packet)
- Exponentially increase congestion window till congestion threshold, then linear increase
- Timeout/missing acknowledgement causes reduction of congestion threshold to half of the current congestion window
- congestion window starts again with one segment

TCP fast retransmit/fast recovery

- TCP sends an ACK only after receiving a packet
- If sender receives duplicate ACKs, this is due to gap in received packets at the receiver
- Receiver got all packets up to the gap and is actually receiving packets
- **Conclusion:** packet loss ***not*** due to congestion, retransmit, continue with current congestion window (do not use slow-start)

Influences of Wireless/mobility on TCP-mechanisms

TCP assumes congestion if packets are dropped

- typically wrong in wireless networks, here we often have packet loss due to *transmission errors*
- furthermore, *mobility* can cause packet loss, if e.g. a mobile node roams from one access point (e.g. foreign agent in Mobile IP) to another while packets in transit to the old access point and forwarding is not possible

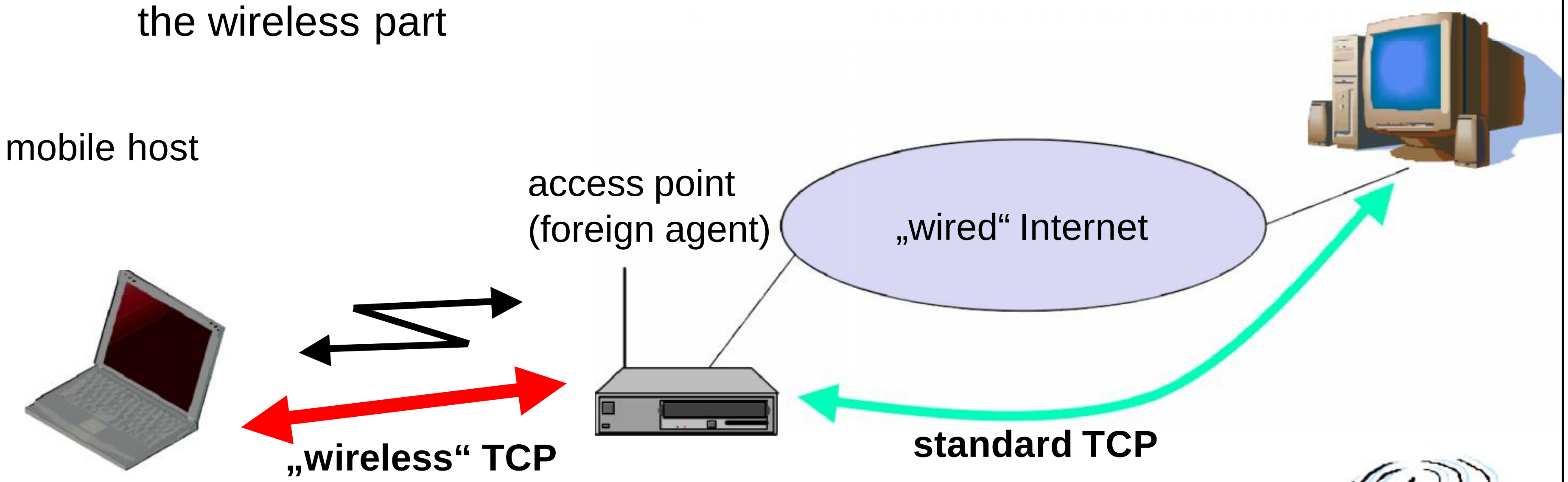
The performance of an unchanged TCP degrades severely

- TCP cannot be changed fundamentally due to large installed base in the fixed network, TCP for mobility has to remain compatible
- the basic TCP mechanisms keep the whole Internet together

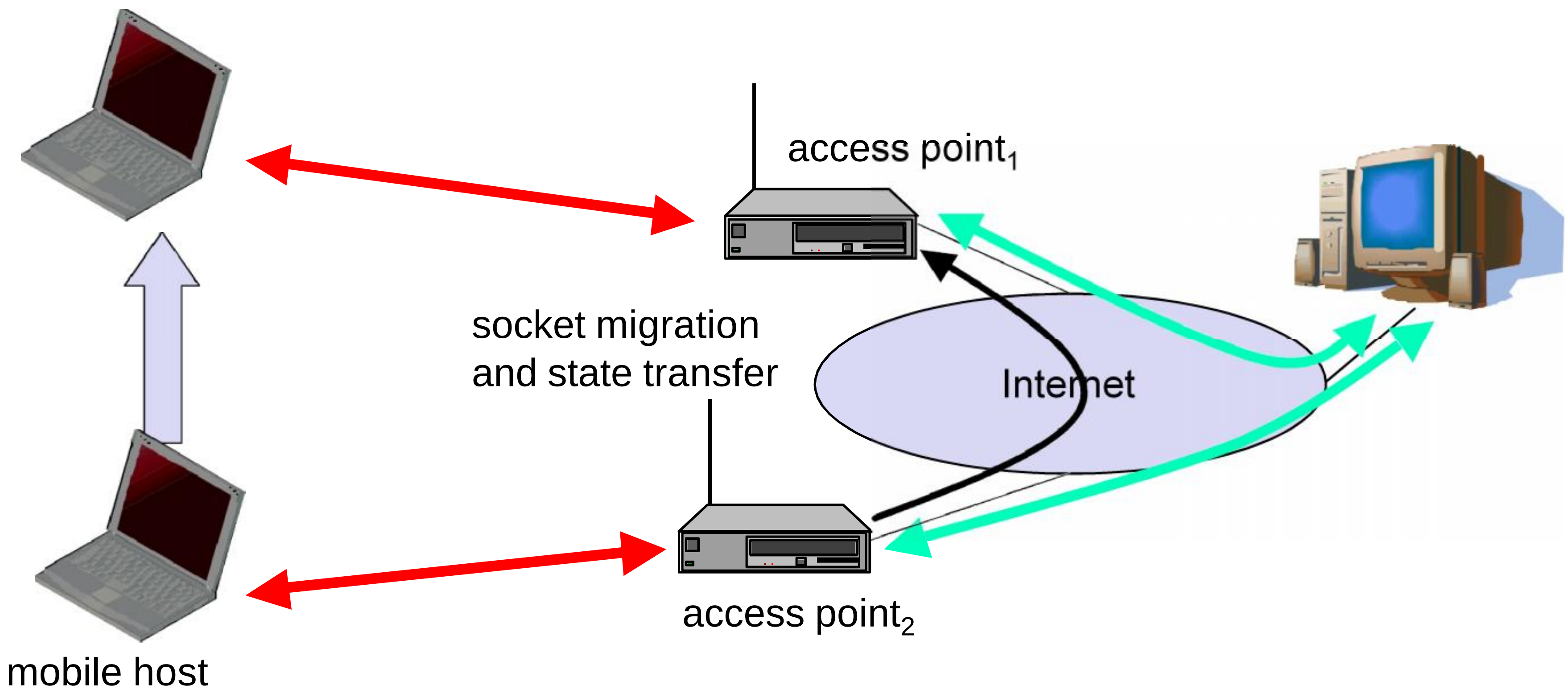
Early approach: Indirect TCP I

Indirect TCP or I-TCP segments the connection

- no changes to the TCP protocol for hosts connected to the wired Internet, millions of computers use (variants of) this protocol
- optimized TCP protocol for mobile hosts
- splitting of the TCP connection at, e.g., the foreign agent into 2 TCP connections, no real end-to-end connection any longer
- hosts in the fixed part of the net do not notice the characteristics of the wireless part



I-TCP socket and state migration



Indirect TCP II

Advantages

- No changes in the fixed network necessary, no changes for the hosts (TCP protocol) necessary, all current optimizations to TCP still work
- Wireless link transmission errors isolated from those in fixed network
- simple to control, mobile TCP is used only for one hop between, e.g., a foreign agent and mobile host
- therefore, a very fast retransmission of packets is possible, the short delay on the mobile hop is known

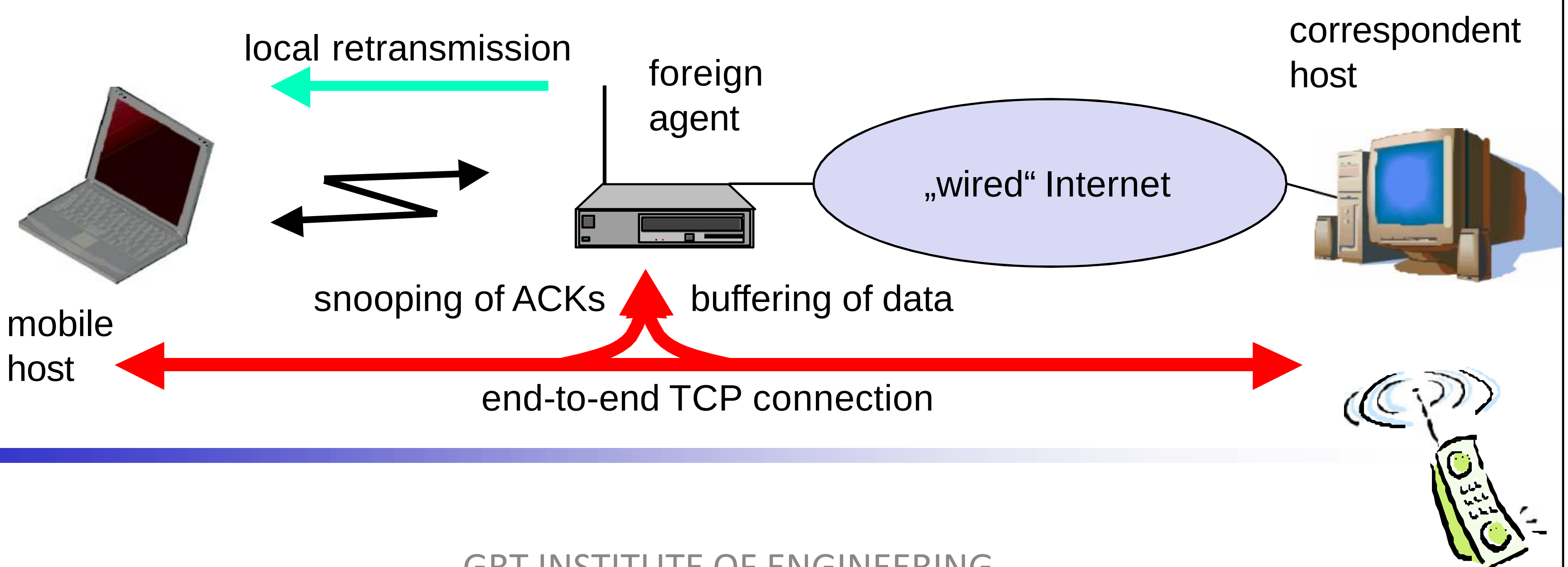
Disadvantages

- loss of end-to-end semantics, an acknowledgement to a sender does now not any longer mean that a receiver really got a packet, foreign agents might crash
- higher latency possible due to buffering of data within the foreign agent and forwarding to a new foreign agent

Early approach: Snooping TCP I

„Transparent“ extension of TCP within the foreign agent

- buffering of packets sent to the mobile host
- lost packets on the wireless link (both directions!) will be retransmitted immediately by the mobile host or foreign agent, respectively (so called “local” retransmission)
- the foreign agent therefore “snoops” the packet flow and recognizes acknowledgements in both directions, it also filters ACKs
- changes of TCP only within the foreign agent



Snooping TCP II

Data transfer to the mobile host

- FA buffers data until it receives ACK of the MH, FA detects packet loss via duplicated ACKs or time-out
- fast retransmission possible, transparent for the fixed network

Data transfer from the mobile host

- FA detects packet loss on the wireless link via sequence numbers, FA answers directly with a NACK to the MH
- MH can now retransmit data with only a very short delay

Integration with MAC layer

- MAC layer often has similar mechanisms to those of TCP
- thus, the MAC layer can already detect duplicated packets due to retransmissions and discard them

Problems

- snooping TCP does not isolate the wireless link as good as I-TCP
- snooping might be tough if packets are encrypted

Early approach: Mobile TCP

Special handling of lengthy and/or frequent disconnections

M-TCP splits as I-TCP does

- unmodified TCP fixed network to supervisory host (SH)
- optimized TCP SH to MH

Supervisory host

- no caching, no retransmission
- monitors all packets, if disconnection detected
  - set sender window size to 0
  - sender automatically goes into persistent mode
- old or new SH reopen the window

Advantages

- maintains semantics, supports disconnection, no buffer forwarding

Disadvantages

- loss on wireless link propagated into fixed network
- adapted TCP on wireless link

Fast retransmit/fast recovery

Change of foreign agent often results in packet loss

- TCP reacts with slow-start although there is no congestion

Forced fast retransmit

- as soon as the mobile host has registered with a new foreign agent, the MH sends duplicated acknowledgements on purpose
- this forces the fast retransmit mode at the communication partners
- additionally, the TCP on the MH is forced to continue sending with the actual window size and not to go into slow-start after registration

Advantage

- simple changes result in significant higher performance

Disadvantage

- Cooperation required between IP and TCP, no transparent approach

Transmission/time-out freezing

Mobile hosts can be disconnected for a longer time

- no packet exchange possible, e.g., in a tunnel, disconnection due to overloaded cells or mux. with higher priority traffic
- TCP disconnects after time-out completely

TCP freezing

- MAC layer is often able to detect interruption in advance
- MAC can inform TCP layer of upcoming loss of connection
- TCP stops sending, but does now not assume a congested link
- MAC layer signals again if reconnected

Advantage

- scheme is independent of data

Disadvantage

- TCP on mobile host has to be changed, mechanism depends on MAC layer

Selective retransmission

TCP acknowledgements are often cumulative

- ACK n acknowledges correct and in-sequence receipt of packets up to n
- if single packets are missing quite often a whole packet sequence beginning at the gap has to be retransmitted (go-back-n), thus wasting bandwidth

Selective retransmission as one solution

- RFC2018 allows for acknowledgements of single packets, not only acknowledgements of in-sequence packet streams without gaps
- sender can now retransmit only the missing packets

Advantage

- much higher efficiency

Disadvantage

- more complex software in a receiver, more buffer needed at the receiver

Transaction oriented TCP

TCP phases

- connection setup, data transmission, connection release
- using 3-way-handshake needs 3 packets for setup and release, respectively
- thus, even short messages need a minimum of 7 packets!

Transaction oriented TCP

- RFC1644, T-TCP, describes a TCP version to avoid this overhead
- connection setup, data transfer and connection release can be combined
- thus, only 2 or 3 packets are needed

Advantage

- efficiency

Disadvantage

- requires changed TCP
- mobility not longer transparent

Comparison of different approaches for a "mobile" TCP

Approach	Mechanism	Advantages	Disadvantages
Indirect TCP	splits TCP connection into two connections	isolation of wireless link, simple	loss of TCP semantics, higher latency at handover
Snooping TCP	"snoops" data and acknowledgements, local retransmission	transparent for end-to-end connection, MAC integration possible	problematic with encryption, bad isolation of wireless link
M-TCP	splits TCP connection, chokes sender via window size	Maintains end-to-end semantics, handles long term and frequent disconnections	Bad isolation of wireless link, processing overhead due to bandwidth management
Fast retransmit/ fast recovery	avoids slow-start after roaming	simple and efficient	mixed layers, not transparent
Transmission/ time-out freezing	freezes TCP state at disconnect, resumes after reconnection	independent of content or encryption, works for longer interrupts	changes in TCP required, MAC dependant
Selective retransmission	retransmit only lost data	very efficient	slightly more complex receiver software, more buffer needed
Transaction oriented TCP	combine connection setup/release and data transmission	Efficient for certain applications	changes in TCP required, not transparent

TCP Improvements I

$$BW \leq \frac{0.93 * MSS}{RTT * \sqrt{p}}$$

- max. TCP **B**and**W**idth
- **M**ax. **S**egment **S**ize
- **R**ound **T**rip **T**ime
- loss **p**robability

Initial research work

- ❑ Indirect TCP, Snoop TCP, M-TCP, T/TCP, SACK, Transmission/time-out freezing, …

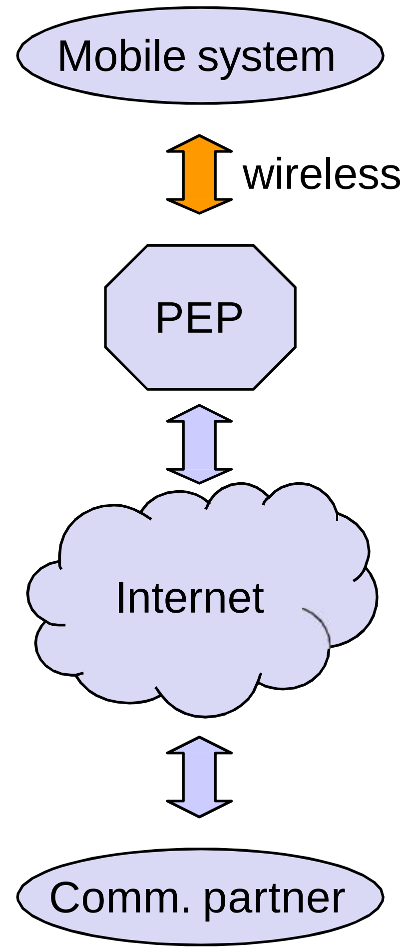
TCP over 2.5/3G wireless networks

- ❑ Fine tuning today's TCP
- ❑ Learn to live with
  - Data rates: 64 kbit/s up, 115-384 kbit/s down; asymmetry: 3-6, but also up to 1000 (broadcast systems), periodic allocation/release of channels
  - High latency, high jitter, packet loss
- ❑ Suggestions
  - Large (initial) sending windows, large maximum transfer unit, selective acknowledgement, explicit congestion notification, time stamp, no header compression
- ❑ Already in use
  - i-mode running over FOMA
  - WAP 2.0 ("TCP with wireless profile")

TCP Improvements II

Performance enhancing proxies (PEP, RFC 3135)

- Transport layer
  - Local retransmissions and acknowledgements
- Additionally on the application layer
  - Content filtering, compression, picture downscaling
  - E.g., Internet/WAP gateways
  - Web service gateways?
- Big problem: breaks end-to-end semantics
  - Disables use of IP security
  - Choose between PEP and security!



More open issues

- RFC 3150 (slow links)
  - Recommends header compression, no timestamp
- RFC 3155 (links with errors)
  - States that explicit congestion notification cannot be used
- In contrast to 2.5G/3G recommendations!

Wide Area Network Technology

- WAN technologies can be traced back to the early days of mainframe computer systems
- WANs give companies the ability to leverage information technology across wide geographic areas
- WANs can be classified in one of the following three ways:
  - Circuit switching involves creating a circuit between two points when needed
  - Packet switching uses virtual circuits for data delivery
  - Cell switching uses virtual circuits but the cells do not vary in size

- Integrated Services Digital Network (ISDN) is a circuit-switching technology similar in function to public switched telephone network (PSTN)
- When using ISDN, you dial a number just as with PSTN but the signal is digital instead of analog

WWAN NETWORK CATEGORY

- **VOICE**- Imitate PSTN

- **DATA**- Data are packetized and send independently over separate path in communication channel. used in world wide wired network(internet)

- **COMBINED NETWORKS-**WAN recognize data and voice transmission so separate protocol have been created that run over same network.

UMTS TERRSTRIAL RADIO ACCESS NETWORK OVERVIEW

- Compared to GSM network architecture radio access network of UMTS is called UTRAN(Universal Terrestrial Radio Access Network) constitute main innovation, and allow data and signaling traffic exchange between UE(USER EQUIPMENT) and core network(CN).
- It handles the allocation and withdraw of radio bearers required for the traffic support on the radio interface and controls some functions related to UE mobility and network access.
- UTRAN is a collective term of the network and equipment that coonects mobile handsets to the PSTN or internet.
- UMTS introduces Node Bs as base stations (BTSs in GSM) and radio network controllers (RNCs) as BSCs in GSM.
- This communication network commonly referred to as 3G and can carry many traffic types from real time circuit switched(CS) to IP based packet switched(PS).

- UTRAN allow connectivity between UE and CN.

Specification of 4 new interfaces:

- The interface between UE and UTRAN is referred to as Uu.
- The interface between UTRAN and a Node B is Iub.
- Similar to GSM and GPRS, MSCs and SGSNs control RNCs through the Iu interface.
- In particular, an MSC connects to an RNC through an Iu – CS (circuit-switching) interface, whereas an
- SGSN connects to an RNC through an Iu – PS (packet-switching) interface.
- Iur → RNC<-> RNC
- Iub → Node b<-> RNC

- Use of CDMA access mode: support microdiversity procedure
- Use of asynchronous transfer mode (ATM): for transport layer of “Iu”, ”Iub”, ”Iur” interface
- Handling of the mobility in the UTRAN :handles mobility at CN and URA (UTRAN registration area) level independently from mobility management handled by CN.

UTRAN ARCHITECTURE

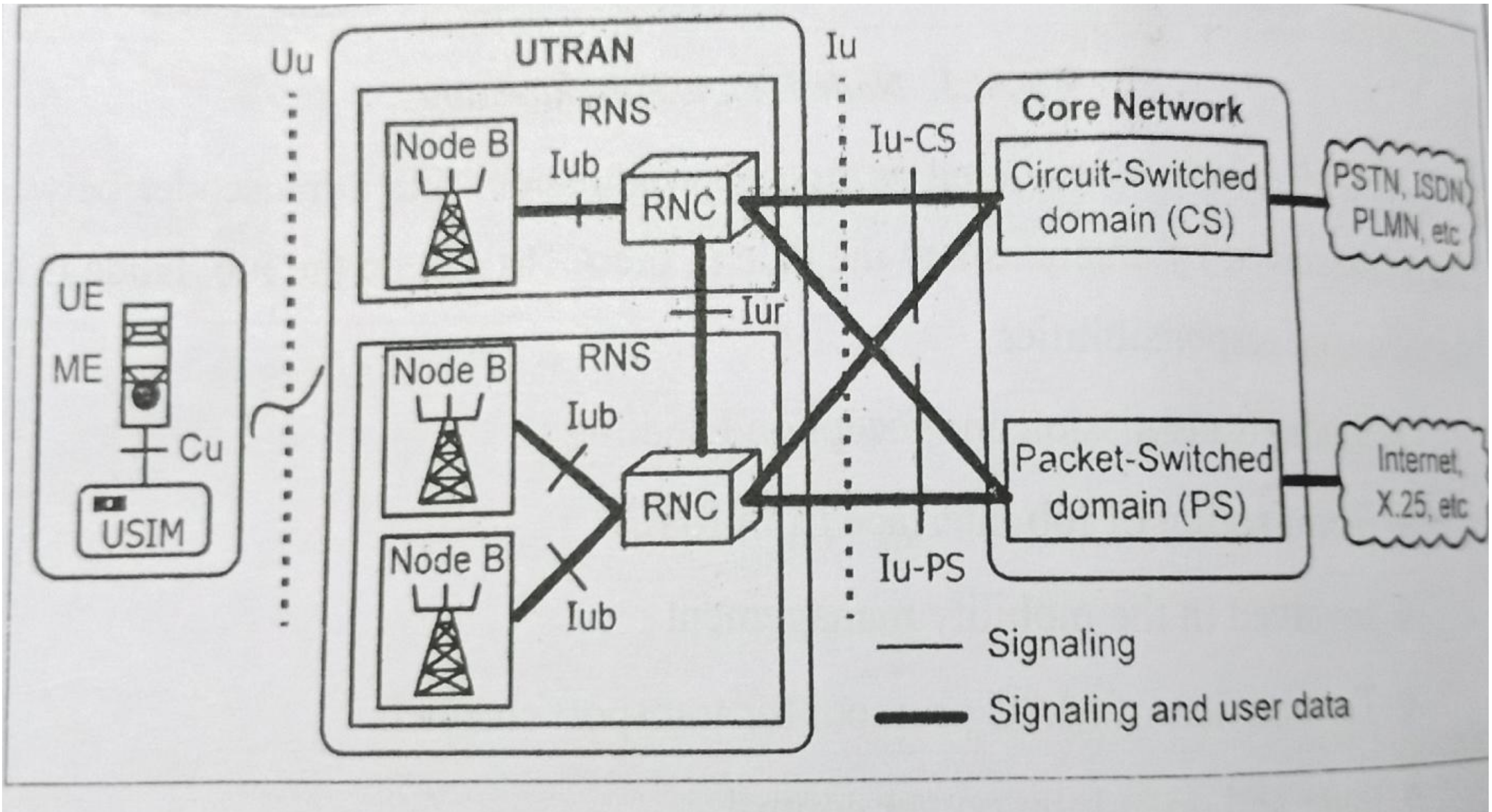


Fig. 4.1. UTRAN detailed architecture

UTRAN architecture can be divided into three main elements:

- User terminal(UE)
- Radio network subsystem
- core network

- **User Equipment (UE)**
  - interfaces with user and radio interface
- **Radio Access Network (RAN, UMTS Terrestrial RAN = UTRAN)**
  - handles all radio-related functionality
- **Core Network**
  - switches and routes calls and data connections to external networks
- UE consists of two parts
  - **Mobile Equipment (ME)**
    - the radio terminal used for radio communication over Uu interface
  - **UMTS Subscriber Identity Module (USIM)**
    - a smartcard that holds the subscriber identity
    - performs authentication algorithms
    - stores authentication and encryption keys
    - some subscription information that is needed at the terminal

RNS

- The UTRAN consists of a set of radio network subsystems (RNSs)
- The RNS has two main logical elements: Node B and an RNC. The RNS is responsible for the radio resources and transmission/reception in a set of cells.
- A cell (sector) is one coverage area served by a broadcast channel.

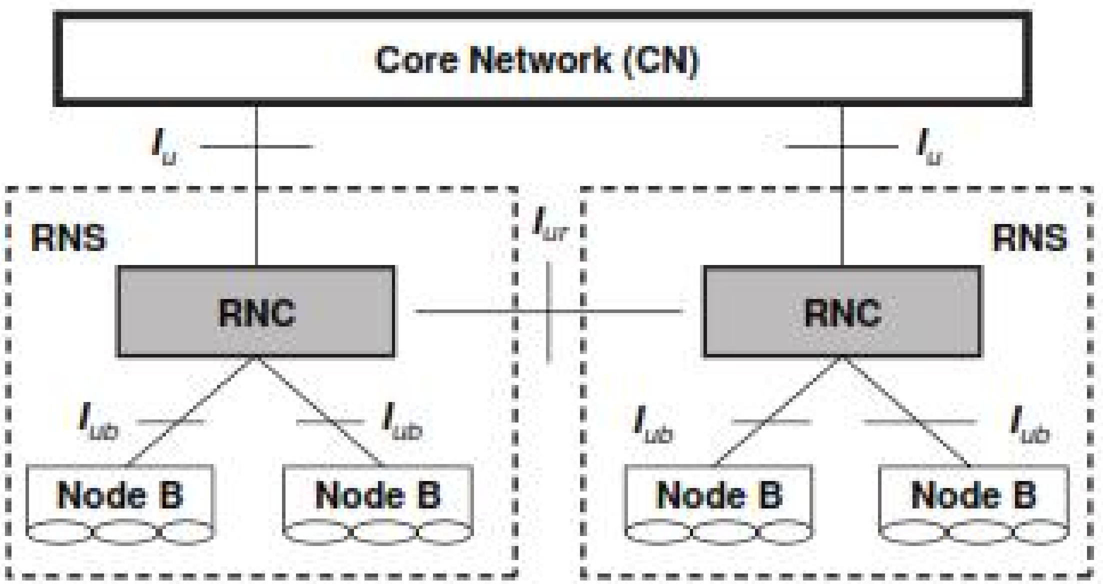
RNC

- An RNC is responsible for the use and allocation of all the radio resources of the RNS to which it belongs.
- The RNC also handles the user voice and packet data traffic, performing the actions on the user data streams that are necessary to access the radio bearers.

- The responsibilities of an RNC are:
  - Intra UTRAN handover
  - Macro diversity combining/splitting of *Iub* data streams
  - Frame synchronization
  - Radio resource management
  - Outer loop power control
  - *Iu* interface user plane setup
  - Serving RNS (SRNS) relocation
  - Radio resource allocation (allocation of codes, etc.)
  - Frame selection/distribution function necessary for soft handover (functions
  - of UMTS radio interface physical layer)
  - UMTS radio link control (RLC) sublayers function execution
  - Termination of MAC, RLC, and RRC protocols for transport channels,
  - i.e., DCH, DSCH, RACH, FACH
  - *Iub*'s user plane protocols termination

NODE B

- A Node B is responsible for radio transmission and reception in one or more cells to/from the user equipment (UE).
- The logical architecture for Node B is shown
- converts data flow between Iub and Uu interfaces
- participates in radio resource management



RNC: Radio Network Controller
RNS: Radio Network Subsystem

The following are the responsibilities of the Node B:

- Termination of *Iub* interface from RNC
- Termination of MAC protocol for transport channels RACH, FACH
- Termination of MAC, RLC, and RRC protocols for transport channels: BCH, PCH
- Radio environment survey (BER estimate, receiving signal strength, etc.)
- Inner loop power control ,Open loop power control
- Radio channel coding/decoding
- Macro diversity combining/splitting of data streams from its cells (sectors)
- Termination of *Uu* interface from UE
- Error detection on transport channels and indication to higher layers
- FEC encoding/decoding and interleaving/deinterleaving of transport channels
- Multiplexing of transport channels and demultiplexing of coded composite transport channels
- Power weighting and combining of physical channels
- Modulation and spreading/demodulation and despreading of physical
- channels
- Frequency and time (chip, bit, slot, frame) synchronization
- RF processing

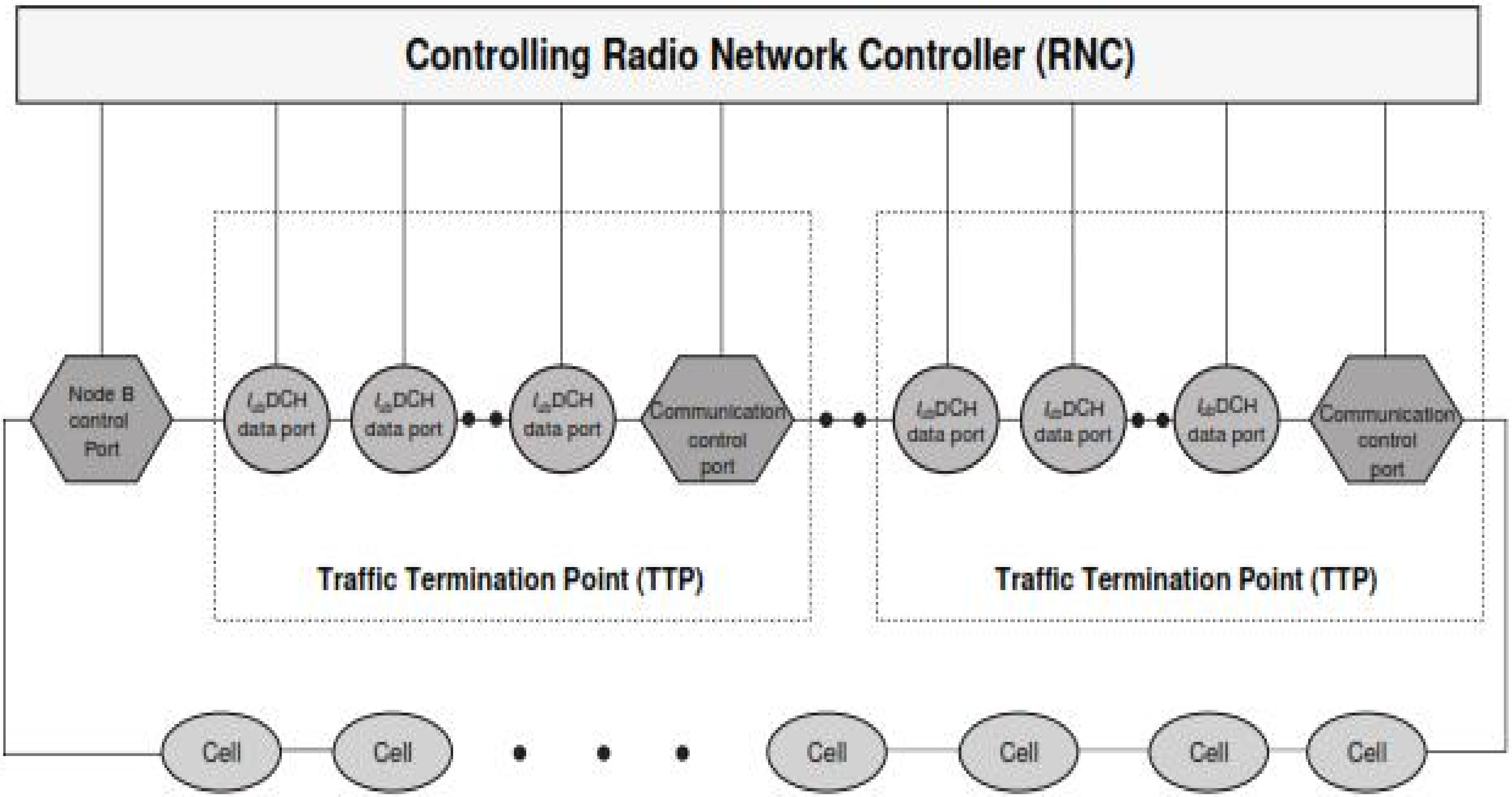


Figure 15.22 Node B logical architecture.

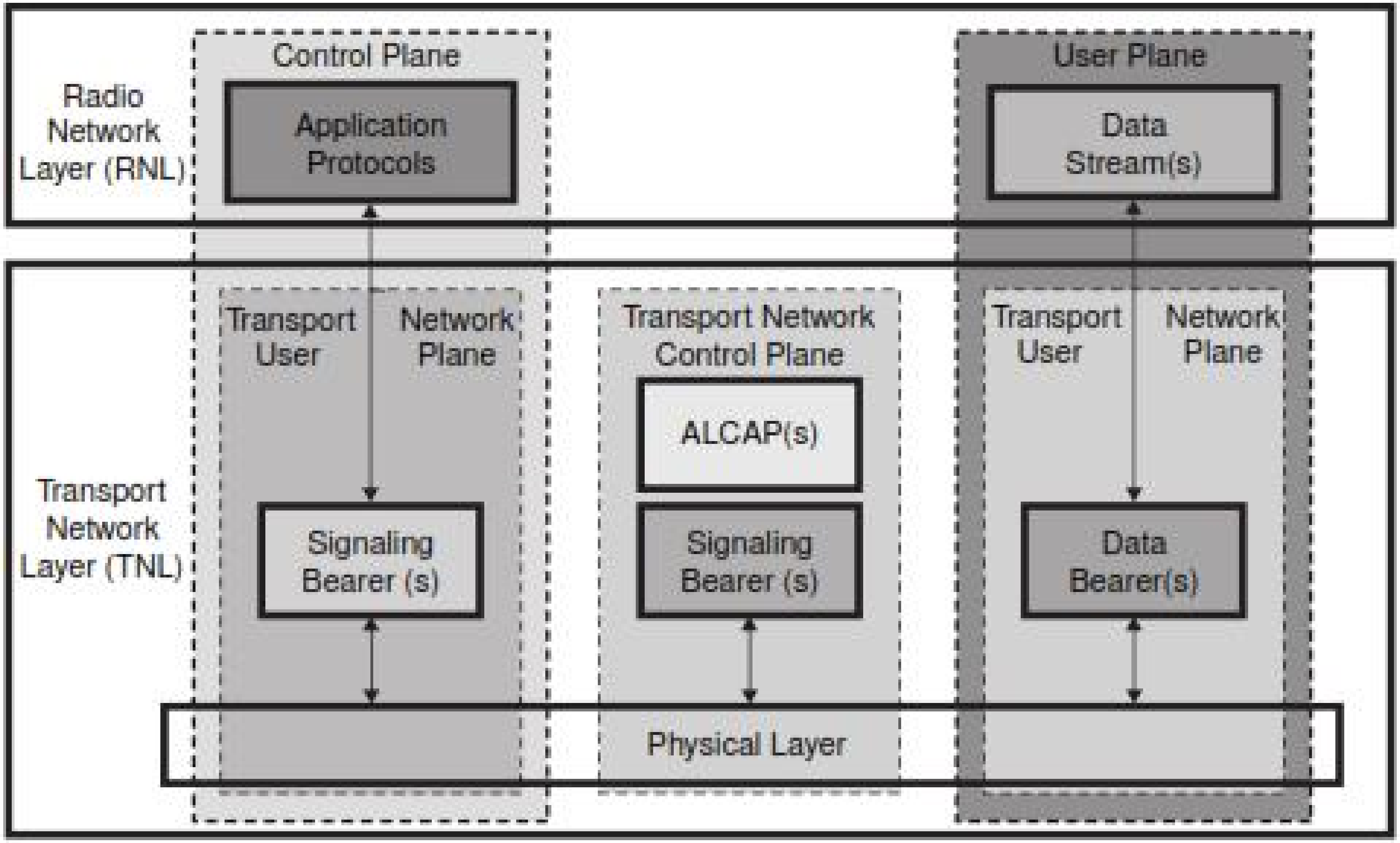
UTRAN Interfaces

There are four interfaces connecting the UTRAN internally or externally to other functional entities. Such interfaces are **Iu, Uu, Iub** and **Iur.**

- The **Iu** interface is an external interface that connects the RNC to the Core Network (CN).
- The **Uu** is also external, connecting the node B with the user equipment (UE).
- The **Iub** is an internal interface connecting the RNC with the node B.
- The **Iur** interface which is an internal interface must of the time, but can, exceptionally be an external interface too for some network architectures. The **Iur** connects two RNCs with each other.

UTRAN Logical Interfaces

- A general protocol model for UTRAN interfaces is shown
- The protocol structure contains two main layers,
  - The radio network layer(RNL)
  - The transport network layer (TNL).
- In the RNL, all UTRAN-related functions are visible, whereas the TNL deals with transport technology selected to be used for UTRAN but without any UTRAN-specific changes.
- RNL is concerned with user data and information.
- Both layers are independent of each other. It make it possible to change transport layer without affecting radio network layer, if required.



ALCAP: Access Link Control Application Part

Figure 15.23 General protocol model for UTRAN interfaces.

- The **control plane** is used for all UMTS-specific control signaling.
- It includes the application protocol (i.e., radio access network application part (RANAP) in *Iu*, radio network subsystem application part (RNSAP) *in Iur*) and node B application part (NBAP) in*Iub*
- The application protocol is used for setting up bearers to the UE.
- In the three-plane structure the bearer parameters in the application protocol are not directly related to the **user plane technology**, but rather they are general bearer parameters.
- User information is carried by the user plane. The user plane includes data stream(s), and data bearer(s) for data stream(s).
- Each data stream is characterized by one or more frame protocols specified for that interface.

- The **transport network control plane** carries all control signaling within the transport layer.
- It does not include radio network layer information.
- It contains ***access link control application part (ALCAP)*** required to set up the transport bearers (data bearers) for the user plane.
- It also includes the signaling bearer needed for the ALCAP.
- The transport plane lies between the control plane and the user plane.
- The addition of the transport plane in UTRAN allows the application protocol in the radio network control plane to be totally independent of the technology selected for the data bearer in the user plane.

- **Transport network user plane**

Transport network user plane contains 2 kind of information.

  - Data Bearers In User Plane
  - Signaling Bearer For Application Protocol.

Iu Interface

- The UMTS *Iu* interface is the open logical interface that interconnects one UTRAN to the UMTS core network (UCN).
- On the UTRAN side the *Iu* interface is terminated at the RNC, and at the UCN side it is terminated at U-MSC.
- The *Iu* interface consists of three different protocol planes — the *radio network control plane (RNCP), the transport network control plane (TNCP), and the user plane (UP).*

The RNCP performs the following functions:

- It carries information for the general control of UTRAN radio network
- operations.
- It carries information for control of UTRAN in the context of each specific
- call.
- It carries user call control (CC) and mobility management (MM) signaling
- messages.

- The control plane serves two service domains in the core network, the
  - packet-switched (PS) domain
  - circuit-switched (CS) domain.

Circuit-switched (CS) domain

- The CS domain supports circuit-switched services. Some examples of CS services are voice and fax.
- The CS domain can also provide intelligent services such as voice mail and free phone.
- The CS domain connects to PSTN/ISDN networks and it is expected to evolve from the existing 2G GSM PLMN.

Packet-switched (PS) Domain

- The PS domain deals with PS services. Some examples of PS services are Internet access and multimedia services.
- Since Internet connectivity is provided, all services currently available on the Internet such as search engines and e-mail are available to mobile users. The PS domain connects to IP networks.
- The PS domain is expected to evolve from the GPRS PLMN.

The Iu circuit-switched and packet-switched protocol architecture are shown in Figures

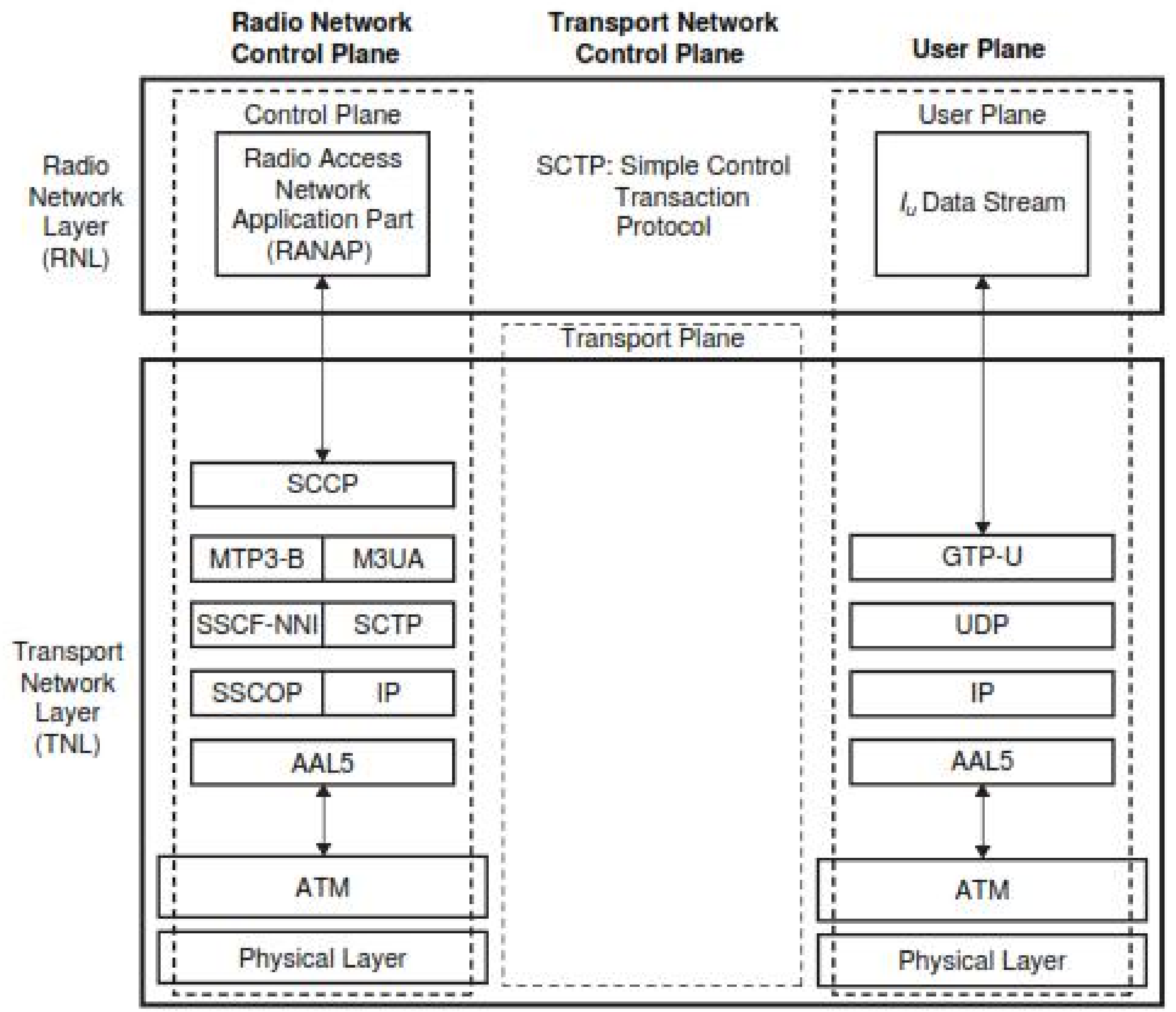


Figure 15.24 PS protocol architecture on I_u interface.

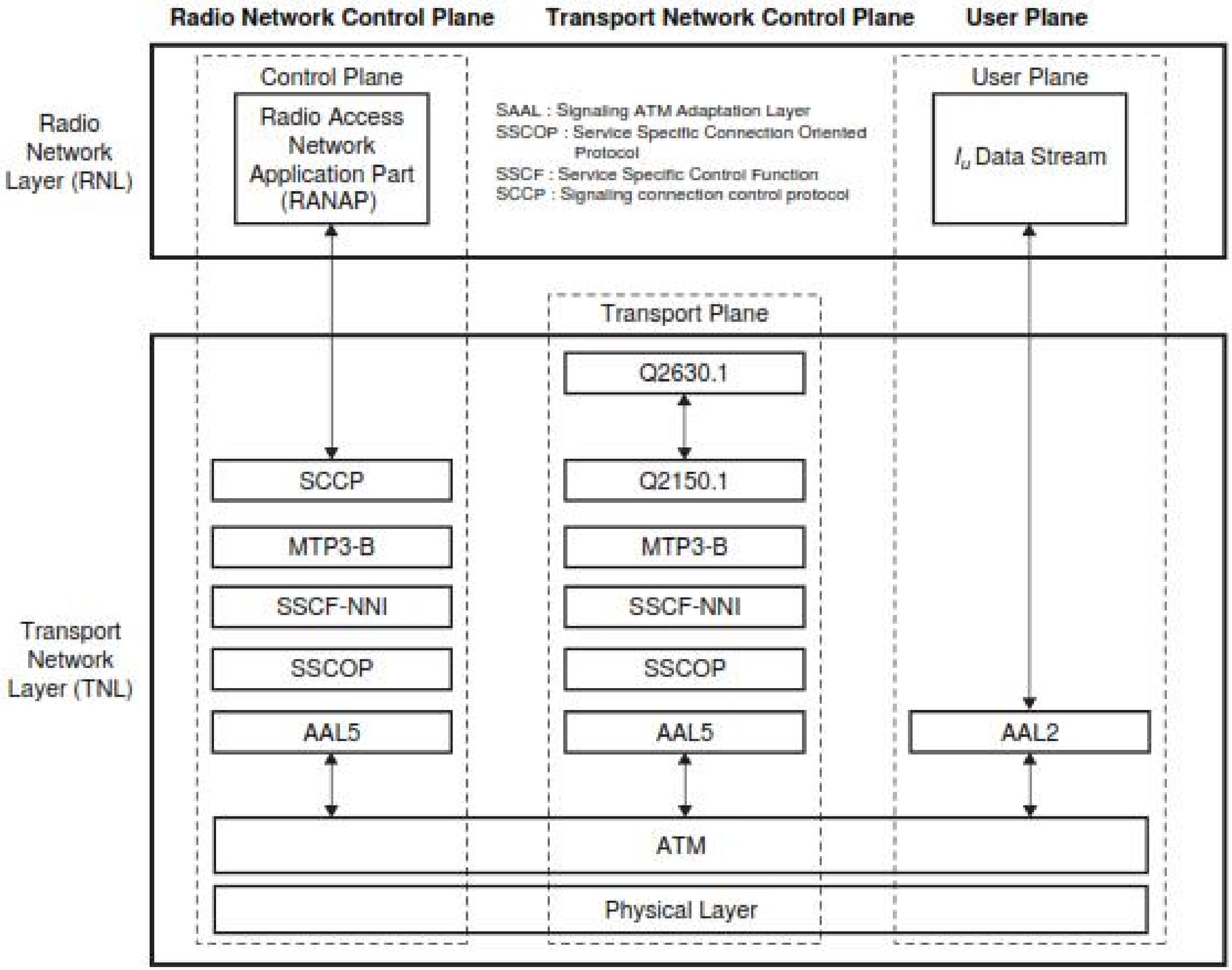


Figure 15.25 CS protocol architecture on I_u interface.

- The control plane protocol stack consists of RANAP on the top of signaling system 7 (SS7) protocols.
- The protocol layers are the signaling connection control part (SCCP), the message transfer part (MTP3-B), and signaling asynchronous transfer mode (ATM) adaptation layer for network-to-network interface

  (SAAL-NNI).
- The SAAL-NNI is divided into service-specific coordination function (SSCF),the service-specific connection-oriented protocol (SSCOP), and ATM adaptation layer 5 (AAL5) layers.
- The SSCF and SSCOP layers are specifically designed for signaling transport in ATM networks, and take care of signaling connection management functions.
- AAL5 is used for segmenting the data to ATM cells.
- As an alternative, an IP-based signaling bearer is specified for the Iu PS

  control plane.
- The IP-based signaling bearer consists of SS7-MTP3—user adaptation layer (M3UA), simple control transmission protocol (SCTP), IP, and AAL5.
- The SCTP layer is specifically designed for signaling transport on the Internet.

- The transport network control plane (TNCP) carries information for the control of transport network used within UCN.
- The user plane (UP) carries user voice and packet data information.
- AAL2 is used for the following services: narrowband speech (e.g., EFR, AMR); unrestricted digital information service (up to 64 kbps,i.e., ISDN B channel); any low to average bit rate CS service (e.g., modem service to/from PSTN/ISDN).
- AAL5 is used for the following services: non-real-time PS data service (i.e., best effort packet access) and real-time PS data.

Iur Interface

- The **connection between two RNCs** (serving RNC (SRNC) and drift RNC (DRNC)) is **the Iur interface.**
- It is **used in soft handoff scenarios** when different macro diversity streams of one communication are supported by Node Bs that belong to different RNCs.
- **Communication between** one RNC and one Node B of **two different RNCs are realized through the Iur interface.**
- **Three different protocol** planes are defined for it:
  - Radio network control plane (RNCP)
  - Transport network control plane (TNCP)
  - User plane (UP)

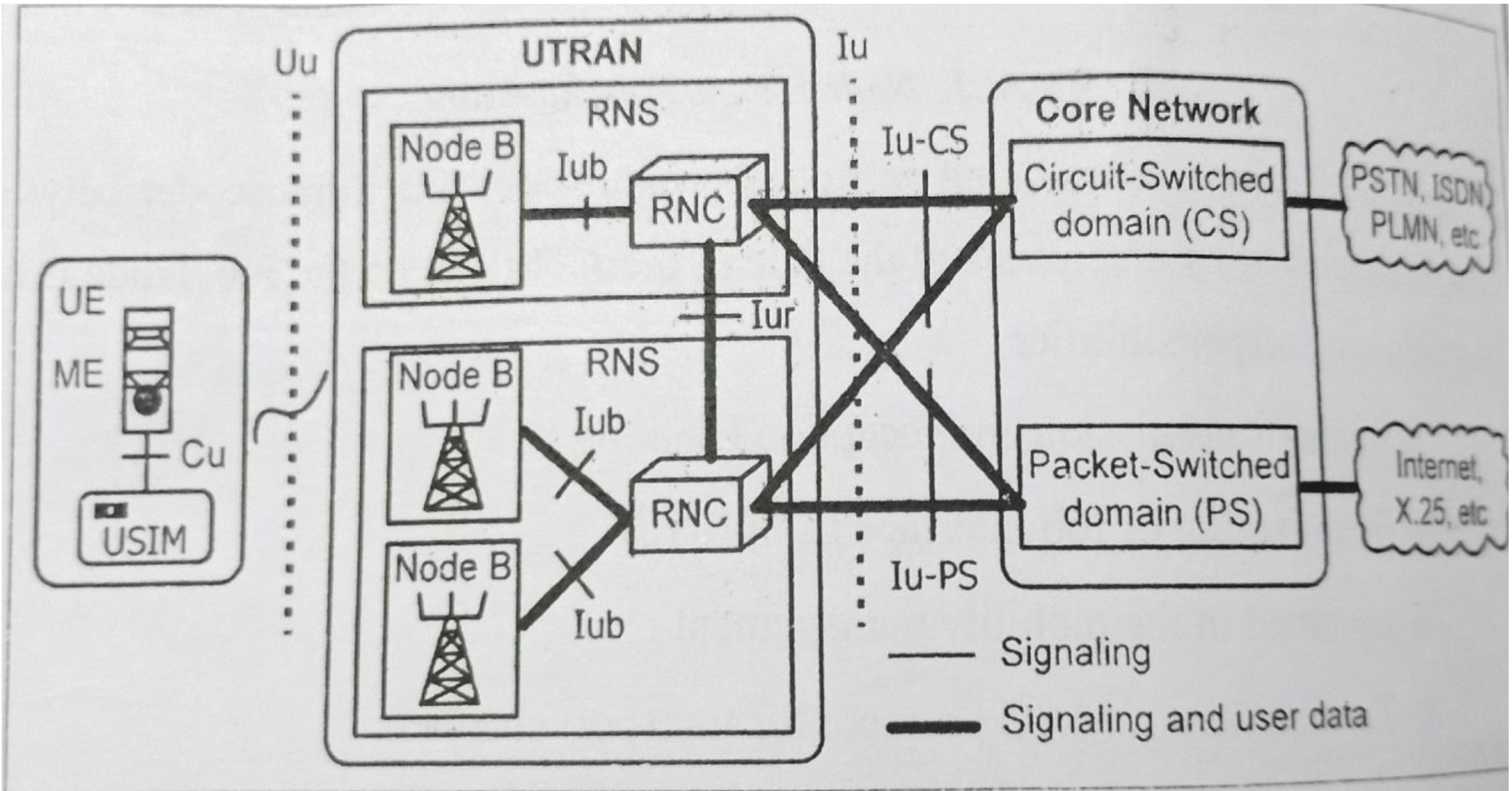


Fig. 4.1. UTRAN detailed architecture

The Iur interface is used to carry:

- **Information for the control of radio resources** in the context of specific service request of one mobile on RNCP
- **Information for the control of the transport network** used within UTRAN on TNCP
- User voice and packet data information on UP

The protocols used on this interface are:

- Radio access network application part (RANAP)
- DCH frame protocol (DCHFP)
- RACH frame protocol (RACHFP)
- FACH frame protocol (FACHFP)
- Access link control application part (ALCAP)
- Q.aal2
- Signaling connection control part (SCCP)
- Message transfer part 3-B (MTP3-B)
- **Signaling ATM adaptation layer for network-to-network interface** (SAALNNI)
- **SAAL-NNI is further divided into**

Service specific coordination function for network to network interface (SSCF-NNI)

Service Specific Connection Oriented Protocol (SSCOP),

ATM adaptation layer 5 (AAL5))

The bearer is AAL2. The protocol structure of the Iur interface is shown in

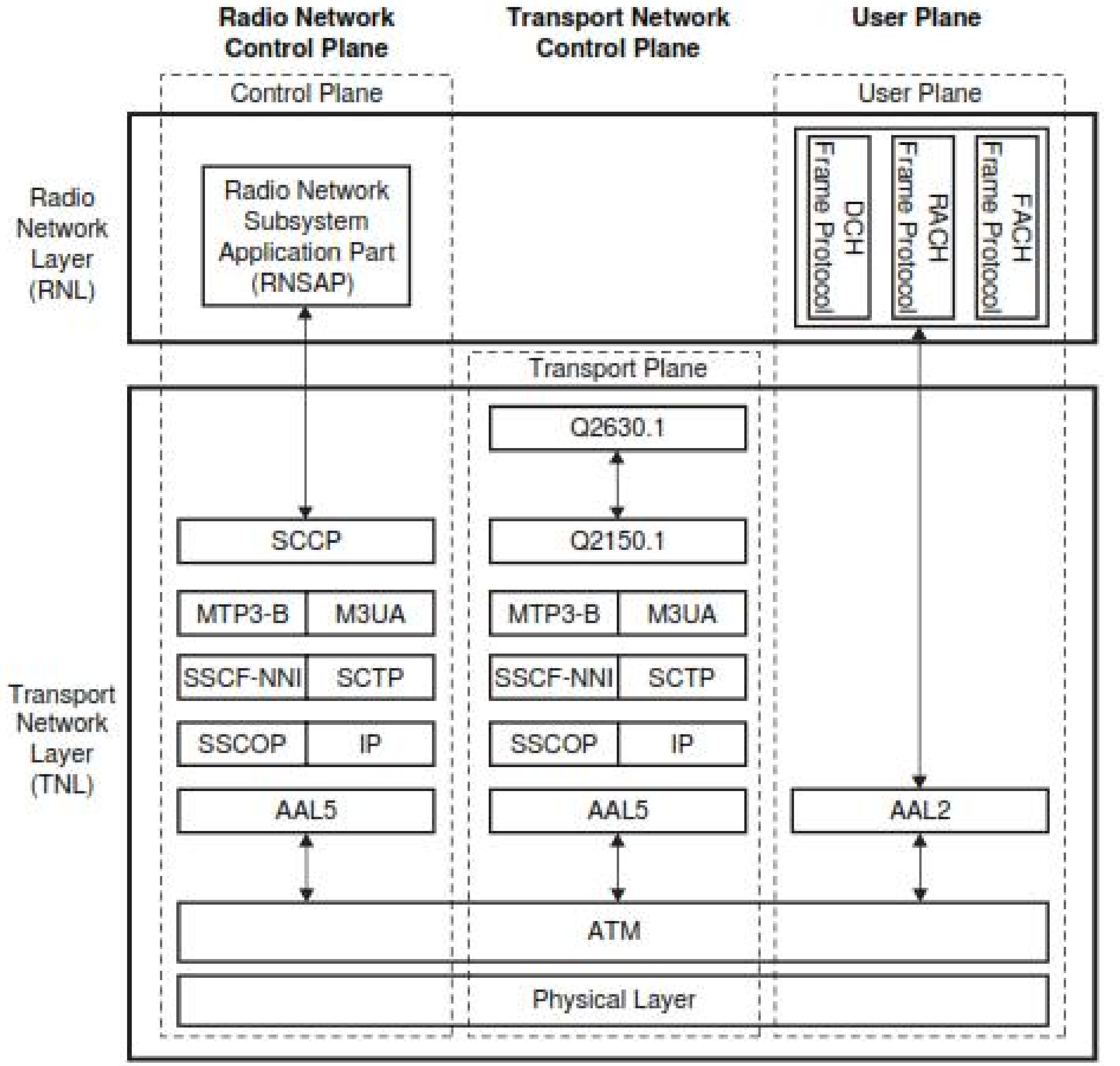


Figure 15.26 Protocol structure of I_{ur} interface.

- Initially, this **interface was designed to support** the **inter-RNC soft handoff**, but more features were added during the development of the standard.

The **Iur provides the following four functions**:

1. **Basic inter-RNC mobility support**

- Support of SRNC relocation
- Support of inter-RNC cell and UTRAN registration area update
- Support of inter-RNC packet paging
- Reporting of protocol errors

2. **Dedicated channel traffic support**

- **Establishment, modification, and release** of a dedicated channel in the DRNC **due to hard and soft handoff in the dedicated channel state**
- **Setup and release of dedicated transport connections** across the *Iur* interface
- **Transfer of DCH transport** blocks **between SRNC and DRNC**
- **Management of radio links** in the DRNS via dedicated measurement report procedures and power setting procedures.

3. **Common channel traffic support**

- **Setup and release of the transport connection** across the *Iur* for common channel data streams
- **Splitting of the MAC layer between the SRNC (MAC-d) and DRNC (MAC-c and MAC-sh)**; the scheduling for downlink data transmission is performed in the DRNC
- **Flow control** between the MAC-d and MAC-c/MAC-sh

4. **Global resource management support**

- **Transfer of cell measurements** between two RNCs
- **Transfer of Node B timing** between two RNCs

Iub Interface

- The **connection between the RNC and Node B** is the *I ub* interface.
- There is **one *Iub* interface for each Node B.**
- *The Iub* interface is used for all of the communications between Node B and the RNC of the same RNS.
- Three different protocol planes are defined for it.
  - Radio network control plane (RNCP)
  - Transport network control plane (TNCP)
  - User plane (UP)

The *Iub* interface is used to carry:

- **Information for the general control of Node B** for radio network operation on RNCP
- **Information for the control of radio resources** in the context of specific service request of one mobile on RNCP
- **Information for the control of a transport network** used within UTRAN on TCNP
- **User CC and MM signaling message** on RNCP
- **User voice and packet data information** on UP

The protocols used on this interface include:

- Node B application part protocol (NBAP)
- DCH frame protocol (DCHFP)
- RACH frame protocol (RACHFP)
- FACH frame protocol (FACHFP)
- Access link control application part (ALCAP)
- Q.aal2
- SSCP or TCP and IP
- MTP3-B
- SAAL-UNI (SSCF-UNI, SSCOP, and AAL5)
- When using multiple low-speed links in the *Iub* interface, Node B supports inverse multiplexing for ATM (IMA).
- The bearer is AAL2.

The protocol structure for the interface *Iub* is shown in Figure 15.27

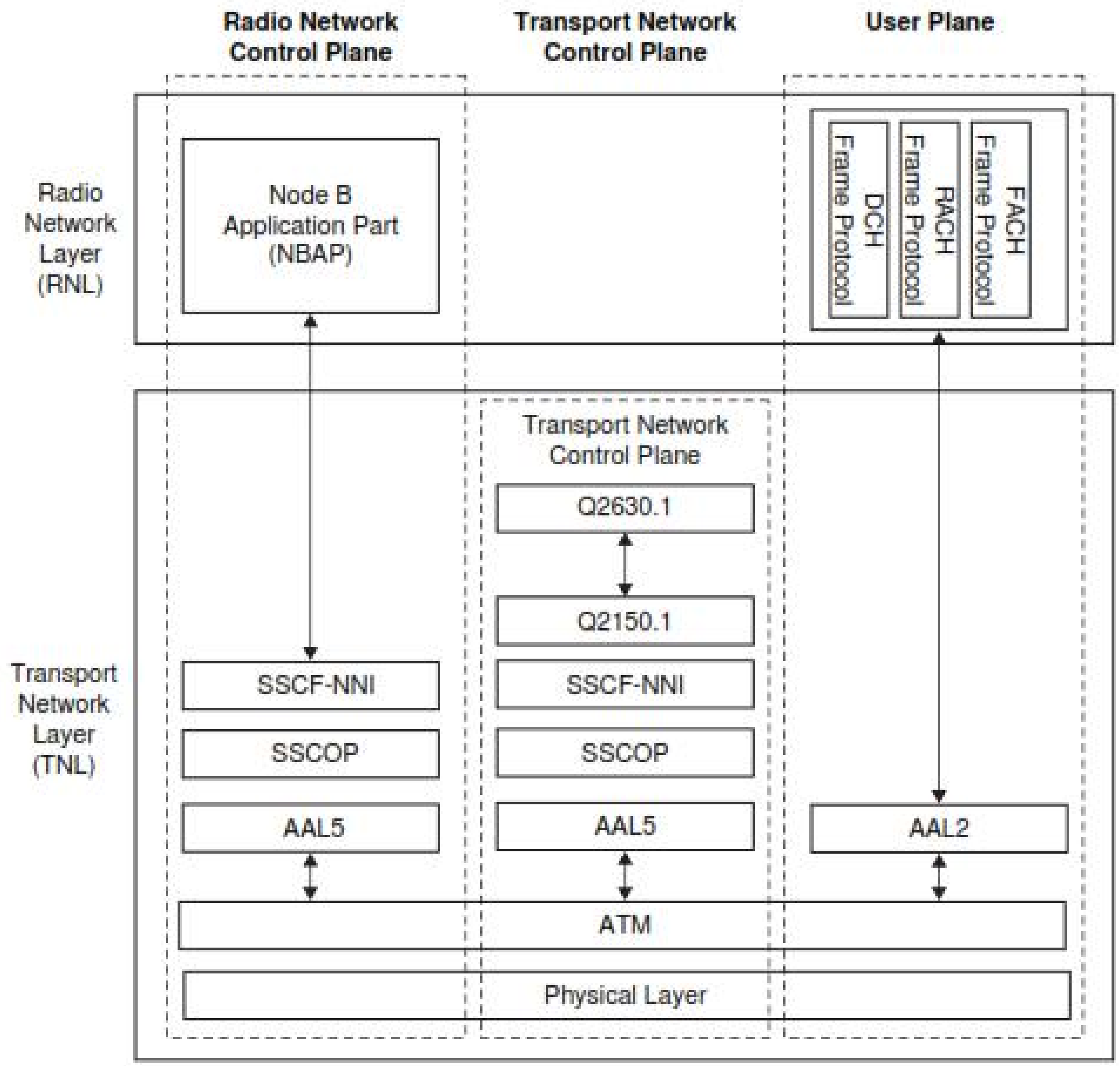


Figure 15.27 Protocol structure of I_{ub} interface.

Uu Interface

- The UMTS *Uu* interface **is the radio interface between a Node B and one of its UE.**
- The *Uu* is the interface through which **UE accesses the fixed part of the system.**

Distribution of UTRAN Functions

Located in the RNC

- Radio resource control (L3 Function)
- Radio link control (RLC)
- Macro diversity combining
- Active cell set modification
- Assign transport format combination set (centralized data base function)
- **Multiplexing/demultiplexing of higher layer PDUs** into/from transport block delivered to/from the physical layer on shared dedicated transport channels (used for soft handover)
- **L1 function**: macro diversity distribution/combining (centralized multipoint termination)
- **Selection of the appropriate transport format** for each transport channel **depending upon the instantaneous source rate — collocate with RRC**
- **Priority handling** between data flows of one user

Located in Node B

- **Scheduling of broadcast, paging, and notification messages; location in Node B** — to reduce data repetition over *Iub and reduce RNC CPU load and* memory space
- **Collision resolution on RACH** (in Node B — to reduce non constructive traffic over *Iub interface and reduce round trip delay)*
- **Multiplexing/demultiplexing of higher layer PDUs** to/from transport blocks delivered to/from the physical layer on common transport channels

UMTS Core Network Architecture

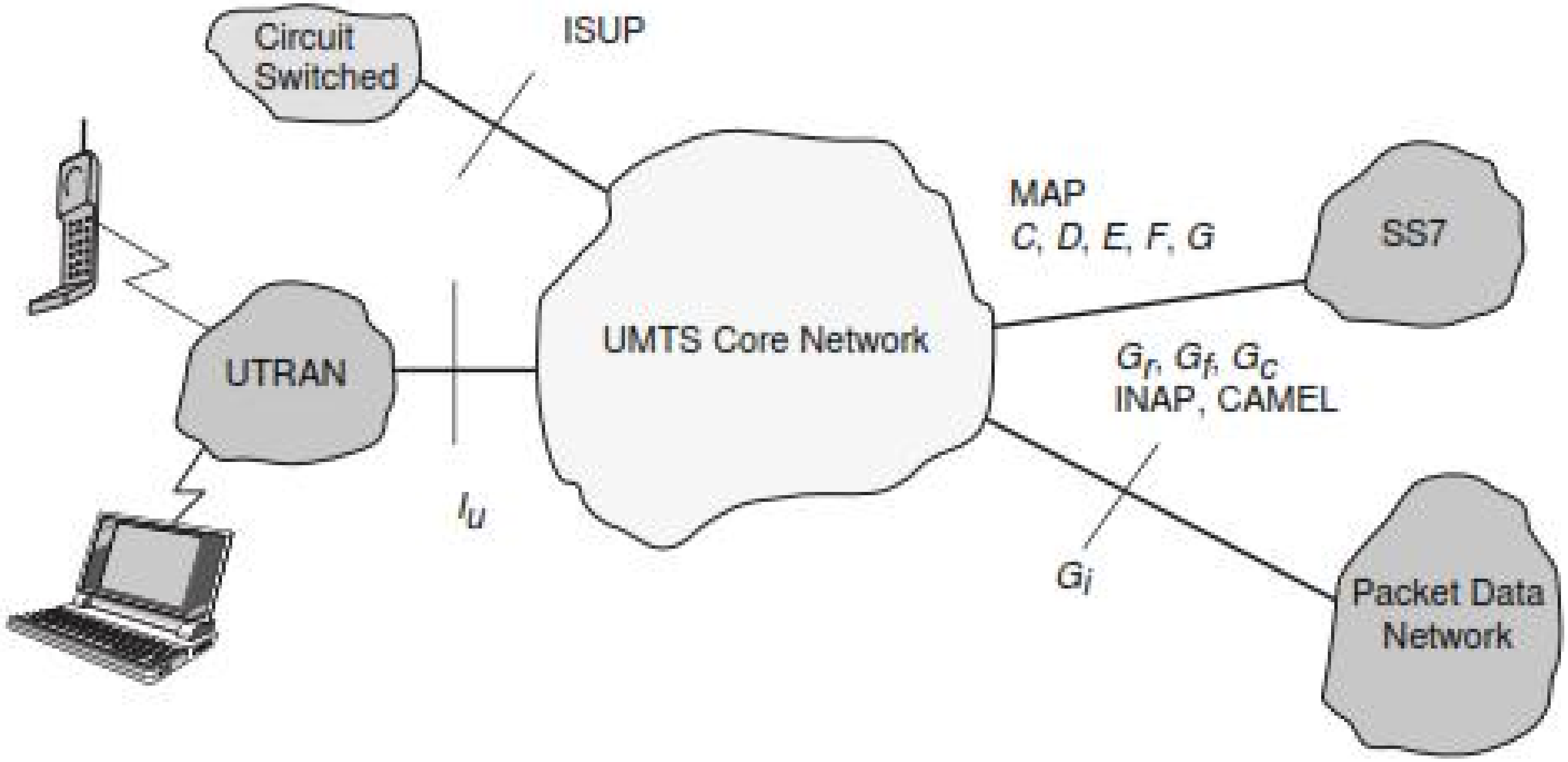


Figure 15.28 UMTS core network architecture.

- Figure 15.28 shows the UMTS core network (UCN) in relation to all other entities within the UMTS network and all of the interfaces to the associated networks.
- The **UCN consists of a CS entity for providing voice** and **CS data services** and a **PS entity for providing packet-based services**.
- The **logical architecture offers** a clear **separation between the CS domain and PS domain.**
- The **CS domain contains the functional entities**:

  Mobile switching center (MSC)

  Gateway MSC (GMSC)

- **The PS domain comprises the functional entities:**

  Serving GPRS Support Node (SGSN)

  Gateway GPRS Support Node (GGSN)

  Domain Name Server (DNS)

  Dynamic Host Configuration Protocol (DHCP)

  Server Packet Charging Gateway

  Firewalls

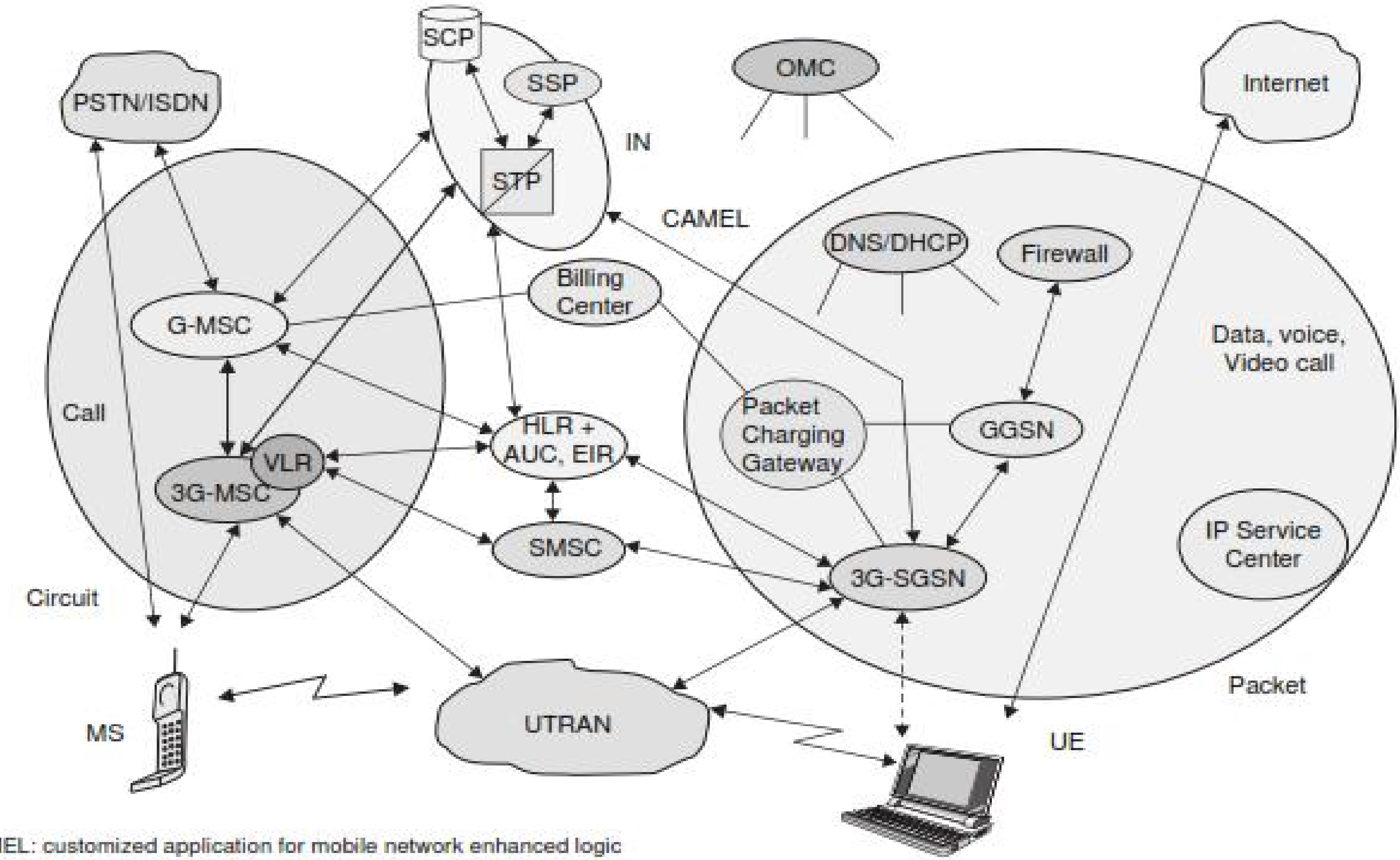
The core network can be split into the following different functional areas:

- Functional entities needed to support PS services (e.g. 3G-SGSN, 3G-GGSN)
- Functional entities needed to support CS services (e.g. 3G-MSC/VLR)
- Functional entities common to both types of services (e.g. 3G-HLR)

Other areas that can be considered part of the core network include:

- Network management systems (billing and provisioning, service management, element management, etc.)
- IN system (service control point (SCP), service signaling point (SSP), etc.)
- ATM/SDH/IP switch/transport infrastructure

shows all the entities that connect to the core network UTRAN, PSTN, the Internet and the logical connections between terminal equipment (MS,UE), and the PSTN/Internet.



CAMEL: customized application for mobile network enhanced logic
SMSC: short message service center
DNS: domain name server
DHCP: dynamic host configuration protocol

Figure 15.29 Logical architecture of the UMTS core network.

3G-MSC

- The 3G-MSC is the **main CN element to provide CS services**.
- The 3G-MSC also **provides the necessary control and corresponding signaling interfaces including SS7, MAP, ISUP (ISDN user part), etc.**
- The 3G MSC **provides the interconnection to external networks like PSTN and ISDN.**

The following functionality is provided by the 3G-MSC:

- **Mobility management**: Handles attach, authentication, updates to the HLR, SRNS relocation, and inter systems handover.
- **Call management**: Handles call set-up messages from/to the UE.
- **Supplementary services**: Handles call-related supplementary services such as call waiting, etc.
- **CS data services**: The IWF provides rate adaptation and message translation for circuit mode data services, such as fax.
- **Vocoding**

- **SS7, MAP and RANAP interfaces:** The 3G-MSC is able **to complete originating or terminating calls in the network in interaction** with other entities of a mobile network, e.g., HLR, AUC (Authentication center). It **also controls/communicates with RNC using RANAP** which may use the services of SS7.
- **ATM/AAL2 Connection to UTRAN for transportation of user plane traffic** across the *Iu* interface. Higher rate CS data rates may be supported using a different adaptation layer.
- **Short message services (SMS):** This functionality **allows the user to send and receive SMS data to and from the SMS-GMSC/SMS-IWMSC (Inter working MSC).**

- **VLR functionality:** The **VLR is a database that may be located within the 3G-MSC** and can **serve as intermediate storage for subscriber data** in order to support subscriber mobility.
- IN and CAMEL.
- OAM (operation, administration, and maintenance) agent functionality.

3G-SGSN

- The 3G-SGSN is the **main CN element for PS services**.
- The 3G-SGSN **provides** the **necessary control functionality both toward the UE and the 3G-GGSN.**
- It also **provides** the appropriate **signaling and data interfaces including connection to an IP-based network** toward the 3G-GGSN, SS7 toward the HLR/EIR/AUC and TCP/IP or SS7 toward the UTRAN.

The 3G-SGSN provides the following functions:

- **Session management**: Handles session set-up messages from/to the UE and the GGSN and operates Admission Control and QoS mechanisms.

- ***Iu* and *Gn* MAP interface:** The 3G-SGSN is able to complete originating or terminating sessions in the network by interaction with other entities of a mobile network, e.g., GGSN, HLR, AUC. It also controls/communicates with UTRAN using RANAP.
- **ATM/AAL5 physical connection** to the UTRAN **for transportation of user data plane traffic across** the *In interface using GPRS tunneling protocol* (GTP).
- **Connection across the *Gn* interface** toward the GGSN for transportation of user plane traffic using GTP. Note that no physical transport layer is defined for this interface.

- **SMS:** This functionality allows the user to send and receive SMS data to and from the SMS-GMSC /SMS-IWMSC.
- **Mobility management:** Handles attach, authentication, updates to the HLR and SRNS relocation, and intersystem handover.
- **Subscriber database functionality**: This database (similar to the VLR) is located within the 3G-SGSN and serves as intermediate storage for subscriber data to support subscriber mobility.
- **Charging**: The SGSN collects charging information related to radio network usage by the user.
- OAM agent functionality.

3G-GGSN

- The GGSN provides interworking with the external PS network. It is connected with SGSN via an IP-based network.
- The GGSN may optionally support an SS7 interface with the HLR to handle mobile terminated packet sessions.

The 3G-GGSN provides the following functions:

- Maintain information locations at SGSN level (macro-mobility)
- Gateway between UMTS packet network and external data networks (e.g. IP, X.25)
- Gateway-specific access methods to intranet (e.g. PPP termination)
- Initiate mobile terminate Route Mobile Terminated packets
- User data screening/security can include subscription based, user controlled, or network controlled screening.

- **User level address allocation:** The GGSN may have to allocate (depending on subscription) a dynamic address to the UE upon PDP context activation.
- This functionality may be carried out by use of the DHCP function.
- **Charging:** The GGSN collects charging information related to external data network usage by the user.
- OAM functionality

SMS-GMSC/SMS-IWMSC

- The overall requirement for these two nodes is to handle the SMS from point to point.
- The functionality required can be split into two parts.
- The SMS-GMSC is an MSC capable of receiving a terminated short message from a service center, interrogating an HLR for routing information and SMS information, and delivering the short message to the SGSN of the recipient UE.

The SMS-GMSC provides the following functions:

- Reception of short message packet data unit (PDU)
- Interrogation of HLR for routing information
- Forwarding of the short message PDU to the MSC or SGSN using the routing information

- The SMS-IWMSC is an MSC capable of receiving an originating short message from within the PLMN and submitting it to the recipient service center.

The SMS-IWMSC provides the following functions:

- Reception of the short message PDU from either the 3G-SGSN or 3G-MSC
- Establishing a link with the addressed service center
- Transferring the short message PDU to the service center

Firewall

- This entity is used to protect the service providers' backbone data networks from attack from external packet data networks.
- The security of the backbone data network can be ensured by applying packet filtering mechanisms based on access control lists or any other methods deemed suitable.

DNS/DHCP

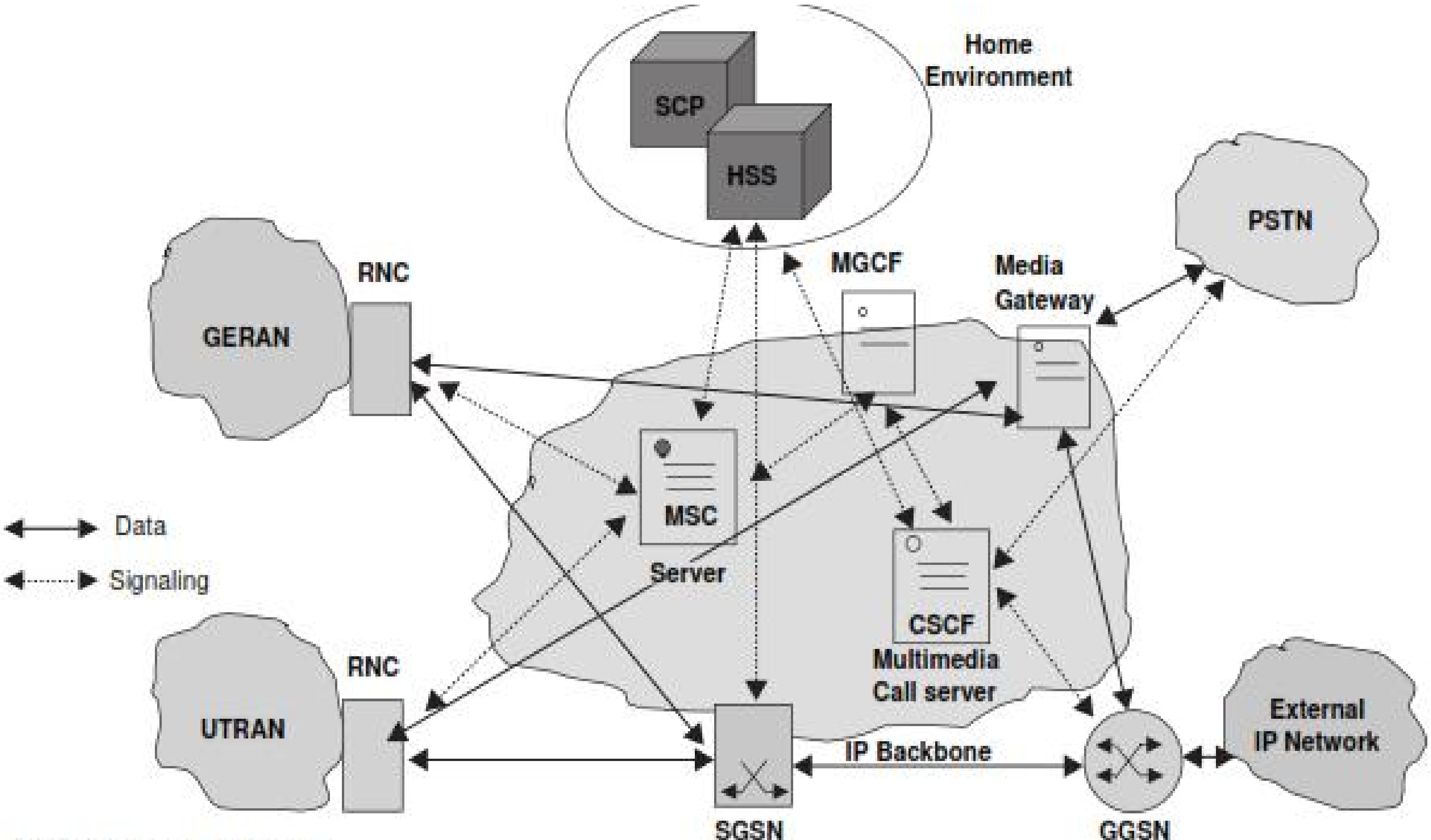
- The DNS server is used, as in any IP network, to translate host names into IP addresses, i.e., logical names are handled instead of raw IP addresses.
- Also, the DNS server is used to translate the access point name (APN) into the GGSN IP address.
- It may optionally be used to allow the UE to use logical names instead of physical IP addresses.
- A dynamic host configuration protocol server is used to manage the allocation of IP configuration information by automatically assigning IP addresses to systems configured to use DHCP.

High-Speed Downlink Packet Access (HSDPA)

- In **third-generation partnership project (3GPP) standards**, Release 4 specifications provide **efficient IP support** enabling **provision of services through an all-IP core network** (see Figures 15.32 and 15.33).
- **Release 5 specifications** focus on HSDPA to **provide data rates up to approximately 8–10 Mbps** to **support packet-based multimedia services.**
- **Multi input and multi output (MIMO) systems** are the work item in **Release 6 specifications**, which will support **even higher data transmission rates of up to 20 Mbps.**
- HSDPA is evolved from and backward compatible with Release 99 WCDMA systems.

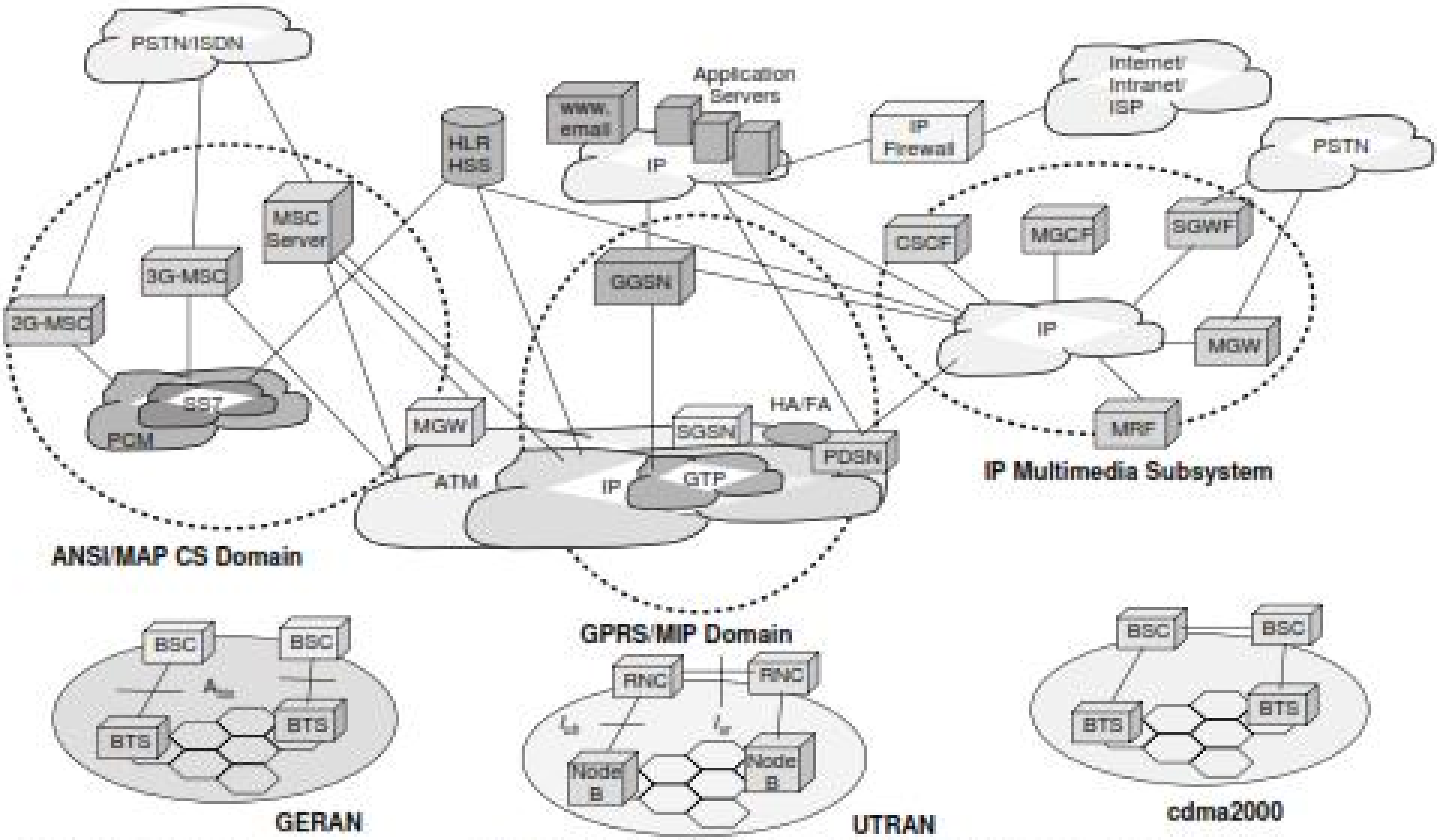
- HSDPA is based on the same set of technologies as high data rate (HDR) to improve spectral efficiency for data services
  - — such as shared downlink packet data channel and high peak data rates
  - — using high-order modulation and **adaptive modulation and coding**, **hybrid ARQ (HARQ) retransmission schemes**, **fast scheduling and shorter frame sizes**.
- HSDPA marks a similar boost for WCDMA that EDGE does for GSM.
- It provides a **two-fold increase** in **air interface capacity** and a **five-fold increase** in **data speeds in the downlink direction**.
- HSDPA also **shortens** the **round-trip time between the network and terminals** and **reduces variance in downlink transmission delay.**

- **The improvements in performance are achieved by:**
- Bringing some key functions, such as **scheduling of data packet transmission and processing of retransmissions** (in case of transmission errors) into the base station that is, closer to the air interface.
- Using a **short frame length** to further accelerate packet scheduling for transmission.
- Employing **incremental redundancy** for **minimizing the air-interface load caused by retransmissions.**
- **Adopting a new transport channel type**, known as high-speed downlink shared channel **(HS-DSCH)** to facilitate air interface channel sharing between several users.
- **Adapting the modulation and coding scheme** according to the quality of the radio link



CSCF: Call state control function
MG: Media gateway
MGCF: Media gateway control function
HSS: Home subscriber server
SCP: Signal Control Point
RNC: Radio Network Controller
SGSN: Serving GPRS Support Node
GGSN: Gateway GPRS Support Node
GERAN: GPRS/EDGE Radio Access Network
UTRAN: UMTS Radio Access Network

Figure 15.32 A simplified all-IP UMTS architecture.



MGW: Media Gateway
MGCF: Media Gateway Control Function
MRF: Media Resource Function
CSCF: Call State Control Function
PSDN: Packet Service Data Node
HSS: Home Subscriber Server
SGWF: Signaling Gateway Function
GTP: GPRS Tunneling Protocol
HA: Home agent
FA: Foreign Agent
PDSN: Packet data serving node
RNC: Radio network controller
ISP: Internet service provider

Figure 15.33 All-IP core network architecture for UMTS.

- **The primary objective behind HSDPA** is to provide a **cost-effective, high- bandwidth, low-delay, packet-oriented service within UMTS.**
- HSDPA is particularly suited to **extremely asymmetrical data services**, which **require significantly higher data rates** for the transmission from the network to the UE, than they do for the transmission from the UE to the network.
- **HSDPA introduces enablers for the high-speed transmission** at the physical layer like the **use of a shorter transmission time interval (TTI) (2 ms),** and **the use of adaptive modulation and coding.**
- **HS-DPCCH** is **used to carry the acknowledgment signals to Node B for each block.** It is also **used to indicate channel quality (CQI)** used for adaptive modulation and coding.
- **HS-DSCH** **uses 2 ms TTI to reduce trip time**, **to increase the granularity in the scheduling process**, and **to track the time varying radio channel better.**

OPERATIONAL PRINCIPLES

The basic operational principles behind HSDPA are relatively simple.

- The **RNC routes data packets** destined for a particular UE to the appropriate Node B.
- Node B **takes the data packets and schedules their transmission** to the mobile terminal over the air interface by **matching the user's priority and estimated channel operating environment with an appropriately chosen coding and modulation scheme** (that is, 16-QAM vs. QPSK).

RESPONSIBLE OF UE

- The UE is responsible for **acknowledging receipt** of the data packet and providing Node B with information regarding **channel condition, power control, and so on.**
- Once it sends the data packet to the UE, Node B waits for an acknowledgment.
- If it does not receive one within a prescribed time, it assumes that the data packet was lost and retransmits it.

UMTS CHANNEL CARD

- **UMTS channel card** comprises a
- ❑ **General-purpose processor** that **handles the miscellaneous control tasks**,
- ❑ a pool of **digital signal processor (DSP) resources** to **handle symbol-rate processing and chip-rate assist functions**, and
- ❑ a pool of **specialized ASIC (application specific intergrated circuit) devices** to **handle intensive chip-rate operations such as spreading, scrambling, modulation, rake receiving, and preamble detection.**

To support HSDPA, two changes must be made to the channel card.

- First, the downlink chip-rate ASIC must be modified to support the new 16-QAM modulation schemes and new downlink slot formats associated with HSDPA.
- In addition, the downlink symbol-rate processing section must be modified to support HSDPA extensions.
- The next change requires a new processing section, called the MAC-h which must be added to the channel card to support the scheduling, buffering, transmission, and retransmission of data blocks that are received from the RNC.

HSDPA CHANNELS

The new channels introduced in HSDPA are

- High-speed Downlink Shared Channel (**HS-DSCH),**
- High-speed Shared Control Channel (**HS-SCCH),**
- High Speed Dedicated Physical Control Channel (**HS-DPCCH)**

High-speed Downlink Shared Channel (HS-DSCH)

- Th e HS-DSCH is the primary radio bearer.
- Its resources can be shared among all users in a particular sector.
- The primary channel multiplexing occurs in a time domain, where each TTI consists of three time slots (each 2 ms). TTI is also referred to as a sub-frame.
- Within each 2 ms TTI, a constant spreading factor (SF) of 16 is used for code multiplexing, with a maximum of 15 parallel codes allocated to HS-DSCH.
- Codes may all be assigned to one user, or may be split across several users.
- The number of codes allocated to each user depends on cell loading, QoS requirements, and UE code capabilities (5, 10, or 15 codes).

- **High-speed Shared Control Channel (HS-SCCH)**
- The HS-SCCH (a fi xed rate 960 kbps, SF 128) is used to carry downlink signaling between Node B and UE before the beginning of each scheduled TTI.
- It includes UE identity, HARQ-related information and the parameters of the HS-DSCH transport format selected by the link-adaptation mechanism.
- Multiple HS-SCCHs can be configured in each sector to support parallel HS-DSCH transmissions.
- A UE can be allocated a set of up to four HS-SCCHs, which need to be monitored continuously.

High Speed Dedicated Physical Control Channel (**HS-DPCCH)**

- used to carry both ACK/NACK
- Quality Feedback Information

LTE NETWORK ARCHITECTURE AND PROTOCOL

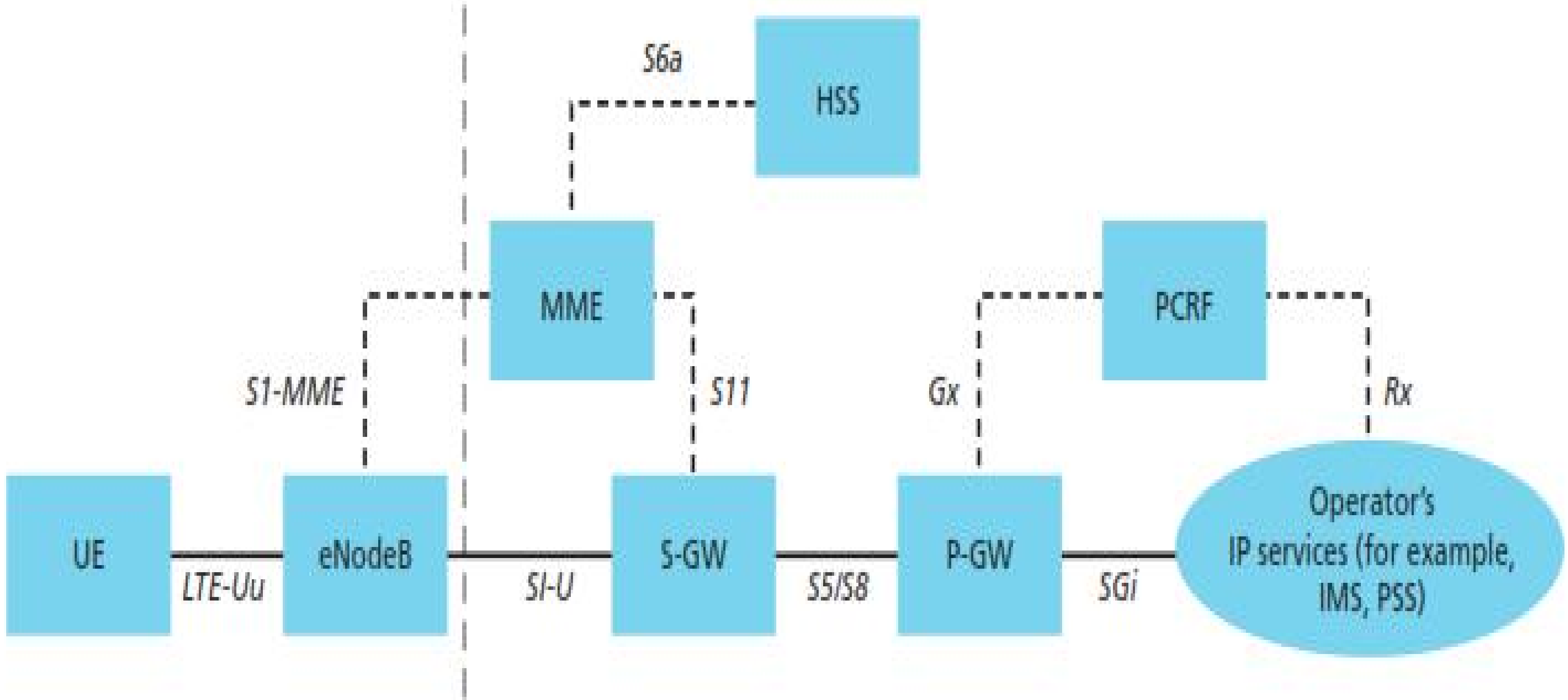
- Long Term Evolution (LTE) is **designed to support packet switched services.**
- **Aims- to provide seamless internet protocol (IP) connectivity between UE and packet data network (PDN)**

  Without disruption to the end user's application during mobility.
- LTE **encompasses** the evolution of the universal mobile telecommunication system (UMTS) radio access though the evolved UTRAN (**E-UTRAN).**
- E-UTRAN is **accompanied** by an **evolution of the non radio aspects** under the term (system architecture evolution(**SAE**) include Evolved Packet Core(**EPC**) network.
- Together LTE and SAE comprise the Evolved Packet System(**EPS**)
- **EPS uses** concept of **EPS bearers to route IP traffi**c from gateway in the **PDN to UE.**
- **Bearer** is an IP packet flow with a **defined quality of service (QoS**) between gateway and UE.

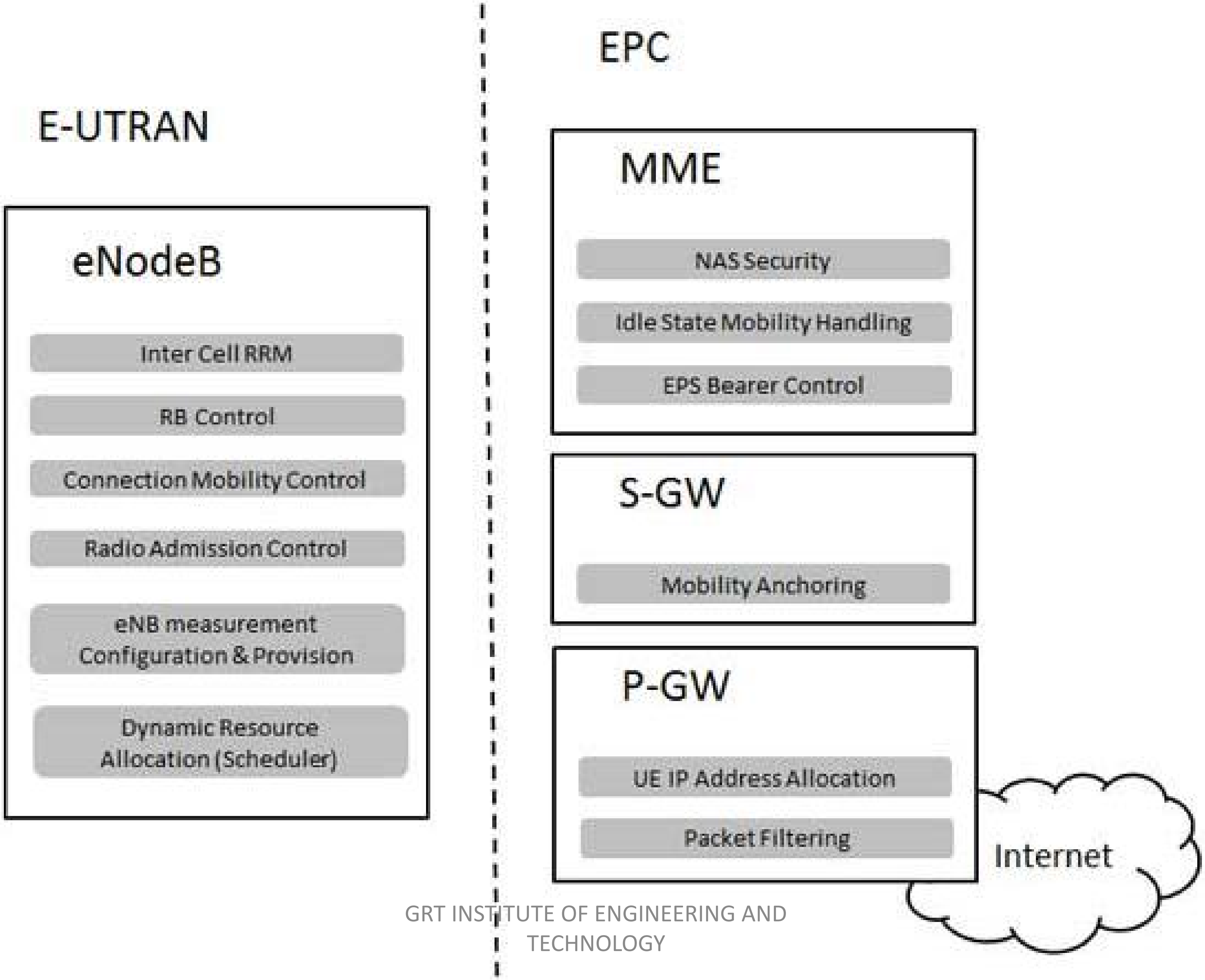
OVERALL ARCHITECTURAL OVERVIEW

- EPS **provide** the user with **IP connectivity** to a PDN for accessing the internet, running services such as (VoIP)
- **Multiple bearers** can be **established** for user in order **to provide different QoS stream**
- VoIP provide necessary QoS for voice call
- Network must also provide **sufficient security and privacy** for the user and **protection for the network against false use**.

Figure 1. The EPS network elements



Functional split between E-UTRAN and EPC



The core network

- The core network (called EPC in SAE) is **responsible for the overall control of the UE and establishment of the bearers**.
- The **main logical nodes of the EPC are**:
    - PDN Gateway (P-GW)
    - Serving Gateway (S-GW)
    - Mobility Management Entity (MME)
- In addition to these nodes, EPC also includes **other logical nodes** and functions such as the Home Subscriber Server (**HSS**) and the Policy Control and Charging Rules Function (**PCRF**).
- Since the **EPS only provides a bearer path** of a **certain QoS, control of multimedia applications such as VoIP** is provided by the IP Multimedia Subsystem (IMS), which is considered to be outside the EPS itself.

PCRF – The Policy Control and Charging Rules Function is **responsible**

for policy control decision-making,

for controlling the flow-based charging functionalities in the Policy Control Enforcement Function (PCEF),

The PCRF provides the **QoS authorization** (QoS class identifier [QCI] and bit rates) that decides how a certain **data flow** will be treated in the PCEF and **ensures** that this is in accordance with the user's subscription profile.

- **HSS – The Home Subscriber Server** contains **users' SAE subscription data such as the EPS-subscribed QoS profile** and **any access restrictions for roaming**.
- It also **holds information about** the **PDNs to which the user can connect-** in the form of an access point name (APN) or a PDN address (indicating subscribed IP address(es)).
- In addition the HSS **holds dynamic information** such as the **identity of the MME** to which the **user is currently attached or registered.**
- The HSS may also **integrate** the **authentication center (AUC),** which **generates the vectors for authentication and security keys**.

- ***P-GW* –** The PDN Gateway is **responsible**

  for IP address allocation for the UE,

  QoS enforcement and

  flow-based charging according to rules from the PCRF.

  the **filtering of downlink user IP packets** into the **different QoS-based bearers.**

- This is performed based on **Traffic Flow Templates (TFTs**).
- The P-GW performs **QoS enforcement for guaranteed bit rate (GBR) bearers**.
- It also **serves as the mobility anchor** for interworking with non-3GPP technologies such as CDMA2000 and WiMAX networks.

S-GW – **All user IP packets** are **transferred through the Serving Gateway**, which **serves** as the local mobility anchor for the data bearers when the UE moves between eNodeBs.

- It also **retains the information** about the **bearers when the UE is in the idle state** (known as "EPS Connection Management — IDLE" [ECM-IDLE]) and **temporarily buffers downlink data** while the MME initiates paging of the UE to reestablish the bearers.
- In addition, the S-GW performs some **administrative functions** in the **visited network** such as **collecting information for charging** (for example, the volume of data sent to or received from the user) and **lawful interception**.
- It also **serves as** the **mobility anchor for interworking** with other 3GPP technologies such as general packet radio service (GPRS) and UMTS

- **MME – The Mobility Management Entity (MME)** is the **control node** that **processes the signaling between the UE and the CN**.
- The **protocols** running **between the UE and the CN** are known as the **Non Access Stratum (NAS) protocols**.

The main functions supported by the MME can be classified as:

- **Functions related to bearer management** – This includes the establishment, maintenance and release of the bearers and is **handled by the session management layer in the NAS protocol**.

- **Functions related to connection management** – This includes the establishment of the connection and security between the network and UE and is **handled by the connection or mobility management layer in the NAS protocol layer.**

ARCHITECTURE REFERENCE MODEL

- Figure 2.1 shows the LTE network reference model, which is a logical representation of the network architecture.
- The network reference model **identifies the functional entities** in the architecture and the **reference points** between the functional entities over which interoperability is achieved.
- The overall architecture has two distinct components:
    - the access network
    - the core network.
- The **access network** is the Evolved Universal Terrestrial Radio Access Network (**E-UTRAN**).
- **The core network** is **all-IP core network** and is fully **Packet Switched (PS).**
- Services like **voice**, which are traditionally Circuit Switched (CS), will be handled using **IP Multimedia Subsystem (IMS) network**

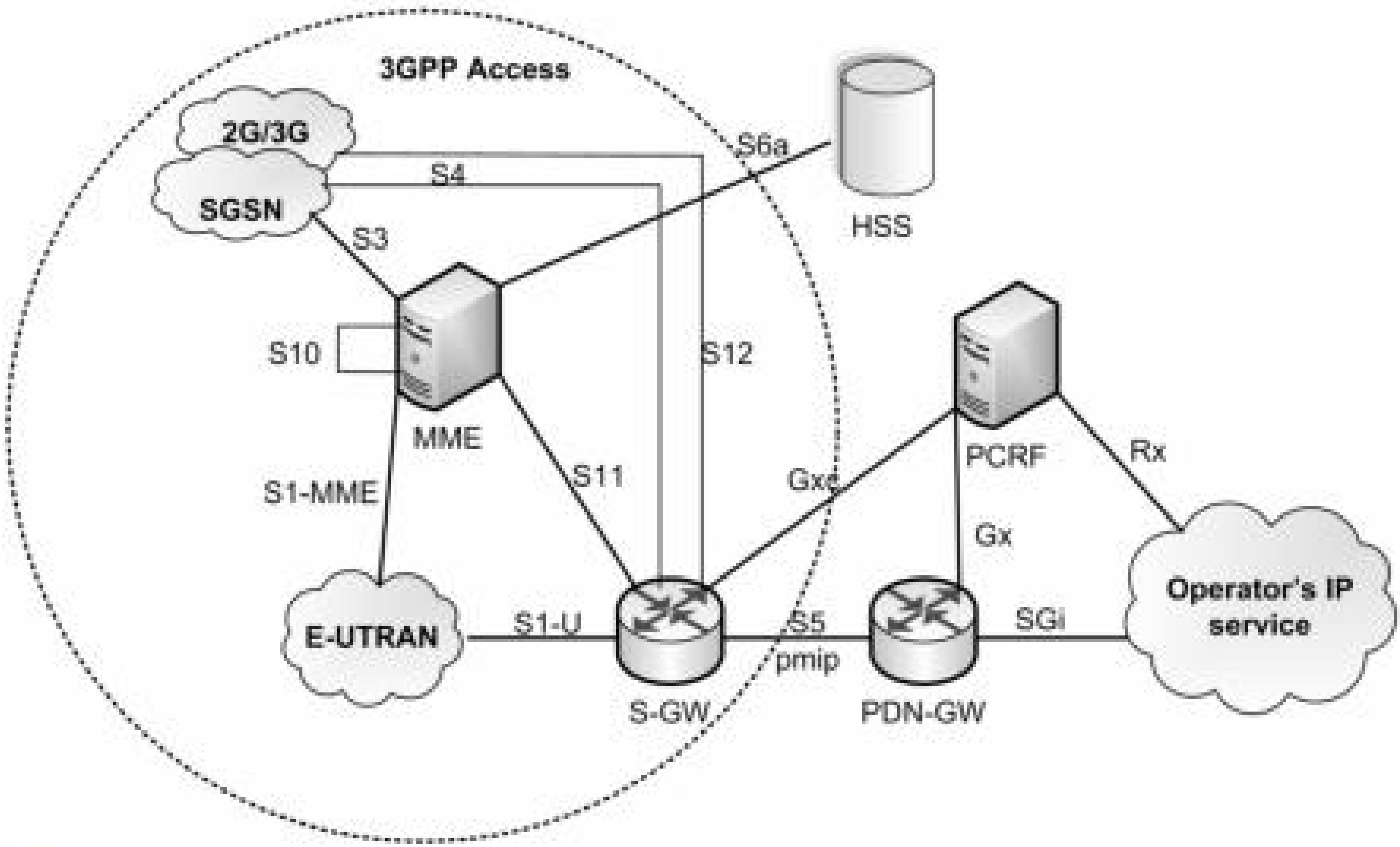


Fig. 2.1 LTE reference model

- The **core network** is called the **Evolved Packet Core(EPC).**
- Network complexity and latency are reduced as there are fewer hops in both the signaling and data plane.
- The EPC is designed to support non-3GPPP access supports for mobile IP.
- **To improve system robustness security, integrity protection, and ciphering** have been **added** and represented by **Non-Access Stratum (NAS)plane,** which is an additional layer of abstraction to protect important information like key and security interworking between 3GPP and non-3GPP network

Both radio access network and core network could achieve many functionalities including

- Network Access Control Functions
- Packet Routing and Transfer Functions
- Mobility Management Functions
- Security Functions
- Radio Resource Management Functions
- Network Management Functions

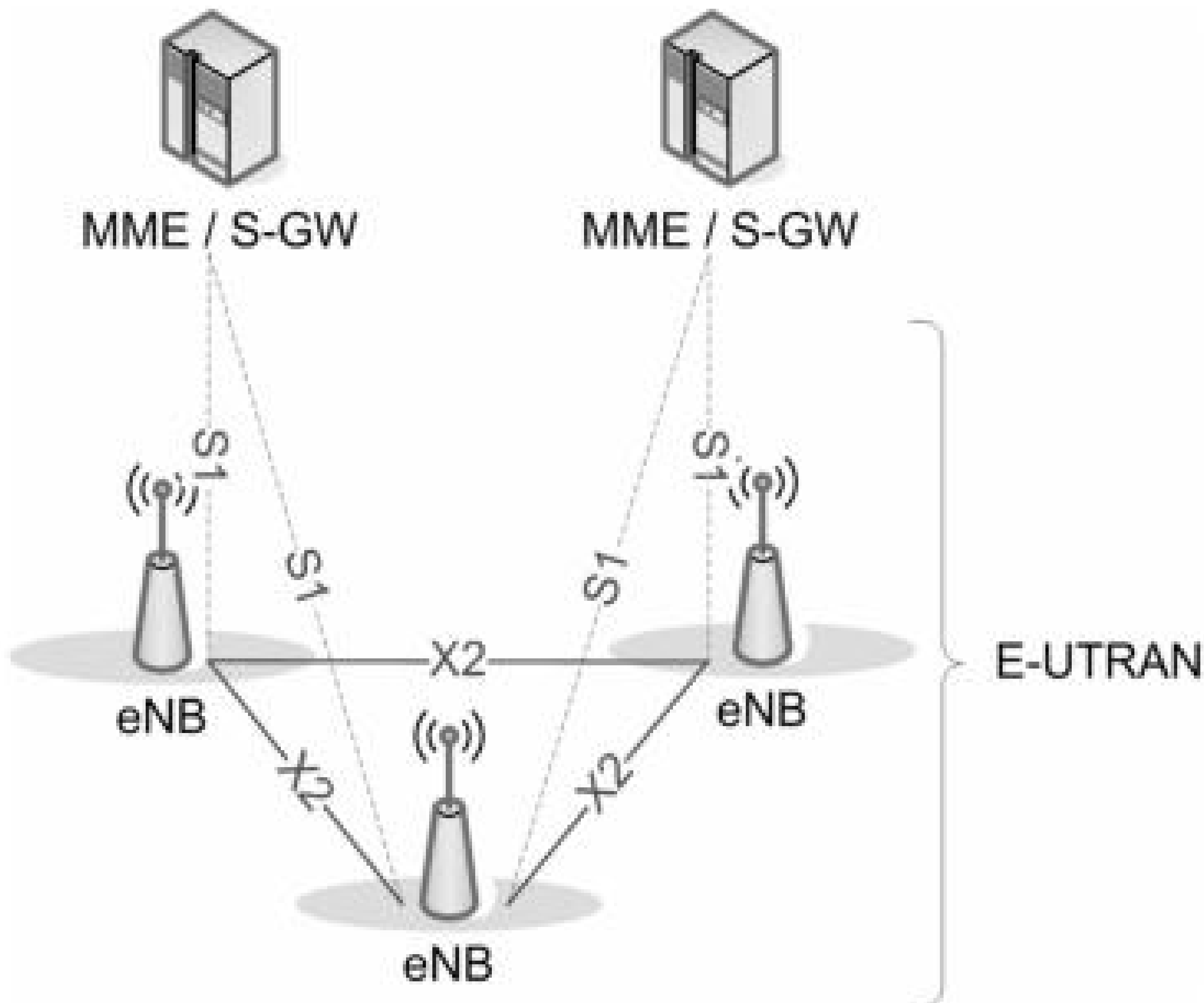
Functional Description of LTE Network

We highlight in this section the functional description of the most important part of the LTE network architecture which is divided into radio access network and core network.

Evolved Universal Terrestrial Radio Access Network (E-UTRAN)

- E-UTRAN is the air interface of 3GPP's Long-Term Evolution (LTE) upgrade path for mobile networks.
- It is a radio access network standard meant to be a replacement of the UMTS, HSDPA, and HSUPA technologies specified in 3GPP releases 5 and beyond.
- LTE's E-UTRAN is an entirely new air interface system, which provides higher data rates and lower latency and is optimized for packet data
- It uses OFDMA radio access for the downlink and SC-FDMA for the uplink.

- The E-UTRAN in LTE architecture consists of a single node, i.e., the **eNodeB** that interfaces with the user equipment (UE).
- The **aim** of this simplification is **to reduce the latency of all radio interface operations.**
- eNodeBs are **connected** to each other via the **X2 interface**, and they connect to the **PS core network** via the **S1 interface** .
- A general protocol architecture of E-UTRAN (Fig. 2.3) splits the radio interface into three layers:
  - a physical layer or Layer 1,
  - the data link layer (Layer 2), and
  - the network layer or Layer 3.



ig. 2.2 E-UTRAN architecture

Protocol architecture

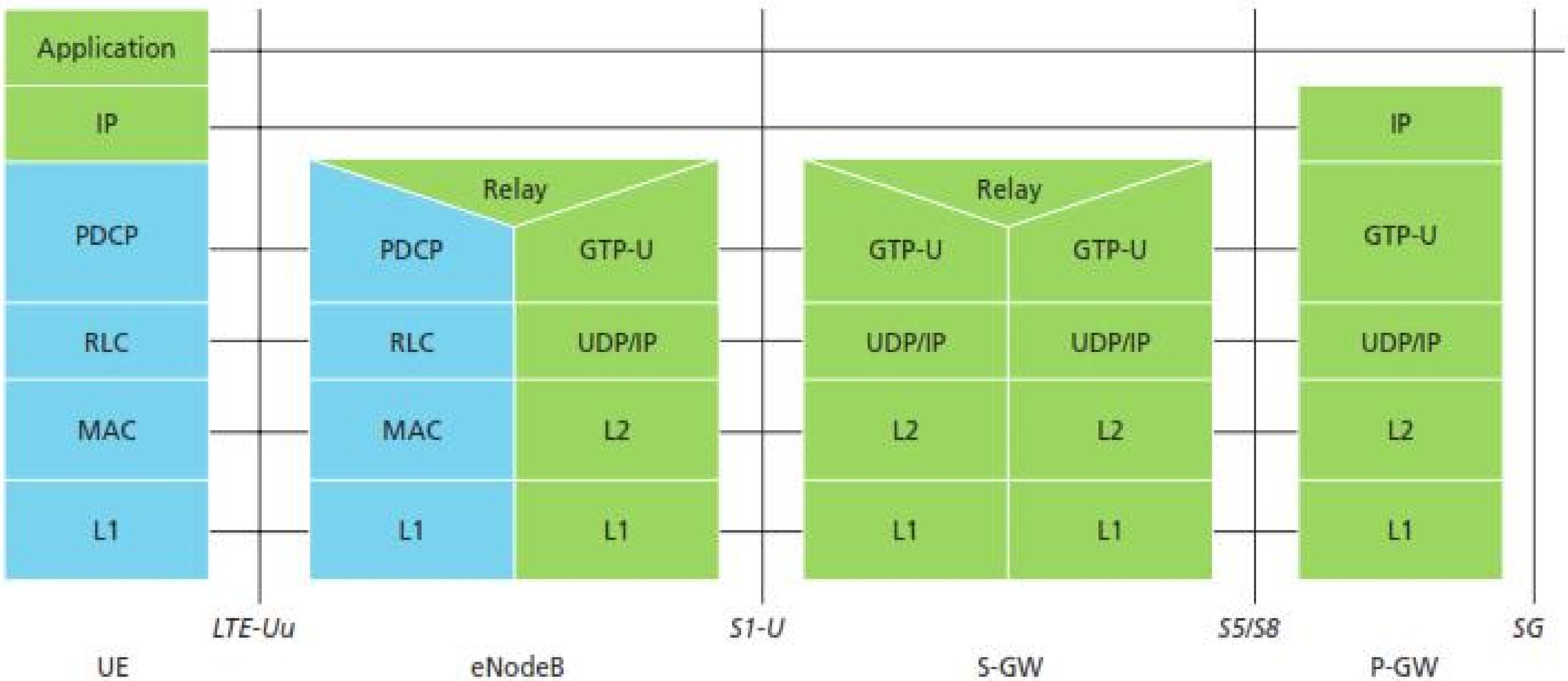
In protocol architecture of LTE, at each interface protocol stack has two planes.
User plane –to handle data generated by user
Control plane- to handle signaling message in the network

The radio interface in LTE is characterized through its protocols where it can be defined by two main groupings according to the final purpose service:

- the user plane protocols and
- the control plane protocols.

User Plane

Figure 6. The E-UTRAN user plane protocol stack



- The radio access uses the protocols **MAC, RLC, and PDCP**.
- The **user plane part of the S1 interface** is based on the **GPRS Tunneling Protocol (GTP),** which uses a **tunneling mechanism** ensuring that IP packets destined to a given UE are delivered to the eNodeB where the UE is currently located.
- **GTP encapsulates** the original IP packet into an outer IP packet which is addressed to the proper eNodeB.
- The S1 interface can be operated over various Layer 1/Layer 2 technologies, e.g., fiber optic cables, leased (copper) lines, or microwave links.

- Figure 2.5 shows also an example TCP/IP-based application, such as web browsing.
- The corresponding peer entities operate in the UE and at the server hosting the web application.
- For simplicity**, peer protocol entities** of the server are drawn in the **Serving Gateway (S-GW)**; however, in general they are located somewhere in the Internet.
- All information sent and received by the UE, such as the **coded voice in a voice call or the packets in an Internet connection**, are transported via **the user plane.**

CONTROL PLANE

- The control plane protocol function is to control the radio access bearers and the connection between the UE and the network, i.e., signaling between E-UTRAN and EPC (Fig. 2.8).
- The control plane consists of protocols for control and support of the user plane functions:

➢ controlling the E-UTRAN network access connections, such as attaching to and detaching from E-UTRAN;

➢ controlling the attributes of an established network access connection, such as activation of an IP address;

➢ controlling the routing path of an established network connection in order to support user mobility;

➢ controlling the assignment of network resources to meet changing user demands.

- **In the control plane,** the NAS protocol, which **runs the MME and the UE,** is used for control purposes such as **network attach, authentication, setting up of bearers, and mobility management**.
- All **NAS messages are ciphered and integrity protected** by the MME and UE.
- The **Radio Resource Control (RRC) layer** in the eNodeB makes

❖ handover decisions based on neighbor cell measurements sent by the UE,

❖ pages for the UEs over the air,

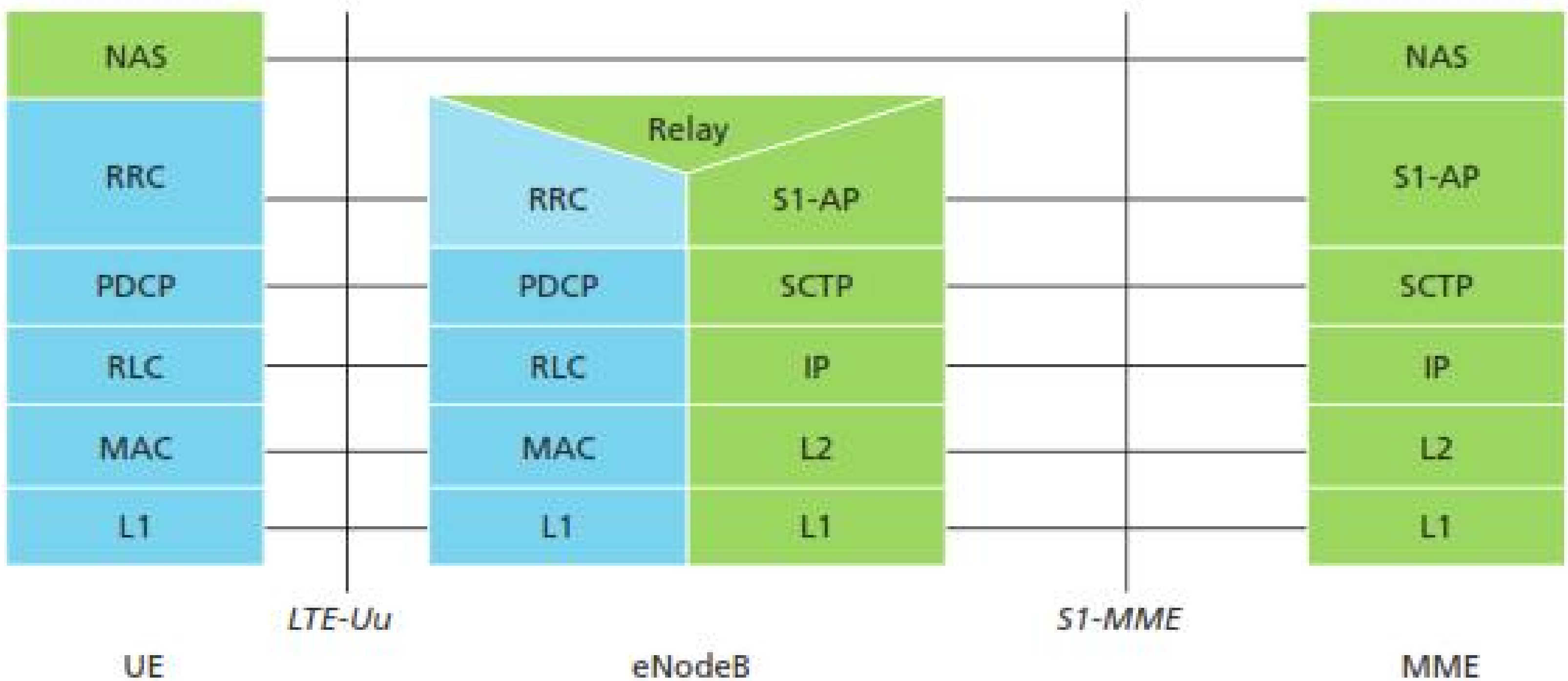
❖ broadcasts system information,

❖ controls UE measurement reporting such as the periodicity of Channel Quality Information (CQI) reports,

❖ Allocates cell-level temporary identifiers to active UEs.

- It also executes transfer of UE context from the source eNodeB to the target eNodeB during handover and does integrity protection of RRC messages.
- The RRC layer is responsible for the setting up and maintenance of radio bearers.

igure 7. Control plane protocol stack



UNIT-V
4G-Networks

What is 4G?

4G

Fourth generation Mobile Communications

Wireless World Research Forum defines 4G as:

-A network that operates on Internet technology, combines it with other applications and technologies such as Wi-Fi, and runs at speeds ranging from 100 Mbps (in cell-phone networks) to 1 Gbps (in local Wi-Fi networks).

- **Other descriptions:**

❖ Beyond 3rd Generation.

❖ Fourth-generation cellular communication system.

❖ Fourth-generation mobile technology.

❖ Fully IP-based wireless internet.

❖ 100 Mbps (outdoor) and 1Gbps (indoor).

❖ End-to-end QoS (Quality of service).

❖ High security.

❖ Any services, anytime, anywhere.

❖ 4G will make us as a part of the Internet.

❖ Always Be Connected (ABC).

- **4G** is used broadly to include several types of broadband wireless access communication systems along with cellular telephone systems.

- The **goal of 4G** systems is to **incorporate and integrate different wireless access technologies** and mobile network architectures so as **to achieve a seamless wireless** access infrastructure.

Evolution of Mobile Technology

(1G,2G,2.5G and 3G)

1G

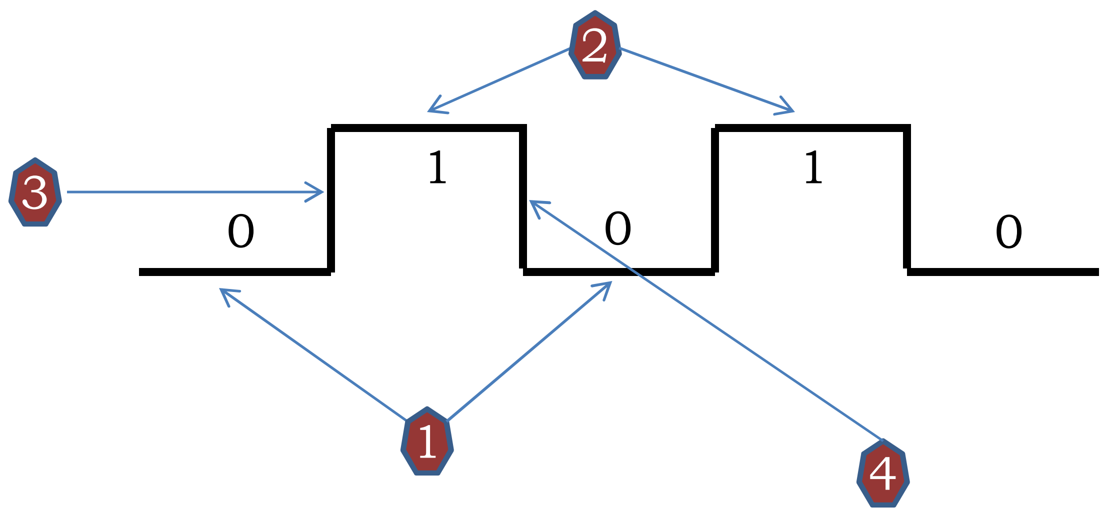
- **1G** (First Generation) is the name given to the first generation of mobile telephone networks.

- Circuit-switched technology.
- FDMA (Frequency Division Multiple Access).
- Analog system.
- Basic mobility.
- Poor voice quality.
- Poor security.

2G

- Digital –consists of 1s and 0s
- Digital signal:

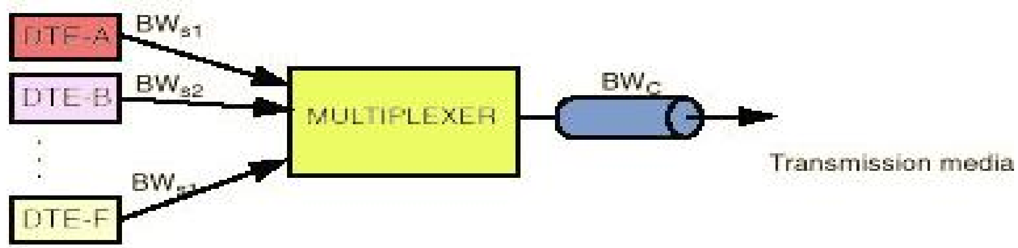
1) Low level,
2) High level,
3) Rising edge,
4) Falling edge

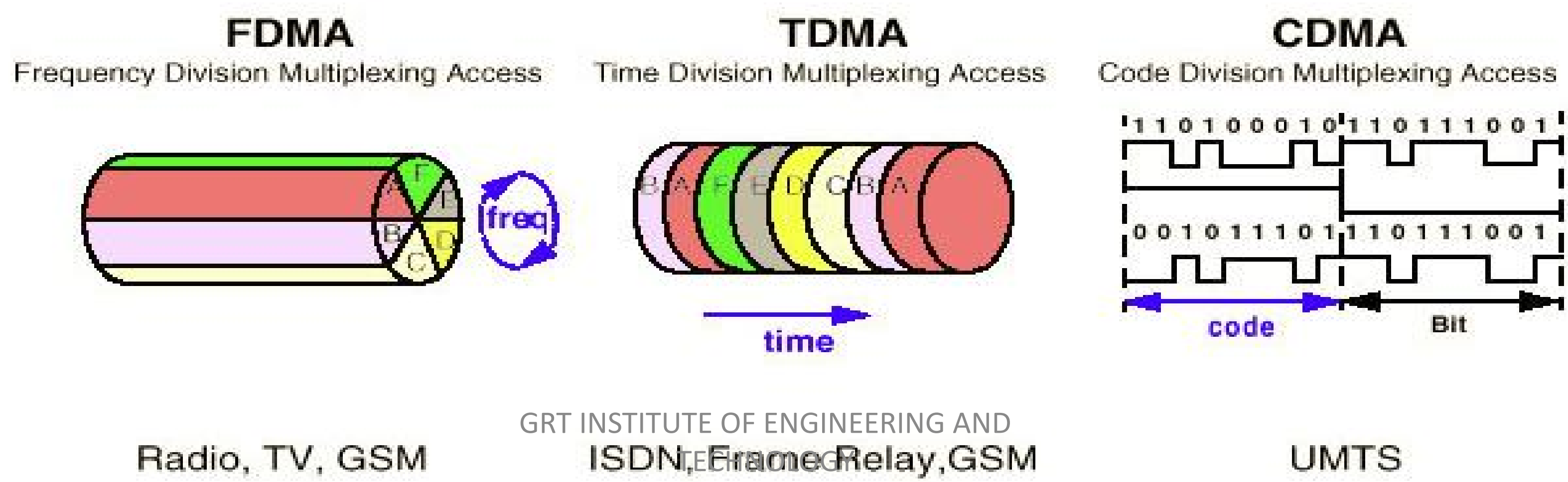


2G

- Digital data can be compressed and multiplexed much more effectively than analog voice encodings.

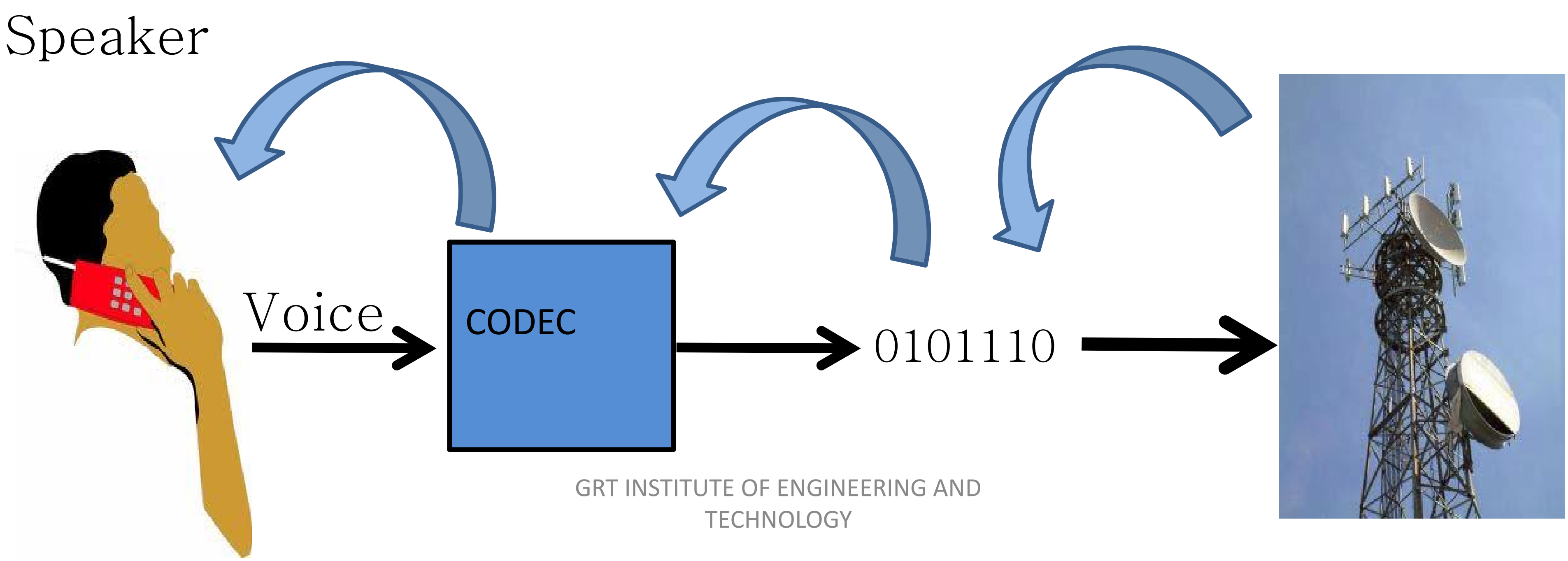
•Multiplexing -multiple analog message signals or digital data streams are combined into one signal.





- Allows for lower powered radio signals that require less battery power.
- Digital voice data can be compressed and multiplexed much more effectively than analog.
- CODEC introduction -program that encodes and decodes digital data stream or signal.

•Translates data from digital to analog and vice .



2G

Advantages:

- The digital voice encoding allows digital error checking
    - increase sound quality
    - lowers the noise level

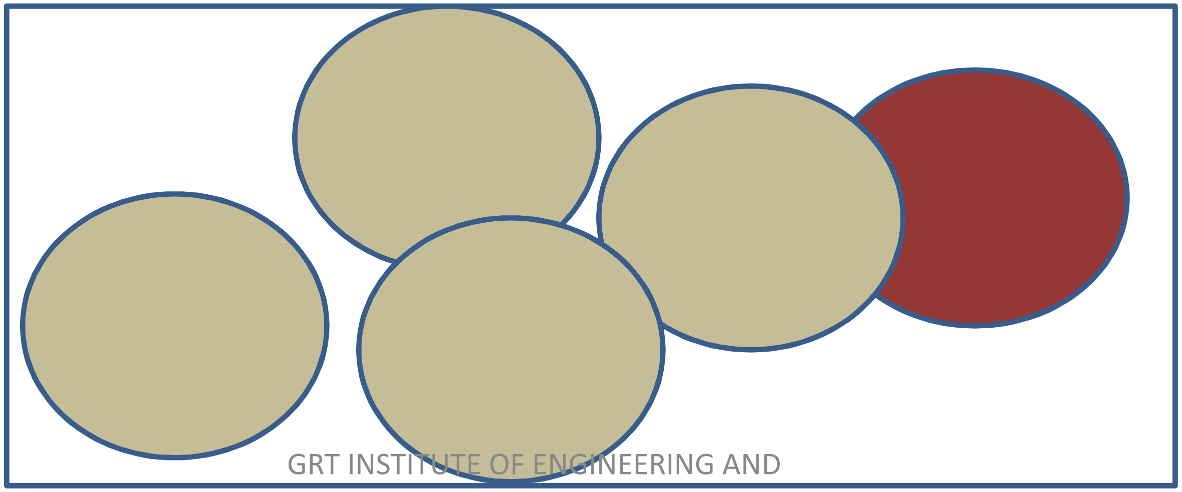
Going all-digital allowed for the introduction of digital data transfer.

- SMS –“short message service”
- E-mail

2G

Disadvantages

- Cell towers had a limited coverage area.
- Built mainly for voice services and slow data.



2.5G

2G Enhanced

- Lies somewhere between **2G** and **3G**.
- The development of **2.5G** has been viewed as a stepping-stone towards **3G**.
- Was prompted by the demand for better data services and access to the internet.
- Provides faster services than **2G**, but not as faster as advanced as the newer **3G** systems.

- Extends the capabilities of **2G** systems by providing additional features, such as a packet-switched connection(**GPRS**) in the **TDMA**-based GSM system, and enhanced data rates (**HSCSD** and **EDGE**).

GPRS: General Packet Radio Services.

EDGE: Enhanced Data for Global Evolution.

HSCSD: High Speed circuit-switched data.

3G

3G

- Large capacity and broadband capabilities.
- Allows the transmission of 384kbps for mobile systems and up to 2Mbps.

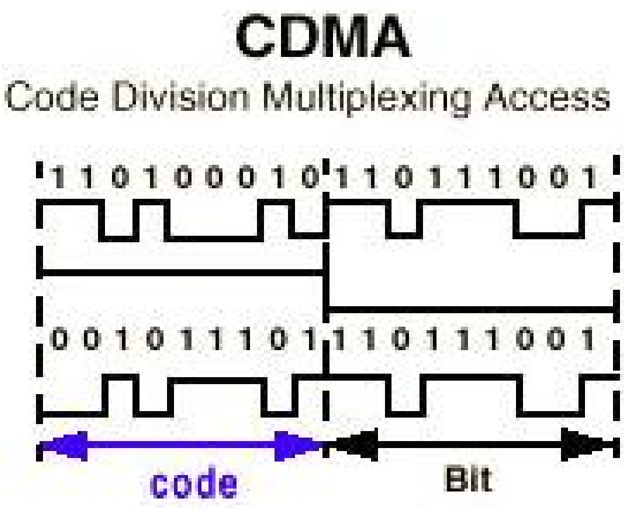
•Increased spectrum efficiency –5Mhz–

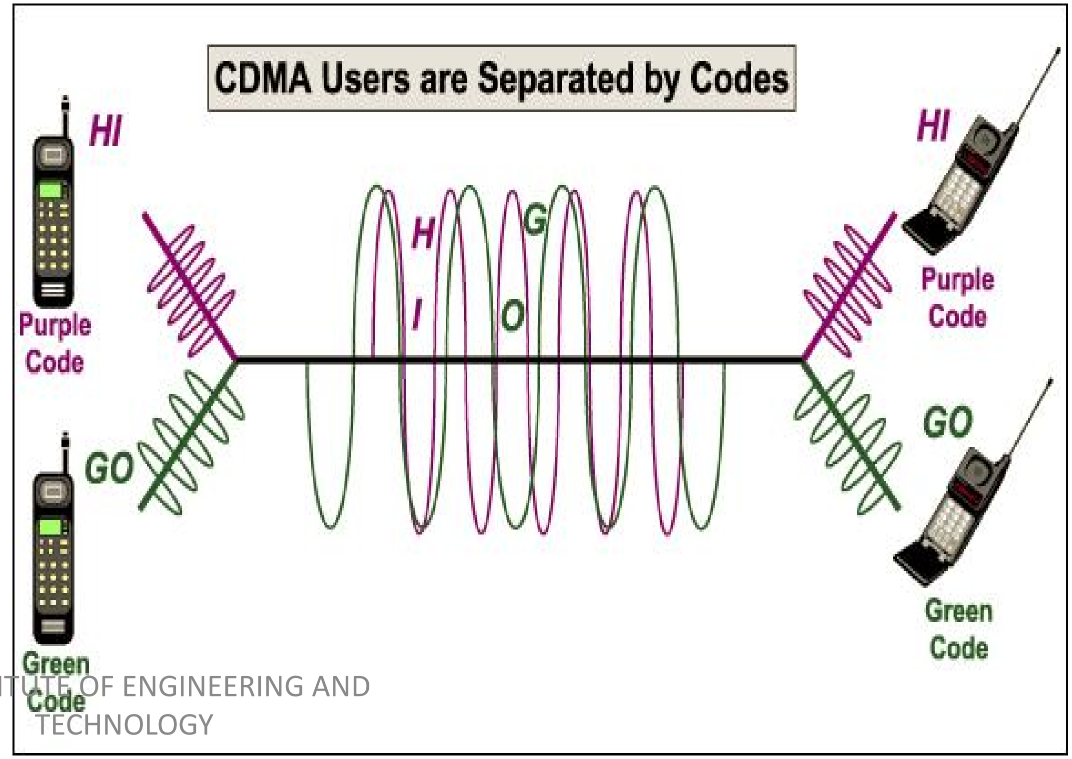
-A greater number of users that can be simultaneously supported by a radio frequency bandwidth.

- High data rates at lower incremental cost than 2G.
- Global roaming

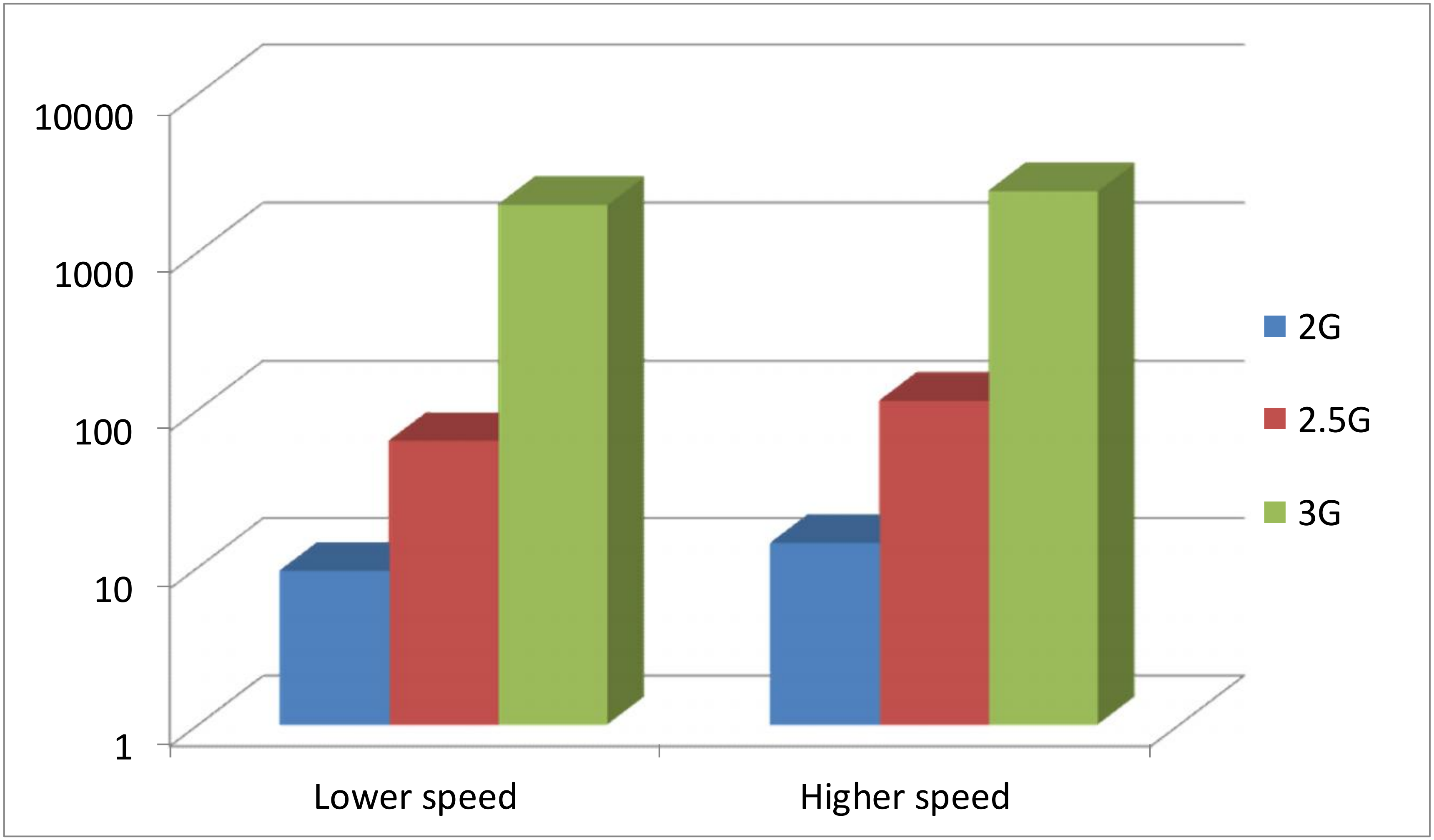
3G

- CDMA –Code Division Multiple Access.
- Does not divide up the channel by time or frequency.
- Encodes data with a special code associated with each channel.

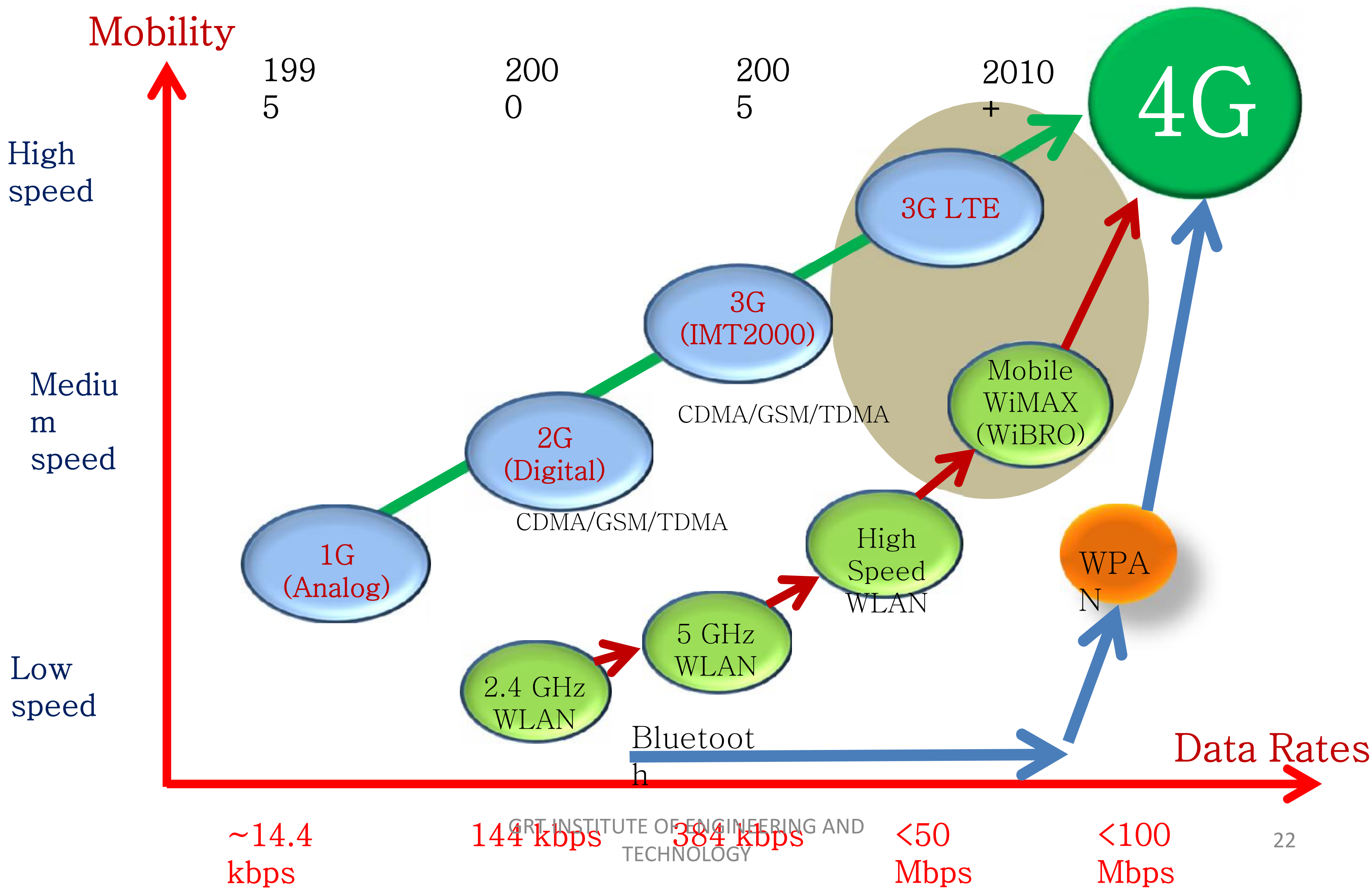




Data Rates Comparison (Kbps)



Technology moving towards 4G

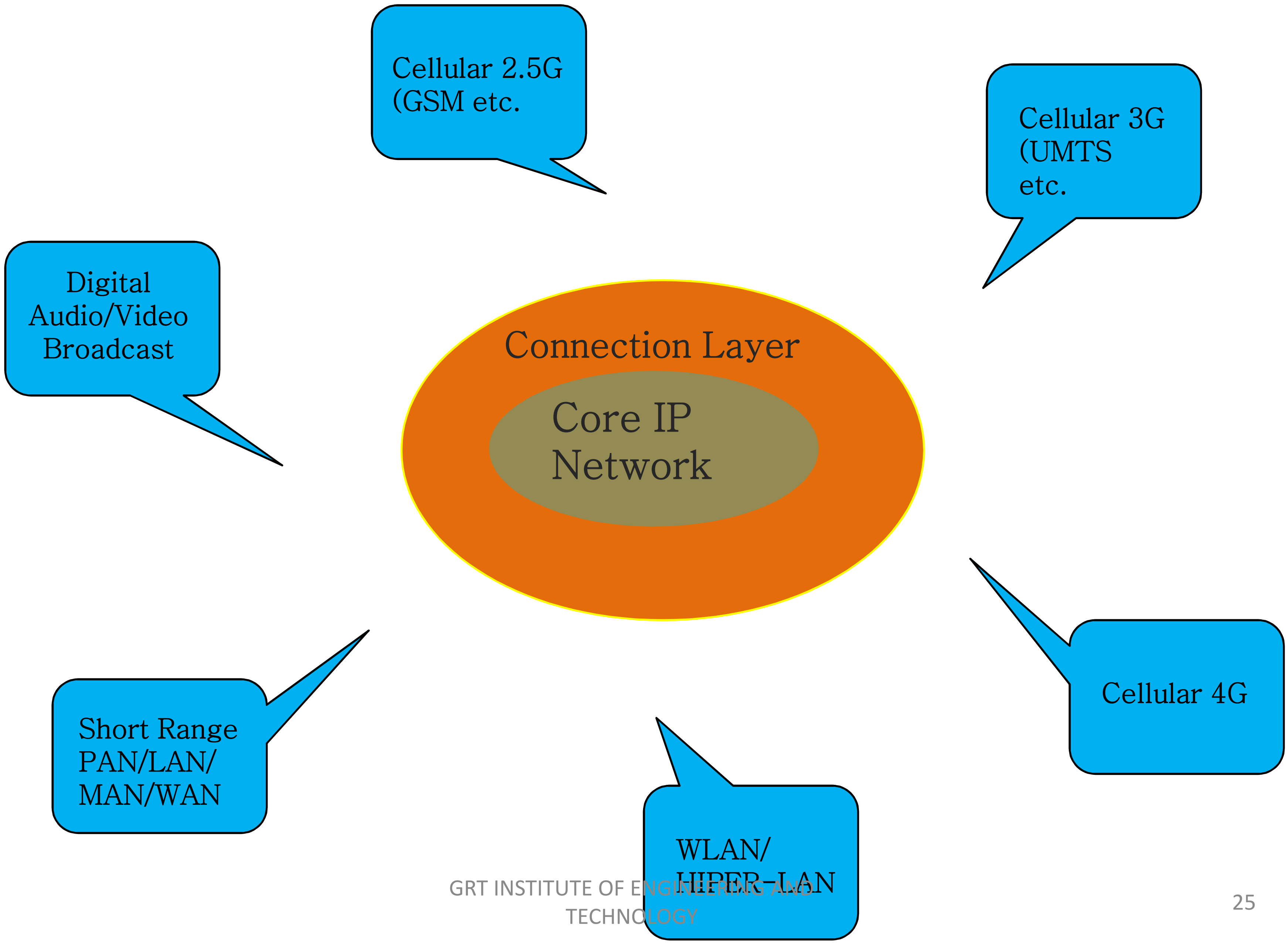


4G
Communication System

Seamless Roaming

- "Seamless" and "wireless," when put together, represent a technology of wireless Internet that hands you off to another network without interruption so you may continue your activities online without even noticing that you connected into another network. Another name for it is "**seamless roaming**."

Seamless Connection of Networks in 4G



vs.

Technology	3G	4G
Frequency Band	1.8 - 2.5GHz	2 - 8GHz
Bandwidth	5-20MHz	5-20MHz
Data Rates	Up to 2Mbps	100Mbps moving - 1Gbps stationary
Access	W-CDMA	VSF-OFCDM and VSF-CDMA
FEC	Turbo-codes	Concatenated codes
Switching	Circuit/Packet	Packet

Table 23.1 Comparison of key parameters of 4G with 3G.

Details	3G including 2.5G (EDGE)	4G
Major requirement driving architecture	Predominantly voice driven, data was always add on	Converge data and voice over IP
Network architecture	Wide area cell-based	Hybrid-integration of WLAN (WiFi, Bluetooth) and wireless wide-area networks
Speeds	384 kbps to 2 Mbps	20 to 100 Mbps in mobile mode
Frequency band	Dependent on country or continent (1.8 to 2.4 GHz)	Higher frequency bands (2 to 8 GHz)
Bandwidth	5 to 20 MHz	100 MHz or more
Switching design basis	Circuit and packet	All digital with packetized voice
Access technologies	WCDMA, cdma2000	OFDM and multicarrier (MC)-CDMA
Forward error correction	Convolutional codes rate ½, ⅓	Concatenated coding schemes
Component design	Optimized antenna design, multiband adapters	Smart antenna, software-defined multiband and wideband radios
Internet protocol (IP)	Number of airlink protocol including IPv5.0	All IP (IPv6.0)
Mobile top speed	200 km/h	200 km/h

- **Conclusion:**

- **4G** system provides an end to end IP solution where **voice** and **data streamed multimedia** can be served to users on an " **Anytime**, **Anywhere** " basis at **higher data rates** than previous generation.
- **Wider** bandwidth.
- End-to-end **QoS**.
- Higher **security**.
- Offering any kind of services **anytime**, **anywhere**.
- Affordable **cost** and one billing.

4G VISION

- The 4G systems are **projected to solve the still-remaining problems of 3G systems.**
- They are **designed to provide** a wide variety of new services**, from high-quality voice to high-definition video to high-data-rate wireless channels.**
- The term 4G is used broadly to include several types of broadband wireless access communication systems, not only cellular systems.

4G is described as MAGIC —

- **M**obile multimedia
- **A**nytime anywhere
- **G**lobal mobility support
- **I**ntegrated wireless solution and
- **C**ustomized personal service

- The 4G systems are about **seamlessly integrating terminals**, **networks**, and applications to **satisfy increasing user demands.**
- Accessing information anywhere, anytime, with a **seamless connection** to a wide range of information and services, and receiving a **large volume of information**, data, pictures, video, and so on, are the **keys of the 4G infrastructure.**
- The **future 4G systems** will consist of a **set of various networks** using IP as a common protocol.
- 4G systems will have **broader bandwidth, higher data rate, and smoother and quicker handoff** and will focus on ensuring seamless service across a multiple of wireless systems and networks.
- The **key is to integrate the 4G capabilities with all the existing mobile technologies** through the advanced techniques of digital communications and networking.

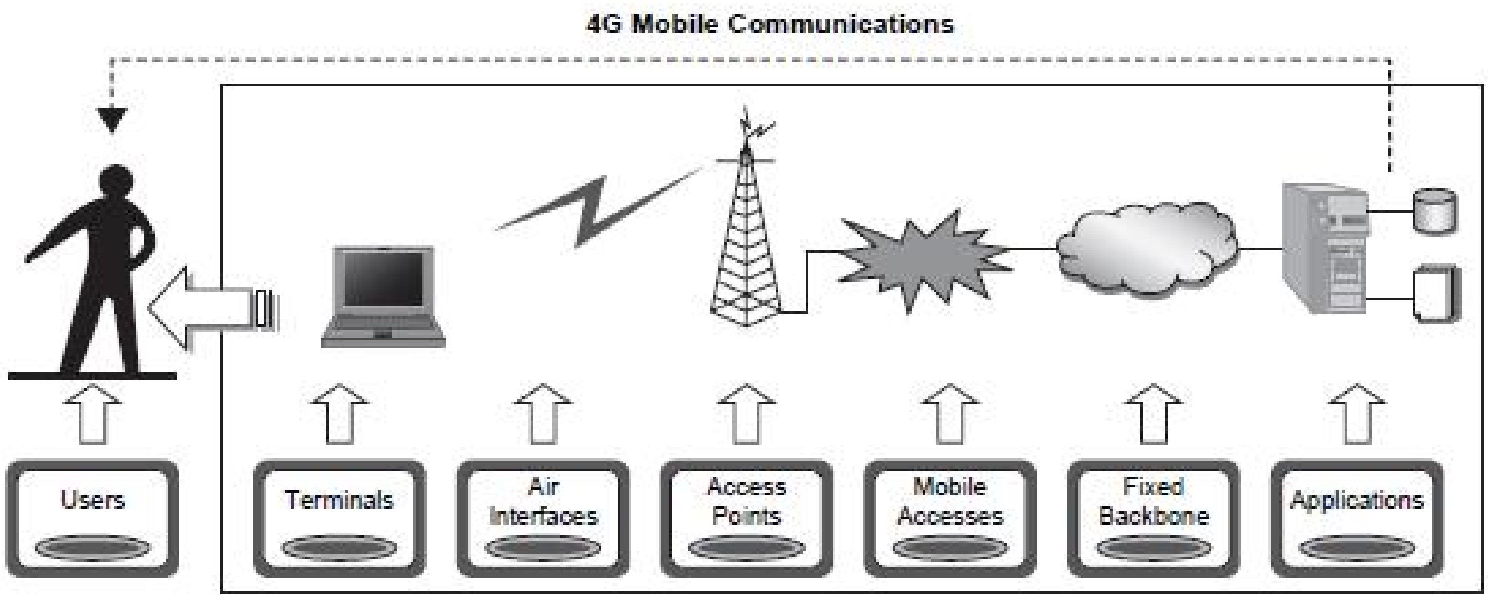


Figure 23.2 4G visions.

4G Features and Challenges

- Some key features of 4G mobile networks are as follows,
- **High usability:** anytime, anywhere, and with any technology
- **Support for multimedia services** at low transmission cost
- **Personalization**
- **Integrated services**

- 4G networks will be **all-IP-based heterogeneous networks** that will allow users to use any system at anytime and anywhere.
- Provides **data and multimedia services**.
- Personalized service will be provided by 4G networks.

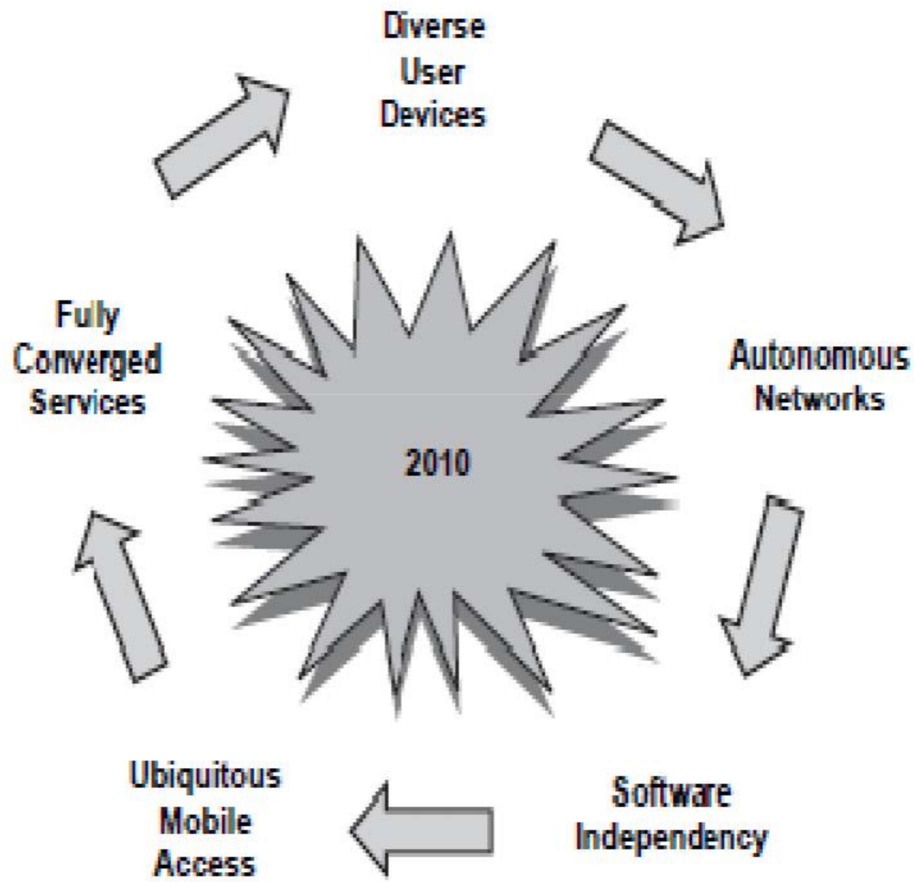


Figure 23.3 4G features.

- High Performance
- Interoperability And Easy Roaming
- Fully Converged Service
- Low Cost
- Scalability

CHALLENGES

- To migrate current systems to 4G with the above mentioned features we have to face a number of challenges.
- **Mobile station**
  - Multimode user terminals
  - Wireless system discovery
  - Wireless system selection
- **System**
  - Terminal mobility
  - Network infrastructure and QoS support
  - Security
  - Fault tolerance and survivability
- **Service**
  - Multioperators and billing system
  - Personal mobility

Mobile Station

- **Multimode user terminals**

Challenges:

- **To design a single user terminal** that can operate in different wireless networks, and overcome design problems such as **limitations in device size, cost power consumption, and backward compatibilities to systems.**

Proposed solutions:

- **A software-defined radio** approach can be used: the user terminal adapts itself to the wireless interfaces of the networks.

Wireless system discovery

Challenges:

- **To discover available wireless systems** by processing the signals sent from different wireless systems (with different access protocols and incompatible with each other).

Proposed solutions:

- **User- or system-initiated discoveries**, with **automatic download of software modules** for different wireless systems.

- **Wireless system selection**

Challenges:

- Every wireless system has its unique characteristics and role. The proliferation of wireless technologies **complicates the selection of the most suitable technology for a particular service at a particular time and place.**

Proposed solutions:

The wireless system can be **selected according to the best possible fit of user QoS requirements**, **available network resources, or user preferences.**

System

Terminal mobility

Challenges:

- **To locate and update the locations** of the terminals in various systems. Also, to perform *horizontal* (within the same system) and *vertical* (within different systems) handoff as required with **minimum handover latency and packet loss**

Proposed solutions:

- Signaling schemes and fast handoff mechanisms are proposed.

Network infrastructure and QoS support

Challenges:

- To **integrate the existing non-IP-based and IP-based systems**, and **to provide QoS guarantee** for end-to-end services that involves different systems.

Proposed solutions:

- A Clear and comprehensive **QoS scheme for the UMTS system has been proposed**. This scheme also **supports interworking** with other common QoS technologies.

Security

Challenges:

- The heterogeneity of wireless networks complicates the security issue. **Dynamic reconfigurable, adaptive, and lightweight security mechanisms** should be developed.

Proposed solutions:

- **Modifications in existing security** schemes may be applicable to heterogeneous systems. **Security handoff support for application sessions** is also proposed.

Fault tolerance and Survivability

Challenges:

- To **minimize the failures** and their **potential impacts** in any level of tree-like topology in wireless networks.

Proposed solutions:

- **Fault-tolerant architectures for heterogeneous networks and failure recovery protocols** are proposed.

Service

Multioperators and billing system

Challenges:

- **To collect, manage, and store the customers' accounting information from multiple service providers**. Also, to bill the customers with simple but detailed information.

Proposed solutions:

- **Various billing and accounting frameworks** are being proposed to achieve this goal.

Personal mobility

Challenges:

- To **provide seamless personal mobility to users without modifying the existing servers** in heterogeneous systems.

Proposed solutions:

- **Personal mobility frameworks** are proposed. Most of them use mobile agents, but some do not.

Applications of 4G

- The following are some of the applications of the 4G system:
- ***Virtual presence*** — 4G will provide user services at all times, even if the user is off-site.
- ***Virtual navigation*** — 4G will provide users with virtual navigation through which a user can access a database of streets, buildings, etc., of a large city. This requires high speed transmission.
- ***Tele-medicine*** — 4G will support the remote health monitoring of patients via video conference assistance for a doctor at anytime and anywhere.
- ***Tele-geo-processing applications*** — 4G will combine geographical information systems (GIS) and global positioning systems (GPS) in which a user will get location querying.
- ***Education*** — 4G will provide a good opportunity to people anywhere in the world to continue their education on-line in a cost-effective manner.

4G Technologies

Multicarrier Modulation

- Multicarrier modulation (MCM) is a **derivative of frequency-division multiplexing.**
- MCM is a **baseband process** that **uses parallel equal bandwidth sub channels to transmit information** and is normally implemented with fast Fourier transform (FFT) techniques.
- It is not a new technology currently used in DSL modems and Digital audio/video broadcast(DAB/DVB)

Advantages:

- Better performance in the inter-symbol-interference environment.
- Avoidance of single-frequency interferers.

Disadvantages:

- MCM increases the peak to-average ratio of the signal.
- To overcome inter-symbol-interference a cyclic extension or guard band must be added to the data.

DIFFERENCE(D)

- The difference, *D*, of the peak-to-average ratio between MCM and a single carrier system is a function of the number of subcarriers, *N*, as:

$$D(\text{dB}) = 10 \log N.$$

The signal to noise ratio of MCM is given as,

$$(\text{SNR})_{\text{loss}} = 10 \log \frac{L_b + L_c - 1}{L_b} \text{ (dB)}$$

- Where Lb is the original length of the code and Lc is the channel's response.

Two types of MCM

- Multicarrier code division multiple access (MC-CDMA) and
- Orthogonal frequency division multiplexing (OFDM) using time division multiple access (TDMA).

- The OFDM divides a broadband channel into many parallel subchannels.
- The subchannel pulse shape is a square wave .The OFDM receiver senses the channel and corrects distortion on each sub channel before the transmitted data can be extracted.
- In OFDM, each of the frequencies is an integer multiple of a fundamental frequency. This ensures that even though subchannels overlap, they do not interfere with each other

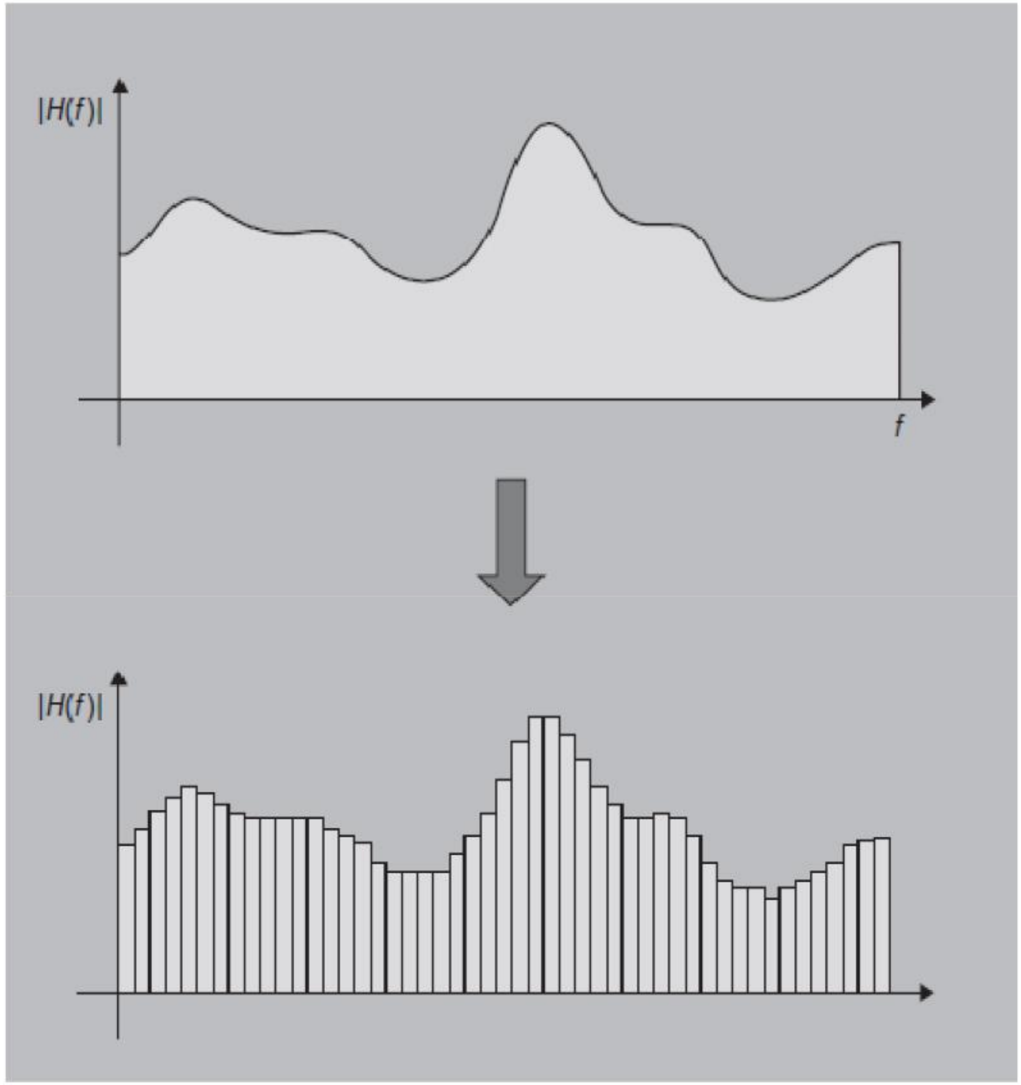


Figure 23.5 A broadband channel divided into many parallel narrowband channels.

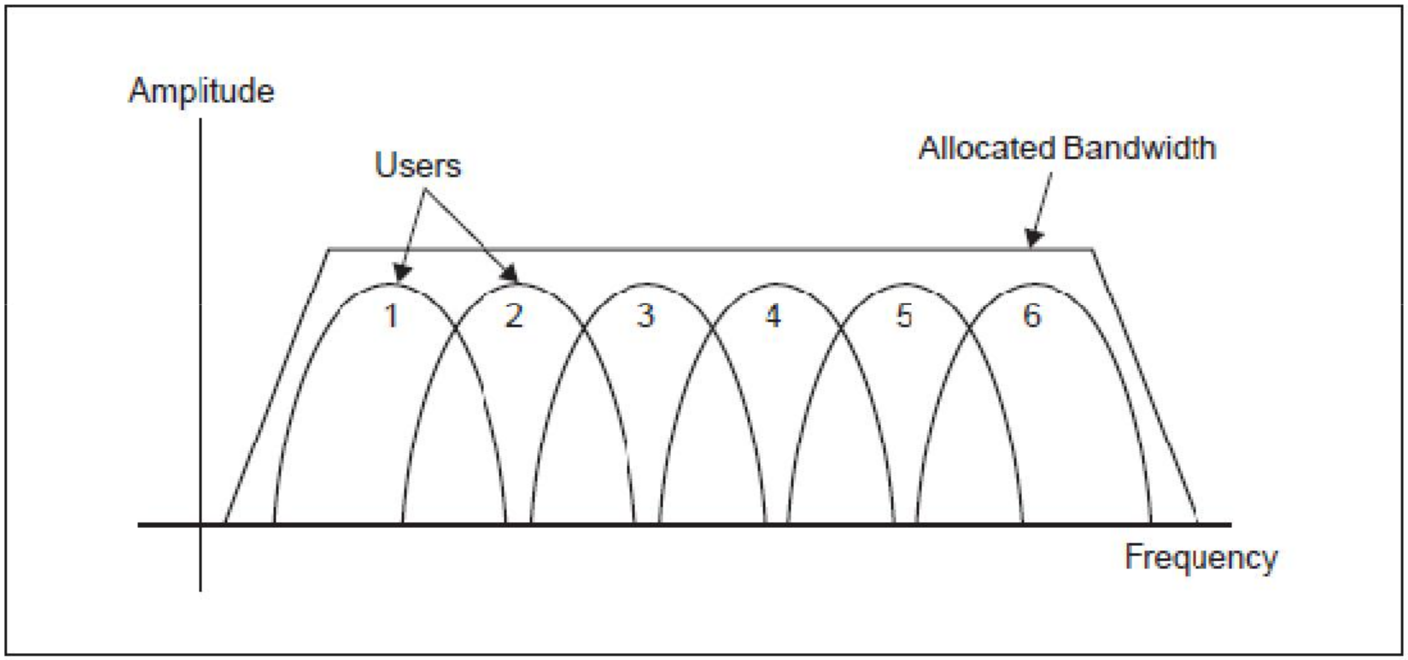


Figure 23.6 Overlapping subchannels.

Smart Antenna Techniques

- Smart antenna techniques, such as multiple-input multiple-output (MIMO) systems, can extend the capabilities of the 3G and 4G systems to provide customers with increased data throughput for mobile **high-speed data applications.**
- MIMO systems use multiple antennas at both the transmitter and receiver to increase the capacity of the wireless channel

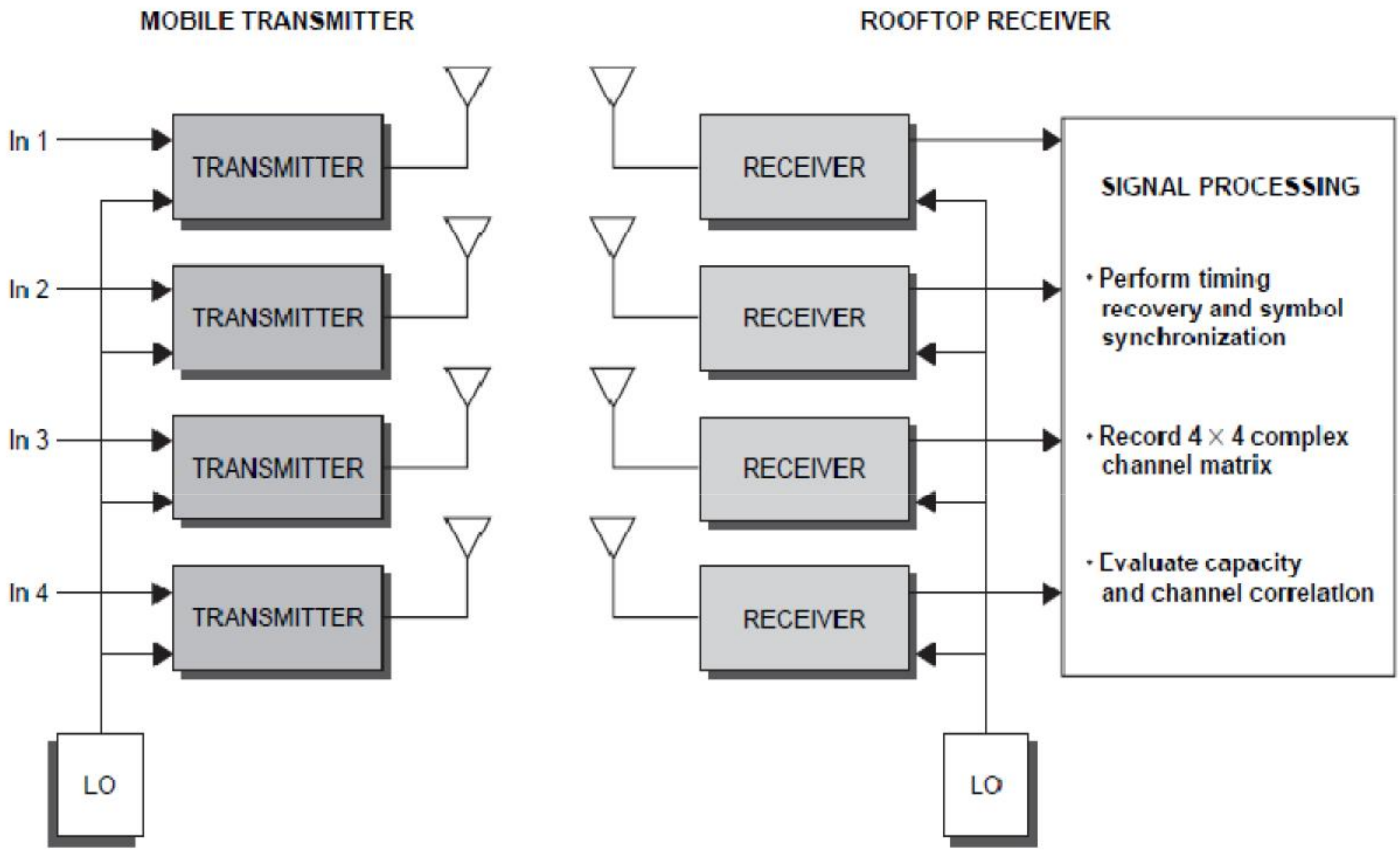


Figure 23.7 MIMO system.

- With MIMO, different signals are transmitted out of each antenna simultaneously in the same bandwidth and then separated at the receiver.
- With four antennas at the transmitter and receiver this has the potential to provide four times the data rate of a single antenna system without an increase in transmit power or bandwidth.

- The number of transmitting antennas is *M*, and the number of receiving antennas is *N*, where $N > M$. We examine four cases:
- Single-Input, Single-Output (SISO)
- Single-Input, Multiple-Output (SIMO)
- Multiple-Input, Single-Output (MISO)
- Multiple-Input, Multiple-Output (MIMO)

Single-input, single-output (SISO)

- A single antenna is used at the source and another single antenna is used at the receiver.
- The channel bandwidth is *B*, the transmitter power is *Pt*, the signal at the receiver has an average signal-to-noise ratio of SNR_0, then
- The Shannon limit on channel capacity *C* is

$$C = B \log 2 (1 + SNR_0)$$

Single-input, multiple-output (SIMO)

- There are *N* antennas at the receiver. If the signals received on the antennas have on average the same amplitude, then they can be added coherently to produce an N^2 increase in signal power.
- There are *N* sets of noise sources that are added coherently and result in an *N*-fold increase in noise power. Hence, the overall increase in SNR will be:

- Hence, the overall increase in SNR will be:

$$\text{SNR} \approx \frac{N^2 \times (\text{signal power})}{N \times (\text{noise})} = N \times \text{SNR}_0$$

- The capacity for this channel is approximately equal to

$$C \approx B \log_2 [1 + N \times \text{SNR}_0]$$

Multiple-input, single-output (MISO)

- We have *M* transmitting antennas. The total power is divided into *M* transmitter branches.
- If the signals add coherently at the receiving antenna, we get an *M*-fold increase in SNR as compared to SISO.
- Because there is only one receiving antenna, the noise level is same as SISO. The overall increase in SNR is approximately

$$\mathrm{SNR} \approx \frac{M^2 \cdot [(\text{signal power})/M]}{\text{noise}} = M \times \mathrm{SNR}_0$$

Multiple-input, multiple-output (MIMO)

- MIMO systems can be viewed as a combination of MISO and SIMO channels. In this case, it is possible to achieve approximately an *MN*-fold increase in the average SNR_0 giving a channel capacity equal to

$$C \approx B \log_2(1 + M \times N \times SNR_0)$$

- Assuming $N > M$, we can send different signals using the same bandwidth and still be able to decode correctly at the receiver.
- The capacity of each one of these channels is roughly equal to,

$$C_{\text{single}} \approx B \log_2\left(1 + \frac{N}{M} \times \text{SNR}_0\right)$$

- Since we have M of these channels (M transmitting antennas), the total capacity of the system is

$$C \approx MB \log_2\left(1 + \frac{N}{M} \times \text{SNR}_0\right)$$

OFDM-MIMO Systems

- OFDM and MIMO techniques can be combined to achieve high spectral efficiency and increased throughput.
- The OFDM-MIMO system transmits independent OFDM modulated data from multiple antennas simultaneously. At the receiver, after OFDM demodulation, MIMO decodes each subchannel to extract data from all transmit antennas on all the subchannels.

Adaptive Modulation and Coding with Time-Slot Scheduler

- In general, TCP/IP is designed for a highly reliable transmission medium in wired networks where packet losses are seldom and are interpreted as congestion in the network.
- On the other hand, a wireless network uses a time varying channel where packet losses may be common due to severe fading.
- This is misinterpreted by TCP as congestion which leads to inefficient utilization of the available radio link capacity.

- There is a need for a system with efficient packet data transmission using TCP in 4G.
- This can be achieved by using a suitable **automatic repeat request (ARQ)** scheme combined with an **adaptive modulation and coding system, and a time-slot scheduler** that uses channel predictions.
- This way, the lower layers are adapted to channel conditions while still providing some robustness through retransmission.
- The time-slot scheduler shares the spectrum efficiently between users while satisfying the QoS requirements.

- If the channel quality for each radio link can be predicted for a short duration (say about 10 ms) into the future and accessible by the link layer,
- Then ARQ along with an adaptive modulation and coding system can be selected for each user to satisfy the bit error rate (BER) requirement and provide high throughput.
- The scheduler uses this information about individual data streams and distributes the time slots among the users.

Cognitive Radio

- With the CR paradigm, spectrum can be efficiently shared in a more flexible fashion by a number of operators/users/systems.

- The CR can be viewed as an enabling technology that will benefit several types of users by,

- Introducing new communications and networking models for the whole wireless world,
- Creating better business opportunities for the incumbent operators
- New technical dimensions for smaller operators.
- Helping shape an overall more efficient approach regarding spectrum requirement.
- Usage in the next generation wireless networks.

- The CR focuses on applying software capabilities that have been developed to support algorithm control across a wide spectrum of signal processing technologies to add smarts to the software that allows it to determine when frequencies are free to use and then use them in the most efficient manner possible.

- Most of the research work currently is focusing on spectrum sensing cognitive radio — particularly on the utilization of TV bands for communication.
- The essential problem of spectrum sensing CR is the design of high quality sensing devices and algorithms for exchanging spectrum sensing data between nodes.
- It has been shown that a simple energy detector cannot guarantee accurate detection of signal presence.

- This calls for more sophisticated spectrum sensing techniques and requires that information about spectrum sensing be exchanged between nodes regularly.

- The goal of CR is to relieve radio spectrum overcrowding, which actually translates to a lack of access to full radio spectrum utilization.

Software-Defined Radio

- A software-defi ned radio (SDR) system is a radio communication system which uses software for the modulation and demodulation of radio signals.
- An SDR performs significant amounts of signal processing in a general purpose computer, or a reconfigurable piece of digital electronics.
- **The goal of this design is to produce a radio that can receive and transmit a new form of radio protocol just by running new software.**

- Software-defined radios have significant utility for cell phone services, which must serve a wide variety of changing radio protocols in real time.
- The hardware of a software-defined radio typically consists of a superheterodyne RF front end which converts RF signals from and to analog RF signals, and analog to digital converters and digital to analog converters,
- which are used to convert digitized intermediate frequency (IF) signals from and to analog form, respectively

- In the long run, SDR is expected to become the dominant technology in radio communications.
- The following are some of the things that SDR can do that haven't been possible before:

➢ Software-defined radios can be reconfi gured "on-the-fly," i.e., the universal communication device would reconfigure itself appropriately for the environment.

- It could be a cordless phone one minute, a cell phone the next, a wireless Internet gadget the next, and a GPS receiver the next.

- Software-defined radios can be quickly and easily upgraded with enhanced features. In fact, the upgrade could be delivered over-the-air.
- Software-defined radios can talk and listen to multiple channels at the same time.
- New kinds of radios can be built that have never before existed. Smart radios or cognitive radios (CRs) can look at the utilization of the RF spectrum in their immediate neighborhood and configure themselves for the best performance.