Advanced Communication Networks, Protocols and Services

Draft v0.6

Chapters 1-4

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1 INTRODUCTION-ARCHITECTURE REVISION

1.1 Networks Layered Architectures

Note : this part can be skipped for those who followed basic networking courses

1.1.1 General Principles and Functional Layers

Architectural Model : set of functions and relations between them, independent of implementation

Objective:

management of high complexity: ("divide et impera") - principle

interoperability among different products

Tools: definition of "functional layers" + interfaces

Network element: terminal, switching node, multiplexer, router, etc. = hierarchical set of levels

-tasks: - information transport (lower layers)

- high level processing of information (upper layers)

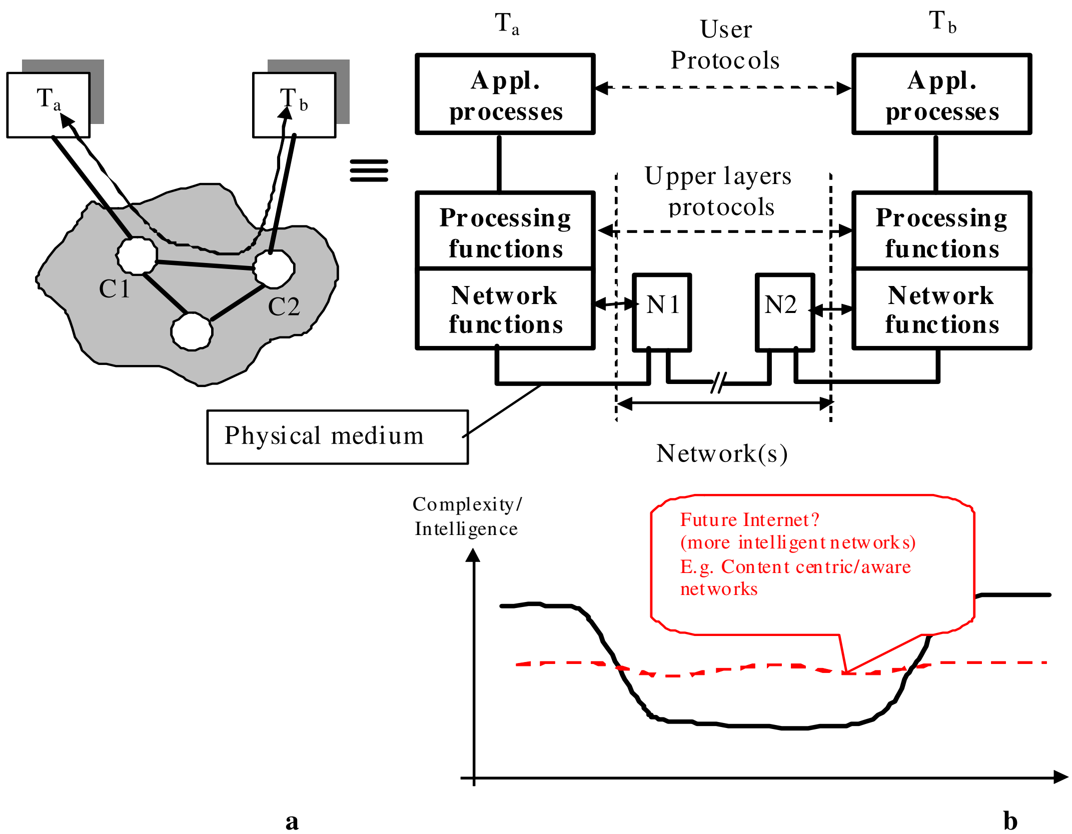

Figure 1-1 Simplified architectural model for communication

a. Network and terminals b.Two level model : T_a, T_b = terminals

- ***application processes*** (usually resident in T_a, T_b - they communicate through a set of rules (***protocol)*** at user level:

Protocols at different levels between:

- application processes
- higher layers processing functions (higher layers)
- network transport functions (lower layers)

- set of layers = ***protocol stack***

Layering principle is extended inside each of the two layer

1.1.2 OSI Reference Model

- **Classical architectural mode (1970-80)**

ISO ("International Standardization Organization"): **OSI - RM** ("Open System Interconnection - Reference Model") – for layered architecture networks

OSI – RM defines: architectural and functional principles for open systems – able to be interconnected no matter the equipment manufacturer

- real world stack can be different of OSI-RM, but the same principles are applied
- OSI, TCP/IP model – one plane architectural model

- **Usage examples of layered architecture networks use:**
  - all human activities domains
  - INTERNET = global network today
  - data, voice video, audio , MM, combinations
  - full geo span: LAN, MAN, WAN
    Newer: BAN, PAN, Spatial and multimedia networks:
  - Intranets, Extranets
  -digital telecommunication wide area networks:
    - fixed communications: ISDN, BISDN, GSM (e.g. – Signalling System No.7 SS7 – used to control the digital telecom networks)
    - networks for mobile communications 2G, 3G,
  - Integrated (convergent) networks
    - TCP/IP based, 3G, 4G, 5G- for fixed or mobile communications
    - Next Generation Networks (ITU-T) ~ 1995-2000
    - Future Internet: evolution/revolution for current Internet (> 2005)

- **Fundamental Architectural Principles:**
  - layer N offers to N+1 a service set
  - that can be accessed through interfaces **(SAP = "Service Access Point")**
  - **service implementation is achieved by the protocol of the lower layer**
  - ***service primitives*** - information transport between adjacent layers
  - **protocols- specify the rules of comm between two peer entities**
- **Criteria for function distribution on layers :**
  - **homogeneity** inside a layer
  - **minimal interactions between layers**
  - **small** number of layers

Note about word "service" usage

- very general term used in a lot of contexts
- much confusion out of this
- OSI model defines very precise semantic for "service"
- Adopting such semantic we distinguish among:
  - Low level services , e.g:
    - L2 service = "connectivity service between two nodes"
    - L3 service = "connectivity service over a network domain"
    - L4 service = E2E connectivity service
    -
  - High level services , e.g:
    - data oriented services: FTP, e-mail, web access to info, transactional services
    - multimedia-oriented services: VoIP, video conf, A/V –streaming, DVB, IPTV, etc.

- **Curent trends:**
  -traditionally we want/have low coupling between layers
  - today this principle is no longer considered good by all professional communities
    - "Cross-layer optimisation" especially in wireless on L1-L3
    - "Content aware networks" and "Network Aware Applications"
    - pros and cons this approach – still open issue

<u>Base</u> <u>layers</u> (1-3) (network access and information transfer through network(s)
<u>Upper</u> <u>layers</u> <u>(4-7)</u>
- higher layer processing functions (closer to user application processes)
- usually – layers 4-7 belong to terminals (end–to-end (E2E) protocols – independent of:
    - Network technology, Number of networks, Fixed or mobile mode

- Important Notes:
    - the same function name can be encountered on different layers but with different semantics
    - Not all functions listed must be present in a layer (large variety in practical stacks)

Layer 1 (Physical- PHY) ; **Layer 2 (Data Link Layer - DL); Layer 3 (Network) :**
Layer 4 (Transport T); Layer 5 (Terminal Session – S); Layer 6 (Presentation);
Layer 7 (Applicaţion) :

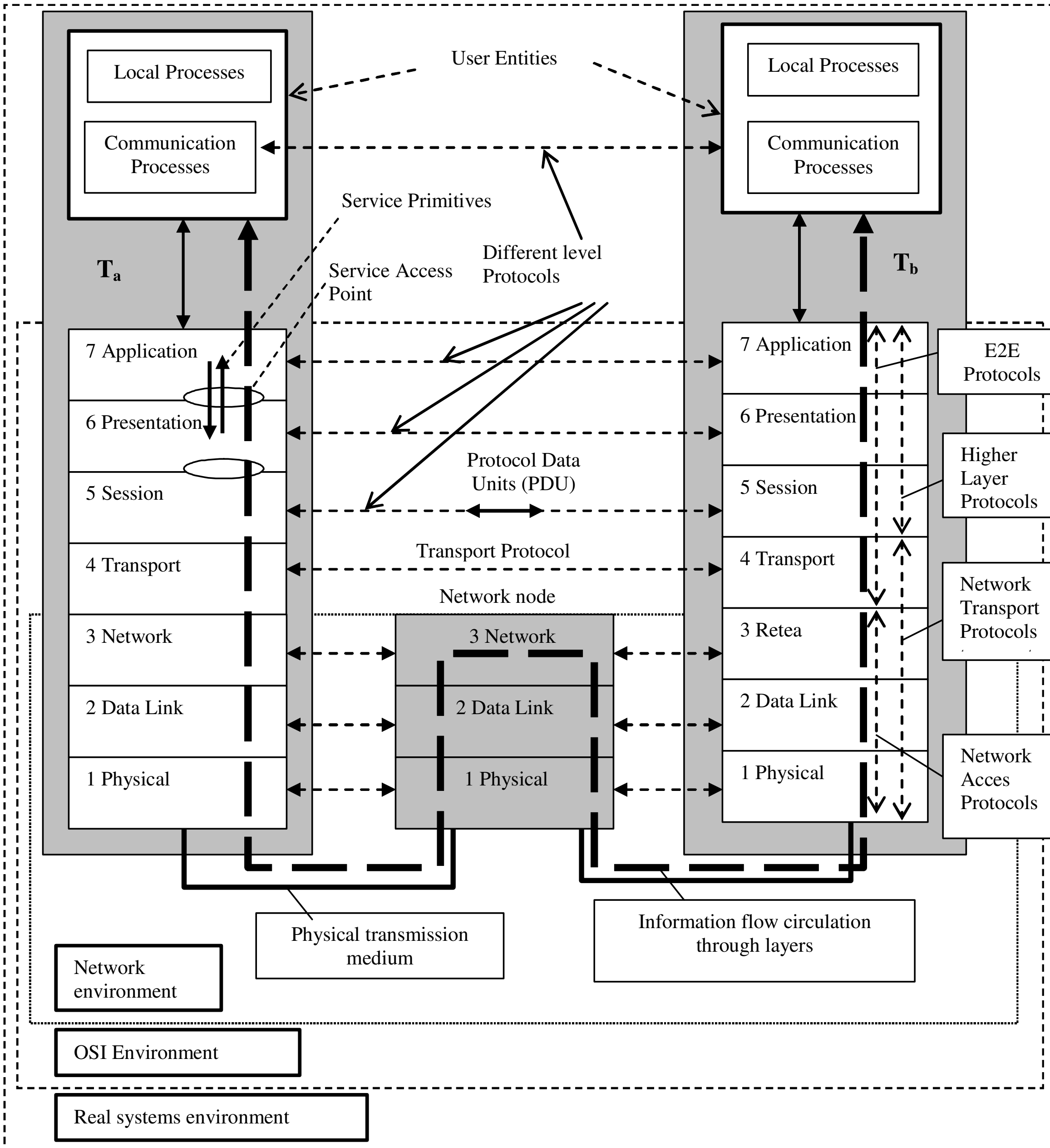

Figure 1-2 OSI Reference Model

1.1.3 Real Stack Examples. Incomplete stacks

1.1.3.1 TCP/IP Stack

- TCP/IP stack – different from OSI
- much greater success (history, simpler stack, market driven)
- WWW/Internet strengthened the usage of TCP/IP stack

- Important note:
  - Advances in microelectronics and huge increase of perf/cost allowed to include the full TCP/IP stack in all terminals (including small mobile devices)
  - This naturally creates the posibility to integrate all kind of high level services based on TCP/IP stack
  - That is why TCP/IP (called "Internet" is accepted today as a basis for full network and services integration

- **Communication models:**
  - Hierachy criterion
    - Classic model: *Client/server* (asymmetric one)
    - After 2000 Peer to peer (P2P) model
      - Symmetric model
      - huge expansion in last years (~70% of the total Internet traffic)
  - Time criterion
    - Synchronous communication (usually r.t: VoIP, AVC, VoD, but also FTP, etc.)
    - Asynchronous communication : e-mail, publish/subscribe
  - Mode to get information: push/pull

- **Original TCP/IP stack – single architectural plain containing several protocols for data transfer and control**

Application (communication between processes or applications on separate hosts)	FTP, E-mail, HTTP, SNMP, Voice, Video P2P Social nets apps
Transport (end-to-end data transfer service reliable or unreliable)	TCP, UDP, etc.
Network layer (network resources mng., routing the data to destination)	IP, MIP Routing : RIP, OSPF , BGP Control: ICMP, IGMP, , etc. QoS
Data link (acces CO or CL to network layer)	(LLC) + MAC
Physical layer	Wireline, wireless, optical

Figure 1-3 Simplified view of the TCP/IP protocol stack

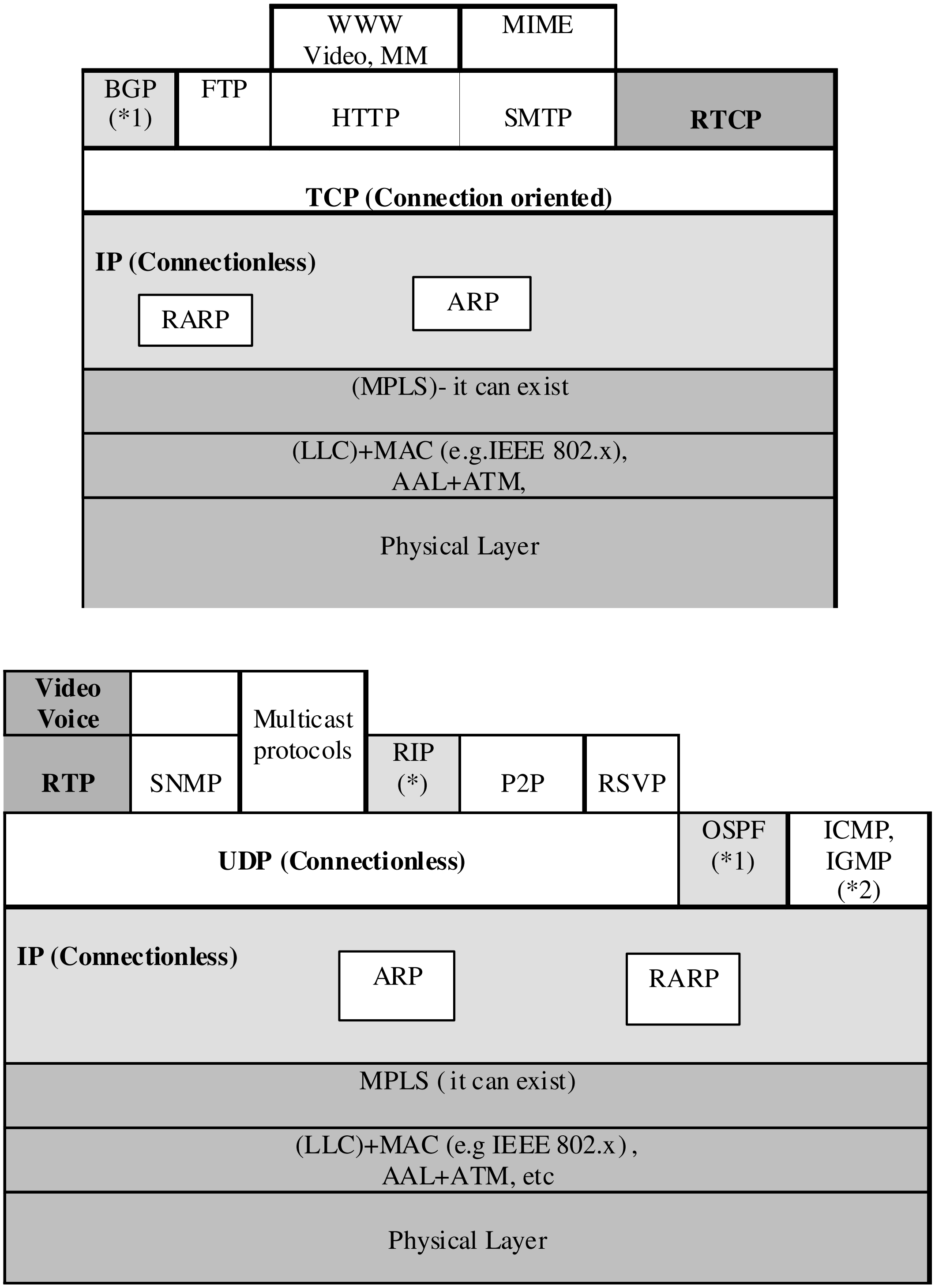

Figure 1-4 Example of TCP/IP stack protocols

(*1) – they are not transport protocols but cooperate with IP

MIME – Multipurpose Internet Mail Extensions
BGP – Border Gateway Protocol
HTTP – Hypertext Transfer Protocol
SMTP – Simple Mail Transfer Protocol
SNMP – Simple Network Management Protocol

FTP – File Transfer protocol

RTP – Real Time Protocol
ICMP – Internet Control Messages Protocol
IGMP – Internet Group Management Protocol
OSPF – Open Shortest Path First Protocol

Transport:
- TCP **–** Transmission Control Protocol (connection oriented -CO)
- UDP – User Datagram Protocol (connectionless CL)

Network: IP –Internet Protocol + ICMP, IGMP, BGP, OSPF
Data link Layer:
LLC – Logical Link Control + MAC- Medium acces Control
Example: AAL – ATM Adaptation Layer + ATM –Asynchronous Transfer Mode

Example: FTP, TCP, IP, (LLC) + MAC (driver Ethernet)

Multicasting:
IGMP – Internet Group Management Protocol (v.1, v.2, v.3)
Multicast routing protocols:
DVMRP – Distance Vector Multicast Routing Protocol
PIM-DM – Protocol Independent Multicast – Dense Mode
PIM-SM – Protocol Independent Multicast – Sparse Mode
CBT – Core based Tree
MOSPF – Multicast OSPF – multicast extension of OSPF
MBGP – Multicast BGP – extension of BGP to multicast
Multicast transport protocols:
RMTP – Reliable Multicast Transport Protocol
SRM – Scalable Reliable Multicast Protocol
MFTP – Multicast File Transfer Protocol
PGM – Pretty Good Multicast

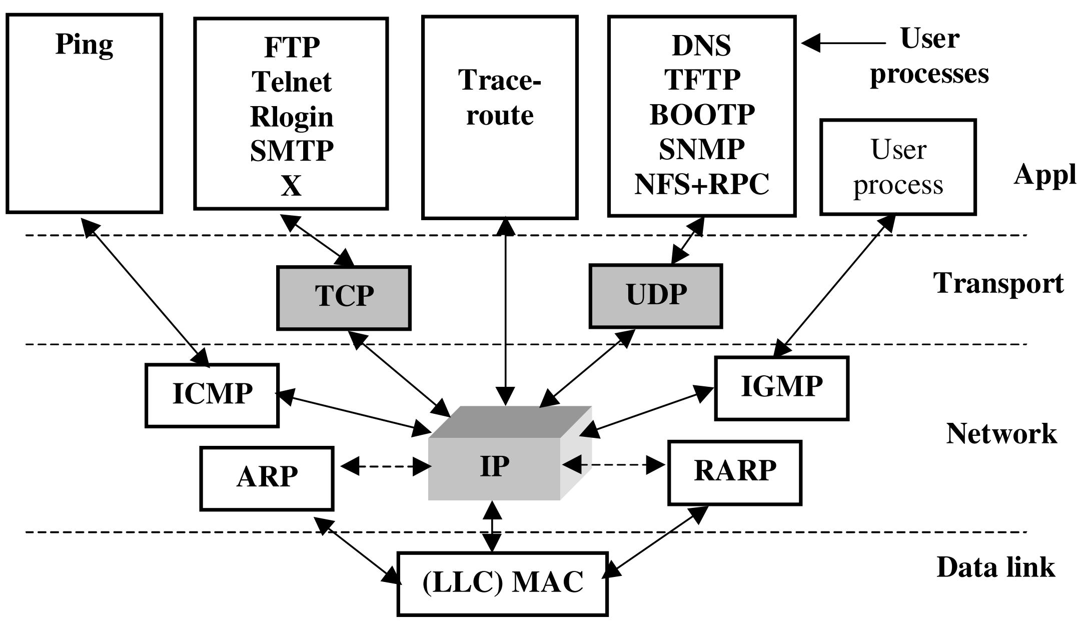

Figure 1-5 Example of logical links between layers

ARP – Address Resolution Protocol
RARP – Reverse Address Resolution Protocol
TFTP – Trivial FTP, BOOTP – Bootstrap Protocol

1.1.3.2 IEEE 802.x standards for LAN, MAN

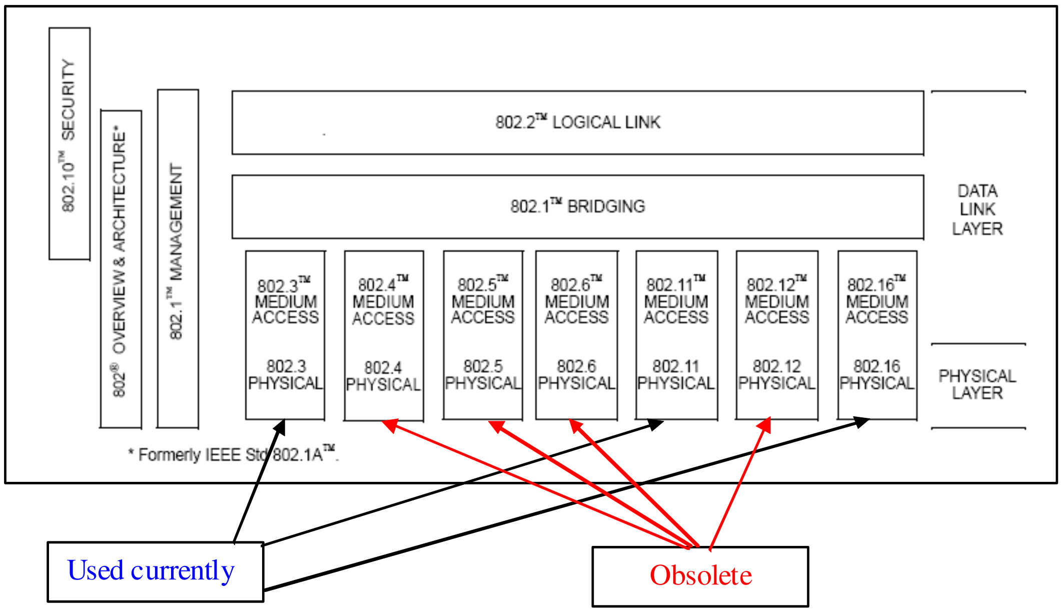

Figure 1-6 IEEE 802 LAN/MAN Standards- examples

Traditional LAN/MAN technologies
- IEEE 802.1Bridging (networking) and Network Management
- IEEE 802.2LLC inactive
- **IEEE 802.3 (highly used)**
- EthernetIEEE 802.4 Token bus (disbanded)
- IEEE 802.5 Defines the MAC layer for a Token Ring (inactive)
- IEEE 802.6MANs (disbanded)
- IEEE 802.7 Broadband LAN using Coaxial Cable (disbanded)
- IEEE 802.8 Fiber Optic TAG (disbanded)
- IEEE 802.9 Integrated Services LAN (disbanded)
- IEEE 802.10 Interoperable LAN Security (disbanded)
- **IEEE 802.11 a/b/g/nWireless LAN (WLAN) & Mesh (Wi-Fi certification) (highly used)**
- IEEE 802.12100BaseVG (disbanded)
- IEEE 802.13 Unused
- IEEE 802.14 Cable modems (disbanded)

Newer technologies
- **IEEE 802.15 Wireless PAN**
- **IEEE 802.15.1Bluetooth certification**
- IEEE 802.15.2 IEEE 802.15 and IEEE 802.11 coexistence
- IEEE 802.15.3 High-Rate wireless PAN
- IEEE 802.15.4 Low-Rate wireless PAN (e.g., ZigBee, WirelessHART, MiWi, etc.)
- IEEE 802.15.5 Mesh networking for WPAN
- **IEEE 802.16 Broadband Wireless Access (WiMAX certification)**
- IEEE 802.16.1 Local Multipoint Distribution Service
- IEEE 802.17 Resilient packet ring
- IEEE 802.18 Radio Regulatory TAG
- IEEE 802.19 Coexistence TAG

- IEEE 802.20 Mobile Broadband Wireless Access
- **IEEE 802.21 Media Independent Handoff**
- IEEE 802.22Wireless Regional Area Network
- IEEE 802.23 Emergency Services Working GroupNew (March, 2010)

1.1.3.3 Signalling System No.7

SS7:

- datagram virtual network for digital circuit switching network (ex. ISDN, GSM) control
- **Control plane** for Telecom Digital Network – containing the signaling protocols

Example for GSM - MSC:
(MSC- Message Switching Centre – main switch in GSM)
- MTP 1-2-3 – subsystem for message transport (layers 1-3)
- Layers 4-5-6 : void
- signaling applications : TUP, ISUP, MAP, etc

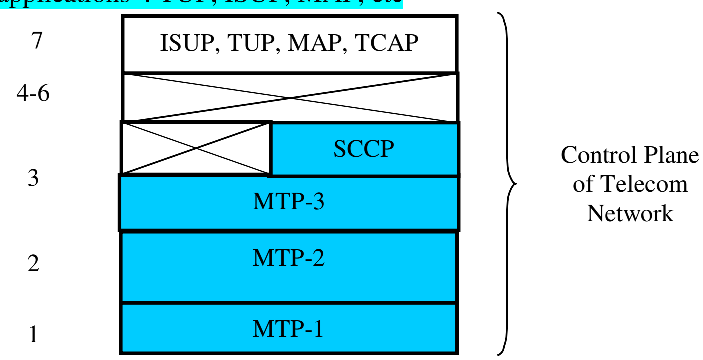

Figure 1-7 Example of incomplete stack: SS7 signalling stack

Signalling Connections Control Part (SCCP) – optionally completes the L3 (CO mode for L3)
- applications :
TCAP -"Transaction Capabilities Application Part" - realizes a common general transaction service offered to other applications
Transaction : communication of type query/response (suitable for low volume of information transfer)

- **Examples of signalling applications :**

TUP - "Telephonic User Part"- telephonic call control
ISUP - "ISDN User Part" - ISDN call control
MAP - "Mobile Application Part" – mobility control in GSM
All these applications use the message transport part MTP1-3
in CL mode (if they work directly over MTP 3)
in CO mode (if they work directly over SCCP)

1.1.3.4 MPLS architecture

- **Packet Routing and Forwarding in IP Networks**
  - **Routing** = intelligent set of actions = paths/route computation by using some algorithms embedded in routing protocols
  - **Forwarding** = low level set of actions consisting in directing an arrived packet towards an output interface

- Each IP hop runs its own instance of the routing algorithm→ fill *forwarding table*
- IP forwarding is done independently at every hop (router)
- IP forwarding decision is made on:
  - Destination address extracted from the packet header,

- Forwarding table contents
- ***Note:*** *Searching in routing table- time consuming operation done for every packet (bcause the global IP address is long – e.g. 32 bits in IPV4, the router cannot have a flat tableof* 2^{32} *words dimension (too expensive). So, a router only stores the needed addresses and therefore*
  - *lower memory dimension is needed*
  - *but search operation is necessary for each packet*

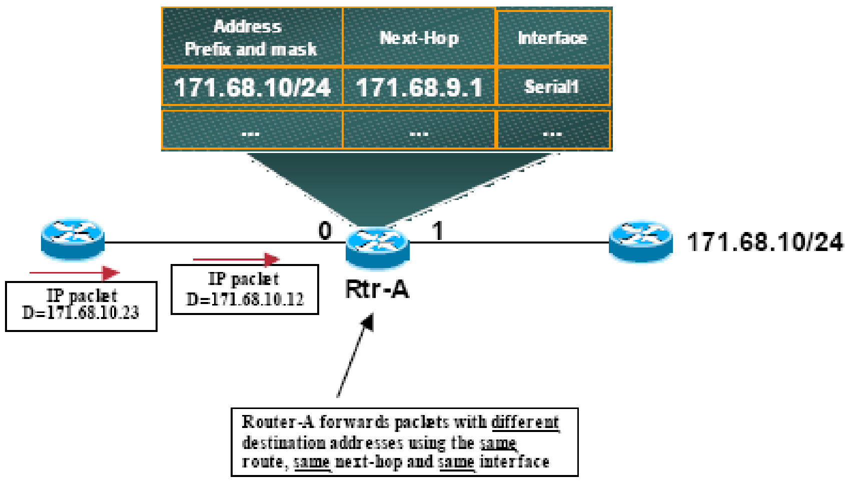

Figure 1-8 IP routing example (Cisco Systems)

- **MPLS ideas**
  - Packet forwarding is done based on *label switching* (not based on IP addresses, no search in the forwarding table of routers) Labels are short (20 bits) – allow indexed addressing- fast switching
  - Labels are assigned *when the packets enter into the network (edge)*
  - Assignment is *result of classification at the ingress node in a MPLS domain (criteria: destination, VPN, QoS, TE, Multicast…)*
  - Packets are classified in *Forwarding Equivalence Classes (FEC)*
  - Each FEC gets a label associated with a link segement between two nodes
    - label is a local *"address"* and not a global one as the IP address, that is why it can be short (20 bits)
  - Labels are *added in front* of the IP packets
  - Special control protocols *(Label Distribution Protocols- LDP)* distribute labels between nodes
  - At each node "label switching" is performed
  - Labels are removd at the egress of the MPLS domain

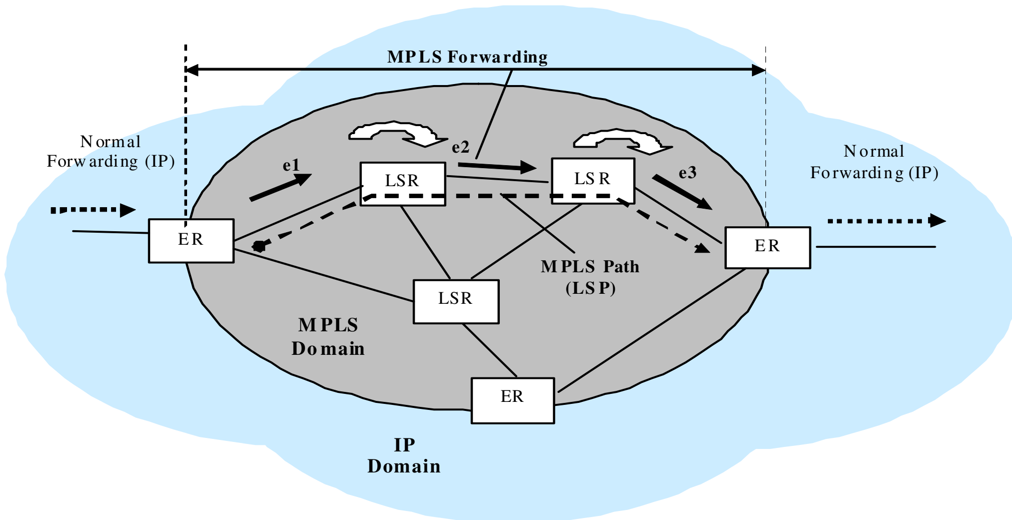

Figure 1-9 Packet forwarding along a Labes Switched Path (1)

LER – (*"Label **E**dge **R**outer")* –boundary node
LSR – (*"Label Switch Router")* – internal node
LSP - *„**L**abel **S**witched **P**ath")*- MPLS path

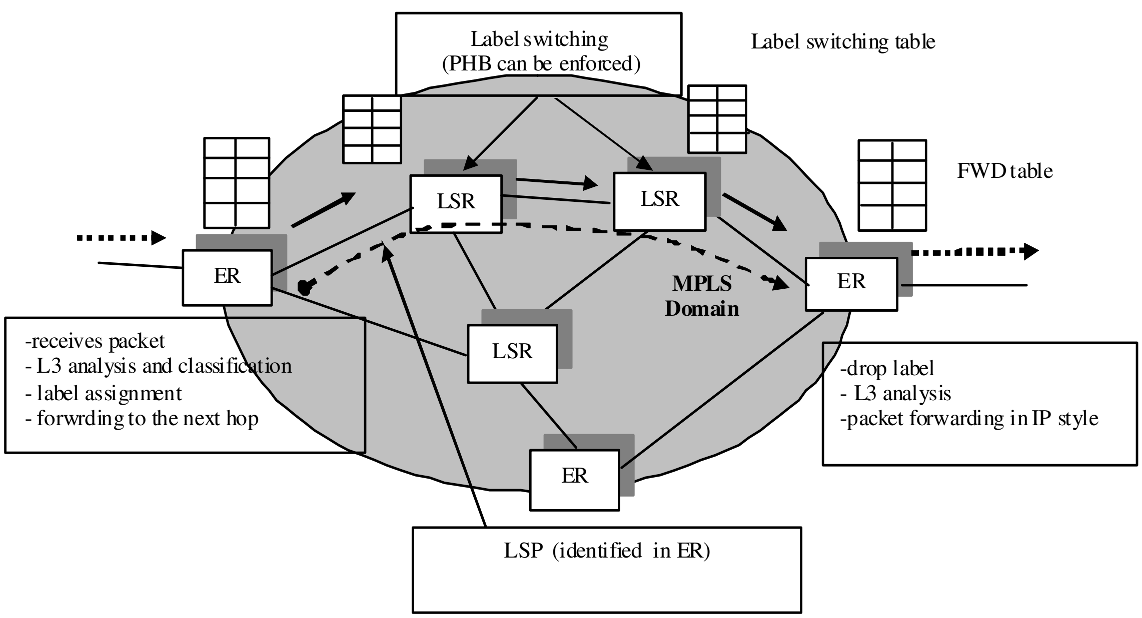

Figure 1-10 Packet forwarding along a Labes Switched Path (2)

*PHB –**P**er **H**op **B**ehaviour* – special set of packet processing functions in a node – to control *Quality of Services* QoS

1.1.3.4.1 MPLS IP stack

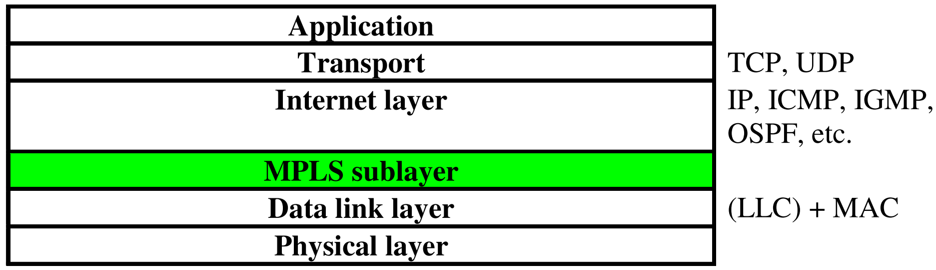

Figure 1-11 MPLS oriented IP stack

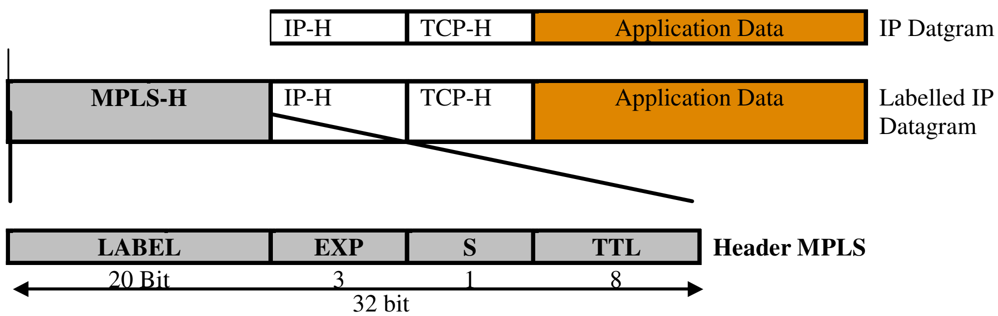

Figure 1-12 MPLS label adding

MPLS advantages related to traditional IP forwarding:

- keeps the routing protocols unchanged, but faster forwarding (HW)
- any L2, L3
- emulate circuit switching but with dynamic transport pipes
- flexible classification of the input packets in Forwarding Equivalence Class
- traffic engineering capabilities (resilience)
- QoS control capabilities and guarantees (cooperation with DiffServ, IntServ)
- VPN capabilities (largely used in practice)
- separation Control plane/Data plane (~ as in new technology Software Defined Networking)
- it can be used in optical networks (GMPLS)

MPLS drawbacks related to traditional IP forwarding:

- less flexibility (partially MPLS has circuit switching similar behaviour)- MPLS paths should be constructed in advance via additional protocols in Control Plane
- more complex control plane (LDP, etc.)
- need more careful planning if reliability is wanted (backup MPLS paths)

1.2 Multiple Planes Architectures

1.2.1 Principles

Ongoing standardization : IETF, ITU-T ETSI, IEEE, 3GPP

- Telecom originated layered architectures: more than one architectural plane
- IETF (TCP/IP- Internet) stack – originally only one plane

Nowadays- recognized the need of defining several cooperating architectural planes

Reasons: Real systems/networks deals with:

- user data flow transfer
- network resources (paths, links, buffers, etc.) should be controlled
  - short time scale, long time scale

- high level services should be controlled (short and long time scale)

Architectural Planes

- **Data plane (DPl)-** transport of user data traffic directly:
    - Examples of functions: traffic classification, packet marking traffic policing, traffic shaping, buffer management, congestion avoidance, queuing and scheduling
    - transfer the user data flows and accomplish the traffic control mechanisms to assure the desired level of QoS
- **Control plane (CPl)**
    - **controls the** pathways for user data traffic: e.g. Admission control, Routing, Resource reservation.
    - short term actions for resource and traffic engineering and control, including routing. In multi-domain environment the *MPl* and also *CPl* are logically divided in two sub-planes: inter-domain and intra-domain. This approach allows each domain to have its own management and control policies and mechanisms.
- **Management plane (MPl)**
    - the operation, administration, and management aspects of the resources and services to serve user data traffic: Monitoring, Management Policies (management based not on fixed configuration of network elements but on set of rules), Service Management, Service and network restoration.
    - long term actions related to resource and traffic management in order to assure the desired QoS levels for the users and also efficient utilization of the network resources

- Examples of early multiple plane architectures (DPl + CPl + MPl):

  ISDN , GSM, BISDN
  - reason: telecom design philosophy (user data have been seen long time ago - from the beginning of telecom systems as separate entities from signalling and management) data s
- TCP/IP :

  - Initially: *mono-plane* (data + control + management)
  - Currently it becomes multi-plane (DPl + CPl + MPl)
  New stacks- multiple plane: IEEE802.16, 3G, 4G

1.2.2 Signalling Issues

Signaling = actions performed in the control plane :

- convey application (or network) performance requirements
- reserve network resources across the network
- discover routes
- general control messages
- QoS related signalling

QoS signaling : *in band* or *out of band*.

In band

- signalling info is part of the associated data traffic(typically presented in a particular header field of the data packets. –(e.g., the TOS field in IPv4 as in DiffServ and 802.1p)
- Performed in the data plane ⇒ neither introduces additional traffic into the network nor incurs setup delay for the data traffic.
- not suitable for resource reservation or QoS routing, which needs to be done a priori before data transmission
- in-band signaling by definition is path-coupled (signaling nodes must be collocated with routers)

Out of band
- signalling info - carried by dedicated packets, separate from the associated data traffic. - introduces extra traffic into the network and incurs an overhead for delivering desired network performance
 it entails the use of a *signaling protocol* and further processing above the network layer, which tends to render slower responses than in-band signaling.
- lends itself naturally to resource reservation or QoS routing.
- depending on whether the signaling path is closely tied to the associated data path, signaling is *path-coupled* or *decoupled*

Path-coupled
- signaling nodes must be collocated with routers
signaling messages - routed only through the nodes that are potentially on the data path.
- advantage of reduced overall signaling processing cost (since it leverages network- layer routing tasks)
 - disadvantage of inflexibility in upgrading routers or in integrating control entities (e.g., policy servers) not on the data path (or nontraditional routing methods)
 If a path-coupled mechanism involves a signaling protocol, routers need to support the protocol and be able to process related signaling messages
- Example of a path-coupled signaling protocol : RSVP

Path-decoupled
- signaling messages are routed through nodes that are not assumed to be on the data path
only out-of-band signaling may be path-decoupled. (to date, most out-of-band QoS signaling schemes are path coupled.)
- signaling nodes should be dedicated and separate from routers
 - advantage of flexibility in deploying and upgrading signaling nodes independent of routers or in integrating control entities not on the data path
- disadvantage of added complexity and cost in overall processing and operational tasks.

Example: Session Initiation Protocol for VoIP, videoconference, etc.

Standardization Effort
- **NSIS (Next Step in Signalling)**

- Standards efforts underway specifically dealing with QoS signaling- e.g. IETF ***nsis*** working group
- developing a flexible signaling framework with path-coupled QoS signaling as its initial major application
- a QoS signaling protocol defined under the framework - expected to address the limitations of RSVP
 On path-decoupled signaling there seems **not enough support** in the IETF for a new project after some explorative discussion

1.3 Business Models for (Multimedia) Communication Architectures

Note: this is a summary- see details in ANNEX 1

1.3.1 Customers and Users

- ***Customer (CST)*** **(may be a "subscriber")** :
  - entity, having legal ability to subscribe to QoS-based services offered by ***Providers*** **(PR)** or ***Resellers (RS)***
  - target recipients of services: ***CST/PR*** or ***CST/RS*** interaction
  - Examples of CS: Householders, SMEs, large corporations, universities or public organisations
    - **Service Level Agreements** (SLA)- concluded between CS and providers

  CST differentiation by : size , type of business, type of services required

- **End User (EU)**
  - entity (human or process) - actually requesting/accessing and using the QoS-based services cf. SLAs

- EUs are end-users of the services, they can only exist in association with a *CST*

Note: In the current public internet, the majority of users are "subscribers" for Connectivity services only and maybe for a small subset of high level services (e.g e-mail)

- there is no SLA concluded for high level services quality; e.g for media A/V streaming, IPTV, etc.
- best effort access to high level services is practised but with no guarantees

Currently the EU can be both content consumer and conetnt producer ("Prosumer")

1.3.2 Providers (PR)

PR types :

- ***(High Level) Service Providers (SP)***
- ***IP Network Providers (NP)***
- ***Physical Connectivity Providers (PHYP) (or PHY infrastructure Providers)***
- ***Resellers (RS)***
- ***Content Providers (CP)***

Network Providers (NPs)

- offer IP **connectivity services** (maybe with QoS assured)
- own and administer an IP network infrastructure
- may interact with *Access Network Providers'* (ANP) or CS can be connected directly to NPs
- Expanding the geographical span of NPs
- Interconnected NPs - corresponding peering agreements
- IP NPs differentiation: small (e.g. for a city) , medium (region) and large (e.g. continental)

(High Level) Service Providers (HLSP or SPs)

- offer higher-level (possible QoS-based) services e.g. : e-mail, VoIP, VoD, IPTV, A/VC, etc.
- owns or not an IP network infrastructure
- administer a logical infrastructure to provision services (e.g. VoIP gateways, IP videoservers, content distribution servers)
- may rely on the connectivity services offered by NPs (SPs Providers' interact with NPs following a customer-provider paradigm based on SLAs
- expanding the geographical scope and augmenting the portfolio of the services offered $\Rightarrow$ SP may interact with each other
- size : small, medium and large

Physical Connectivity Providers (PHYP)

- offer physical connectivity services between determined locations
- services may also be offered in higher layers (layer-3 e.g. IP), (but only between specific points)
- distinguished by their target market:
  - ***Facilities (*****Infrastructure*****) Providers (FP)***
  - ***Access Network Providers (ANP)* (could be seen as distinct stakeholders)**

FPs services - are mainly offered to IP NPs (link-layer connectivity , interconnect with their peers
FPs differentiation : size of technology deployment means

ANPs - connect CST premises equipment to the SPs or NPs equipment
- own and administer appropriate infrastructure
- may be differentiated by
  - technology (e.g. POTS, FR, ISDN, xDSL, WLAN, Ethernet, WiMAX, hybrid)
  - their deployment means and their size
- may not be present as a distinct stakeholder in the chain of QoS-service delivery
- may be distinct administrative domains, interacting at a business level with SPs /NPs and/or CSTs

Interactions between Providers

- mainly governed by the legislations of the established legal telecom regulation framework
- may follow a customer-provider and/or a consumer-producer paradigm on the basis of SLAs

Reseller (RS)

- intermediaries in offering the services of the PRs to the CSTs

RSs examples: Dealers, electronic/computers commercial chains, service portals

Content Provider (CP)

- an entity (organisation) gathering/creating, maintain, and distributing digital information.
- owns/operates hosts = source of downloadable content
- might not own any networking infrastructure to deliver the content
- content is offered to the customers or service providers.
- can contain : Content Manager(CM); several Content Servers (CS

New enties (in the perspective of Future Internet)

Virtual Network Provider (VNP)

- composes and configures and offer Virtual Network slices, i.e., a set of virtual resources at request of higher layers, as a consequence of its provisioning policy or during self-healing operations
- this approach avoids for the higher layers to establish direct relationships with infrastructure providers and to take care of inter-domain connections at physical layer.

Virtual Network Operator (VNO)

- manages and exploits the VNEt s provided by VNPs , on behalf of HLSPs or end users

Note: the same organisational entity migh play the both roles :VNP and VNO

1.3.3 Multiple Plane Architecture and Business Actors

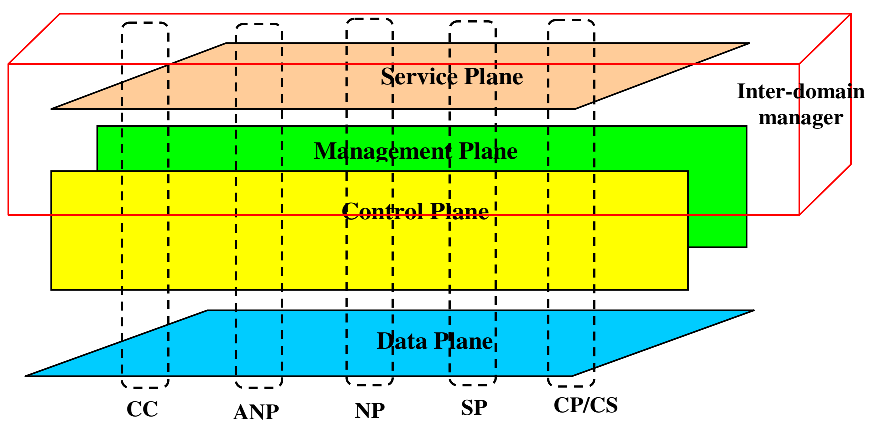

Figure 1-13 Example: generic arh. multi-domain multi-plane

- ***"Business" actors***

High Level - Service Providers (SP)
Content Providers (CP) (can own separate Content Servers- CS)
Connectivity Services - Network Providers (NP)
Content Consumers (CC)
Access Services - Network Providers (AC)

- Any actor might have several roles

1.3.4 Service Level Agreements/Specifications (SLA/SLS)

SLA

- **it is a contract :** documented result of a negotiation between a *customer* and a *provider* of a service that specifies the levels of availability, serviceability, performance, operation or other attributes of the transport service
- SLA contains *technical* and *non-technical* terms and conditions
- May be established offline or online (using negotiation oriented-protocols)

Service Level Specification (SLS)

- It is a part of SLA
- SLS = set of technical parameters and their values, defining the service, offered by the provbider to the customer
  - e.g. service offered to a traffic stream by a network domain (e.g. Diffserv domain)

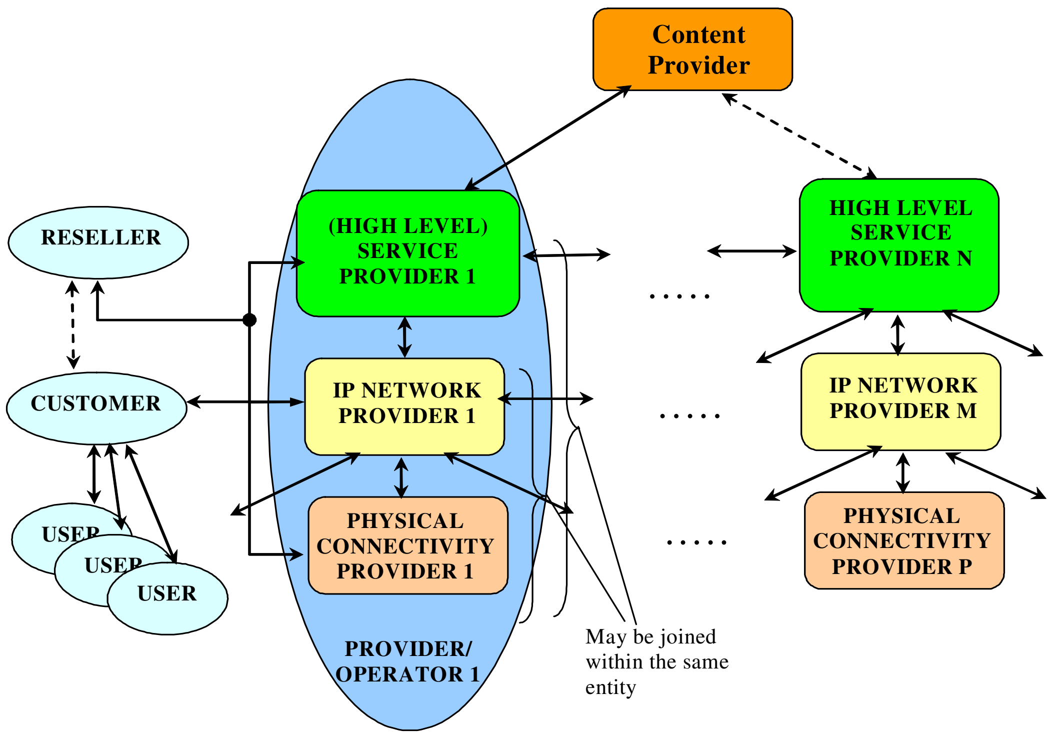

Figure 1-14 Generic IP Business Model (I) - and business relationships (SLA)

1.4 Examples of Multiple Plane Architectures

1.4.1 IEEE 802.16 multi-plane stack

IEEE 802.16 : PHY + MAC

Multiple plane architecture: Data Plane(DPl), Control Plane (CPl), Management Plane (MPl)

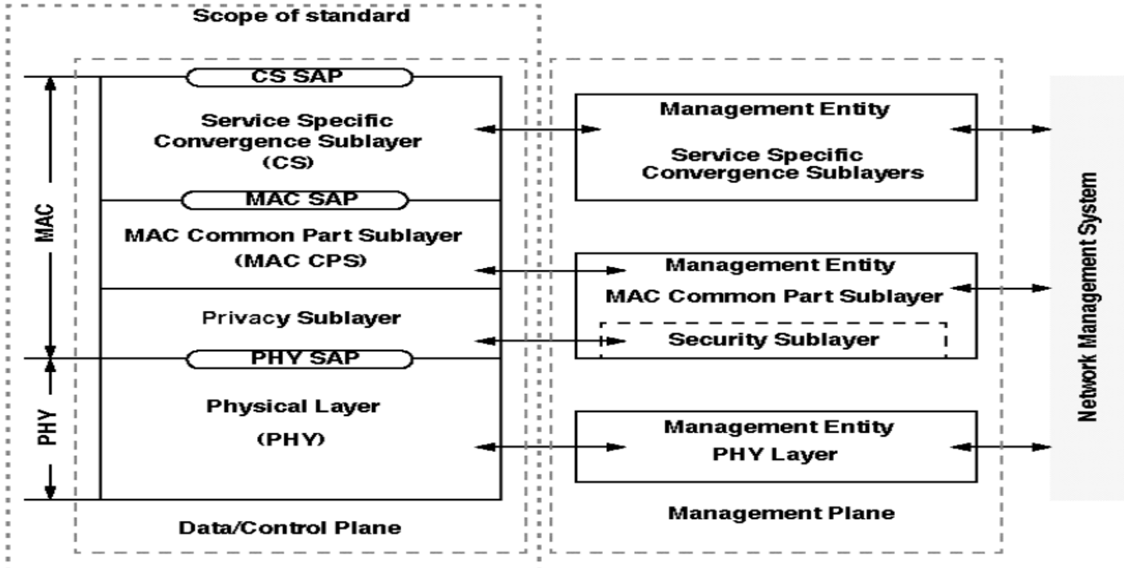

Figure 1-15 Basic IEEE 802.16 multi-plane protocol stack

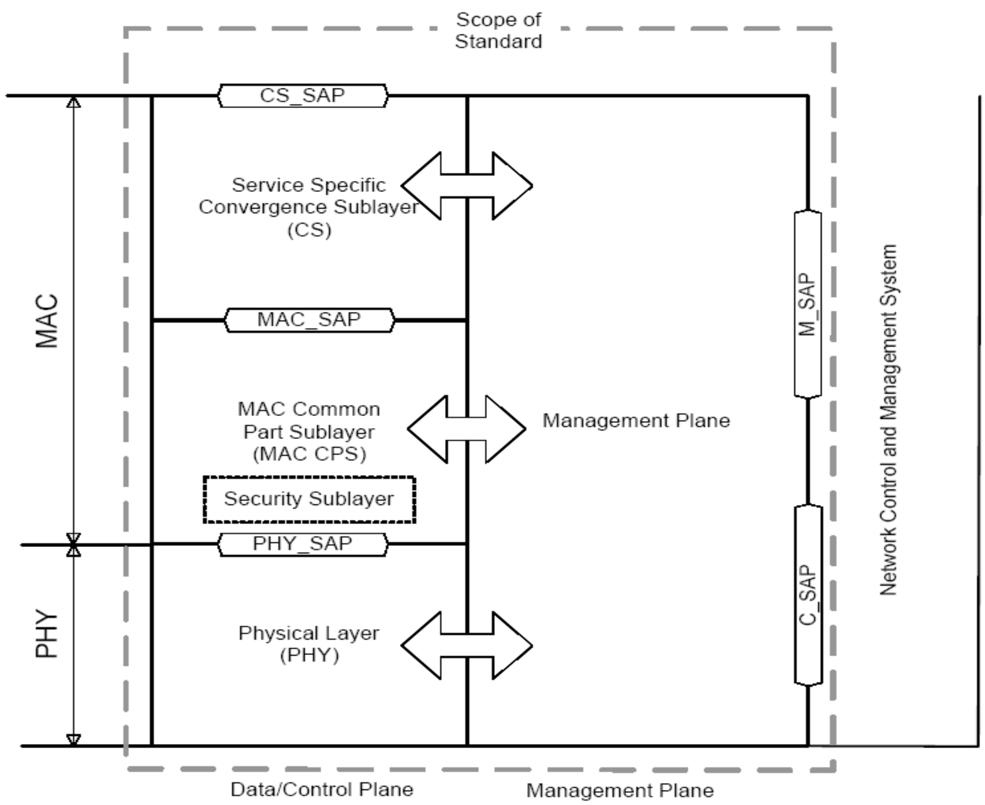

Figure 304—802.16g Protocol Architecture Model

Figure 1-16 (IEEE 802.16g-05/008r2, December 2005)

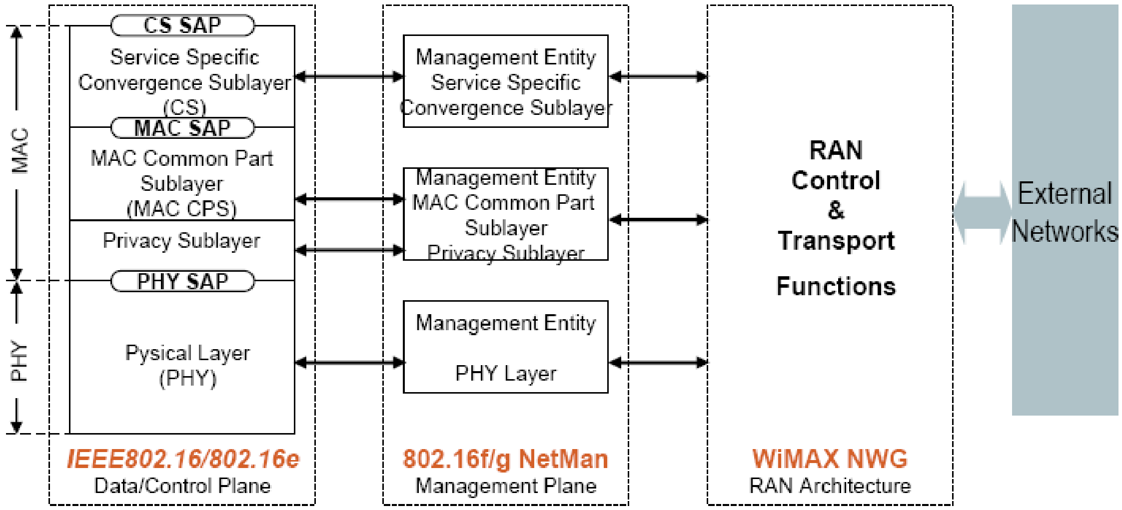

Figure 1-17 Relation IEEE802.16 vs. WiMAX NWG

1.4.2 Generic Example of a multi-plane architecture

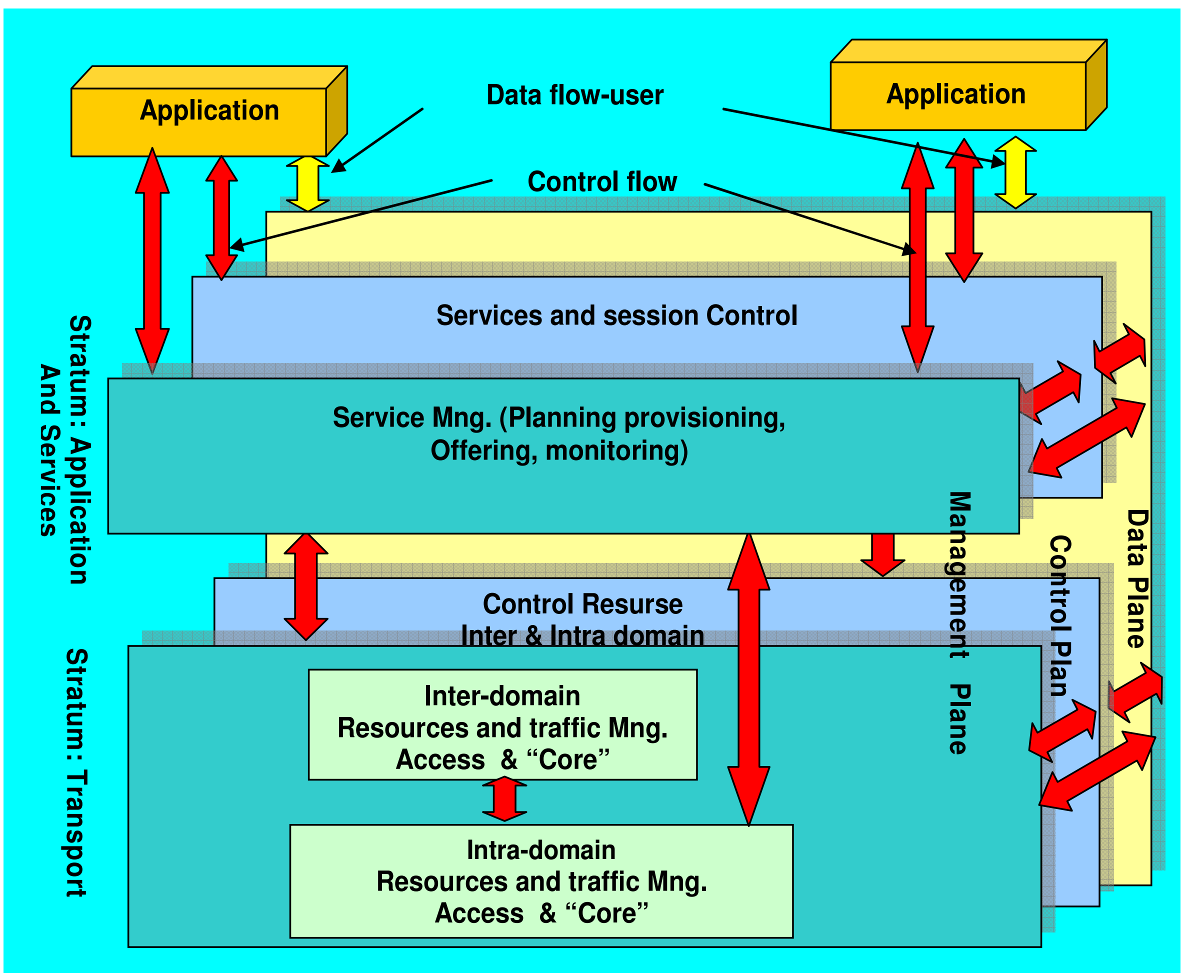

Figure 1-18 Generic example of a multi-plane architecture

1.4.2.1 An Architecture oriented to multimedia distribution over multiple domains networks

Example: Enthrone" European FP6 research 2006-2008 project

"End-to-End QoS through Integrated Management of Content, Networks and Terminals"

Business Actors: Includes the complex business model: CP, SP, CC, NP, ANP

- CC- Content consumer (Company, End users)
  - Customer (org), End user
- CP- Content Provider
  - CPM content provider manager
  - CS1, CS2, - Content Servers
- SP- Service Provider (high level services)
- NP- Network Provider (connectivity services)
- ANP – Access Network Providers

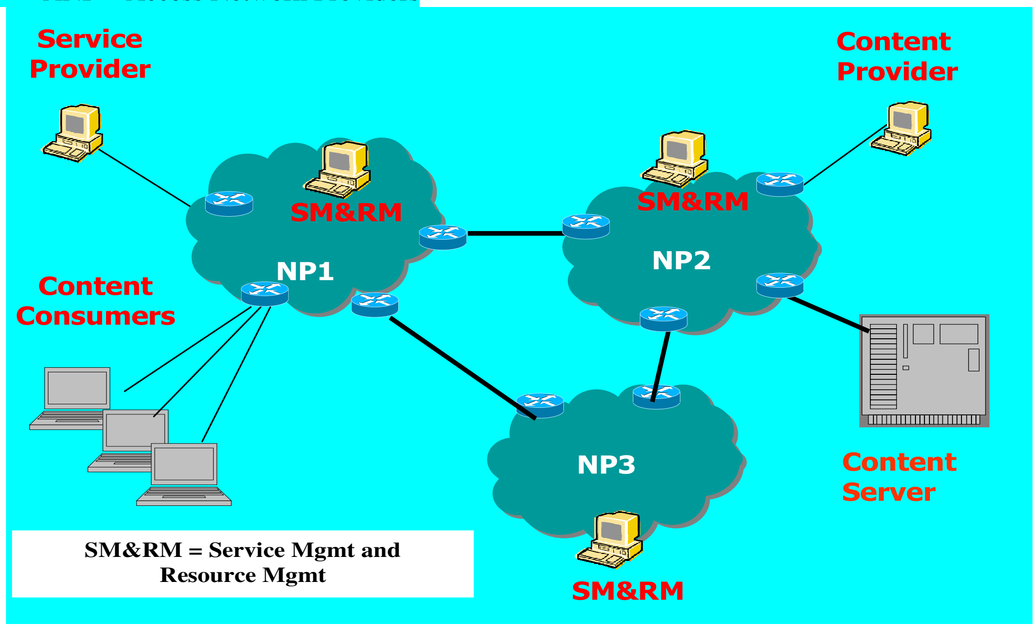

Figure 1-19 Business actors and multi-domain infrastructure

General objectives:

- to Offer high level services: Video on Demand (VoD), Streaming, E-learning, Multimedia distribution, IPTV (basically uni-directional)
- over heterogeneous network technology and Over multiple independent domains
- to manage, in an integrated way the whole chain of protected content handling transport and delivery to user terminals across heterogeneous networks, while offering QoS-enabled services
  - methods of QoS control:
    - **provisioning** (offline and online)
    - **adaptation** of flows to network capabilities

1.4.3 Next Generation Networks Architecture- high level view

- **Standardization Players**

- **ATIS NGN FG:** Alliance for Telecommunication Industry Solutions, Next Generation Networks Focus Group - USA
- **ITU-T NGN FG:** International Telecommunication Union (Telecom), Next Generation Networks Focus Group
- **ETSI TISPAN:** European Telecommunications Standards Institute, Telecoms & Internet converged Services & Protocols for Advanced Networks
- **3GPP:** Third Generation Partnership – standardization in Mobile 3G networks

NGN

- packet-based network
- able to provide Telecommunication multiple services
- able to make use of multiple broadband,
- QoS-enabled transport technologies
- service-related functions are independent from underlying transport-related technologies.
- enables unfettered access for users to networks and to competing service providers and/or services of their choice.
- supports generalized mobility which will allow consistent and ubiquitous provision of services to users.

Key requirements of an NGN Architecture

- **Trust:** Operator should be able to trust the network. User should be able to trust the operator
- **Reliability:** Users should find it reliable
- **Availability:** Network should always be available
- **Quality:** Able to control Quality of the Service
- **Accountability:** Determine usage of the Service
- **Legal:** Comply with laws in the local jurisdictions
- **Generalized** Mobility support

Note: Classical Internet cannot respond in very controllable manner to the above requirements

NGN characteristics

NGN: new telecommunications network for broadband fixed access

- facilitates convergence of networks and services
- enables different business models across access, core network and service domains
- it is an IP based network
- IETF *Session Initiation Protocol (SIP)* will be used for call & session control
- *3GPP release 6 (2004) IMS* will be the base for NGN IP Multimedia Subsystem
- enables any IP access to Operator IMS; from
  - Mobile domain
  - Home domain
  - Enterprise domain
- enables service mobility
- enables interworking towards circuit switched networks
- maintains Service Operator control for IMS signaling & media traffic

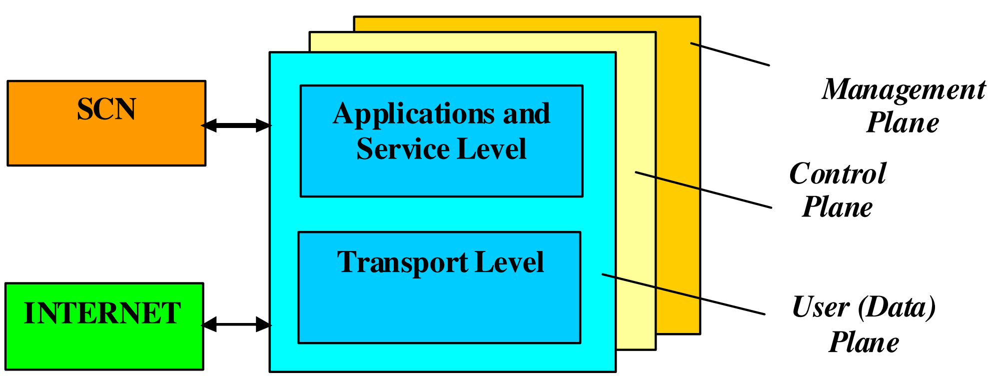

Figure 1-20 NGN Architecture

1.4.3.1 Architectural layers: vertical and horizontal decomposition

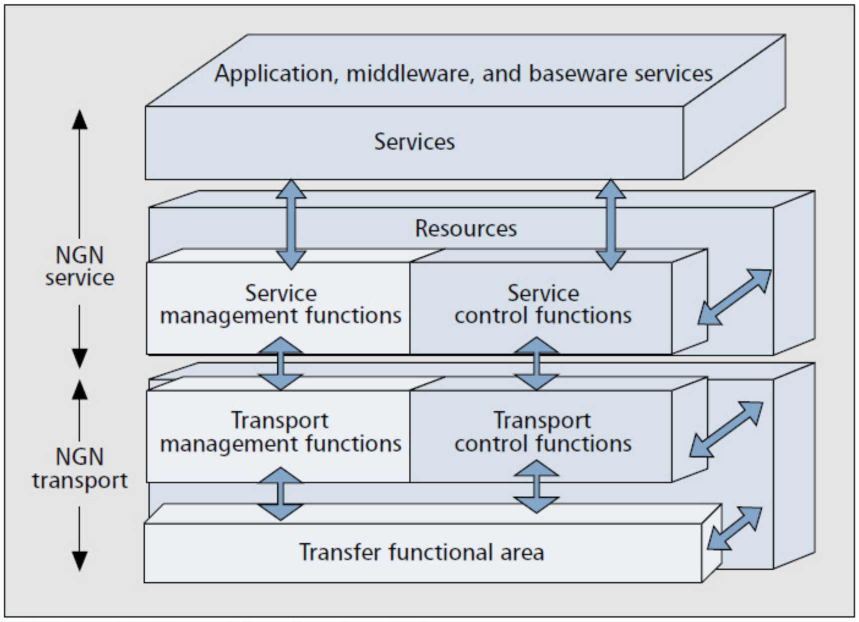

Figure 1. *General functional model.*

Figure 1-21 NGN layered architecture [4]

- The NGN functions are divided into **service** and **transport** strata according to Recommendation Y.2011.
- End-user functions are connected to the NGN by the **user-to-network** interface (UNI),
- Other networks are interconnected through the **network-to-network** interface (NNI).
    - Clear identification of the UNI and NNI is important to accommodate a wide variety of off-the-shelf customer equipment while maintaining business boundaries and demarcation points in the NGN environment.
- The **application-to-network** interface (ANI) forms a boundary with respect to third-party application providers.
-

1.4.3.1.1 Transport Stratum (TS) Functions

- provide connectivity for all components and physically separated functions within the NGN.
- IP – is the transport technology for NGN.
- provides IP connectivity for both EU equipment outside the NGN, and controllers and enablers that usually reside on servers inside the NGN.
- provides end-to-end QoS, (desirable NGN feature)
- TS is divided into ***access networks*** and the ***core network*,** with a function linking the two portions.

Access Functions

- manages end-user access to the network
- access-technology-dependent (W-CDMA, xDSL, Cable access, Ethernet, optical, etc.)

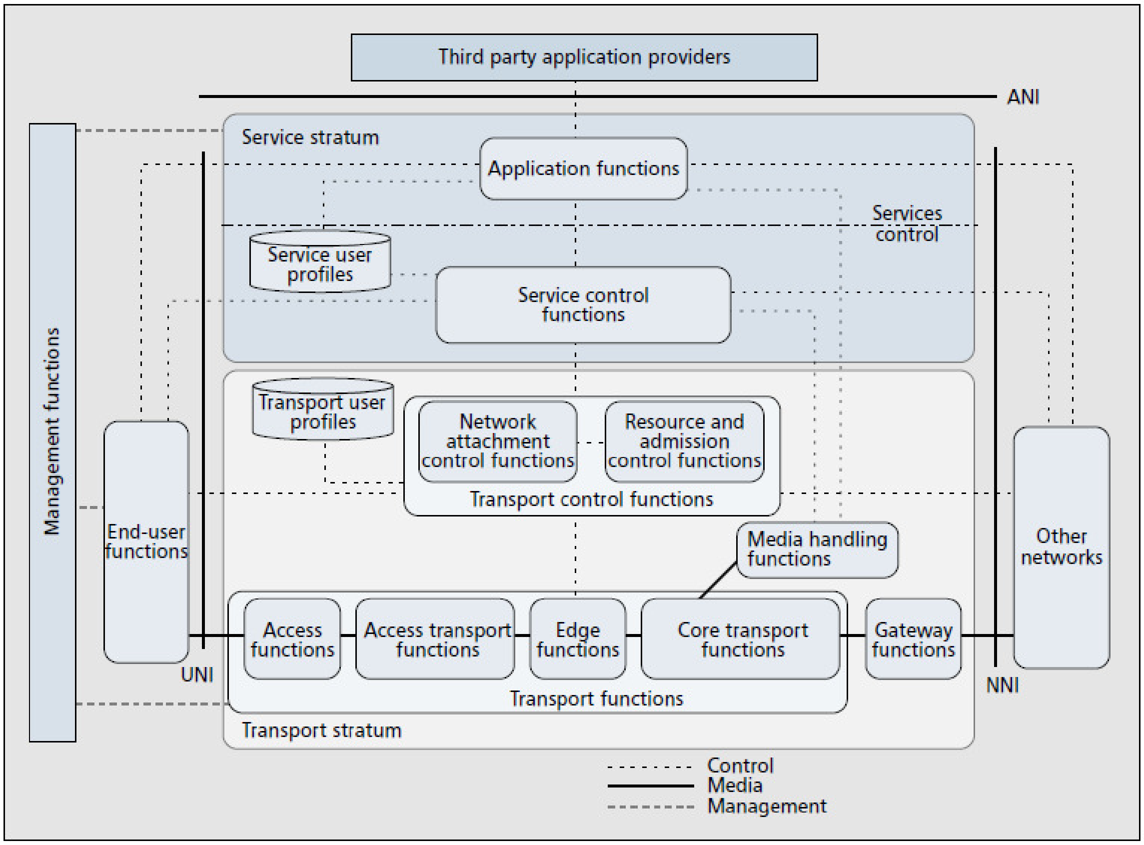

Figure 1-22 NGN Functional Architecture [4]

Access Transport Functions(Data Plane)

- transports information across the access network.
- provide QoS control mechanisms dealing directly with user traffic: buffer management, queuing and scheduling, packet filtering, traffic classification, marking, policing, and shaping.

Edge Functions —used for traffic processing when access traffic is merged into the core network.

Core Transport Functions (Data Plane) - information transport throughout the core network.

- differentiate the quality of transport in the network, according to interactions with the transport control functions.
- provide QoS mechanisms dealing directly with user traffic: buffer management, queuing and scheduling, packet filtering, traffic classification, marking, policing and shaping, gate control, and firewalls.

Network Attachment Control Functions (NACF)

- provide registration at the access level and initialization of end-user functions for accessing NGN services.
- provide network-level identification/authentication
- manage the IP address space of the access network, and authenticate access sessions
- announce the contact point of the NGN service and application functions to the end user.
  -i.e. NACF assist end-user equipment in registering and starting use of the NGN.

Resource and Admission Control Functions (RACF)

- provide AC and gate control functionalities, including control of network address and port translation (NAPT) and differentiated services field code points (DSCPs).
- AC involves checking authentication based on user profiles, through the network attachment control functions.
  - It also involves authorization based on user profiles, (cf. operator-specific policy rules and resource availability: AC function verifies whether a resource request (e.g., for

bandwidth) is allowable given the remaining resources, as opposed to resources that are already provisioned or used).

The RACFs interact with *transport functions* to *control* one or more of the following functionalities in the transport layer: packet filtering, traffic classification, marking and policing, bandwidth reservation and allocation, NAPT, antispoofing of IP addresses, NAPT/FW traversal, and usage metering.

Transport User Profile Functions

- This FB represents the compilation of user and other control data into a single "user profile" function in the transport stratum.
- This function may be specified and implemented as a set of cooperating DBs with functionality residing in any part of the NGN.

Gateway Functions

- provide capabilities to interwork with other networks: e.g. PSTN, ISDN-based networks and the Internet.
- support interworking with other NGNs belonging to other administrators.

- The NNI for other networks applies to both the control and transport levels, including border gateways.

- Interactions between the control and transport levels may take place directly or through the transport control functionality.

Media Handling Functions —media resource processes for providing services, such as generating tone signals, transcoding, and conference bridging.

1.4.3.1.2 Service Stratum Functions

- provide *session-based* and *nonsession-based services*, including subscribe/notify for presence information and a message method for instant message exchange.
- provide all of the network functionality associated with existing PSTN/ISDN services and capabilities and interfaces to legacy customer equipment.

Note: **session** is a semi-permanent interactive information interchange, also known as a dialogue, a conversation or a meeting, between two or more communicating devices, or between a computer and user

A session is set up or established at a certain point in time, and then torn down at some later point. An established communication session may involve more than one message in each direction.

A session is typically, but not always, stateful, meaning that at least one of the communicating parts needs to save information about the session history in order to be able to communicate, as opposed to stateless communication, where the communication consists of independent requests with responses.

An established session is the basic requirement to perform a connection-oriented communication. A session also is the basic step to transmit in connectionless communication modes. However any unidirectional transmission does not define a session.

Service and Control Functions —session control functions, a registration function, and authentication and authorization functions at the service level. They can include functions controlling media resources (i.e., specialized resources).

Service User Profile Functions —

- represent the compilation of user data and other control data into a single user profile function in the service stratum.
- This function may be specified and implemented as a set of cooperating databases with functionality residing in any part of the NGN.

Application Functions —

- NGNs support open APIs enabling third-party service providers to apply NGN capabilities to create enhanced services for NGN users.
- All application functions (both trusted and untrusted) and third-party service providers access NGN service stratum capabilities and resources through servers or gateways in the service stratum.

1.4.3.1.3 Management Functions

- enable the NGN operator to manage the network and provide NGN services with the expected quality, security, and reliability.

- These functions are allocated in a distributed manner to each functional entity (FE).

- They interact with network element (NE) management, network management, and service management FEs.

[**Note :** Classic Telecom vision on management (TMN = TEleco Mgmt Network)

TMN defines a hierarchy of logical layers:

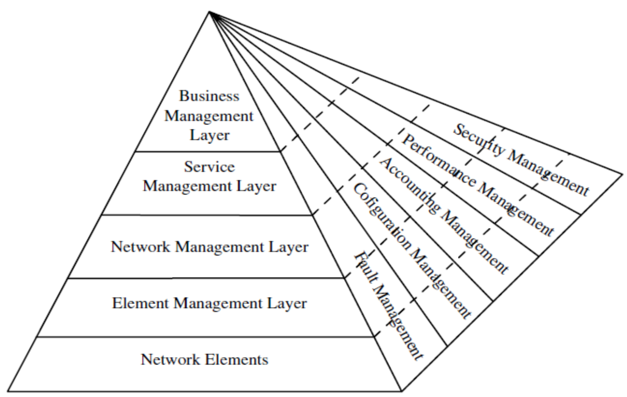

Figure 1-23 Layered Architectural Management Model and Function Areas (FCAPS)

The classic TMN functionalities: 5 major areas of management
- **F: fault**
- **C: configuration**
- **A: accounting**
- **P: performance**
- **S: security.**

End note]

The NGN management functions include charging and billing functions.

These functions interact with each other in the NGN to collect accounting information, which provides the NGN operator with resource utilization data enabling the operator to properly bill users.

The charging and billing functions support the collection of data for both later processing (offline charging) and near-real-time interactions with applications such as those for prepaid services (online charging).

1.4.3.1.4 End-User Functions

The interfaces to the end user are both physical and functional (control) interfaces,

No assumptions are made about the diverse customer interfaces and customer networks that may be connected to the NGN access network.

All customer equipment categories are supported in the NGN, from singleline legacy telephones to complex corporate networks.

End-user equipment may be either mobile or fixed.

2 NETWORKING TECHNOLOGIES AND PROTOCOLS – FOR WIDE AREA WIRELESS NETWORKS - I

2.1 Introduction

- Types of networks (geographical span)
    - Traditional: LAN MAN WAN
    - Newer : PAN, BAN, Inter-plenetary (DTN)

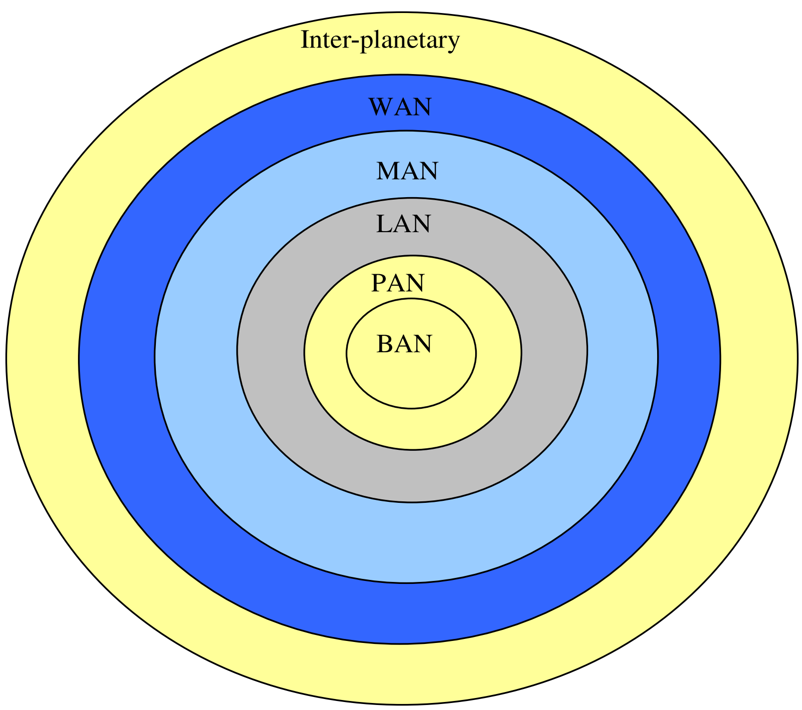

Figure 2-1 Types of networks (geo-span)

- **Types of networks- roles**
    - LAN/Home, Access/aggregation Core networks

Multiple access schemes

- Frequency Division Multiple Access (FDMA)
  - Frequency channels
- Time Division Multiple Access (TDMA)
  - Temporal channels
- Code Division Multiple Access (CDMA)
  - Use of orthogonal codes to separate different transmissions
  - Each symbol of bit is transmitted as a larger number of bits using the user specific code – Spreading spectrum
-

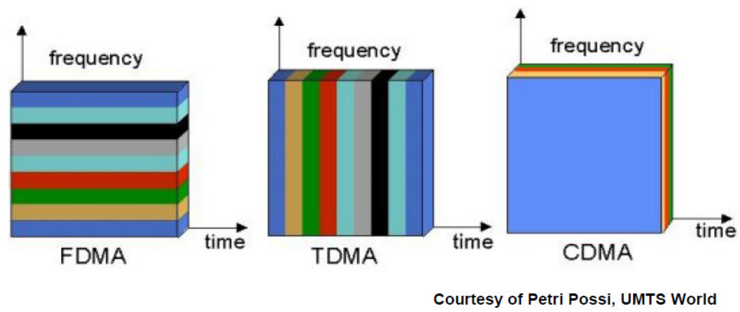

Figure 2-2 Multiple access methods

2.2 Cellular Technologies- Basics

- There are many types of cellular services
- Cellular network/telephony is a *radio*-based technology(access part) + fixed network (core part)
- Most used bands are in the 850 MHz, 900 MHz, 1800 MHz, and 1900 MHz

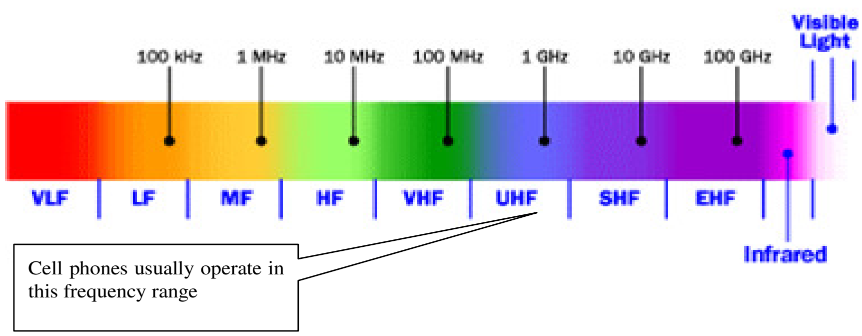

Figure 2-3 Spectral bands

2.2.1 General Overview

What are 1G, 2G, 3G and 4G networks ?

"G" = "generation" of the underlying wireless network technology.

1G networks

(NMT, C-Nets, AMPS, TACS)

- first analog cellular systems, ~1980s.
- before that, there were radio telephone systems
- conceived and designed for voice calls only with almost no consideration of data services (with the possible exception of built-in modems in some headsets)
- data: 2.4kbps.

(-) Poor Voice Quality ; Poor Battery Life; Large Phone Size; No Security; Limited Capacity

2G networks
(GSM, CDMAOne, D-AMPS) ~1991

- circuit switching technologies
- first digital cellular systems, ~1990s (network's switching station are digital)
- voice, data
- improved sound quality, better security and higher total capacity.
- circuit-switched data (CSD), allowing users to place dial-up data calls digitally,
- low data rates on temporal channels (~64kbps)
- SMS service

(-) These systems are unable to handle complex data such as Videos

2.5G networks
(GPRS, CDMA2000 1x)

- enhanced 2G versions with theoretical data rates up to about 144kbit/s.
- GPRS offered the first always-on data service
- 2.5G bridgeds 2G to 3G; it has faster and higher-capacity data transmission
- 2.5G has advances aiming to 3G networks (including packet-switching)
- 2G and 3G have been officially defined as wireless standards by the (ITU); however 2.5G has not been defined like std. and was interim solution- market driven
- 2.5 G includes EDGE (part of the GSM family) and CDMA 2000 1X; at times these technologies are called 3G as they both meet some of the ITU requirements for 3G standards.
- Phone, e-mail, data, camera phones, web browsing – services
- 6-9 mins. to download a 3 mins. Mp3 song
-

3G networks (~ 2000)
(UMTS FDD and TDD, CDMA2000 1x EVDO, CDMA2000 3x, TD-SCDMA, Arib WCDMA, EDGE, IMT-2000 DECT)

- newer cellular networks that have data rates of 384kbit/s and more.
- **UN's ITU IMT-2000** standard requires stationary speeds of 2Mbps and mobile speeds of 384kbps for a "true" 3G.
- 3G systems belong to ITU's Int'l Mobile Telecommunications 2000 (IMT-2000)
- Services:
    - 3G : faster data trs. speeds, greater network capacity, advanced network services
    - Data 144kbps - 2Mbps
    - Video Conferencing / 3D Gaming
    - TV Streaming/ Mobile TV/ Phone Calls
    - Large Capacities and Broadband Capabilities
    - 11 sec – 1.5 min. time to download a 3 min Mp3 song
    - High Speed Web / More Security

- **UMTS-HSPA** is the world's leading 3G technology.
- by 2015, UMTS-HSPA and LTE 3G expectation
    - ~3.9 billion global subscriptions
    - compared to 569 million CDMA EV-DO subscriptions and 59 million WiMAX subscriptions.

[Note:
HSPA denotes:
HSDPA:

- upgrade of WCDMA (<14 Mbit/s with significantly reduced latency)
- based on shared channel transmission and its key features are shared channel and multi-code transmission, higher order modulation short transmission time interval (TTI), fast link adaptation and scheduling along with fast hybrid automatic repeat request (HARQ).

HSUPA

- WCDMA UL upgrade (3GPP Release 6); it is usually only a software update.
- Enhanced UL adds a new transport channel to WCDMA: Enhanced Dedicated Channel (E-DCH).
    - It supports new applications : VoIP, uploading pictures and sending large e-mail messages.
- The enhanced UL data rate is <5.8 Mbit/s, and also reduces latency.
- improvements are similar to HSDPA: multi-code transmission, short Transmission Time Interval (TTI), fast scheduling and fast HARQ Hybrid Automatic Repeat reQuest

3.5G ("beyond 3G")

- 3.5G is not an officially recognized standard by the ITU.
- Interim/ evolutionary step to the next generation of cellular technology that will be known as IMT-Advanced
- IMT-Advanced will comprise the 4G
- 3.5G is also known as *4G Americas* does not use the terms 3.5G (or 2.5G) in respect of the official definitions provided by the ITU.
- The technologies within the GSM family, considered as beyond 3G, include HSPA+ and LTE. These 3.5G technologies are often called *pre-4G* as well.

4G technology

- 4G is defined by the ITU and its Radiocomm Sector (ITU-R) and established as an agreed upon and globally accepted definition in *IMT-Advanced*
- **September 2009, ITU**
    - LTE – Long Term Evolution standardized by the 3GPP
    - WiMAX - 802.16m standardized by the IEEE (i.e. mobile WiMAX)

ITU Requirements for 4G

- all-IP packet switched network
- Peak data rates
    - of up ~ 100 Mbit/s for high mobility
    - up to ~1 Gbps for low mobility (nomadic/local wireless access
- Dynamically share and use the network resources to support more simultaneous users per cell
- Scalable channel bandwidth 5–20 MHz, optionally up to 40 MHz
- Peak link spectral efficiency of *15 bit/s/Hz* in the downlink, and *6.75 bit/s/Hz* in the uplink (meaning that 1 Gbps in the downlink should be possible over less than 67 MHz bandwidth)
- System spectral efficiency of up to 3 bit/s/Hz/cell in the downlink and 2.25 bit/s/Hz/cell for indoor usage
- Smooth handovers across heterogeneous networks
- Ability to offer high quality of service for next generation multimedia support
- Specs are so aggressive that no commercialized standard currently meets them.

History

In Release 10, *3rd Generation Partnership Project (3GPP)* addressed the *IMT-Advanced* requirements in a version of LTE, called LTE-Advanced, for which specifications became available in 2011.
WiMAX addressed the *IMT-Advanced* requirements in a version called Mobile WiMAX 2.0, specified in IEEE 802.16m.

WiMAX and Long-Term Evolution (LTE) standards - generally accepted to succeed both CDMA2000 and GSM,

- labeled as "4G technologies,"
- but that's only partially true:
    - they both make use of a newer, extremely efficient multiplexing scheme (OFDMA, as opposed to the older CDMA or TDMA),
    - however, WiMAX tops at around 40Mbps and LTE at around 100Mbps theoretical speed;
        - they don't fully comply with the planned requirements of 1 Gbps for stationary reception and 100 Mbps for mobile.
    - Practical, real-world commercial networks using WiMAX and LTE range between 4Mbps and 30Mbps.
    - Even though the speeed of WiMAX and LTE is lower than values of IMT-Advanced's standard, they're very different than 3G networks and carriers around the world refer to them as "4G"';
        - The common argument for branding LTE and WiMAX systems as 4G is that they use different frequency bands to 3G technologies
    - Updates to these standards -- **WiMAX 2** and **LTE-Advanced**, respectively -- will increase througput further, but neither has been finalized yet.

Summary of evolution

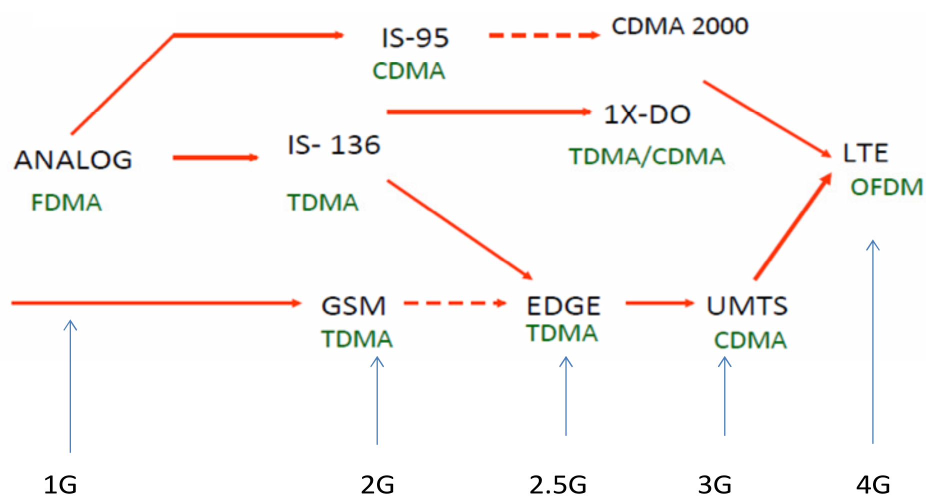

Figure 2-4 Mobile technologies evolution (I)

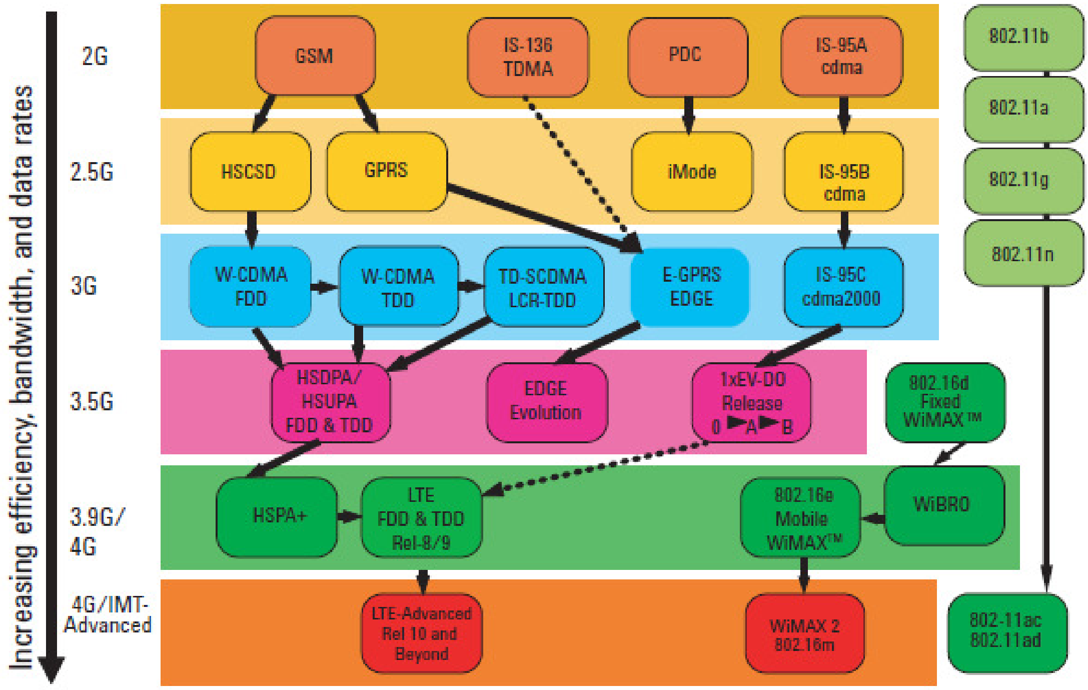

Figure 2-5 Mobile technologies evolution (II)

5G Vision

Key Drivers and general requirements

5G - evolution of mobile *broadband networks* + *new unique network and service capabilities*:

It will ensure *user experience continuity* in various situations

- high mobility (e.g. in trains)
- very dense or sparsely populated areas
- regions covered by heterogeneous technologies.

5G -key enabler for the Internet of Things

- by providing a platform to connect a massive number of sensors
- rendering devices and actuators with stringent energy and transmission constraints.

Mission critical services :

- high reliability, global coverage and/or very low latency (now handled by specific networks), public safety

It will integrate networking, computing and storage resources into one programmable and unified infrastructure.

- optimized and more dynamic usage of all distributed resources
- convergence of fixed, mobile and broadcast services.
- support multi tenancy models, enabling players collaboration
- leveraging on the characteristic of current cloud computing -> the single digital market further,

Additional requirements:

sustainable and scalable technology.

energy consumption reduction and energy harvesting

cost reduction through human task automation and hardware optimization ecosystem for technical and business innovation.

Application fields: network solutions and vertical markets: automotive, energy, food and agriculture, city management, government, healthcare, manufacturing, public transportation, and so forth.

5G disruptive capabilities

- an order of magnitude Improvement in performance : more capacity, lower latency, more mobility, more accuracy of terminal location, increased reliability and availability.

- connection of many devices simultaneously and to improve the terminal battery capacity life

- help citizens to manage their personal data, tune their exposure over the Internet and protect their privacy.

- enhanced spectrial efficiency: consume a fraction of the energy that a 4G networks consumes today

- reduce service creation time and facilitate the integration of various players delivering parts of a service

- built on more efficient hardware

- flexible and interworking in heterogeneous environments.

Design principles

- high flexibility and be driven by a service approach
- adapt to a broad range of usage requirements and deliver converged services preserving security and privacy across a versatile architecture with unified control of any type of ICT resources.
- enable new business models in a programmable manner; APIs) should be available at different levels (resources, connectivity and service enablers

5G Key technological components

Heterogeneous set of integrated air interfaces

Cellular and satellite solutions.

Seamless handover between heterogeneous wireless access technologies

Use of simultaneous radio access technologies

ultra-dense networks with numerous small cells

- this require new interference mitigation, backhauling and installation techniques.

Driven by SW

- unified operating system in a number of points of presence, especially at the edge of the network for meeting performance targets
- to achieve the required performance, scalability and agility it will rely on

- **Software Defined Networking (SDN),**
- **Network Functions Virtualization (NFV),**
- **Mobile Edge Computing (MEC)**
- **Fog Computing (FC)**

Ease and optimize network management operations
- cognitive features
- advanced automation of operation through proper algorithms will allow optimizing complex business objectives (e.g., E2E energy consumption).
- Data Analytics and Big Data techniques -> monitor the users QoE through new metrics combining network and behavioral data while guaranteeing privacy.

Summary of 5G very ambitious goals:

1,000 X in mobile data volume per geographical area reaching a target ≥ 10 Tb/s/km2

1,000 X in number of connected devices reaching a density ≥ 1M terminals/km2

100 X in user data rate reaching a peak terminal data rate ≥ 10Gb/s

1/10 X in energy consumption compared to 2010

1/5 X in end-to-end latency reaching 5 ms for e.g. tactile Internet and radio link latency reaching a target ≤ 1 ms for e.g. Vehicle to Vehicle communication

1/5 X in network management OPEX

1/1,000 X in service deployment time reaching a complete deployment in ≤ 90 minutes

2.2.2 GSM (2G)

2.2.2.1 Network Infrastructure and general architecture

A GSM network is made up of three subsystems:
- The Mobile Terminal (MT)
- The Base Station Sub-system (BSS) – comprising a BSC and several BTSs
- The Network and Switching Sub-system (NSS) – comprising an MSC and associated registers

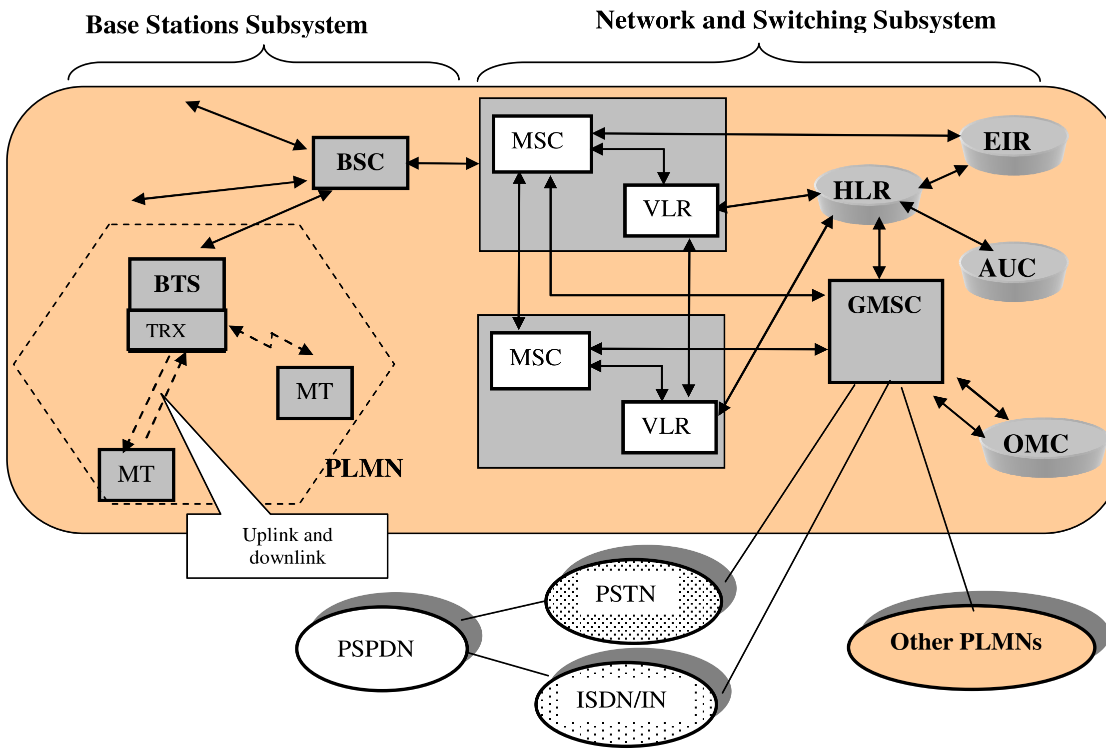

Figure 2-6 GSM Network General Architecture

PLMN Public Land Mobile Network

MS – Mobile Station

BTS – Base Tranceiver Station

TRX – Transceiver

BSC Base Station Controller

MSC Mobile Switching Center

GMSC Gateway MSC

HLR/VLR Home/Visitor Location Register

EIR – Equipment Identity Register

AUC- Authentication Center

OMC – Operations and Maintenance Center

ISDN Integrated Services Digital Network

PSPDN Packet Switched Public Data Network

PSTN – Public Switched Telephone Network

- **GSM MT - Mobile Terminal** = Terminal Equipment (TE) + Terminal Adapter (TA) Mobile Station (MS)
  - TE, TA may be missing
- ***BSS (Base Station Subsystem)***
  - BTS - Base Transceiver Station (including antenna)

  - receives / sends data units from / to MN via radio interface

  - BSC - Base Station Controller

  - controls radio network specific signaling
  - manages radio network resources
- ***NSS – Network Switching Subsystem***
  - **MSC -** *Mobile Services Switching Center:* routing, signaling, collection of charging info, mobility management
  - **GMSC -** *(Gateway) Mobile Services Switching Center:* data and signalling translation to be compatible to external networks (ISDN, PSTN, ...)
  - **HLR** – *Home Location Register:* storage of subscriber profiles e.g. for authentication / authorisation; storage of current MSC
  - **VLR -** Visited Location Register: temporary storage of data on subscribers currently attached to an MSC

OSS (Operation Subsystem)

AUC – *Authentication Center*, **EIR** - *Equipment Identity Register*

OMC - *Operation and Maintenance Center*

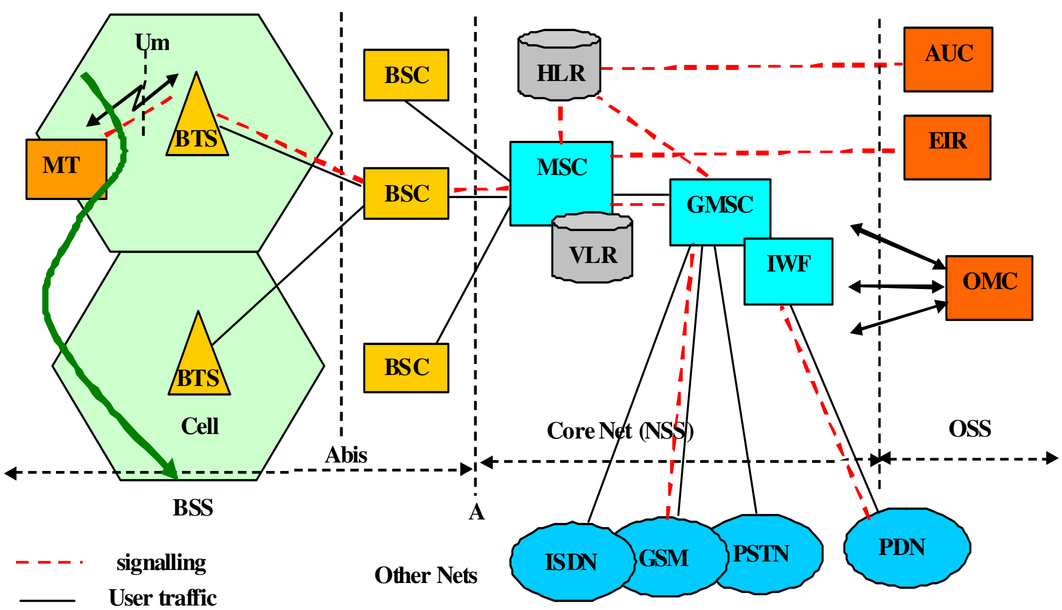

Figure 2-7 GSM interfaces; Data and Control Plane

The interfaces defined between each of these sub systems include:

- 'A' interface between NSS and BSS
- 'Abis' interface between BSC and BTS (within the BSS)

• 'Um' air interface between the BSS and the MS

Hierarchy of service areas

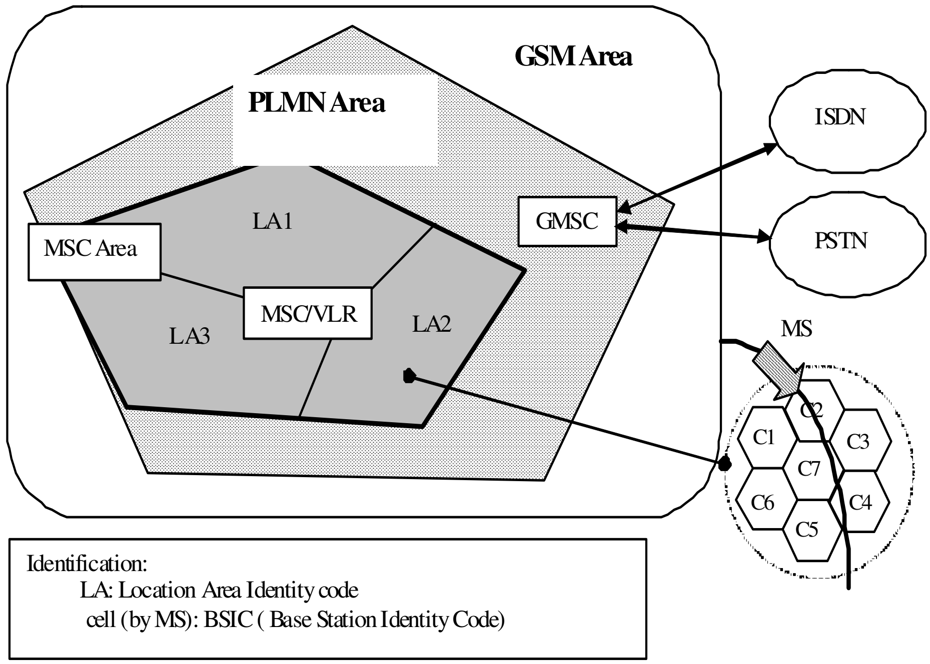

Figure 2-8 Hierarchy of service areas in GSM

Hierarchy : definition of several service areas
• ***GSM area*** – total area resulted from combinations of national networks
• ***PLMN area***- network managed by an operator
• ***MSC service area*** –zone served by a MSC/VLR switch
• ***location area LA*** – zone in which a MS may occupy any location without being necessary location update
• ***cell*** – part of an LA, served by an BTS
• ***mobile station - MS***.

2.2.2.2 Architectural Components

2.2.2.2.1 Mobile Terminal

- physical equipment used by a PLMN subscriber to connect to the network.
-It comprises the **Mobile Equipment (ME) + Subscriber Identity Module (SIM).**
- The ME is part of the **Mobile Termination (MT)**
- which, depending on the application and services, may also include various types of **Terminal Equipment (TE)** and associated **Terminal Adapter (TA).**

MT = TE(e.g laptop) + TA+ MS (i.e SIM +ME)

Identification principles - summary

MS equipment and subscriber- distinctly identified

ME has an **IMEI** unique **("International Mobile Equipment Identity")** – equipment Id (Can be checked for stolen equipment)

Subcriber Identification: several addresses (different points of view)**:**

• **MS-ISDN ("Mobile Subscriber ISDN Number")** - number (address) used to call MS from PSTN, ISDN.
• **IMSI ("International Mobile Subscriber Identity")** – unique number in the context of the mobile network
• **TMSI ('Temporar Mobile Subscriber Identity")** - temporary number assigned to the subscriber by the GSM syatem

Mapping to SIM
The SIM stores **permanent and temporary** data about the **mobile, the subscriber and the network,** including :

• **International Mobile Subscribers Identity (IMSI)**
identifies the subscriber within the GSM network
• MS **ISDN number of subscriber**
• **Authentication key (Ki)** and algorithms for authentication check
Security is provided by the use of an authentication key and by the transmission of a **TMSI** across the radio I/F where possible (to avoid using the permanent IMSI identity)

IMSI – International Mobile Subscriber Identifier- details

When a subscriber registers with a network operator, a unique IMSI identifier is issued and stored in the SIM of the MS as well as in the HLR .
An MS can only function fully if it is operated with a valid SIM inserted into an MS with a valid IMEI. IMSI consist of three parts:

IMSI = MCC + MNC + MSIN
MCC = Mobile Country Code
MNC = Mobile Network Code
MSIN = Mobile Station Identification Number

TMSI –Temporary Mobile Subscriber Identity- details

- A TMSI is used to protect the true identity (IMSI) of a subscriber.
- It is issued by and stored within a VLR (not in the HLR) when an IMSI attach takes place or a Location Area (LA) update takes place.
- At the MS it is stored in the MS's SIM. The issued TMSI only has validity within a specific LA.
- Since TMSI has local significance, the structure may be chosen by the administration. It should not be more than four octets.

MSISDN – Mobile Station ISDN Number- details

The MSISDN represents the 'true' or 'dialled' number associated with the subscriber. It is assigned to the subscriber by the network operator at registration and is stored in the SIM.

According to the CCITT recommendations, it is composed in the following way:
MSISDN = CC + NDC + SN
CC = Country Code
NDC = National Destination Code
SN = Subscriber Number

MSRN – Mobile Station Roaming Number

- The MSRN is a temporary, location-dependent ISDN number issued by the parent VLR to all MSs within its area of responsibility.
- It is stored in the VLR and associated HLR but not in the MS.

- The MSRN is used by the VLR associated MSC for call routing within the MSC/VLR service area.

2.2.2.2.2 Base Station Subsystem (BSS)

1 x BSC + several BTSes

BTS :
- provide radio access to the mobile stations
- manage the radio access aspects of the system

BTS contains:
- Radio Transmitter/Receiver (TRX)
- Signal processing and control equipment
- Antennas and feeder cables

BSC:
- allocates a channel for the duration of a call
- maintains the call:
  monitors quality
  controls the power transmitted by the BTS or MS
  generates a handover to another cell when required

Access network
-is a connection between MS and NSS,
- comprise of BTSs & BSCs.
- It is responsible for radio management.

The radio equipment of a BSS may support **one or more cells.**

Possible BSS configurations
- Collocated BTS+ BSC
- Remote BTS + Star Configuration (example of connection BTS-BSC: via E1-type channel)
- Daisy Chain BTS (BTS1—BTS2-- BTS3-----BSC----MSC)
- Loop Configuration (BTS1 -- BTS2---BTS3-----BSC---BTS1, + (BSC----MSC)

BSS Interfaces

External I/Fs
- Air I/F: Radio I/F BTS --- Mobile to supports frequency hopping and diversity.

- **A I/F** : BSS ----NSS usually carried by a 2-Mb link
  - At this interface level transcoding takes place.

- OMC Interface: data I/F – e.g. X25 Link.(old I/F)

Internal I/Fs
Abis Interface
A-bis is used if the **BTS and BSC** are not combined (otherwise, BS interface will be used)
Several frame unit channels are multiplexed on the same PCM support and BSC and BTS can be remote from each other.

Abis main functions:
- Conversion of 260 – bit encoded blocks (corresponding to 160x8 – bit samples for 20ms)
- Encoded block synchronization
- Vocal activity detection
- Alarm dispatch to BSC via PCM
- Test loop back operation

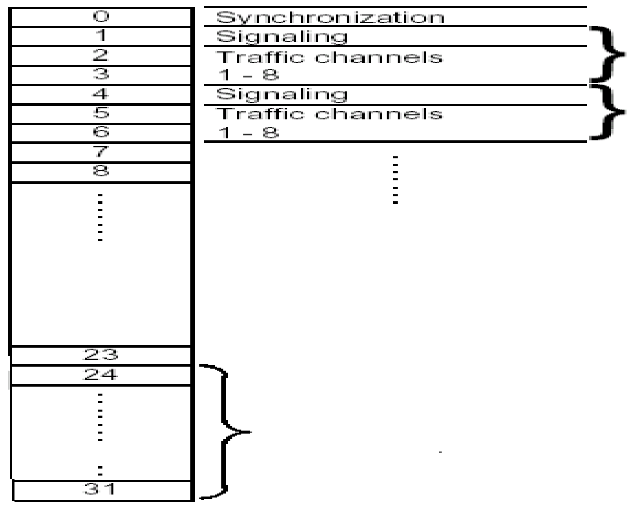

Figure 2-9 Mapping of the temporal channels in BSC

2.2.2.2.3 Network Switching Subsystem (NSS)

NSS : all the major activities like **switching of calls, routing, security functions, call handling, charging, operation & maintenance, handover decisions**.

Key elements of the NSS:
- Mobile Switching Center (MSC)
- Visitor Location Register (VLR)
- Home Location Register (HLR)
- Authentication Center (AuC)
- Equipment Identity Register (EIR)
- Gateway MSC (GMSC)

These elements are interconnected by Signalling System No 7 (SS7) – Control Plane

The NSS combines
the call routing switches (MSCs and GMSC) with
database registers required
to keep track of subscribers' movements and use of the system.

Call routing between MSCs is taken via existing PSTN or ISDN networks.
Signaling between the registers uses **Signaling System No. 7** protocols.

<u>LAI – Location Area Identity</u>

Each LA within the PLMN has an associated internationally unique id (LAI).
The LAI is broadcast regularly by BTSs on the ***Broadcast Control channel (BCCH),*** thus uniquely identifying each cell with an associated LA.

LAI = MCC + MNC + LAC

MCC = Mobile Country Code, same as in IMSI
MNC = Mobile Network Code, same as in IMSI
LAC = Location Area Code, identifies a location area within a GSM PLMN network.
Maximum length of LAC is 16 bits.

<u>Mobile Switching Center</u>

Functions of the MSC:

- Switching calls, controlling calls and logging calls
  - Interface with PSTN, ISDN, PSPDN
  - Mobility management over the radio network and other networks
- Radio Resource management - handovers between BSCs
- Billing Information

Difference between a MSC and an exchange in a fixed network is - MSC has to take into account the impact of the allocation of radio resources and the mobile nature of the subscribers and has to perform in addition, at least the following procedures:

- required for location registration
- procedures required for handover

An MSC can be connected to only one VLR.

Therefore, all MS that move around under base stations connected to the MSC are always managed by the same VLR.

An MSC would communicate typically with one EIR.

While it is possible for an MSC to communicate to multiple EIRs, this is highly unlikely since the EIR provides a centralized and geographic independent function.

2.2.2.3 Physical Layer characteristics summary

- **Characteristics of Radio I/F: e.g. GSM 900**
  - **FDM + TDM (124 carriers, 8TS/carrier)**
  - **FDD**
  - **Type of temporal channels:**
    - Traffic channels (TCH, in Data Plane):
      - ~22Kb/s or 11Kb/s – voice
      - < 14.4 Kb/s – data in transparent channels- **very low!!**
    - **Control Channels (Control Plane)**
      - *Common* Channels
        - Broadcast (BCCH)
        - Paging (PCH)
        - Random Access (RACH)
        - Access Grant (AGCH)
      - *Dedicated*
        - DCCH-fast/slow
  - **Temporal Frame hierarchy:** frame, multiframe, superframe, hyperframe

- **GSM frequencies**

- **Originally designed on 900MHz** range, now also available on 800MHz, 1800MHz and 1900 MHz ranges.
- **Separate Uplink and Downlink frequencies**
  - One example channel on the 1800 MHz frequency band, where RF carriers are space every 200 MHz

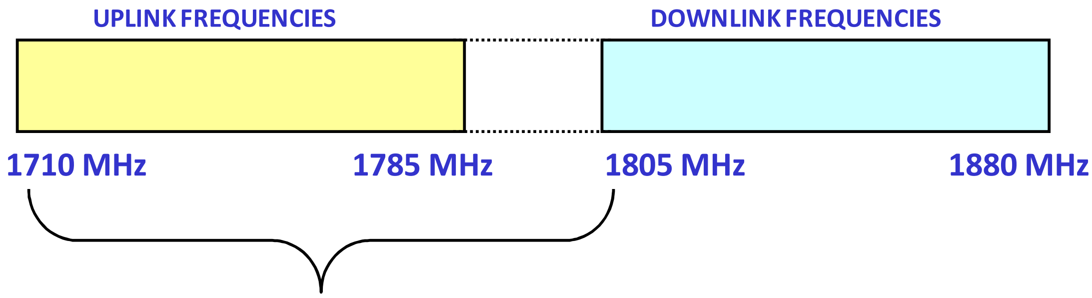

Figure 2-10 Uplink and downlink bands example

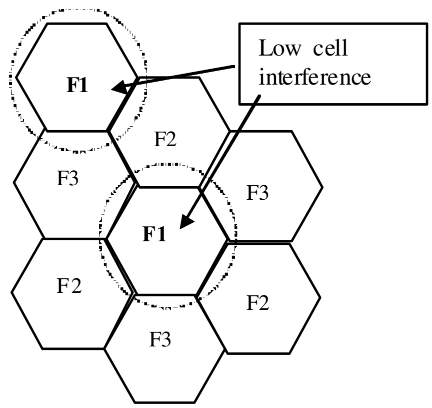

Figure 2-11 Simple allocation of carrier frequencies for cells (F1, F2, F3)- to avoid interference

2.2.2.4 Control Plane and Signalling Protocols

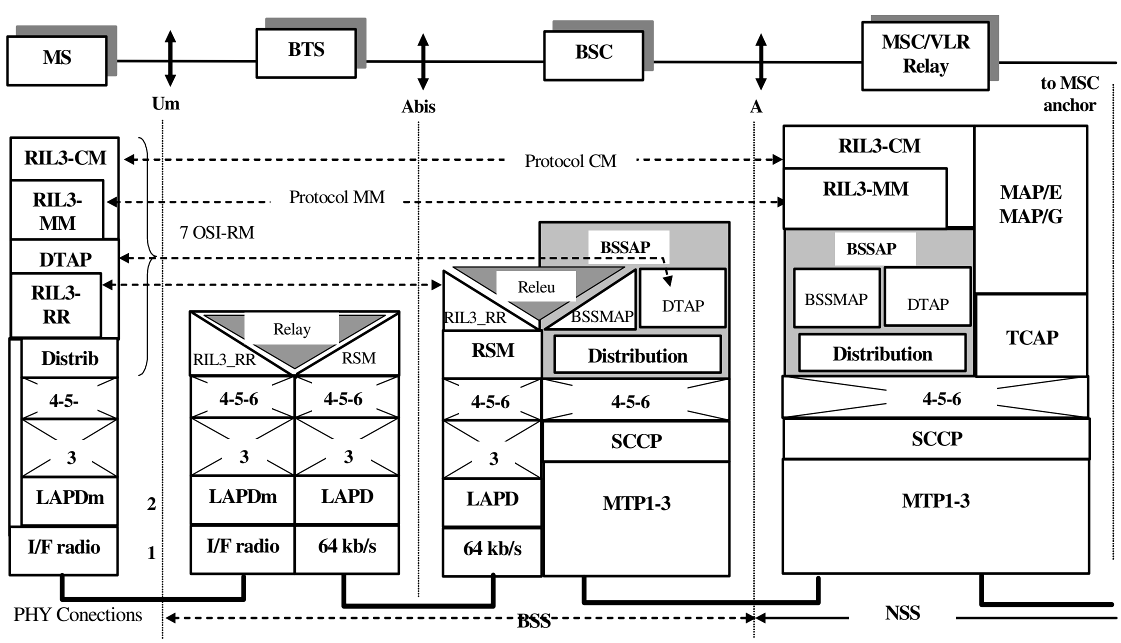

Figure 2-12 Control Plane in GSM

RIL3 - Radio Interface Layer;
CM, MM, RR - Connection, Mobility, Radio Resource - Management

RR – Radio Resources
Distrib – distribution
RSM - Radio Subsystem Management
DTAP - Data Transaction Application Part
BSSAP - Base Station Subsystem Appl. Part
BSS – BS subsystem
NSS – Network Subsystem

SS7 components:

MTP – Message Transport Part (SS7)
LAPD – Link Access Protocol for D channel – layer 2 for ISDN
LAPDm – modification of LAPD for mobility
SCCP - Signalling Connection Control Part (CO mode for L3)
TCAP – Transaction Capabilities App. Part
MAP – Mobile Appl. Part

2.2.2.5 Input Call – Example

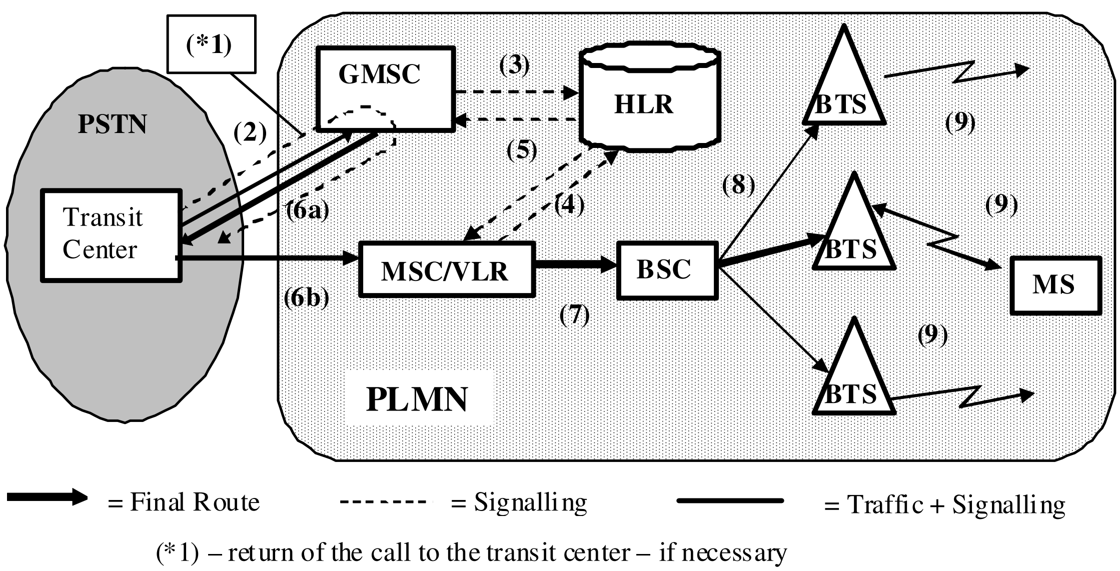

Figure 2-13 Input call processing - example

3 NETWORKING TECHNOLOGIES AND PROTOCOLS – FOR WIDE AREA WIRELESS NETWORKS - II

3.1 Introduction LTE

- **Evolution: GSM → UMTS→ Earlier 3GPP → LTE**
- LT E started as a project in 2004 by telecom body (3GPP).
- SAE (System Architecture Evolution) is the corresponding evolution of the GPRS/3G packet core network evolution.
- **The term LTE is typically used to represent both LTE and SAE**

- The related specifications were formally known as the evolved UMTS terrestrial radio access (E-UTRA) and evolved UMTS terrestrial radio access network (E-UT RAN).
- **First version of LTE : Release 8 of the 3GPP specs.**

- Why LTE?? : A rapid increase of mobile data usage and emergence of new applications such as *MMOG (Multimedia Online Gaming*), *mobile TV, Web 2.0, streaming contents* → 3GPP worked on the LTE for 4G mobile.

Main goals:

- high data rate, low latency and packet optimized RAT supporting flexible bandwidth deployments; support packet-switched traffic with seamless mobility and QoS

Evolution:

Mar 2000	Release 99 - UMT S/WCDMA
Mar 2002	Rel 5 - HSDPA
Mar 2005	Rel 6 - HSUPA
Year 2007	Rel 7 - DL MIMO, IMS (IP Multimedia Subsystem)
Nov 2004	Work start on LT E specs
Jan 2008	**Spec finalized and approved with Release 8**
2010	**First deployment**

LTE main characteristics

- ~ **50 times perf.** improvement and much better spectral efficiency to cellular networks.
- **high data rates**: 300 Mbps peak DL and 75 Mbps peak UL
  - data rates > 300Mbps can be achieved in a 20 MHz carrier, under very good signal conditions.
- support for **services** : **VOIP, streaming multimedia, videoconf., high-speed cellular modem**.
- **duplex modes**: both TDD and FDD mode.
- supports **flexible carrier bandwidths**, from 1.4 - 20 MHz as well as both FDD and T DD.
  - scalable carrier bandwidth from 1.4 MHz up to 20 MHz ; the bandwidth used depends on the frequency band and the amount of spectrum available with a network operator.
- All LTE **devices have to support MIMO transmissions**,
  - (BS can transmit several data streams over the same carrier simultaneously).
- **All I/Fs between network nodes in LTE are IP based,** including the backhaul connection to the radio base stations.
  - Significant simplification compared to earlier technologies initially based on E1/T 1, ATM and frame relay links, with most of them being narrowband and expensive.

- **QoS mechanism** have been standardized on all I/Fs to ensure that the requirement of voice calls for a constant delay and bandwidth, can still be met when capacity limits are reached.
- Works with **GSM/EDGE/UMTS** systems utilizing existing 2G and 3G spectrum and new spectrum.

- Supports **handover and roaming** to existing mobile networks.

LTE Advantages

- **High throughput**
- **Low latency** (time required to connect to the network is ~ 10^2 ms and power saving states can now be entered and exited very quickly).
- **FDD and TDD in the same platform**:
- **Superior QoE :** Optimized signaling for connection establishment and other air interface and mobility management procedures have further improved the user experience. Reduced latency (to 10 ms) for better user experience.
- **Seamless connection to existing networks such as GSM, CDMA and WCDMA**.
- **Plug and play**: no need to manually install drivers for devices.
    - The system automatically recognizes the device, loads new drivers for the hardware if needed, and begins to work with the newly connected device.
- **More simple architecture**: → low operating expenditure (OPEX).

LTE - QoS

- LTE supports E2E **hard QoS,** with guaranteed bit rate (GBR) for radio bearers.
- **Various levels of QoS** can be applied to LT E traffic for different applications.
- Because the LT E **MAC is fully scheduled**, QoS is a natural fit.

- **Evolved Packet System (EPS)** bearers provide 1-to-1 correspondence with RLC radio bearers and provide support for Traffic Flow Templates (TFT).
    - There are four types of EPS bearers:
        - **GBR Bearer:** resources permanently allocated by admission control
        - **Non-GBR Bearer** no admission control
        - **Dedicated Bearer** associated with specific TFT (GBR or non-GBR)
        - **Default Bearer** Non GBR, **catch-all** for unassigned traffic

3.2 LTE Basic Parameters

Table 3-1 LTE basic parameters

Parameters	**Description**	
Frequency range	UMTS FDD bands and TDD bands defined in 36.101(v860) Table 5.5.1, given below	
Duplexing	FDD, TDD, half-duplex FDD	
Mobility	350 km/h	
Channel Bandwidth (MHz)	1.4; 3; 5; 10; 15; 20	
T ransmission Bandwidth Configuration NRB: (1 resource block = 180kHz in 1ms T T I)	6;15;25;50;75;100	
Coverage	5 - 100km with slig ht deg radation after 30km	
QoS	E2E QOS allowing prioritization of different class of service	
Latency	End-user latency < 10mS	

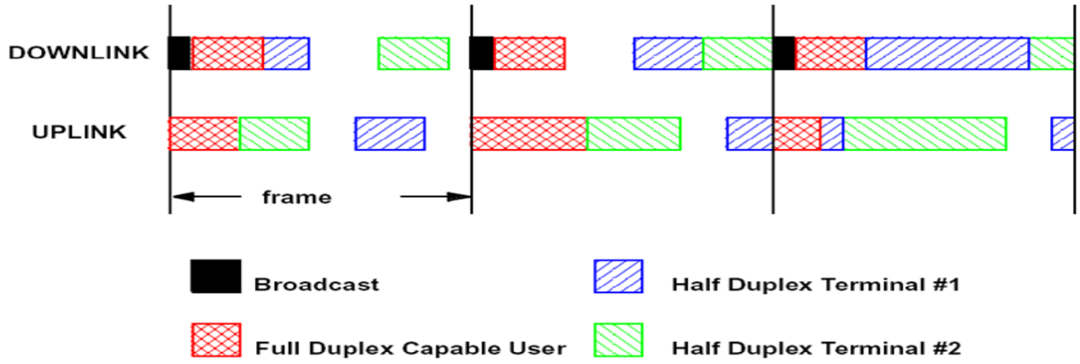

Figure 3-1 FDD modes

E-UTRA Operating Bands

Table 3-2 E-UTRA operating bands taken from LT E Sepecification 36.101(v860)

E-UTRA Operating Band	Uplink (UL) operating band BS receive UE transmit			Downlink (DL) operating band BS transmit UE receive			Duplex Mode
	F_{UL_low}	–	F_{UL_high}	F_{DL_low}	–	F_{DL_high}	
1	1920 MHz	–	1980 MHz	2110 MHz	–	2170 MHz	FDD
2	1850 MHz	–	1910 MHz	1930 MHz	–	1990 MHz	FDD
3	1710 MHz	–	1785 MHz	1805 MHz	–	1880 MHz	FDD
4	1710 MHz	–	1755 MHz	2110 MHz	–	2155 MHz	FDD
5	824 MHz	–	849 MHz	869 MHz	–	894MHz	FDD
6	830 MHz	–	840 MHz	875 MHz	–	885 MHz	FDD
7	2500 MHz	–	2570 MHz	2620 MHz	–	2690 MHz	FDD
8	880 MHz	–	915 MHz	925 MHz	–	960 MHz	FDD
9	1749.9 MHz	–	1784.9 MHz	1844.9 MHz	–	1879.9 MHz	FDD
10	1710 MHz	–	1770 MHz	2110 MHz	–	2170 MHz	FDD
11	1427.9 MHz	–	1447.9 MHz	1475.9 MHz	–	1495.9 MHz	FDD
12	698 MHz	–	716 MHz	728 MHz	–	746 MHz	FDD
13	777 MHz	–	787 MHz	746 MHz	–	756 MHz	FDD
14	788 MHz	–	798 MHz	758 MHz	–	768 MHz	FDD
17	704 MHz	–	716 MHz	734 MHz	–	746 MHz	FDD
...							
33	1900 MHz	–	1920 MHz	1900 MHz	–	1920 MHz	TDD
34	2010 MHz	–	2025 MHz	2010 MHz	–	2025 MHz	TDD
35	1850 MHz	–	1910 MHz	1850 MHz	–	1910 MHz	TDD
36	1930 MHz	–	1990 MHz	1930 MHz	–	1990 MHz	TDD
37	1910 MHz	–	1930 MHz	1910 MHz	–	1930 MHz	TDD
38	2570 MHz	–	2620 MHz	2570 MHz	–	2620 MHz	TDD
39	1880 MHz	–	1920 MHz	1880 MHz	–	1920 MHz	TDD
40	2300 MHz	–	2400 MHz	2300 MHz	–	2400 MHz	TDD

3.3 LTE Network Architecture [1],[3]

Three main components:

- **User Equipment** (UE).
- **Evolved UMTS Terrestrial Radio Access Network** (E-UTRAN).
- **Evolved Packet Core (EPC).**
  - o EPC communicates with packet data networks in the outside world such as the internet, private corporate networks or the IP multimedia subsystem.

The interfaces : **Uu, S1 and SGi**

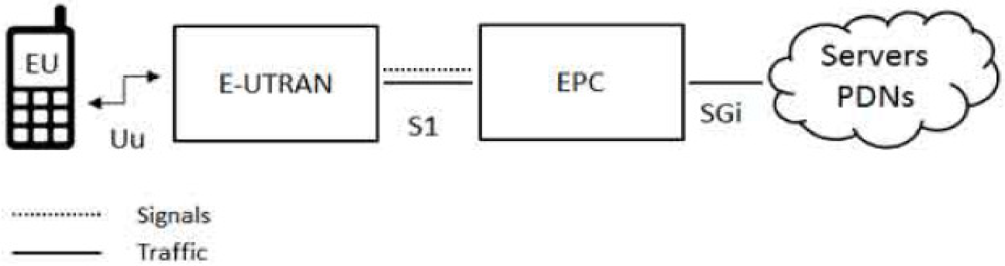

Figure 3-2 High level LTE architecture

3.3.1 User Equipment (UE)

- The EU internal architecture of the user equipment for LTE is identical to the one used by UMTS and GSM, i.e. Mobile Equipment (ME).
- Modules:
  - **Mobile Termination (MT):** handles all the communication functions.
  - **T erminal Equipment (T E):** terminates the data streams.
  - **Universal Integrated Circuit Card (UICC):** known as the SIM card for LTE equipments.
    - It runs an application known as the **Universal Subscriber Identity Module (USIM).**
- A **USIM** stores user-specific data very similar to 3G SIM card. This keeps information about the user's phone number, home network identity and security keys, etc.

3.3.2 E-UTRAN (The access network)

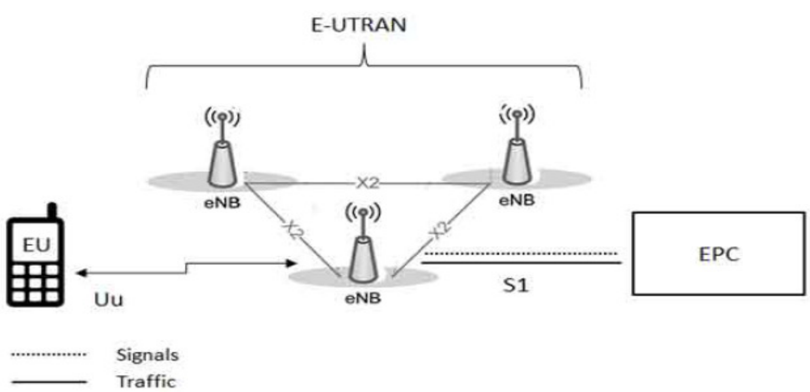

Figure 3-3 E-UTRAN components

- **E-UTRAN handles the radio communications between the mobile and EPC**
  - has *one component,* the *evolved base stations*, called **eNodeB** or **eNB**.
  - Each eNB is a BS that controls the mobiles *in one or more cells.*
- The BS that is communicating with a mobile is known as its **serving eNB**.
- LTE Mobile communicates with just one BS and one cell at a time
- **Two main eNB functions:**
  - sends and receives radio transmissions to mobiles using the analogue and DSP functions of the LTE air I/F.
  - controls the low-level operation of all its mobiles, by sending them signalling messages such as handover commands.
- Each eNB is connected to

- EPC by S1 I/F
- (it can be) to nearby base stations by the X2 I/F (used for signalling and packet forwarding during handover).

- A **home eNB (HeNB)** is a BS that has been purchased by a user to provide femtocell coverage within the home.
  - A home eNB belongs to a closed subscriber group (CSG) and can only be accessed by mobiles with a USIM that also belongs to the closed subscriber g roup.

3.3.3 Evolved Packet Core (EPC) (core network)

Figure 5.4 shows a simplified picture of EPC architecture.

Several components have not been shown in the diagram to keep it simple e.g.
Earthquake and Tsunami Warning System (ETWS),
Equipment Identity Register (EIR)
Policy Control and Charg ing Rules Function (PCRF))

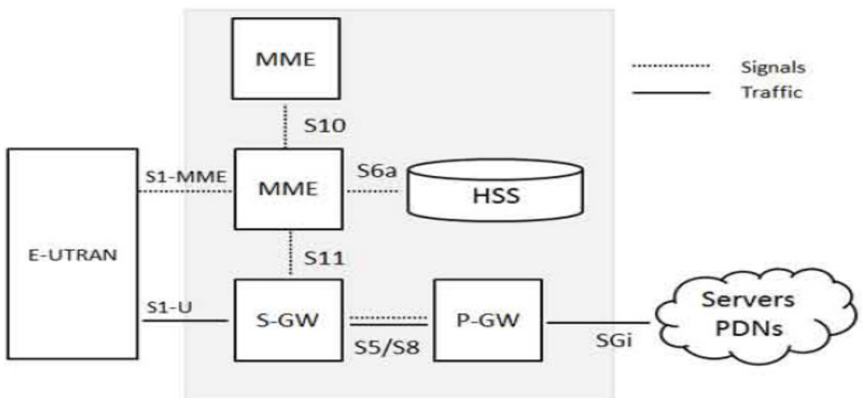

Figure 3-4 Simplified EPC architecture

Description:

- ***Home Subscriber Server (HSS)***
  - continuation of HLR - UMTS and GSM
  - is a central database that contains information about all the network operator's subscribers.

- ***Packet Data Network (PDN) Gateway (P-GW)*** communicates with the outside world i.e. using SGi interface.
  - Each packet data network is identified by an *access point name (APN)*.
  - PDN gateway role – is similar as the
    - *GPRS support node (GGSN)*

- ***Serving gateway (S-GW)*** *acts as a router,* and forwards data between the BS and the PDN gateway.
    - Similar role to the *serving GPRS support node (SGSN)* with UMTS and GSM.

- ***Mobility management entity (MME)***
  - controls the high-level operation of the mobile by means of signalling messages and HSS
-
- ***Policy Control and Charging Rules Function (PCRF)***
  - is a component which is not shown in the above diagram but it is responsible for *policy control decision-making,* as well as for controlling the flow-based charging

functionalities in the *Policy Control Enforcement Function* (PCEF), which resides in the P-GW.

- **S5/S8 is the I/F between the serving and PDN gateways.**
  - This has two slightly different implementations,
    - S5 if the two devices are in the same network
    - S8 if they are in different networks.

3.3.3.1 Functional split between the E-UTRAN and the EPC

Following diagram shows the functional split between the E-UTRAN and the EPC for an LTE network:

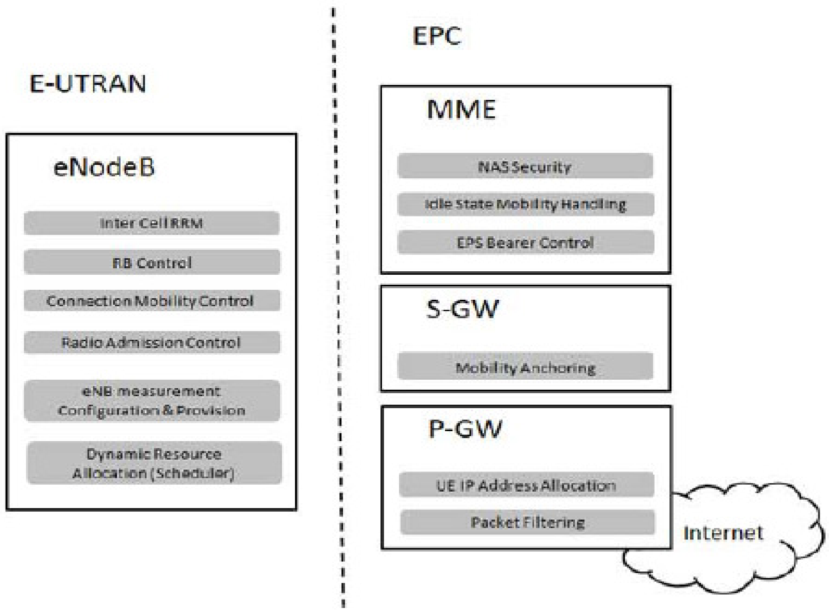

Figure 3-5 Main functions of E-UTRAN and EPC (simplified view)

Below DRA – there are several protocols: RRC, PDCP, RLC, MAC, PHY – to be discussed later

RB – Radio Bearer
NAS – Non Access Stratum
Evolved Packet System (EPS) describes the evolution of the 3G/UMTS standard introduced by the 3rd Generation Partnership Project (3GPP) standard committee.

This topic is looked at from a system perspective, from the radio interface to network and service architecture.

Many standards have been defined about EPS

3.3.3.2 2G/3G Versus LTE

Following table compares various important Network Elements & Signaling protocols used in 2G/3G and LTE.

Table 3-3 2G/3G versus LTE

2G/3G	LTE
GERAN and UTRAN	E-UTRAN
SGSN/PDSN-FA	S-GW
GGSN/PDSN-HA	PDN-GW
HLR/AAA	HSS
VLR	MME
SS7-MAP/ANSI-41/RADIUS	Diameter
DiameterGTPc-v0 and v1	GTPc-v2
MIP	PMIP

FA Foreign Agent
HA Home Agent
MIP Mobile IP
PMIP Proxy MIP

3.3.4 LTE Roaming Architecture (summary)

- Roaming = the user moves and uses the resources of other PLMN (Visited-PLMN).
- A roaming user is connected to the E-UTRAN, MME and S-GW of the ***visited LTE network.***
- **However, LTE/SAE allows the P-GW of either the visited or the home network to be used**

- The home network's P-GW allows the user to access the home operator's services even while in a visited network.
- A P-GW in the visited network allows a "local breakout" to the Internet in the visited network.
- The I/F between the *serving* and *PDN gateways* is as S5/S8.
    - slightly different implementations,
        - S5 if the two devices are in the same network,
        - S8 if they are in different networks.

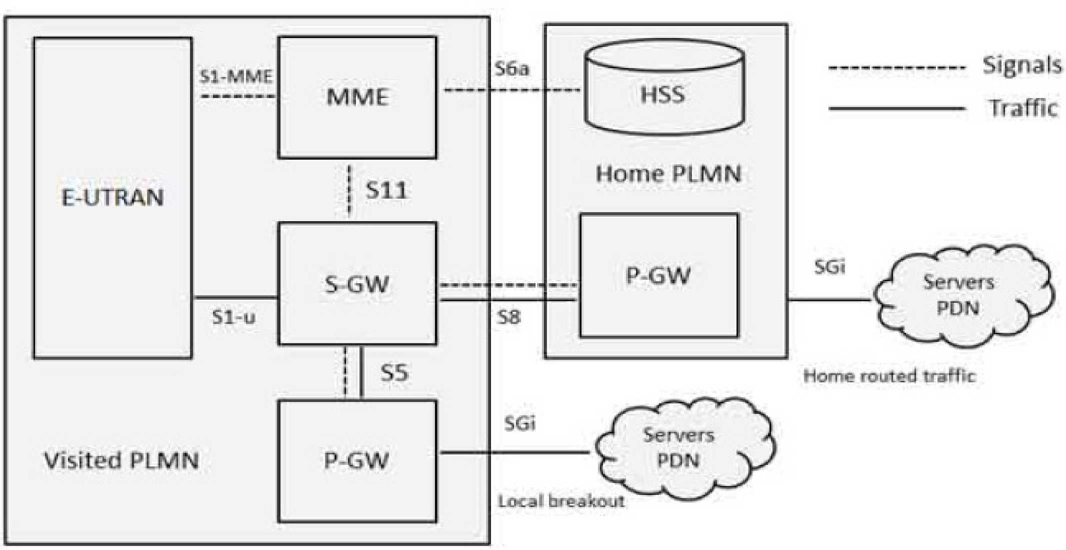

Figure 3-6 LTE Roaming architecture

3.3.5 LTE Numbering and Addressing

An LT E network area is divided into three different types of geographical areas

MME pool areas

- area through which the mobile can move without a change of serving MME
- every MME pool area is controlled by one or more MMEs on the network.

S-GW service areas

- area served by $n \geq 1$ serving S-GW, through which the mobile can move without a change of serving GW

Tracking areas

- MME pool areas and the S-GW service areas are both made **from smaller, non-overlapping units** known as **tracking areas (TAs).**
- They are similar to the location and routing areas of UMTS and GSM and will be used to track the locations of mobiles that are on standby mode.

Network IDs

- The network is identified using ***Public Land Mobile Network Identity (PLMN-ID)*** having
  - three digit mobile country code (MCC)
  - and a two or three digit mobile network code (MNC).
  - **PLMN-ID = MCC, MNC**

For example, the
MCC for the UK = 234; Vodafone's UK network MNC = 15.

MME IDs

Each MME has three main identities.

- An **MME code (MMEC)** uniquely identifies the MME within all the pool areas.
- A group of MMEs is assigned an ***MME Group Identity (MMEGI)*** which works along with MMEC to make MME identifier (MMEI).
- A **MMEI** uniquely identifies the MME within a particular network.
- **MMEI = MMEGI, MMEC**

If we **combine PLMN-ID with the MMEI** then we arrive at a ***Globally Unique MME Identifier (GUMMEI),*** which identifies an MME anywhere in the world:

- **GUMMEI = PLMN-ID, MMEI**

The Tracking Area IDs

Each tracking area has **two main identities.**

- tracking area code (TAC) identifies a tracking area within a particular network
- and if we combine this with the PLMN-ID then we get a
  - ***Globally Unique Tracking Area Identity (TAI).***

The Cell IDs

- Each cell in the network has **three types of identity**.
- ***E-UT RAN cell identity (ECI)*** identifies a cell within a particular network,
- ***E-UT RAN cell global identifier (ECGI)*** identifies a cell anywhere in the world.
- The physical cell identity, which is a number from 0 to 503 and it distinguishes a cell from its immediate neighbours.

The Mobile Equipment ID

- ***International Mobile Equipment Identity (IMEI)*** is a unique identity for the mobile equipment
- ***International Mobile Subscriber Identity (IMSI)*** is a unique identity for the UICC and the USIM.
- ***M temporary mobile subscriber identity (M-TMSI)*** identifies a mobile to its serving MME.

Adding the MME code in M-TMSI results in a ***S temporary mobile subscriber identity (S-TMSI),*** which identifies the mobile within an MME pool area.

- **S-TMSI= MMEC, M-TMSI**

Finally adding the MME group identity and the PLMN identity with S-TMSI results in the ***Globally Unique Temporary Identity (GUTI).***

- **GUTI= PLMN-ID, MMEGI, S-TMSI**

3.3.6 LTE – Radio Protocol Architecture

Main Refs: [1] [2]

Control plane + User (Data) plane

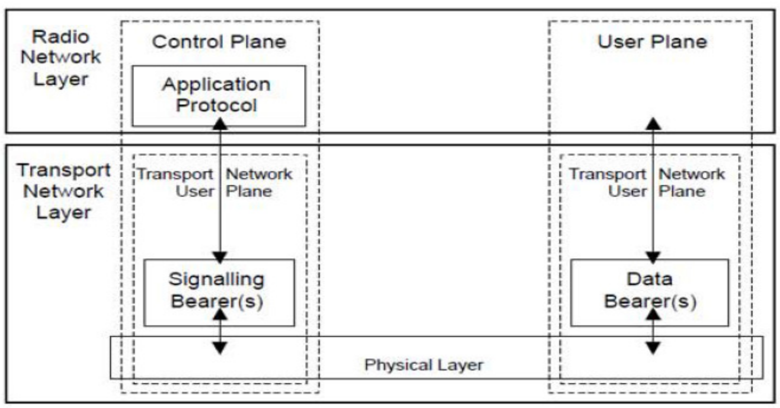

Figure 3-7 LTE Radio Protocol Architecture [1-2]

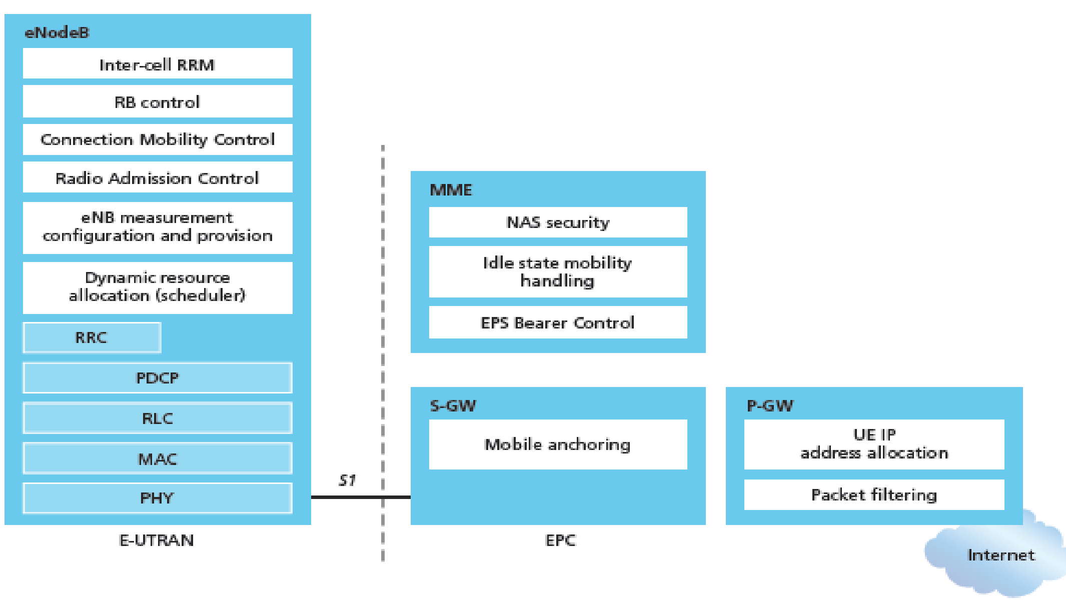

Figure 3-8 Functional split between E-UTRAN and EPC (details)

User plane : transports the data packets ; the stack is : ***appl., TCP, UDP, IP, etc***
Control plane: *Radio resource control (RRC)* protocol – via signalling messages BS- MN

In both cases, the information is processed by the

- ***Packet Data Convergence Protocol (PDCP)***
- ***Radio Link Control (RLC) protocol*** and
- ***Medium Access Control (MAC)*** protocol.

3.3.6.1 User Plane

- PDCP (Packet Data Convergence Protocol)
- RLC (radio Link Control)
- Medium Access Control (MAC).

- Packets in the core network (EPC) are encapsulated in a specific EPC protocol and
  - **Tunnelled between the P-GW and the eNodeB.**
- Different tunneling protocols are used depending on the interface.
- On the S1 and S5/S8 I/Fs it is used GPRS Tunneling Protocol (GTP)
- SDUs and PDUs are defined in details in the standards

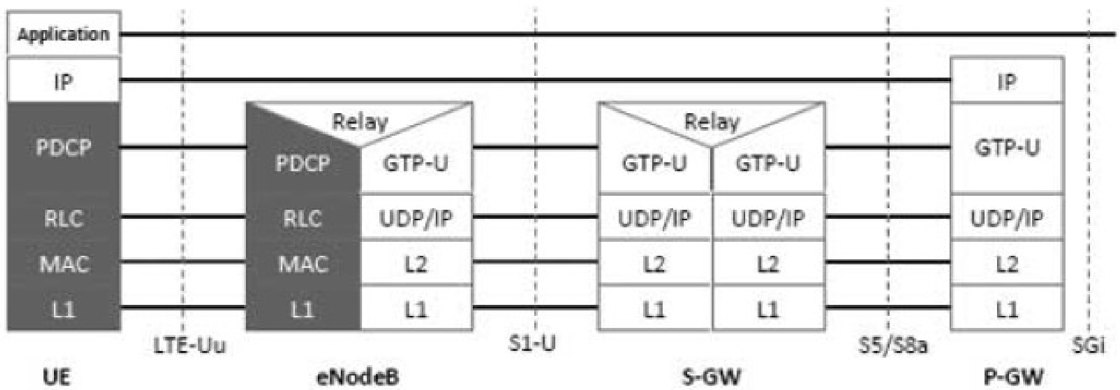

Figure 3-9 User Plane stack

3.3.6.2 Control Plane(CPl)

CPl

includes additionally the *Radio Resource Control layer (RRC)*, responsible for configuring the lower layers.

handles radio-specific functionality which depends on the UE state (idle or connected)

Idle UE

- UE associates itself to a cell
  - following a cell selection or reselection process based on parameters like radio link quality, cell status and also on radio access technology
- UE also monitors a paging channel to detect incoming calls and acquires system information.
- CPl runs cell selection and reselection procedures.

Connected UE

- UE supplies the E-UT RAN with DL channel quality and neighbor cell information to enable the E-UT RAN to select the most suitable cell for the UE.
  - CPl includes the Radio Resource Control (RRC) protocol.
- The lower layers : the same functions as for the user plane; but no header compression function
-

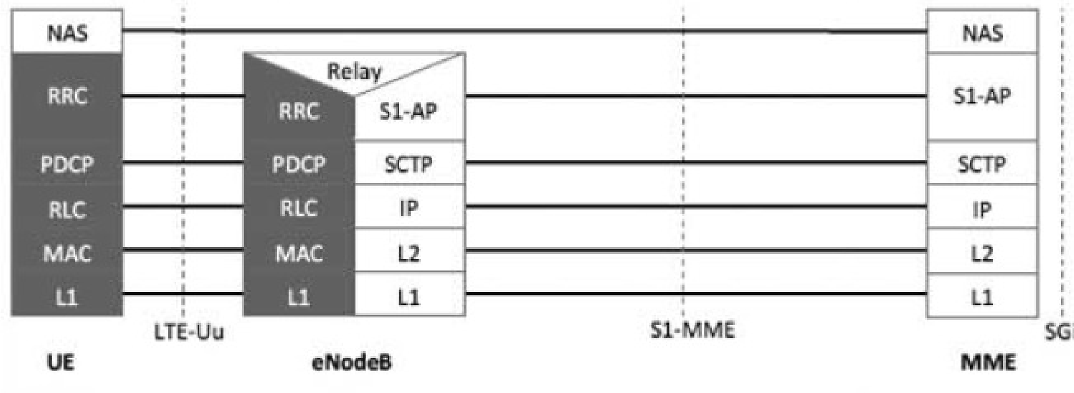

Figure 3-10 Control Plane stack

Grey zone – access stratun

Stream Control Transmission Protocol (SCTP)- RFC 2960

Designed initially to transport PSTN signaling messages over IP networks, but is capable of broader applications.

SCTP: is a reliable transport on top of IP

SCTP services offered to its users:

- acknowledged error-free non-duplicated transfer of user data,
- data fragmentation to conform to discovered path MTU size,
- sequenced delivery of user messages within multiple streams, with an option for order-of-arrival delivery of individual user messages,
- optional bundling of multiple user messages into a single SCTP packet
- network-level fault tolerance through supporting of multi-homing at either or both ends of an association.
- the design includes appropriate congestion avoidance behaviour and resistance to flooding and masquerade attacks.

3.3.6.3 LTE – E-UTRAN Protocol stack layers

Physical Layer (L1)

- carries MAC transport channels info over the fixed and air interface.
- link adaptation (AMC), power control, cell search (for initial synchro and handover purposes)
- L1 measurements (inside the LTE system and between systems) for the RRC layer.

Medium Access Layer (MAC)

- mapping : logical channels and transport (Phy) channels
- multiplexing of MAC SDUs from one or different logical channels onto transport blocks (TB) to be delivered to PHY on transport channels
- demultiplexing of MAC SDUs from one or different logical channels from transport blocks (TB) delivered from the PHY on transport channels
- scheduling information reporting
- error correction through HARQ
- priority handling between UEs by means of dynamic scheduling
- priority handling between Logical channels of one UE, LogicalChannel prioritization.

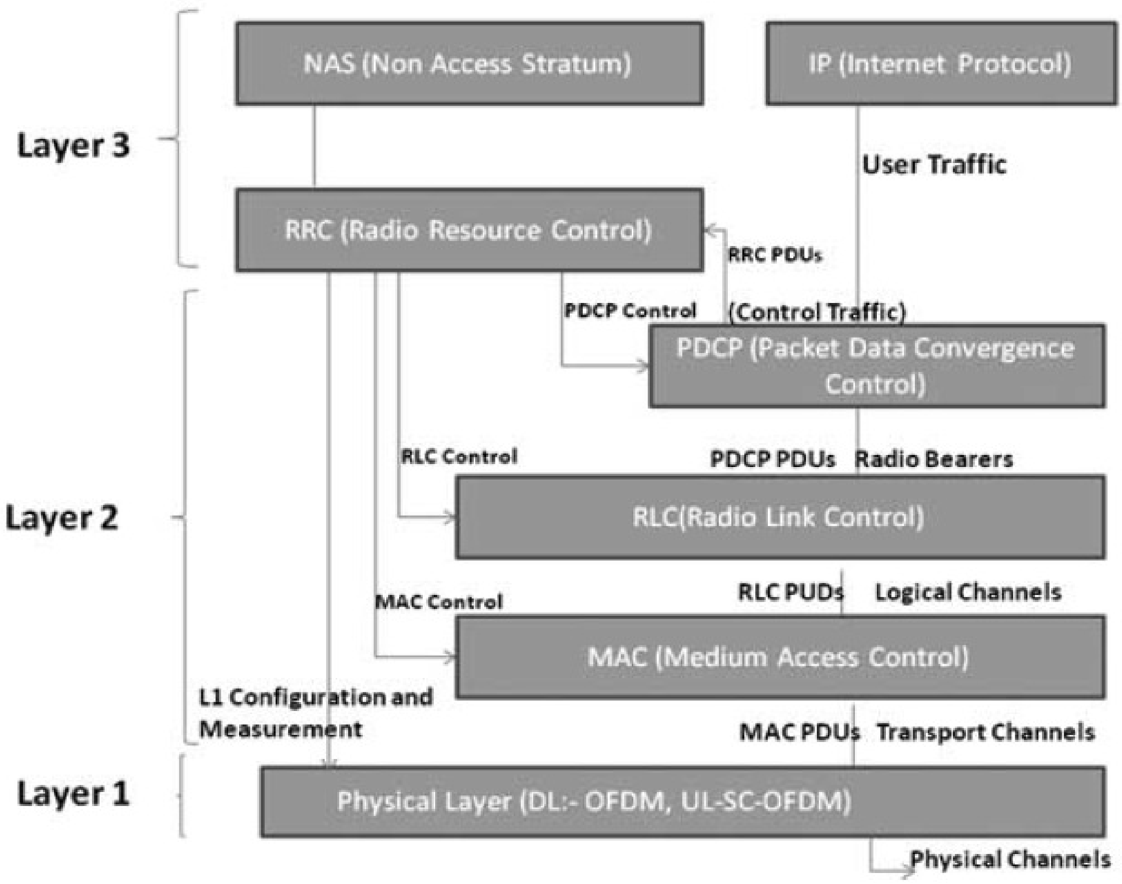

Figure 3-11 Protocol stack layers

Radio Link Control (RLC)
Operation modes:

- **Transparent (TM)**
- **Unacknowledged (UM)**
- **Acknowledged (AM)**

Functions:

- RLC Layer transfers the upper layer PDUs
- error correction throug HARQ (Only for AM)
- concatenation, segmentation and reassembly of RLC SDUs (Only for UM and AM data transfer).
- for re-segmentation of RLC data PDUs (Only for AM data transfer)
- reordering of RLC data PDUs (Only for UM and AM data transfer)
- duplicate detection (Only for UM and AM data transfer), RLC
- SDU discard (Only for UM and AM data transfer)
- RLC re-establishment and protocol error detection (Only for AM data transfer).

Radio Resource Control (RRC)
The main services and functions

- broadcast of System Information related to the
  - nonaccess stratum (NAS)
  - access stratum (AS)
- paging
- establishment, maintenance and release of an RRC connection between the UE and E-UT RAN
- security

Packet Data Convergence Control (PDCP)

- Header compression and decompression of IP data
- Transfer of data (user plane or control plane)
- Maintenance of PDCP Sequence Numbers (SNs)
- In-sequence delivery of upper layer PDUs at re-establishment of lower layers
- Duplicate elimination of lower layer SDUs at re-establishment of lower layers for radio bearers mapped on RLC AM
- Ciphering and deciphering of user DPl and CPl data
- Integrity protection and integrity verification of control plane data
- Timer based discard
- PDCP is used for Signalling Radio Bearer (SRBs) and Data Radio Bearer (DRBs) mapped on DCCH and DTCH type of logicalchannels.

Note:
Signalling Radio Bearers" (SRBs) are defined as **Radio Bearers (RB)** that are used only for the transmission of RRC and NAS messages.:

(1) SRB0 is for RRC messages using the CCCH logical channel;

(2) SRB1 is for RRC messages (which may include a piggybacked NAS message) as well as for NAS messages prior to the establishment of SRB2, all using DCCH logical channel;

(3) SRB2 is for NAS messages, using DCCH logical channel. SRB2 has a lower-priority than SRB1 and is always configured by E-UTRAN after security activation.

Non Access Stratum (NAS) Protocols

- they form the highest stratum of the CPl between the user equipment (UE) and MME.
- support the mobility of the UE and the session management procedures to establish and maintain IP connectivity between the UE and a PDN GW.

NAS is a functional layer in the UMTS and LTE wireless telecom protocol stacks between the core network and user equipment.

- used to manage the establishment of communication sessions and for maintaining continuous communications with the user equipment as it moves
- **The NAS is defined in contrast to the Access Stratum** which is responsible for carrying information over the wireless portion of the network
- NAS is a protocol for messages passed between the UE, and Core Nodes
    - (e.g. Mobile Switching Center, Serving GPRS Support Node, or Mobility Management Entity) that is passed transparently through the radio network.
- **Examples of NAS messages**
    - Update or Attach messages, Authentication Messages, Service Requests and so forth.
- Once the UE establishes a radio connection, the UE uses the radio connection to communicate with the core nodes to coordinate service.
-
- The distinction is that the
    - Access Stratum is for **dialogue explicitly between the mobile equipment and the radio network**
    - **NAS is for dialogue between the mobile equipment and core network nodes.**

3.3.6.4 LTE – Layers Data Flow

- IP Layer submits PDCP SDUs (IP Packets) to the PDCP layer.
- **PDCP layer**
  - o Performs header compression and adds PDCP header to these PDCP SDUs.
  - o submits PDCP PDUs (RLC SDUs) to RLC layer.

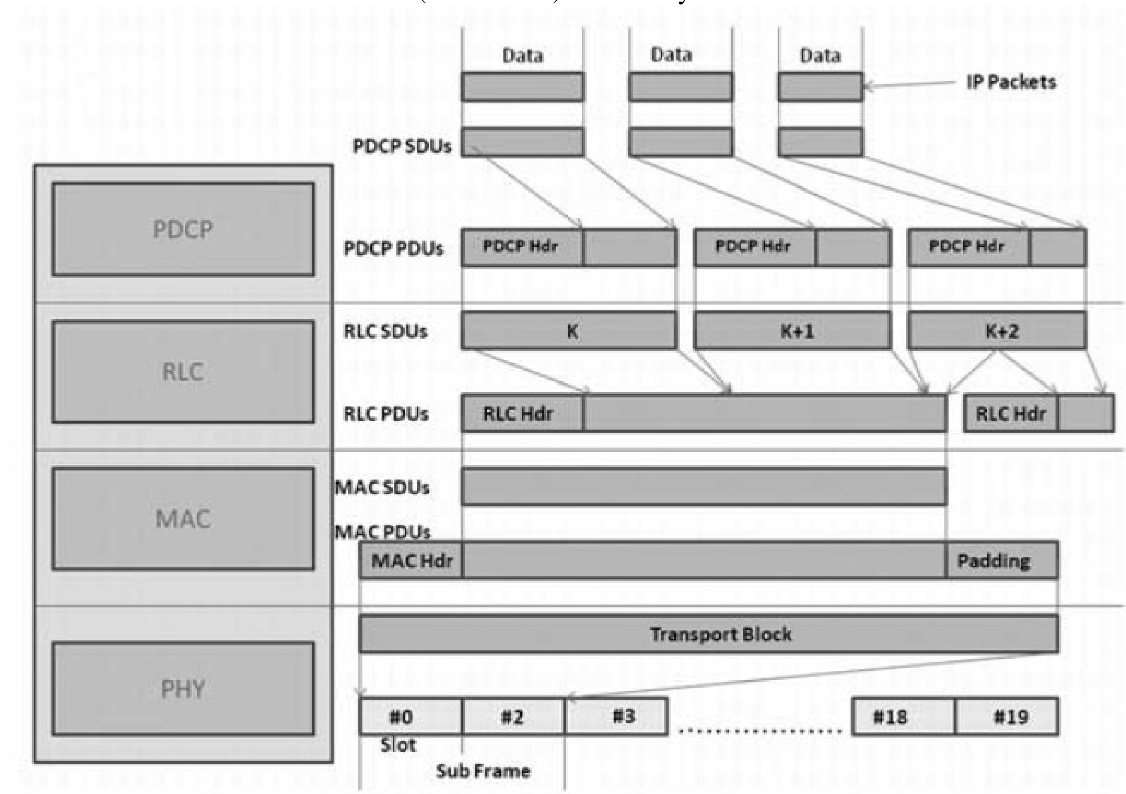

Figure 3-12 Data Plane SDUs and PDUs at various layers

PDCP Header Compression:

PDCP removes IP header (Minimum 20 bytes) from PDU, and adds Token of 1-4 bytes (Overhead savings)

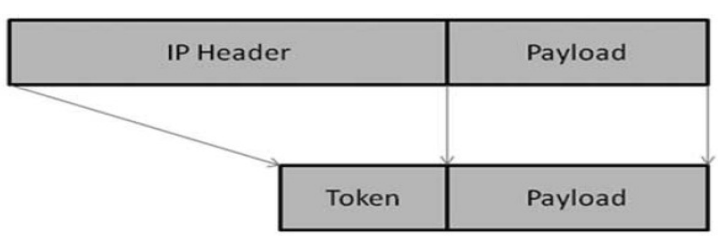

Figure 3-13 Header Compression

RLC layer

- may aply segmentation of the SDUS to make smaller RLC PDUs.
- May pack SDUs in larger PDUs
- adds header based on RLC mode of operation.
- submits these RLC PDUs (MAC SDUs) to the MAC layer.

3.3.6.5 LTE – Communication Channels [3]

LTE uses several different types of **logical**, **transport** and **physical** channel, for different info types and processing

Logical Channels:

- **Define info type** which is transmitted over the air, e.g . traffic/control channels, system broadcast, etc.
- Data and sgn. messages are carried on **logical channels** between the RLC and MAC

Transport Channels:

- Define **how is** data transmitted over the air
    - e.g . what are encoding, interleaving options used to transmit data
- Defined between the **MAC and PHY**

Physical Channels:

- Define **where is** something transmitted over the air, e.g . first N symbols in the DL frame.
- Data and sgn. messages are carried on PHY channels between the different levels of the PHY

Logical Channels (LC) details

- **These channels define the data-transfer services offered by the MAC layer.**
- LCs can be divided into ***control*** channels and ***traffic*** channels.
    - ***Control Channel*** : common channel or dedicated channel.
        - common channel means that can be used by all users in a cell (PMP)
        - dedicated channel - means a channel that can be used only by one user (Point to Point).
    - ***Traffic Channel*** : carry data in the user plane

Table 3-4 Logical Channels

Channel Name	Acronym	Control channel	Traffic channel
Broadcast Control Channel	BCCH	X	
Paging Control Channel	PCCH	X	
Common Control Channel	CCCH	X	
Dedicated Control Channel	DCCH	X	
Multicast Control Channel	MCCH	X	
Dedicated Traffic Channel	DTCH		X
Multicast Traffic Channel	MTCH		X

Transport Channeles

- define ***how*** and with ***what type of characteristics*** the data is transferred by the PHY layer.
- are distinguished by the ways in which the transport channel processor manipulates them.

Table 3-5 Transport Channels

Channel Name	Acronym	Downlink	Uplink
Broadcast Channel	BCH	X	
Downlink Shared Channel	DL-SCH	X	
Paging Channel	PCH	X	
Multicast Channel	MCH	X	
Uplink Shared Channel	UL-SCH		X
Random Access Channel	RACH		X

The **transport channel** processor composes several types of control information, to support the low-level operation of the physical layer.

Table 3-6 Transport channels information

Field Name	Acronym	Downlink	Uplink
Downlink control information	DCI	X	
Control format indicator	CFI	X	
Hybrid ARQ indicator	HI	X	
Uplink control information	UCI		X

Physical Channels

- **Physical Data Channels**
- **Physical Control Channels**

Physical data channels

They are distinguished by

- **the ways in which the PHY channel processor manipulates them**,
- and by the ways in which they are mapped onto the symbols and sub-carriers used by OFDMA)

Table 3-7 Physical Data Channels

Channel Name	Acronym	Downlink	Uplink
Physical downlink shared channel	PDSCH	X	
Physical broadcast channel	PBCH	X	
Physical multicast channel	PMCH	X	
Physical uplink shared channel	PUSCH		X
Physical random access channel	PRACH		X

Physical Control Channels

- The ***transport channel processor*** also creates control info that supports the low-level operation of the PHY layer and sends this information to the ***physical channel processor*** in the form of physical control channels.
- The information travels as far as the transport channel processor in the receiver, but is invisible to higher layers.

- Similarly, the **physical channel processor creates physical signals, which support the lowest-level aspects of the system.**

Table 3-8 Physical Control Channels

Channel Name	Acronym	Downlink	Uplink
Physical control format indicator channel	PCFICH	X	
Physical hybrid ARQ indicator channel	PHICH	X	
Physical downlink control channel	PDCCH	X	
Relay physical downlink control channel	R-PDCCH	X	
Physical uplink control channel	PUCCH		X

3.3.6.6 LTE - OFDM and SC Technology

OFDM

- **LTE uses OFDM (based on digital multi-carrier modulation method) for the DL** to overcome the effect of multi path fading problem available in UMTS
    - to transmit the data over **many narrow band careers of 180 KHz each**

- OFDM meets the LTE requirement for spectrum flexibility and enables cost-efficient solutions for very wide carriers with high peak rates.
- The basic LTE DL PHY resource can be seen as a time-frequency grid,
- The **OFDM symbols are grouped into resource blocks**.
    - The resource blocks have a total size of **180kHz in the frequency domain and 0.5ms** in the time domain.
    - Each **1ms Transmission Time Interval (TTI) consists of two slots (T slot)**

- **Each user is allocated a number of so-called resource blocks in the time.frequency grid.**

- The more resource blocks a user gets, and the higher the modulation used in the resource elements, the higher the bit-rate.

- Which resource blocks and how many the user gets (at a given point in time) depend on **advanced scheduling mechanisms** in the F-T dimensions (similar to WiMAX scheduling) .
- The scheduling mechanisms in LTE are similar to those used in HSPA, and enable optimal performance for different services in different radio environments.

Additional comments

- The LTE physical resource is a **time-frequency resource grid**
    - where a **single resource element** corresponds to one **OFDM subcarrier** during one OFDM symbol interval with carrier spacing (Δf = 15kHz).
    - 12 consecutive subcarriers are grouped to constitute a **resource block,** the basic unit of resource allocation.
- In normal CP (cyclic prefix) mode, one time slot contains 7 OFDM symbols and in extended CP there are 6 symbols.

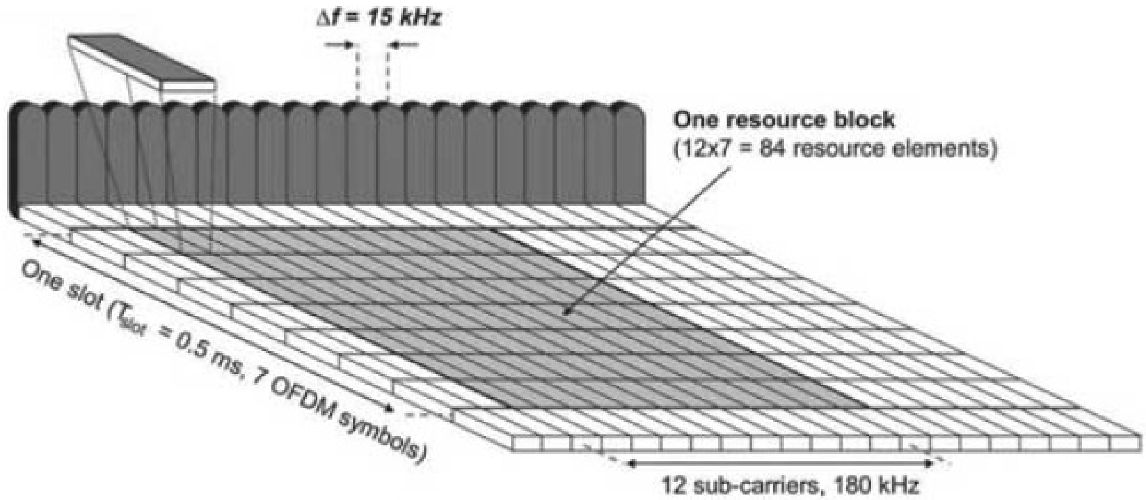

Figure 3-14 OFDM in LTE [3]

OFDM Advantages (over SC)

- Ability to **cope with severe channel conditions**
  - (for example, attenuation of high frequencies in a long copper wire, narrowband interference and frequency-selective fading due to multipath) without complex equalization filters.
  - Channel equalization is simplified because OFDM may be viewed as using many slowly-modulated narrowband signals
- The low symbol rate → use of a guard interval between symbols affordable, making it possible to eliminate inter symbol interference (ISI).
  - facilitates the design of single frequency networks (SFNs), where several adjacent transmitters send the same signal simultaneously at the same frequency, as the signals from multiple distant transmitters may be combined constructively, rather than interfering as would typically occur in a traditional SC system.

OFDM Drawbacks

High peak-to-average ratio
Sensitive to frequency offset, hence to Doppler-shift as well.

SC-FDMA Technolog y

- LTE uses in the UL ***Single Carrier Frequency Division Multiple Access (SC-FDMA)***
- to compensate for a **drawback with OFDM, which has a very high *Peak to Avg.Power Ratio (PAPR)***
- High PAPR requires
  - **expensive and inefficient power amplifiers** with high requirements on linearity
  - **increases the cost of the terminal and consumes the battery faster.**

- SC-FDMA solves this problem by grouping together the resource blocks in such a way that reduces the need for linearity, and so power consumption, in the power amplifier.
- A low PAPR also improves coverage and the cell-edge performance.

eNB Scheduler [11]

It is a **key component for the achievement of a fast adjusted and efficiently utilized radio resource**.

The **Transmission Time Interval (TTI)** is set to only 1 ms.

During each TTI the eNB scheduler shall:

- consider the physical radio environment per UE.
  - The UEs report their perceived radio quality, as an input to the scheduler to decide which Modulation and Coding scheme to use.
  - The solution relies on rapid adaptation to channel variations, employing HARQ (Hybrid Automatic Repeat Request) with soft-combining and rate adaptation.

- prioritize the QoS service requirements amongst the UEs.
  - **LTE supports both delay sensitive real-time services as well as datacom services** requiring high data peak rates.
- **inform the UEs of allocated radio resources.**
  - The eNB schedules the UEs both on the downlink and on the uplink.
  - For each UE scheduled in a TTI the user data will be carried in a *Transport Block (TB).*
  - DL there can be a maximum of two TBs generated per TTI per UE – if spatial multiplexing is used.
  - The TB is delivered on a transport channel.

In LTE the number of channels is decreased compare to UMTS. For the user plane there is only one shared transport channel in each direction. The TB sent on the channel, can therefore contain bits from a number of services, multiplexed together.

3.4 Integration LTE- 2G/3G

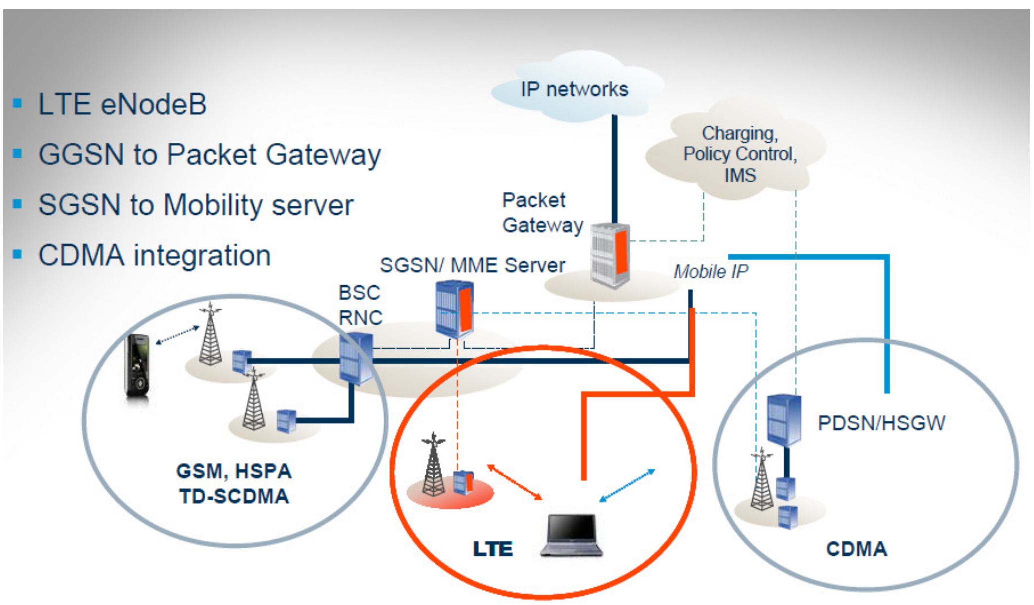

Figure 3-15 Integration of LTE with 2G/3G technologies

4 ARCHITECTURES AND TECHNOLOGIES FOR FUTURE INTERNET NETWORKS

4.1 Software Defined Networking

Why SDN?

- Future Internet challenges -> need to solve the current Internet limitation and ossification- as to support global integration of various forms of communications
  - **Evolutionary approach**
  - **Clean slate approach**
  - **New trends**

- **Software Defined Networks◊ Software Defined Internet Architectures**
- **Cloud computing**
- **(ICN/CCN) Information/Content Centric Networking, (CON) Content Oriented Networking, (CAN) Content Aware Networking, …**
- **Combinations**

- Current network architectures only partially meet today's requirements

4.1.1 Current network technologies limitations

- **Complexity that leads to stasis:**
  - Current status : many discrete sets protocols, separately defined for specific purposes
  - No fundamental network abstractions -> complexity
  - To add/move any device, IT admin. must (re) configure multiple specific HW/SW entities using device-level management tools
  - Today's networks reconfigurations are performed relatively in static way (to minimize the risk of service disruption)
- The static nature of networks
  - not good for today's dynamic server environment, (server virtualization, VM migration)
    - applications are distributed across multiple virtual machines (VMs), which exchange traffic flows with each other.
    - VM migration : challenge for many aspects of traditional networking (addressing schemes, namespaces segmented, routing-based design).
- **Limited capability for dynamic differentiated QoS** levels because of – usually static provisioning; not enough capability for dynamic adaptation to changing traffic, application, and user demands.
-
- **Inconsistent policies:**
  - Network-wide policy implementation -> need to configure ~10^3 - 10^4 devices and mechanisms
  - Today's networks complexity ◊ difficult to apply a consistent set of access, security, QoS, and other policies

- **Scalability issues:**
  - Complex network (10**5 network devices in data centers)

  - Over-subscription based on predictable traffic patterns is no more good;
    - in today's virtualized data centres, traffic patterns are highly dynamic and it is difficult to predict

  - Mega-operators (e.g. Google, Yahoo!, Facebook): scalability challenges
    - The number of of computing elements exploded
    - data-set exchanges among compute nodes can reach petabytes
  - Need "hyper-scale" networks to provide high-performance, low-cost connectivity among many physical servers (need automation)
  - Carriers have to deliver better-differentiated services to customers
  - Multi-tenancy : the network must serve **large groups** of users with different applications and needs

- **Vendor dependency**
  - Carriers/enterprises want rapid response to changing business needs or user demands
  - They are limited by vendors' equipment product cycles (years)
  - Lack of standard, open I/F - limits the network operators ability to tailor the network to their individual environments

4.1.2 Requirements for new network architectures

To answer to

- **Changing traffic patterns:**
  - *Traffic patterns have changed significantly* within the enterprise data center: today's applications access different DBs and servers, creating a high M2M traffic before returning data to the end user device (different from classic client-server applications)
  - *Users- network traffic patterns changing:* they want access to corporate content and apps. from **any type of device, anywhere, at any time**
  - Enterprises : need of flexible computing model: *private public or hybrid cloud,* → additional traffic across the WANs
- **Need of flexible access to IT resources:**
  - *Increasing usage of mobile personal devices* such as smart-phones, tablets, and notebooks to access the corporate network
  - Need to accommodate these personal devices while *protecting corporate data and intellectual property* and meeting compliance mandates
- **Cloud services development:**
  - Significant growth of public and private cloud services (SaaS, PaaS, IaaS, NaaS,..) on demand and à la carte
  - IT's needs for cloud services : security, compliance, auditing requirements, elastic scaling of computing, storage, and network resources,etc.
- **Need for more bandwidth:**
  - today's high volume of data requires massive parallel processing on thousands of inter-connected servers
  - demand for additional network capacity in the data center
  - data center networks : need of scaling to very large size, while maintaining any-to-any connectivity
  - Media/content traffic high increase- need of more bandwidth

4.1.3 SDN approach – main features

- **Software- Defined Networking (SDN)** – aiming to transform networking architecture
- **Open Networking Foundation** (ONF- non-profit industry consortium) ◊ OpenFlow I/F specifications for SDN

- **SDN major characteristics:**
  - the *Control Plane (CPl)* and *Data Planes (DPl)* are decoupled
  - network intelligence and state are logically centralized
  - underlying network infrastructure is abstracted from the applications
  - network programability
- *Note: after many years of strongly defending a completely distributed control approach in TCP/IP architecture- now a more centralized approach is proposed ….*

- **Promises for enterprises and carriers** :
  - higher programmability opportunities, automation, and network control
  - enabling them to build highly scalable, flexible networks
  - fast adapt to changing business needs

- *Source: Software-Defined Networking: The New Norm for Networks ONF White Paper April 13, 2012*

- **SDN + OpenFlow I/F(first standard) advantages:**
  - *high-performance, granular traffic control* across multiple vendors' network devices; ability to apply comprehensive and wide-ranging policies at the session, user, device, and application levels
  - *centralized M&C* improving automation and management
  - *common APIs abstracting the underlying networking* details from the orchestration and provisioning systems and applications;
  - *flexibility:* new network capabilities and services with no need to configure individual devices or wait for vendor releases
  - *programmability* by operators, enterprises, independent software vendors, and users (not just equipment manufacturers) using common programming environments
  - *Increased network reliability* and *security* as a result of centralized and automated management of network devices, uniform policy enforcement, and fewer configuration errors
  - *better end-user experience* as applications exploit centralized network state information to seamlessly adapt network behavior to user needs
  - *protects existing investments* while future-proofing the network
  - SDN allows evolution to an extensible service delivery platform capable of responding rapidly to changing business, end-user, and market needs.

- **SDN – problems/open issues**
  - **Centralization**
    - **(single point of failures)- reliability**
    - **Real time capability of network control**
  - **horizontal and vertical scalability**
  - **backward compatibility**
  - **security**
  - **Manufacturers/operator resiliency**
  - **etc.**

4.1.4 Earlier technologies related to SDN

- **Open Signaling**
  - **OPENSIG WG** (~1995)- attempt to make Internet, ATM, and mobile networks more open, extensible, and programmable"
  - Ideas: separation between the communication HW and control SW
- **IETF WG** - > General Switch Management Protocol (GSMP
  - GSMPv3, June 2002, WG has been concluded
  - general purpose protocol to control a label switch.
  - establish and release connections across the switch
- **Active Networking** ~1995-2000
  - - programmable network infrastructure (for customized serviceses)
    - (1) user-programmable switches, in-band data transfer and out-of-band management channels
    - (2) control information organized in "capsules", which were program fragments that could be carried in user messages; program fragments would then be interpreted and executed by routers.
  - No large scale / significant success in practice - issues: security and perf.
- **4D Project** [5]~2004, a clean slate design
  - separation between the routing decision logic and the protocols governing the interaction between network elements.
  - Consequences: NOX = operating system for networks in OF context

- **NETCONF**, 2006
  - IETF Network Configuration WG (still active) : NETCONF defined a management protocol for modifying the configuration of network devices.
    - network devices have APIs - (to send /retrieve) configuration data
  - still - no separation Control/Data Plane

- **Ethane**, 2006- precursor to SDN
  - new network architecture for enterprise networks
  - centralized controller to manage policy and security in a network
  - two components:
    - a controller to decide if a packet should be forwarded
    - Ethane switch : a flow table and a secure channel to the controller

- **IETF WG ForCES Forwarding and Control Element Seperaration, 2003.**
  - A parallel approach to SDN
  - some common goals with SDN and ONF
  - Differences:
    - ForCES: the internal network device architecture is redefined as the control element separated from the forwarding element, but the combined entity is still represented as a single network element to the outside world
      - Aim: to combine new forwarding hardware with third-party control within a single network device where the separation is kept within close proximity (e.g., same box or room)

Howevere, in SDN: Contrl Plane (CPl) is totally moved out from net device

  - FORCES published docs on : arch. framework, interactions, modelling language, forwarding element (FE) functions, protocol between Ctrl and FE

Early SDN products and activities examples

- 2008: Software-Defined Networking (SDN) : NOX Network Operating System [Nicira]; OpenFlow switch interface [Stanford/Nicira]
- 2011: Open Networking Foundation (72 members) : Board: Google, Yahoo, Verizon, DT, Msoft, F'book, NTT ; Members: Cisco, Juniper, HP, Dell, Broadcom, IBM,…..

4.2 SDN Basic Architecture

Evolutionary architecture (seamless deployment – possible)

- CPl and DPl are separated
- Network intelligence is (logically) centralized in SW-based SDN controllers, which maintain a global view of the network.
- Execute CPl SW on general purpose HW
- Decoupled from specific networking HW
- CPl can use use commodity servers
- Data Plane (DPl) is programmable
- Maintain, control and program data plane state from a central entity
- The architecture defines the control for a network (and not for a network device) The network appears to the applications and policy engines as a single, logical switch
- This simplified network abstraction can be efficiently programmed

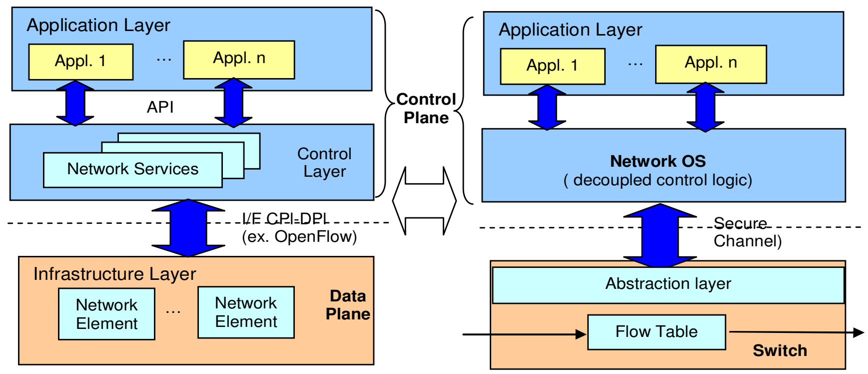

Figure 4-1 SDN generic architectture

- **Control Plane**
    - **Control Applications/Program**
        - operates on view of network **:**
        - performs different functions (routing, traffic engineering, QoS, security, etc.)
        - **Input**: global network view (graph/database)
        - **Output**: configuration of each network device
        - Control program is not a distributed system
        - Abstraction hides details of distributed state
    - **Network OS:** distributed system that creates a consistent, global and up-to-date network view
        - In SDN it runs can on controllers (servers) in the network
        - It creates the "lower layer" of the Control Plane
        - Examples: NOX, ONIX, Trema, Beacon, Maestro, …

- **Data Plane** : forwarders/switches (Forwarding elements -FE)
    - NOS uses some abstraction to:
        - Get state information from FE
        - Give control directives to FE

- **Advantages**
- **Centralization allows:**
    - To alter network behavior in real-time and faster deploy new applications and network services (hours, days not weeks or months as today).
    - flexibility to configure, manage, secure, and optimize network resources via dynamic, automated SDN programs (not waiting for vendors) .

- APIs facilitate implementation of:
    - common network services: routing, multicast, security, access control, bandwidth management, QoS, traffic engineering, processor and storage optimization, energy usage
    - policy management, custom tailored to meet business objectives
        - Easy to define and enforce consistent policies across both wired and wireless connections on a campus

- SDN control and applications layers, business apps can operate on an **abstraction of the network**, leveraging network services and capabilities without being tied to the details of their implementation
- Manage the entire network : intelligent orchestration and provisioning systems
- ONF studies open APIs to promote multi-vendor management:
    - possibility for **on-demand resource allocation, self-service provisioning,** truly virtualized networking, and secure cloud services.

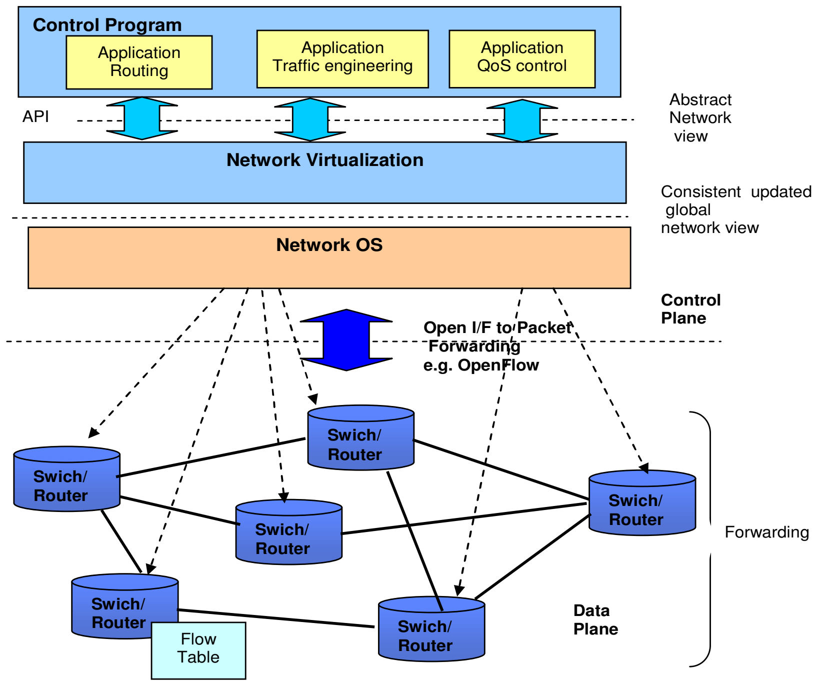

Figure 4-2 Basic SDN architecture

NOS = Network Operating System

- **Network OS:**
    - Distributed system that creates a consistent, updated network view
    - Executed on servers (controllers) in the network
    - Examples: NOX, ONIX, HyperFlow, Floodlight, Trema, Kandoo, Beacon, Maestro,..
- Uses forwarding abstraction in order to:
    - Collect state information from FE
    - Generate commands to FE

- **OpenFlow summary**
    - the **first SDN standard** communications: CPl-DPl I/F
    - allows direct access to the Fwd. Plane of network devices (FE = switches and routers), both physical and virtual (hypervisor-based)
    - allows to move CPl out of the FEs to logically centralized control software
    - specifies basic primitives to be used by an external SW application to program the FwdPl (~ instruction set of a CPU)

- ***Flow concept*** *:* to identify network traffic based on pre-defined match rules that can be statically or dynamically programmed by the SDN control SW

- network can be programmed on a per-flow basis (provides – if wanted- extremely granular control), enabling the network to respond to real-time changes at the application, user, and session levels

- allows IT admin to define how traffic should flow through FEs based on parameters such as usage patterns, applications, and cloud resources

Open flow capable switches

Source Ref1: "OpenFlow: Enabling Innovation in Campus Networks"- *N.McKeown, T.Anderson, H.Balakrishnan, G.Parulkar, L.Peterson, J.Rexford, S.Shenker, J.Turner*

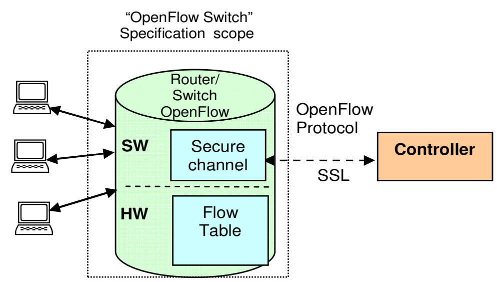

Figure 4-3 Idealized OpenFlow Switch.

The Flow Table is controlled by a remote controller via the Secure Channel.

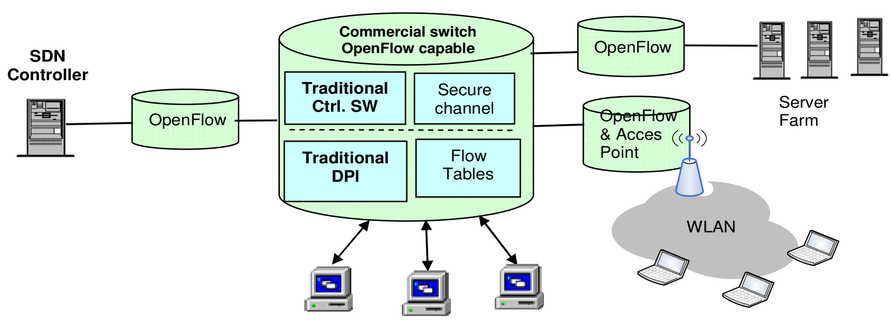

Figure 4-4 Example of a network of OpenFlow-enabled commercial switches and routers.

In	VLAN	Ethernet			IP			TCP	
Port	ID	SA	DA	Type	SA	DA	Proto	Src	Dst

Table 1: The header fields matched in a "Type 0" OpenFlow switch.

Figure 4-5 Example of fields characterising a flow

4.3 SDN Applications

4.3.1 Enterprise Networks

-
- SDN – unify and improve M&C;
  - support to programmatically enforce/ adjust network policies as well as help net monitoring and tune performance.
  - eliminate middleboxes (NAT, firewalls, load balancers, access control, DPI, etc.) by integrating their functionality within the controller
  - configuration changes (currently- common networks instability source) can be performed in a more flexible and consistent way
  - a set of high-level abstractions are proposed that allow admin to update the entire network
  - packets are processed in consistent way at network level based on flow concepts

4.3.2 Data Centers

- High volume and dynamic traffic, large scale
- Management and policy enforcement is critical especially to avoid service disruption.
- Still some Data Center are provisioned based on estimation of peak demand
  - (-) high percentage of time under-utilization
  - (+) but answer to high demand is very fast

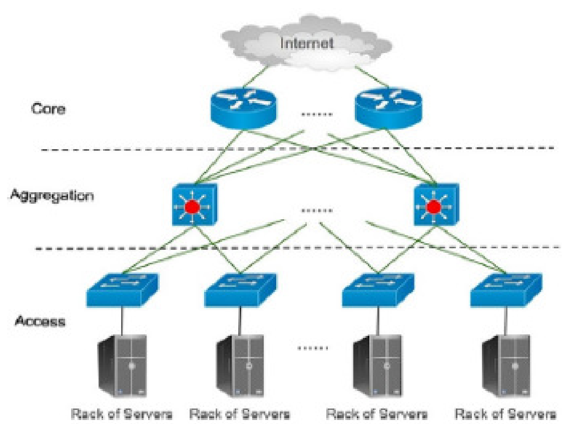

Figure 4-6 Basic layered design of data center network infrastructure

- **Aggregation/acces and mobile-backhaul networks (AAN)**
- **Dynamic service-chaining** (source: Ericsson)
  - Usually for inline services (DPI, firewalls (FWs), NAT, etc.), operators use special middleboxes hosted on HW/VMs.
  - *Service chaining is required* to route certain subscriber traffic through more than one such service.
  - Today: no protocols or tools to perform flexible, dynamic traffic steering
  - Currently solutions : static or non-flexible solutions
- **Packet-optical integration**
- **Virtual Home Gateway (VHG)**
- **Home Networks (HN) and Small Business**

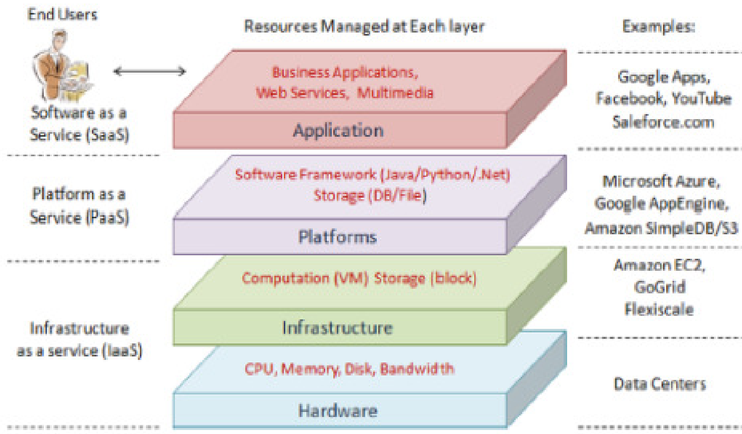

Figure 4-7 Cloud computing Architecture

- **Energy consumption** – important in big Data Centers (10-20% for networking) → need of better energy management
    - Proposal: SDN based Network-wide power management, (elastic tree, savings 20-65% depending on traffic conditions-have been shown)

    - Savings can be increased if used in cooperation with server management and virtualization
        - controlling the migration of VMs as to increase the number of machines and switches that can be shut down
        - however such traffic management must be balanced with scalability and performance overheads.

Other Issues :OF sometimes excessively centralises control processing while only few "significant" flows need to be managed → bottlenecks in the control communication (if fine granularity is wanted)

- Solutions: proactive policies and wild-card rules, but the cost is paid with less to manage traffic and gather statistics.

- Proposals done: design changes like
    - keep control of flows as much as possible in the data plane while maintaining enough visibility at controller level for effective flow management.
    - pushing back again responsibility on many flows to the switches and adding more efficient statistics collection mechanisms, for significant" flows (e.g. long-lived, high-throughput) identified and managed by the controller.
    - Effect: reducing the control overhead and having fewer flow table entries

4.3.3 SDN in wireless networks

- **Infrastructure-based Wireless Access Networks**

4.3.3.1 OpenRoads project [21]

- users move across different wireless infrastructures, managed by various providers.
- SDN-based architecture, backwards-compatible, yet open and sharable between different SPs

- testbed using OF-enabled wireless devices such as WiFi APs and WiMAX base stations controlled by NOX and Flowvisor controllers
- Result: improved performance on handover events.

- Current work is done for: specific requirements and challenges in deploying a software-defined cellular network.

4.3.3.2 Odin[22] : programmability in enterprise wireless LAN environments.

- - it builds an Access Point (AP) abstraction at controller level,
  - separating the association state from the physical AP
  - enabling proactive mobility management and load balancing without changes to the client.

4.3.3.3 OpenRadio[23] : programmable wireless data plane

- flexibility at the PHY and MAC layers
- provide modular I/Fs able to process traffic subsets using WiFi, WiMAX, 3GPP LTE-Advanced, etc.

- Separation of the decision and forwarding planes allows:
  - an operator may express decision plane rules and corresponding actions
  - assembled from processing plane modules (e.g., FFT, decoding, etc.)

4.3.3.4 A Generic 5G architecture based on cloud and SDN/NFV

A major challenge in defining a 5G architecture, while taking advantages from modern cloud concepts and SDN/NFV architectures and thechnologies, is

- how too split the functionalities between core and access part, between hardware and software

how to separate CPl and DPl as to finaly meet the strong requirements summarised at the beginning of this Chapter.

Several works [14-16], propose generic architectures, consisting from a RAN part coupled with a core part, where the core could be seen as a cloud.

A general architecture is presented in [14], based on two logical network layers -

- a network cloud performing higher layer functionalities and
- a *Radio Network* (RN) performing a minimum set of L1/L2 functionalities.

Three main design concepts are considered and integrated:

- NFV and SDN with control/user plane split, to provide flexible deployment and operation;
- ultra-dense small cell deployments on licensed and unlicensed spectrum, to support high capacity and data rate challenges;
- the network data are intelligently used in the cloud, to optimise network resources use and for QoS provisioning and planning.

Within the network cloud different functions could be dynamically instantiated and scaled based on SDN/NFV approach. A redesigned protocol stack eliminates the redundant functionalities and integrates the

- *Access Stratum* (AS) and
- *Non Access Stratum* (NAS).

- The architecture enables provisioning of required capacity and coverage based on splitting the Control/User (data) planes and using different frequency bands for coverage and capacity.

- Relaying and nesting configuration are used in order to support multiple devices, group mobility, and nomadic hotspots.
- The network intelligence is data-driven, allowing to optimise network resource planning and usage. Connectionless and contention-based access is proposed with new waveforms for asynchronous access of massive numbers of *machine-type communications* (MTC) devices like connected cars, connected homes, moving robots, and sensors. Figure 4-8 presents a simplified high level view of this architecture.

- The NFV based network cloud is split into CPl and DPl (following the SDN principle) and a 'network intelligence- NI' layer could be put on top of them.
- The CPl can perform tasks as mobility management, radio resource control, NAS-AS integration, security functions (e.g. authentication, etc.).

- The DPl (User Plane) assures the data flow paths between different RANs and to/from Internet. Specifically, the DPl contains gateway functions, data processing functions, mobility anchors, security control on the air interface, etc.

- The NI performs the services orchestration, i.e., makes traffic optimisation, QoS provisioning, caching control, and so on; additionally the NI can analyse the big data collected from the different components (core, RAN) and infer appropriate actions.
-
- In Figure 4-8 the RAN might have macrocells, covering cells and small cells. The SDN principle of CPl/DPl (or C/U) split is also applied in the RAN. All elements in RAN may have a set of L1/L2 functions. Additionally the main base station (BS) may have low carrier frequencies (CF) for respectively non-orthogonal multiple access - as fall back for coverage and high CF for Massive MIMO wireless backhaul.

- The small cels stations may high CF and/or unlicensed spectrum for local capacity and switch-on-demand capabilities. The Remote Radio Units (RRU) have high CF with Massive MIMO for capacity.

- Network controlled direct communication Device to Device (D2D) is possible, between terminals, while applying different D2D variants: inband or outband, in underlay or overlay style, thus saving significant radio resources . The Mobile Terminals may have dual connectivity and independent DPl/CPl mobility.

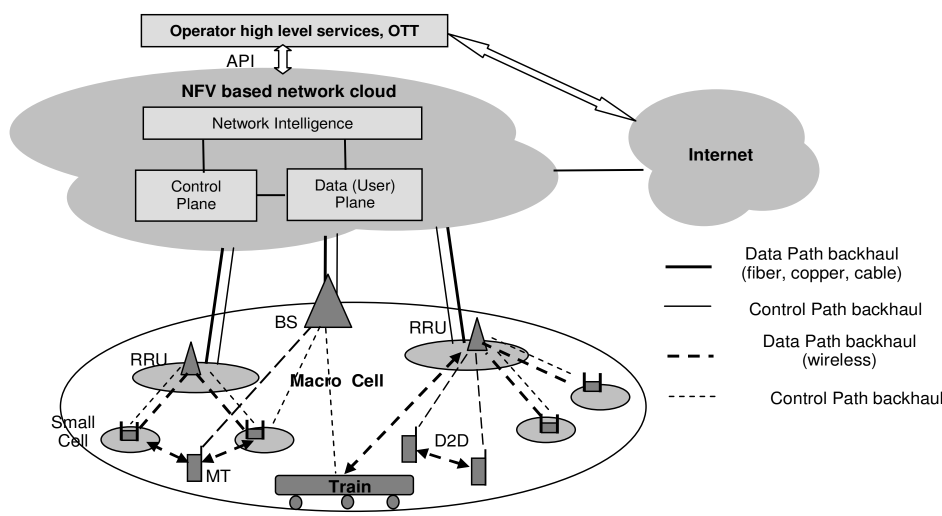

Figure 4-8 Example of 5G network generic architecture

RRU –Remote Radio Unit; D2D – Network controlled Device to Device; MTC – Machine type Communication; OTT- Over the Top; MT – Mobile Terminal; NFV- Network Function Virtualisation; API- Application Programmer Interface

- The proposed architecture allows a flexible deployment and management. The network cloud realisation could be also flexible; CPl and DPl instances can be seen as "data centers" having high amount of resources.

- Each data center can control one or several macrocells and/or RRUs. The DPl and CPL entities could be located close to base stations and also to RRUs if some latency- critical services requirements should be met. Therefore the operator can deploy both large and small data centers to support specific service needs.
-
- On the other hand, base stations are simpler and more efficient in energy consumption than in conventional 4G case. The network cloud allows for resource pooling, reducing overprovisioning and underutilisation of network resources.

- By employing SDN and NFV, the architecture allows a dynamic deployment and scaling on demand of network functions. The local data centers can borrow resources from each other, should the traffic load conditions require this; they also can be enriched (installing new software) to support other applications.

- The cloud-computing model flexibility is present in the network cloud: when the traffic demand is low, the available cloud resources can be lent out, whereas additional resources can be rented through infrastructure as a service (IaaS) when the demand is high.

- The business model supported by the generic architecture described above can be enriched to provide specific network functionalities as a service (i.e., XaaS) to customers (e.g., network operators, OTT players, enterprises) having some specific requirements. Examples of such services are: "mobile network as a service", "radio network as a service" and even CPl o DPl entities can be offered as a service. Third parties (e.g., like OTT players) might rent defined parts of the platform, e.g., to serve applications with low latency requirements.

- However, when considering detail functioning of the proposed system, some mutual conflicts of the conceptual components have been identified [2]. Further work is necessary to decide on balancing between different allocation of functions and specifically how to incorporate small cells with NFV and SDN in a cost effective manner use in small cells in different frequency regimes. The problem of constructing intelligent algorithms is open to better utilise the available network resources and provide a consistent end-user QoS/QoE.

4.3.4 Service Provider -SDN Approach

There is a strong interest of SP/NP for SDN developments

Source: SDN: the service provider perspective, Ericsson Review, February 21, 2013

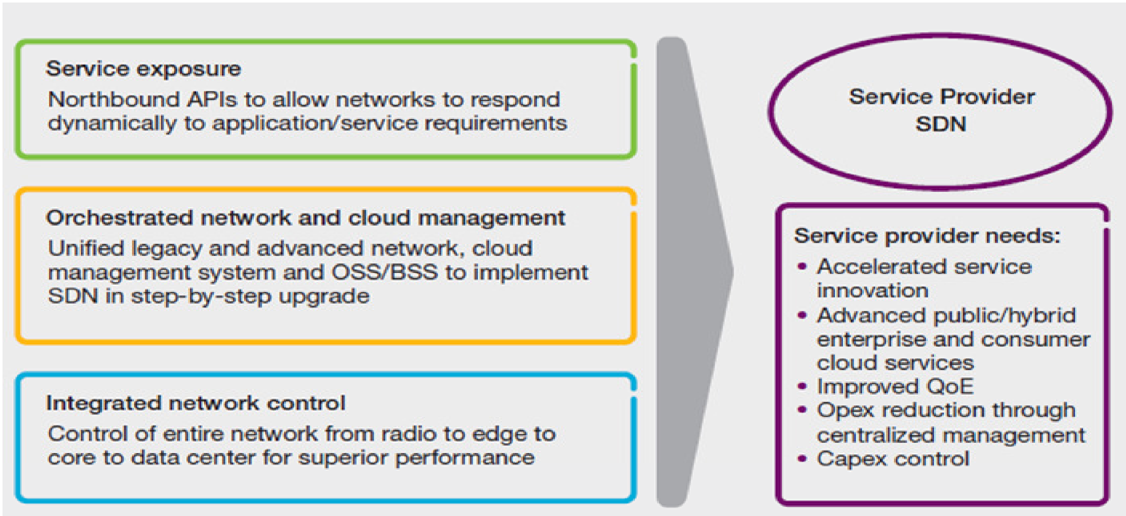

Figure 4-9 Service Provider domains to apply SDN

- **Aggregation/acces and mobile-backhaul networks (AAN)**
- **Dynamic service-chaining** (source: Ericsson)
    - Usually for inline services (DPI, firewalls (FWs), NAT, etc.), operators use special middleboxes hosted on HW/VMs.
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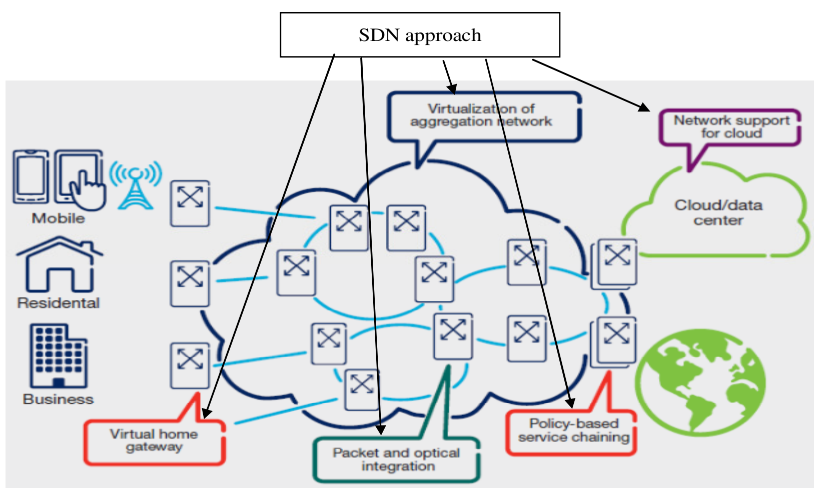

Figure 4-10 Examples of a SDN applied in SP subsystems

- **Bandwidth on Demand (BWoD)**
    - *Source: Operator Network Monetization Through OpenFlow-Enabled SDN, ONF Solution Brief, April 3, 2013, https://www.opennetworking.org/images/stories/downloads/sdn-resources/solution-briefs/sb-network-monetization.pdf*

  - WAN bandwidth demand ratio *peak info rate/mean rate* ~ 10 to 20 (cloud networking, ad hoc inter-enterprise collaboration, etc.)
    - peaks duration – very variable: 1 hour or less to several weeks or more.
  - Contracting *Peak Information Rate* (PIR) is costly and wasteful.

  - *Bandwidth on Demand (BWoD)* – dynamically adjustable if wanted (pay what you consume)
    - Connection types: subscribers; subscriber to a service GW (e.g., a cloud data center); subscriber to a third-party interconnect point.
  -
  - Current model of BWoD services (limited number of operators)
    - Lack of automation → difficult to roll out self-provisioned services and respond to time-sensitive changes in bandwidth requirements.
    - customers are given some control; they invoke the services through a portal but very limited in scope.
    - Frequent changes in a distributed control environment sometimes lead to transient overloads → congestion and instability.
    - Lack of a standard I/F → operators today must interface their OSS/BSS systems to a vendor-specific network infrastructure. (need to redesign control applications for each vendor)

- **SDN Solution :** BWoD from an OF - SDN architecture with a programmatic north API
  - operators have centralized, granular control over the networking infrastructure.

- Customers can *automatically request dynamic changes to bandwidth allocation* and other QoS parameters at the packet and/or optical layers, either immediately or scheduled in the future.

- The SDN control layer can leverage topology-aware path computation to cost-effectively enable bandwidth on demand.

- SDN : real-time topological view of the network,
  - enables network virtualization, and
  - allows *network bandwidth reservation* to provide guaranteed *performance on a per-connection or flow basis to meet SLA requirements.*

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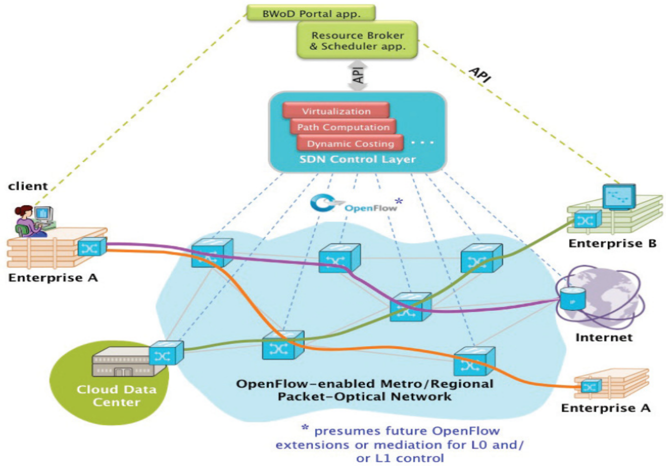
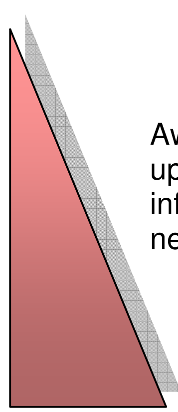


Figure 4-11 Bandwidth on demand SDN solution

4.4 Other new advanced trends in networking architecture

- **Network neutrality-** hot topics in discussion related to FI
    - Socio-economical aspects
    - Technical implications
    - Actions in the courts (FCC / companies (e.g. ComCast))
- **Traditional Internet: no traffic type discrimination**
- Still a lot of people wants this to continue in this way (users, P2P SPs, etc.)
- However
    - ISPs/operators seem to have different opinions
        - Overload created by some applications (E.g. P2P)
        - Want to offer QoS guaranteed – payment based
        - Different security levels are needed
        - ….
    - **Current and future Internet: more and more content/service oriented**
    - This will forward to "no more network neutrality"

- Approaches:
- Best effort
- Qos-based virtual splitting
- Content aware networks (CAN)/
    - Recent extension: content centric networks
- Service aware networking
- Application aware networking
    - and
- Network aware Applications



Awareness on upper layer information at network level

Figure 4-12 Higher layer -awareness degree of the network level

- CAN:
    - special processing (routing/forwarding, QoS, security, filtering, caching, etc.) of packet flows

- based on content-type information (extracted fom the packets, metadata or signalling-obtained)

- Initial Internet arch.: hourglass shape. This shows the data plane functionality of the Internet, but omits the capabilities and the mechanisms needed for the control or management.
- In the last 40 years a lot of changes have created a control plane, which loses the simplicity of the data plane, leading to the "hefty waist" shape shown on the right in Figure 2-2

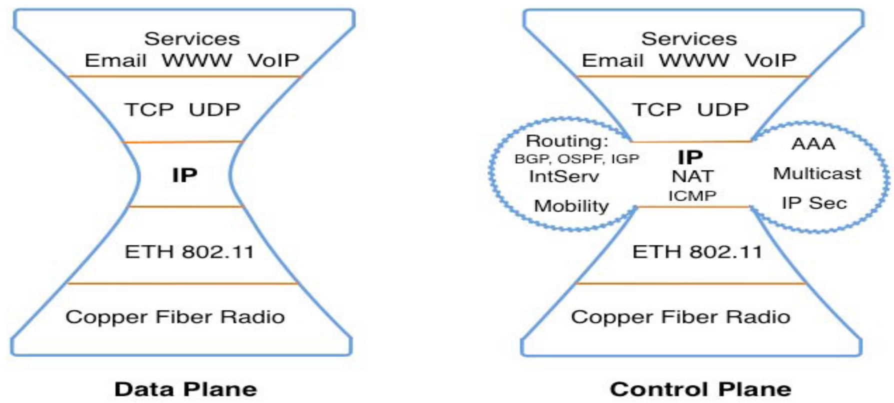


Figure 4-13 Current Internet Architecture

- **New Terminology**
  - Not standardised, different (overlapping) semantics…
    - **CAN- Content Aware Networking**
    - **CON - Content Oriented Networking**
    - **CCN - Content Centric Networking**
    - **ICN – Information Centric Networking**

4.4.1 Content-Aware Network (CAN) and Network Aware Application (NAA) - Concepts

- Question: can one enable better interactions (content-network) but still preserving the architecture modularity?
- CAN : adjusting network resource allocation based on limited understanding of the nature of the content
- NAA: network-aware content processing : adjusting the way contents are processed and distributed based on limited understanding of the network condition

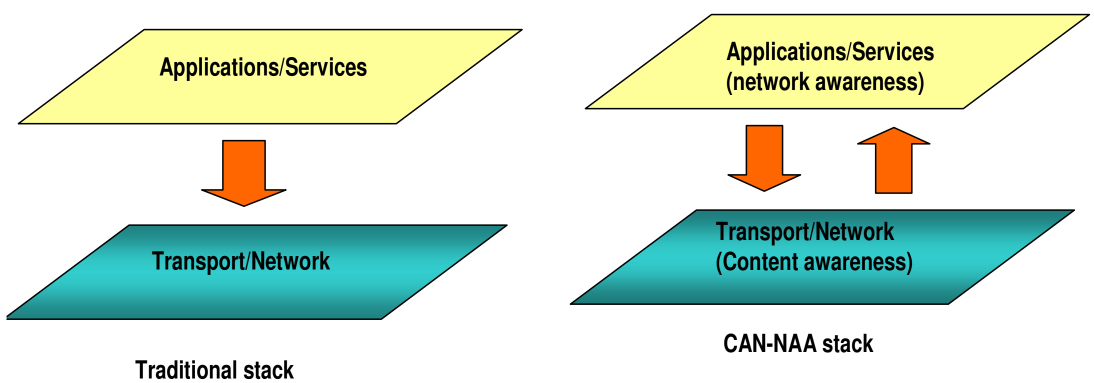


Figure 4-14 Traditional stack and CAN-NAA stack

Recent example: NGN architecture: ITU-T, ETSI, ..

4.4.2 Information Centric Networking (ICN)

Source: *D. Kutscher, B.Ahlgren, H.Karl, B. Ohlman, S.Oueslati I.Solis, Information-Centric Networking— Dagstuhl Seminar — 2011*

- the principal paradigm is not E2E communication between hosts
- high amount of content need efficient distribution
  - information objects as a first-class abstraction;
  - focusing on the properties of such objects and receivers' interests to achieve efficient and reliable distribution of such objects
  - In-network storage, multiparty communication through replication, and interaction
  - publish-subscribe models generally available for all kinds of applications,
  - without need of dedicated systems such as peer-to-peer overlays and proprietary CDNs

4.4.3 Content Oriented Networking (CON)

Source: *J.Choi, Jinyoung Han, E.Cho, Ted Kwon, and Y.Choi,A Survey on Content-Oriented Networking for Efficient Content Delivery, IEEE Communications Magazine • March 2011*

- **Content-oriented concepts**
  - CON node performs ***routing by content names***, not by (host) locators.
    - Identifying hosts is replaced by identifying contents.
    - The location of a content file is independent of its name
  - CON has location independence in *content naming* and *routing*
    - and is free from mobility and multi-homing problems
  - **Publish/subscribe** is the main communication model in CON:
    - A content source announces (or *publishes*) a content file
    - An user requests (or *subscribes* to) the content file.
    - P/S ***decouples the content generation and consumption*** in time and space, so contents are delivered efficiently and scalably (e.g., multicast/anycast).
- **Content-naming**
  - **Hierarchical Naming**
  - CCN and others: introduce a hierarchical structure to name a content file.
  - A content file is often named by an identifier like a web URL (e.g. /www.acme.com/main/logo.jpg),
  - → the naming mechanism can be compatible with the current URLbased applications/services, (lower deployment hurdle)
  - Hierarchy can help routing scalability (routing entries for contents might be aggregated)
  - Limitation:
    - if content files are replicated at multiple places, the degree of aggregation decreases.
    - components in a hierarchical name have semantics, which does not allow *persistent* naming
      - Persistence : once a content name is given, people would like to access the content file with the same name as long as possible.
  - **Flat names**
    - flat and self-certifying names - by defining a content identifier as a cryptographic hash of a public key.
    - Flatness (a name is a random looking series of bits with no semantics) → persistence and uniqueness are achieved.
  - Limitation:
    - flat naming aggravates the routing scalability problem due to no possibility of aggregation.
    - flat names are not human-readable,--> additional "resolution" between (application-level) human-readable names and content names may be needed

4.4.4 CON example: Content Centric Concepts (CCN) short outline

Source: Van Jacobson Diana K. Smetters James D. Thornton Michael F. Plass, Nicholas H. Briggs Rebecca L. Braynard, Networking Named Content, Palo Alto Research Center, Palo Alto, CA, October 2009

- CCN : transformation of the traditional network stack from IP to chunks of named content
- Traditional networking : connections based on hosts locations (need mapping *what* -> *where).*
- CCN proposes to treat content as a primitive – decoupling location from identity, security and access, and retrieving content by name
- New approaches to routing named content, derived from IP, one can achieve scalability, security and performance

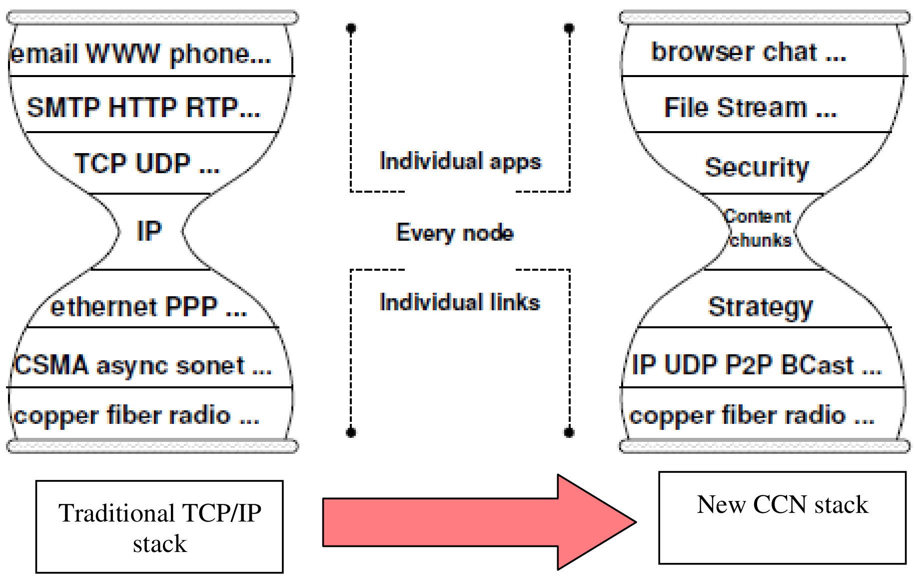


Figure 4-15 Possible evolution of the architectural stack to CCN

Application	Applications: browser chat, file stream:
	Security
	Content chunks
	Strategy
	P2P, ..
TCP, UDP, …	UDP
IP	Intra-domain routing:OSPF, .. Inter-domain routing: BGP, ... (placed here to show their role)
Data link	Any Layer 2
Physical Layer (wireline, wireless)	Any PHY

Figure 4-16 Alternative view of CCN stack (if it run on top of IP)

CCN specific features- different from IP

- **Strategy and security:** new layers - can use multiple simultaneous connectivity (e.g., Ethernet, 3G, 802.11, 802.16, etc.) due to its simpler relationship with layer 2.
    - Strategy layer : *makes dynamic optimization* choices - to best exploit multiple connectivity under changing conditions
    - Security Layer: *CCN secures the content objects* rather than the connections over which it travels *(this is to be discussed more..)* avoiding many of the host-based vulnerabilities of current IP networking
- **CCN high level description**
    - The content producers advertise their content objects
    - The nodes store the interfaces from where content can be reachable
        - Some "forwarding tables" are filled
    - The consumers *broadcast* their ***interest*** for some ***content***
    - Any node hearing the *Interest* and having the required content can respond with ***Data*** packet
    - *Data* are returned as a response to an interest only and consumes this *interest (1-to- 1 relationship Interest-Data)*
    - Multiple nodes interested in the same content may share the Data Packets: CCN is naturally multicast enabled
    - Content characterisation:
        - Data 'satisfies' an Interest if the *ContentName* in the *Interest Packet* is a prefix of the *ContentName* in the *DataPacket*

CCN Naming

- CCN names :opaque, binary objects composed of some (explicitly specified) number of components
- Hierarchical structure of names => the above prefix match is equivalent to
- *Data_Packet* is in the *name subtree* specified by the *Interest_Packet*

- Similarity with hierarchical structure of IP addresses ((net, subnet, ..)
- Name prefixes can be context dependent

  e.g. *"This_building/this_room"*

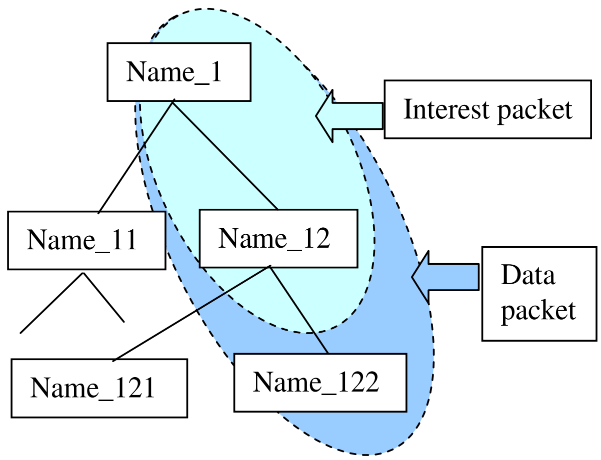


Figure 4-17 CCN Naming principle

CCN packets

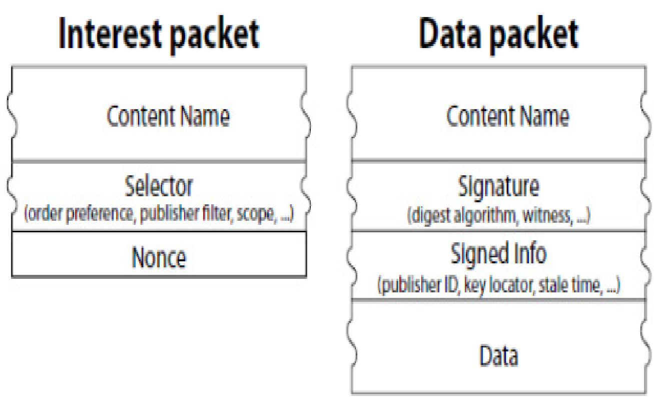


Figure 4-18 CCN packets

CCN Forwarding Engine Model

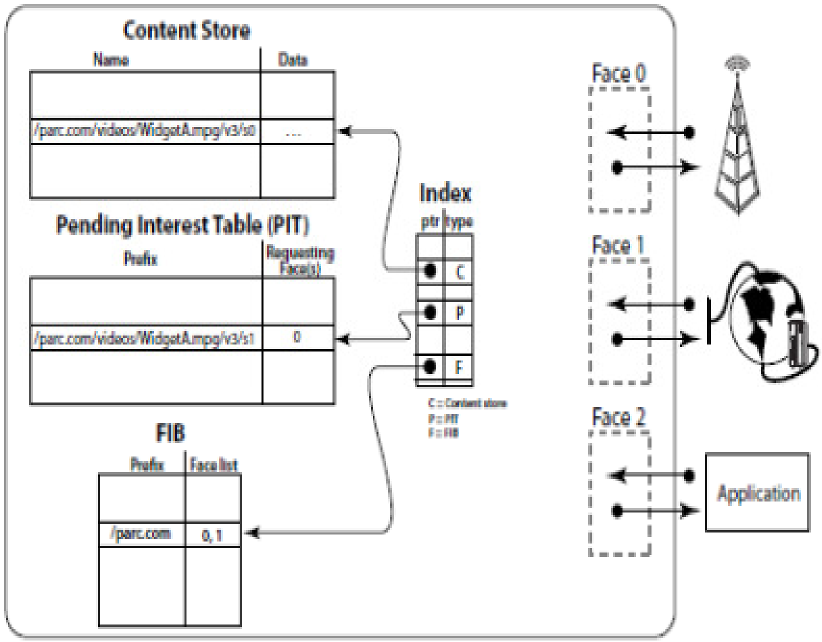


Figure 4-19

FIB (Forwarding Information Base)
CS (Content Store – i.e. buffer memory)
PIT (Pending Interest Table)

- FIB
  - used to forward an *Interest Packets* towards potential (sources)
  - Similar to IP FIB
  - But admits several I/Fs
    - multiple sources that can act in parallel
    - CCN is not limited to the spanning tree as in IP routing
- CS
  - Same as buffer memory in IP router
  - stores the *Data Packets* to be used in the future by other recipients (different w.r.t. IP router which forgets a packet after it has been forwarded)
  - It has a different replacement policy
  - Allows "caching" at every node – depending on its capabilities
  - Content delivery performance is increased due to caching
- **Pending Interest Table (PIT)**
  - Stores the pending requests for content, i.e

  - It keeps track of *Interest-Packets* forwarded upstream toward content source(s) so that returned Data can be sent downstream to its requester(s)

  - In CCN the routes are computed for Interest Packets packets only, (when they propagates upstream towards the data sources)

  - Each unsolved Interest Packet is stored in PIT → Data Packets will be forwarded on the reverse (towards the requester(s) path when they come)

- **Basic operation at a CCN node**
  - similar to IP node (router) when performing forwarding phase

- If a Packet arrives on an I/F (*Interest* or *Data*)
- (note that in original CCN documents these are named *faces* – as to emphasize their logical roles – an I/F can be in the same machine towards an application
- Longest match look-up is performed based on its *ContentName*
- Appropriate actions are done based on the result

- **Interest Packet arrives**
  - Longest match lookup is done based on its *ContentName*
  - Priorities of the search: CS, PIT, FIB
  - If there is a a content in the CS matcheing the *Interest Packet*
    - Then a *Data Packet* is be sent in the reverse direction on the I/F the *Interest Packet* arrived
    - Discard the *Interest Packet* (the request has been solved)

  - Otherwise: If there is an exact match to to PIT
    - then a new I/F is added to the pending list
    - *Interest Packet* is discarded (similar to IGMP registration protocol in multicast)
  - Otherwise: If a FIB matching is found
    - then the request (*Interest Packet*) is sent upstream towards the data source(s) on all I/Fs except the input I/F
  - If no match for *Interest Packet* then discard it

- **Data packet arrives**
  - Data Packets generally follows the route back conforming the PIT information

  - Longest-match lookup is done at *Data Packet* arrival on its Content Name
  - CS match => Data Packet is a duplicate, discard
  - PIT match (there can be more that one) => then it is performed:
    - Data validation (security)
    - Data are added to the CS (caching)
    - Data are sent towards the pending entities (list in PIT)
    - The PIT- corresponding pending requests are solved (erased)

  - In CCN each new packet of data is sent only after a new interest is expressed
    - This approach is similar to TCP ACks(giving a new window to the transmitter) + Data packets
    - Senders are stateless, so retransmission if necessary is requested by the application (the strategy level has the task to determine the policies)
    - CCN has in such a way a flow control mechanism

CCN routing and forwarding

- **Routing task: to construct FIBs**
- General characteristics
  - Routing between CCN nodes can occur over *unmodified* Link State Interior Gateway Protocols IGP (OSPF, IS-IS, ..)
  - Consequence: possible incremental CCN deployment
  - No spanning trees constraints are existent
  - Loops are avoided
  - Multiple paths are possible

- **Intra-Domain Routing**
  - CCN Content Names can be aggregated -> gives the possibility to apply "longest match" method in forwarding
  - How to distribute *Content Names* among routers?
    - OSPF, IS-IS can distribute content prefixes in TLV (Type Length Value) form
  - Conclusion: CCN Interest/Data forwarding can be built on top of existing IP infrastructure without any modification to the routers.

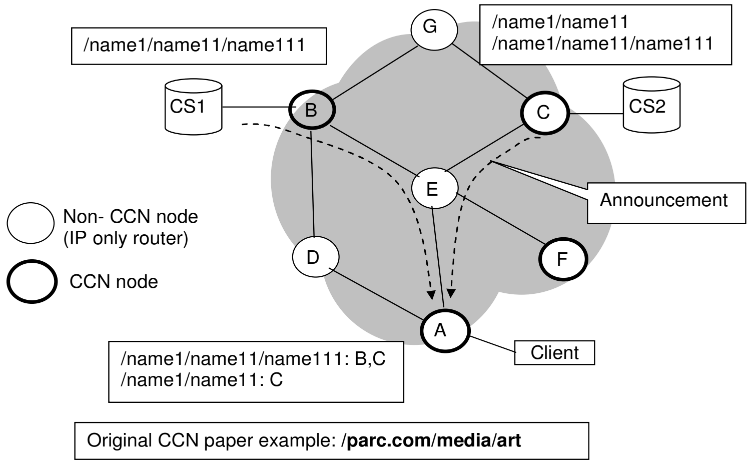


Figure 4-20 CCN routing

- **CAN/CCN : pros and cons**
  - **Pros**
    - Adapted to the current characteristics of the FI from the services point of view (content and service orientation)
    - More flexible (policies applicable for different functions)
    - Decoupling identity / location
    - Better security
    - Implementable : seamlessly or revolutionary-style
      - based on network virtualisations and overlays (achievable in parallel Internet planes)
    - …..
  - **Cons**
    - No more network neutrality
    - Destroy the traditional TCP/IP stack layering concepts (partially)
    - Significantly increase of the network nodes complexity (speed problems in routers)
    - No more – traditional concept : intelligence at the edge and network: simple, stupid, but flexible
    - …..

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7 LIST OF ACRONYMS

General List

AAA	Authentication, Authorisation and Accounting
AAL	ATM Adaptation Layer
ABR	Available Bit Rate
AC	Admission Control
ADSL	Asymmetric Digital Subscriber Line
AF	Assured Forwarding
AN	Access Network
ANG	Access Network Gateway
AP	Access Point
API	Application Programming Interface
AQ&S	Advanced Queuing and Scheduling
AQM	Advanced (Queue) Management
AR	Access Router
ARP	Address Resolution Protocol
ARQ	Automatic Repeat Request
AS	Autonomous System
ATM	Asynchronous Transfer Mode
BA	Behaviour Aggregate
BB	Bandwidth Broker
BE	Best Effort
BGP	Border Gateway Protocol
B-ICI	Broadband Intercarrier Interface
BISDN	Broadband Integrated Services Digital Network
BR	Border Router
CA	Congestion Avoidance
CAC	Connection Admission Control
CAS	Channel Associated Signalling
CBQ	Class Based Queuing
CBR	Constraint-based Routing
CBR	Constant Bit Rate
CC	Content Consumer
CDMA	Code Division Multiple Access
CDV	Cell Delay Variation
CER	Cell Error Rate
CES	Circuit Emulation Service
CIM	Common Information Model
CL	Connectionless
CLI	Command Line Interface
CLP	Cell Loss Priority
CLR	Cell Loss Rate
CMR	Cell Misinsertion Rate
CO	Connection Oriented
COPS	Common Open Policy Service Protocol
CP	Content Provider
CPCS	Common Part Convergence Sublayer
CPE	Customer Premises Equipment
CR	Core Router
CS	Convergence sublayer (adaptation)
cSLA	Customer Service Level Agreement
cSLS	SLS between customers and providers

cSLS	Customer Service Level Specification
DB	Database
DCCP	Datagram Congestion Control Protocol
DI	Digital Item
DiffServ	Differentiated Services
DLCI	Data Link Connection Identifier
DNS	Domain Name Service
DS	Differentiated Services (DiffServ), IETF Working Group
DSCP	Differentiated Services Code Point
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
DVA	Distance Vector Algorithm
DVB-S	Digital Video Broadcast- Sattelite
DVB-T	Digital Video Broadcast- Terrestrial
E2E	End-to-End
ECN	Explicit Congestion Notification
EF	Expedited Forwarding
EFSM	Extended Finite State Machines
EG	Exterior(Border) Gateway
ER	Edge Router
ES/H	End System/Host
FCFS	First Come First Served
FDM	Frequency Division Multiplexing
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FEC	Forward Error Control
FEC	Forwarding Equivalence Class
FIFO	First-In First-Out (queue)
FR	Frame Relay
GFC	Generic Flow Control
GK	Gate Keeper
GOP	Group of Pictures
GPS	Global Position System
GRED	Generalized RED
GSM	Global System for Mobile Communication
GW	Gateway
HDSL	High bit-rate Digital Subscriber Line
HEC	Header Error Check
HTML	Hypertext Mark-up Language
HTTP	Hyper Text Transfer Protocol (IETF, W3C)
H-WRR	Hierarchical WRR
IAB	Internet Architecture Board
ICMP	Internet Control Messages Protocol
IE	Information Element
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IG	Interior Gateway(Router)
IMA	Inverse Multiplexing ATM
IMS	Integrated Multimedia Subsystem
IntServ	Integrated Services
IP	Internet Protocol
IPC	Inter Process Communication
IRTF	Internet Research Task Force
IS	Intermediate System
LAN	Local Area Network
LANE	LAN emulation
LAPD	Link Access Procedure for D Channel

LB	Leaky Bucket
LDAP	Large Directories Access Protocol
LDP	Label Distribution Protocol
LLC	Logical Link Control
LSP	Label Switched Path
LSR	Label Switched Route
LTE	Long Term Evolution
LVC	Label Virtual Circuit
MAC	Medium Access Control
MAN	Metropolitan Area Network
MCTD	Mean Cell Transfer Delay
MDT	Mean down-time
MF	Multi Field
MGCP	Media Gateway Control Protocol
MGW	Media Gateway
MIB	Management Information Base
MPEG	Moving Picture Experts Group
MPLS	Multiprotocol Label Switching
MPOA	Multiprotocol over ATM
MSC	Message Sequence Chart
MT	Mobile Terminal
MTTR	Mean time to repair/patch
NC	Network Controller
NE	Network Element
NGN	Next Generation Network
NLRI	Network Layer Reachability Information
NM	Network Manager
NNI	Network Network Interface
NP	Network Provider
NPA	Network Point of Attachment (Physical Address)
NQoS	Network QoS
nrt-VBR	Non-real-time Variable Bit Rate
NSAP	Network Service Access Point
NSIS	Next Steps in Signalling
NTP	Network Time Protocol
OA	Ordered Aggregate
OAM	Operation and Maintenance
OFDM	Orthogonal Frequency Division Multiplexing
OSF	Open Software Foundation
OSI - RM	Open System Interconnection - Reference Model
OSPF	Open Shortest Path First
PBM	Policy Based Management
PBNM	Policy Based Network Management
PCM	Pulse Code Modulation
PDB	Per Domain Behaviour
PDH	Plesiochronous Digital Hierarchy
PDP	Policy Decision Point
PDU	Protocol Data Unit
PDV	Packet Delay Variation
PEP	Policy Enforcement Point
PHB	Per Hop Behaviour
PHP	Penultimate Hop Popping
PID	Program Identifier
PIM	Protocol Independent Multicast
PMD	Physical Medium Dependent
PMT	Policy management tool
PNNI	Private Network-Network Interface

POSIX	Portable Operating System Interface
POTS	Plain Old Telephone Service
PPP	Point to Point Protocol
PQ	Priority Queuing
PQoS	Perceived QoS
PR	Policy Repository
PRIO	Priority
pSLA	Provider Service Level Agreement
pSLS	SLS between providers
pSLS	Provider Service Level Specification
PSTN	Public Switched Telephone Network
PT	Payload Type
PTD	Packet Transfer Delay
QC	Quality of Service Class
QoS	Quality of Services
RARP	Reverse Address Resolution Protocol
RED	Random Early Drop
RFC	Request for Comments
RIP	Routing Information Protocol
RM	Resource Manager
RSVP	Resource reservation protocol
rt -VBR	Real-time Variable Bit Rate
RTCP	Realtime Control Protocol
RTD	Round Trip Delay
RTP	Realtime Transport Protocol
RTT	Round Trip Time
SAC	Subscription Admission Control
SAP	Service Access Point
SAR	Segmentation/reassembling
SCTP	Stream Control Transmission Protocol
SDH	Synchronous Digital Hierarchy
SDR	Service Discovery Repository
SDU	Service Data Unit
SIP	Session Initiation Protocol
SLA	Service Level Agreement
SLS	Service Level Specification
SM	Service Manager
SMI	Structure of Management Information
SMTP	Simple Mail Transfer Protocol
SNDAP	Subnetwork Dependent Network Access Protocol
SNDCP	Subnetwork Dependent Convergence Protocol
SNMP	Simple Network Management Protocol
SOAP	Simple Object Access Protocol
SONET	Synchronous Optical Network
SP	Service Provider
SQL	Structured Query Language
SS7	Signalling System No.7
SSCOP	Service Specific Connection Oriented Protocol
SSCS	Service Specific Convergence Sublayer
STP	Signaling Transfer Point
SVC	Signalling Virtual Channels
TBF	Token Bucket Flow
TC	Traffic Control
TCP	Transmission Control Protocol
TCS	Traffic Conditioning Specification
TD	Traffic Demand
TDD	Time Division Duplex

TDM	Time Division Multiplexing
TDM	Terminal Device Manager
TDMA	Time Division Multiple Access
TE	Traffic Engineering
TLI	Transport Layer Interface
TP	Traffic Policing
TS	Traffic Shaping
TSAP	Transport Service Access Point
TSPEC	Traffic Specification
TT	Traffic Trunk
UBR	Unspecified Bit Rate
UDP	User Datagram Protocol
UNI	User network Interface
UPC	Usage Parameter Control
UTRAN	Universal Terrestrial Radio Access Network
VBR	Variable Bit Rate
VC	Virtual Channel
VCC	Virtual Channel Connection
VCI	Virtual Channel Identifier
VoD	Video on-demand
VoIP	Voice over IP
VP	Virtual Path
VPC	Virtual Path Connection
VPI	Virtual Path Identifier
VPN	Virtual Private Network
WAN	Wide Area Network
WDM	Wavelength Division Multiplexing
WFQ	Weighted Fair Queuing
WRR	Weighted Round Robin
XML	Extensible mark-up language

Mobile Technologies – specific Acronyms

3GPP	Third Generation Partnership Project
AMPS	Advanced Mobile Phone System
ARIB	Association of Radio Industries and Businesses
BS	Base Station
CDMA	Code Division Multiple Access
D-AMPS	Digital AMPS
DECT	Digital Enhanced Cordless Telecommunications
DL	Downlink
DSL	Dig ital Subscriber Line
DSP	Digital Signal Processing
EDGE	Enhanced Data Rates for GSM Evolution
EPC	Evolved Packet Core
EVDO	Enhanced Voice-Data Optimized or Enhanced Voice-Data Only
E-UT RAN	Evolved - UMTS Terrestrial Radio Access Network
ETSI	European T elecommunications Standards Institute
FDD	Frequency Division Duplex
FDM	Frequency Division Multiplexing
FDMA	Frequency Division Multiple Access
GSM	Global System for Mobile Communication
GPRS	General Packet Radio Service
HSPA	High Speed Packet Access (HSDPA + HSUPA)
HSDPA	High Speed Downlink Packet Access
HSS	Home Subscriber Server

HSUPA	High Speed Uplink Packet Access
HARQ	Hybrid Automatic Repeat reQuest
IMT-dvanced	International Mobile Telecommunications-Advanced
LTE	Long Term Evolution
LTE-A	Long Term Evolution - Advanced
ME	Mobile equipment
MIMO	Multiple Input Multiple Output
MIP	Mobile IP
MBMS	Multimedia Broadcast Multicast Service
MME	Mobility Management Entity
MN	Mobile Node
MT	Mobile Terminal
NAS	Non- Access Stratum
NMT	Nordic Mobile Telephony
NGMN	Next Generation Mobile Networks
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PAPR	Peak to Averag e Power Ratio
PDCP	Packet Data Convergence Protocol
PSTN	Public Switched Telephone Network
RAN	Radio Access Network
RAT	Radio Access Technology
RRC	Radio Resources Control
SAE	System Architecture Evolution
SGSN	Serving GPRS Support Node
TDD	Time Division Duplex
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
TD-SCDMA	Time Division Synchronous Code Division Multiple Access
TTI	Transmission T ime Interval
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecom System
USIM	Universal Subscriber Identity Module
UTRA	UMTS terrestrial radio access
UTRAN	UMTS terrestrial radio access network
WIMAX	Worldwide Interoperability for Microwave Access
WCDMA	Wideband Code Division Multiple Access

8 ANNEX 1

8.1 Business Models for (Multimedia) Communication Architectures

8.1.1 Customers and Users

- ***Customer (CST)*** **(may be a "subscriber")** :
    - entity, having legal ability to subscribe to QoS-based services offered by ***Providers*** **(PR)** or ***Resellers (RS)***
    - target recipients of QoS-based services: ***CST/PR*** or ***CST/RS*** interaction
    - Examples of CS: Householders, SMEs, large corporations, universities or public organisations
        - **Service Level Agreements** (SLA)- concluded between CS and providers

  CST differentiation by : size , type of business, type of services required

- **User (US)**
    - entity (human or process) - named by a *CST* and appropriately identified by *PR* for actually requesting/accessing and using the QoS-based services cf. SLAs
    - USs are end-users of the services, they can only exist in association with a *CST*
    - may be associated with one or several *CST* using services according to the agreed SLAs of the respective *CST*. (e.g. Company = Customer, End User = employee)

Note: In the current public internet, the majority of users are "subscribers" for Connectivity services only and maybe for a small subset of high level services (e.g e-mail)
- there is no SLA concluded for high level services quality; e.g for media A/V streaming, IPTV, etc.
- best effort access to high level services is practised but with no guarantees

8.1.2 Providers (PR)

PR types :
- ***(High Level) Service Providers (SP)***
- ***IP Network Providers (NP)***
- ***Physical Connectivity Providers (PHYP) (or PHY infrastructure Providers)***
- ***Resellers (RS)***
- ***Content Providers (CP)***

Network Providers (NPs)
- offer QoS-based plain IP **connectivity services**
- own and administer an IP network infrastructure
- may interact with *Access Network Providers'* (ANP) or CS can be connected directly to NPs
- Expanding the geographical span of NPs
- Interconnected NPs - corresponding peering agreements
- IP NPs differentiation: small (e.g. for a city) , medium (region) and large (e.g. continental)

(High Level) Service Providers (HLSP or SPs)
- offer higher-level (possible QoS-based) services e.g. : e-mail, VoIP, VoD, IPTV, A/VC, etc.
- owns or not an IP network infrastructure
- administer a logical infrastructure to provision services (e.g. VoIP gateways, IP videoservers, content distribution servers)
- may rely on the connectivity services offered by NPs (SPs Providers' interact with NPs following a customer-provider paradigm based on SLAs

- expanding the geographical scope and augmenting the portfolio of the services offered $\Rightarrow$ SP may interact with each other
- size : small, medium and large

Physical Connectivity Providers (PHYP)

- offer physical connectivity services between determined locations
- services may also be offered in higher layers (layer-3 e.g. IP), (but only between specific points)
- distinguished by their target market:
  - ***Facilities (*****Infrastructure)** ***Providers (FP)***
  - ***Access Network Providers (ANP)*** **(could be seen as distinct stakeholders)**

FPs services - are mainly offered to IP NPs (link-layer connectivity , interconnect with their peers
FPs differentiation : size of technology deployment means

ANPs - connect CST premises equipment to the SPs or NPs equipment
- own and administer appropriate infrastructure
- may be differentiated by
  - technology (e.g. POTS, FR, ISDN, xDSL, WLAN, Ethernet, WiMAX, hybrid)
  - their deployment means and their size
- may not be present as a distinct stakeholder in the chain of QoS-service delivery
- may be distinct administrative domains, interacting at a business level with SPs /NPs and/or CSTs

Interactions between Providers

- mainly governed by the legislations of the established legal telecom regulation framework
- may follow a customer-provider and/or a consumer-producer paradigm on the basis of SLAs

Reseller (RS)

- intermediaries in offering the QoS-based services of the PRs to the CSTs
- offer market-penetration services (e.g. sales force, distribution/selling points) to PRs for promoting and selling their QoS-based services in the market
- may promote the QoS-based services of the PRs either 'as they are' or with 'value-added', however adhering to the SLAs of the services as required by the 'Providers'
- interact with :
  - CSTs on a customer-provider paradigm (SLA based)
  - PRs based upon respective commercial agreements..

Different types RSs:

- according to whether they introduce value-added or not
- their market penetration means
- size (# of of points of presence and/or sales force)

RSs examples: Dealers, electronic/computers commercial chains, service portals

Content Provider (CP)

- an entity (organisation) gathering/creating, maintain, and distributing digital information.
- owns/operates hosts = source of downloadable content
- might not own any networking infrastructure to deliver the content
- content is offered to the customers or service providers.
- can contain : Content Manager(CM); several Content Servers (CS

New enties (in the perspective of Future Internet)

Virtual Network Provider (VNP)

- composes and configures and offer Virtual Network slices, i.e., a set of virtual resources at request of higher layers, as a consequence of its provisioning policy or during self-healing operations

- this approach avoids for the higher layers to establish direct relationships with infrastructure providers and to take care of inter-domain connections at physical layer.

Virtual Network Operator (VNO)

- manages and exploits the VNEt s provided by VNPs , on behalf of HLSPs or end users

Note: the same organisational entity migh play the both roles :VNP and VNO