Mobile Networks

Mobile and cyber-physical systems

Federica Paganelli

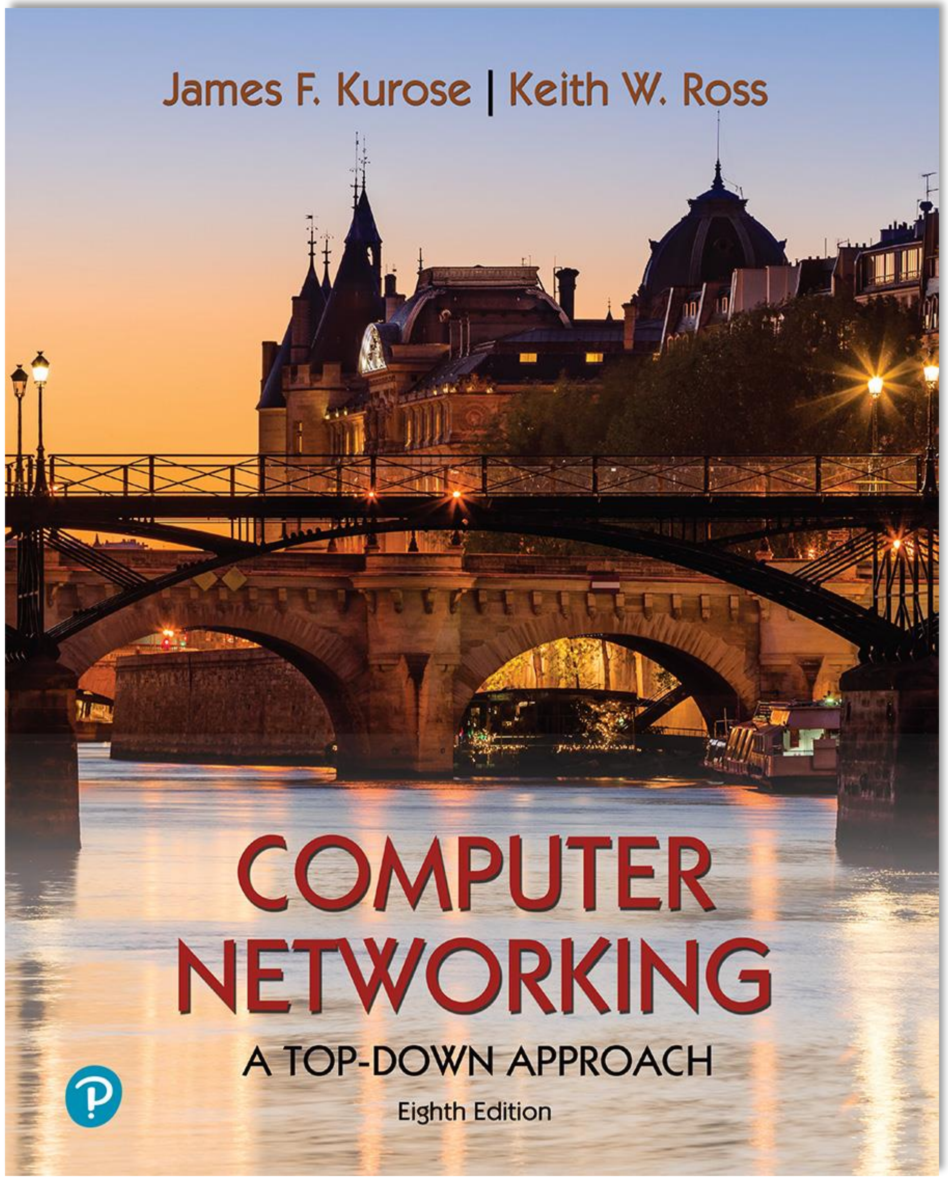
A NOTE ON THESE SLIDES

They are a (free) adaptation of the original

slides provided with the book:

Computer Networking: A Top-Down Approach

8th edition, Jim Kurose, Keith Ross, Pearson, 2020



Wireless and Mobile Networks: context

- more wireless (mobile) phone subscribers than fixed (wired) phone subscribers (10-to-1 in 2019)!
- more mobile-broadband-connected devices than fixed-broadband-connected devices devices (5-1 in 2019)!
  - 4G/5G cellular networks now embracing Internet protocol stack, including SDN
- two important (but different) challenges
  - wireless: communication over wireless link
  - mobility: handling the mobile user who changes point of attachment to network

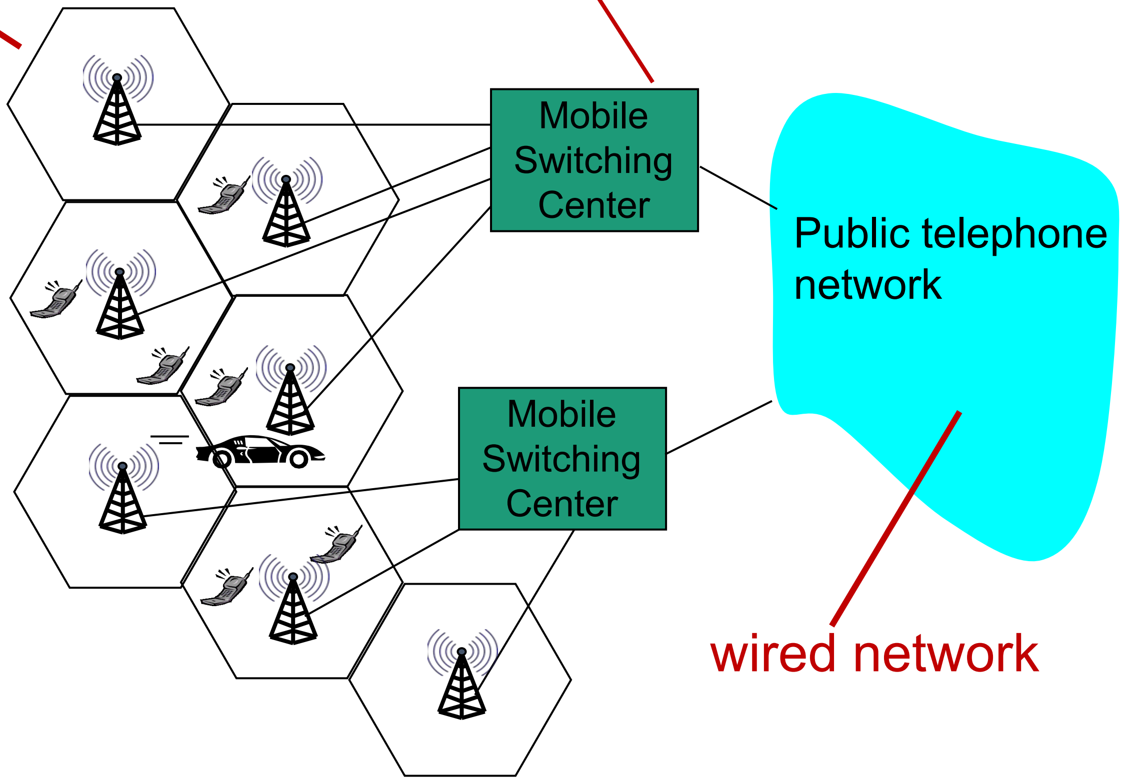
Outline

- Cellular networks
    - Cellular network evolution (1G, 2G, 3G)
    - 4G and 5G networks
- Mobility
    - Mobility management: principles
    - Mobility management: practice
        - Mobility management in 4G/5G networks
        - Mobile IP
- Mobility: impact on higher-layer protocols

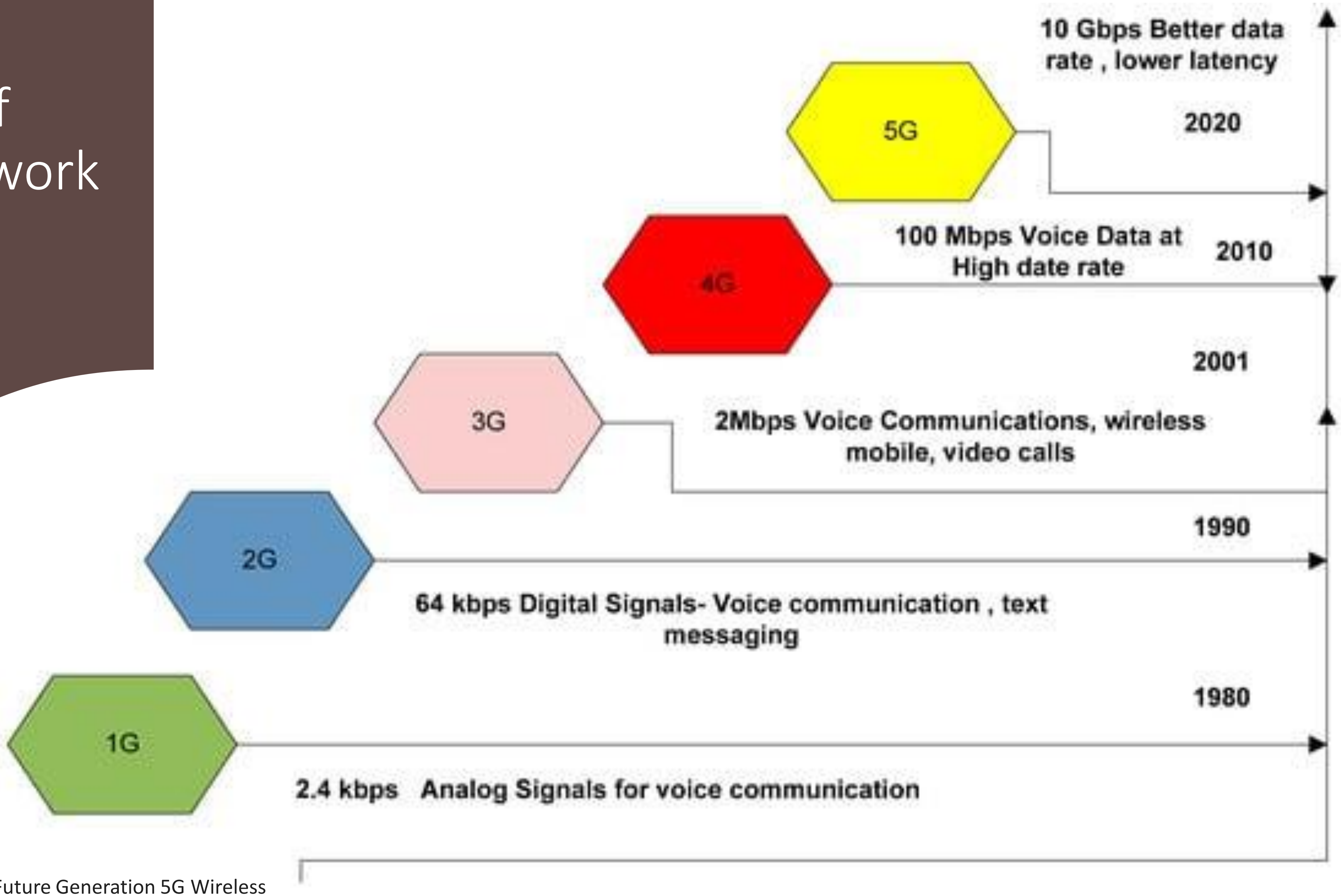
Components of cellular network architecture

cell
- covers geographical region
- *base station* (BS) analogous to 802.11 AP
- *mobile users* attach to network through BS
- *air-interface:* physical and link layer protocol between mobile and BS

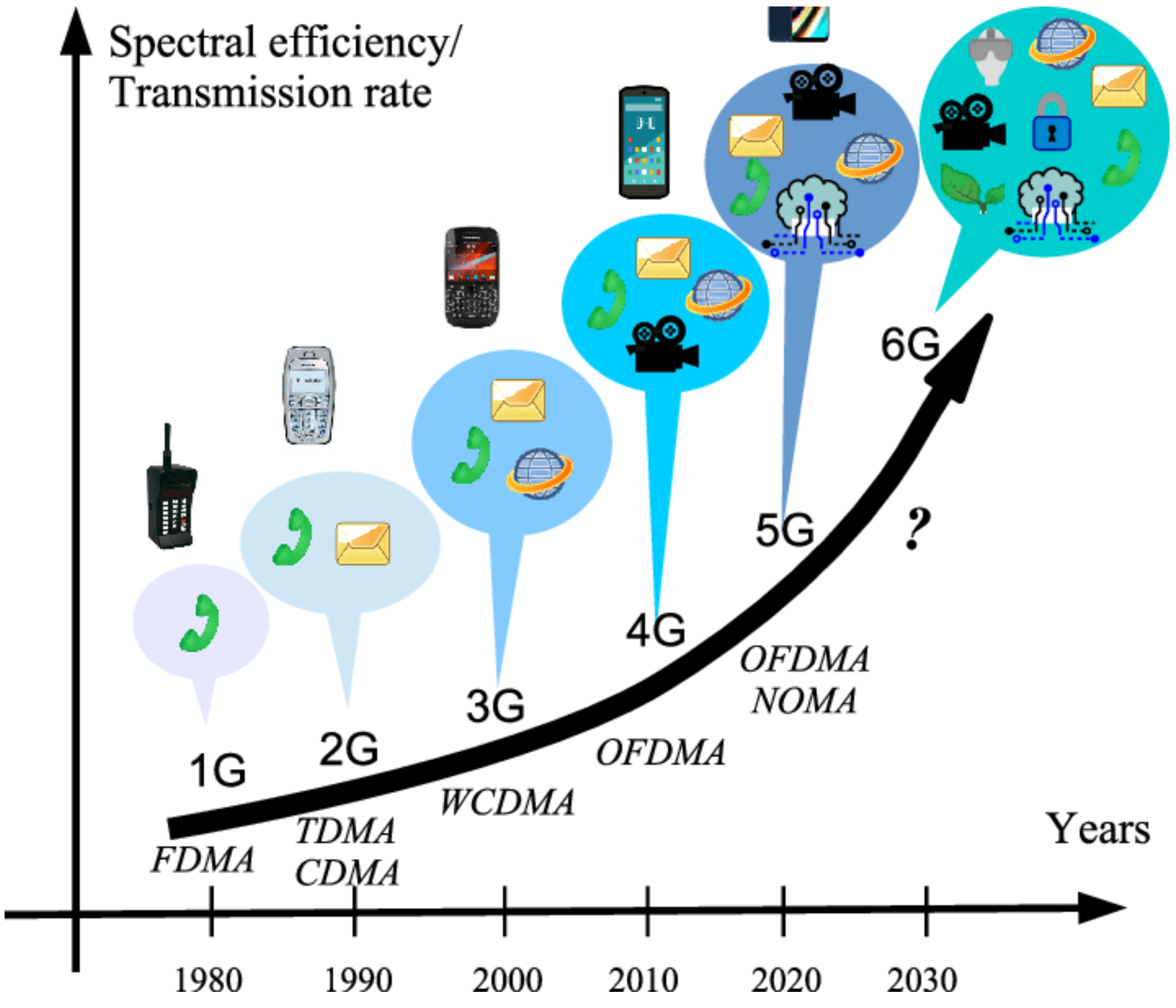
MSC
- connects cells to wired tel. net.
- manages call setup (more later!)
- handles mobility (more later!)



Evolution of mobile network technology



S SR, Dragičević T, Siano P, Prabaharan SRS. Future Generation 5G Wireless Networks for Smart Grid: A Comprehensive Review. *Energies*. 2019; 12(11):2140. https://doi.org/10.3390/en12112140



Evolution of mobile network technology

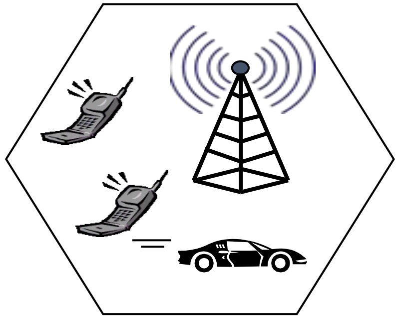
Access techniques

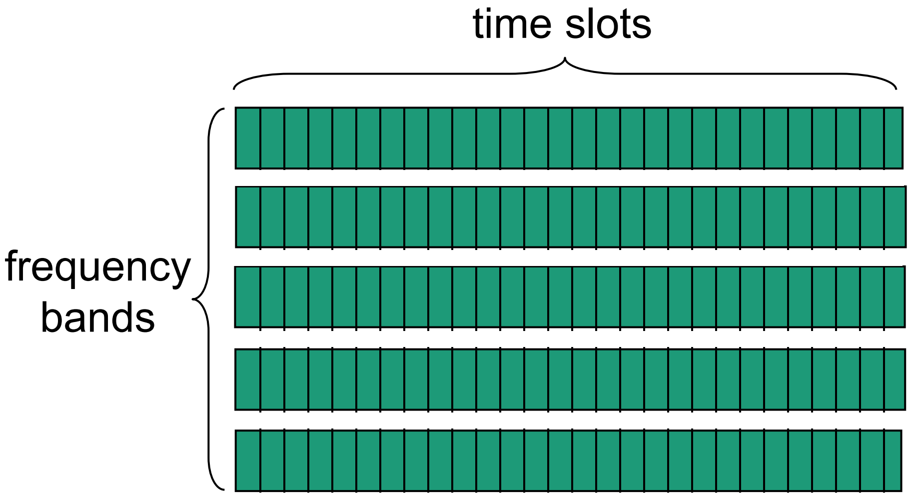
Gutierrez, Carlos & Caicedo, Mauricio & Campos Delgado, Daniel Ulises. (2021). 5G and Beyond: Past, Present and Future of the Mobile Communications (English Version). IEEE Latin America Transactions. 19. 1702-1736.

Cellular networks: the first hop

Two techniques for sharing mobile-to-BS radio spectrum

- combined FDMA/TDMA: divide spectrum in frequency channels, divide each channel into time slots
- CDMA: code division multiple access

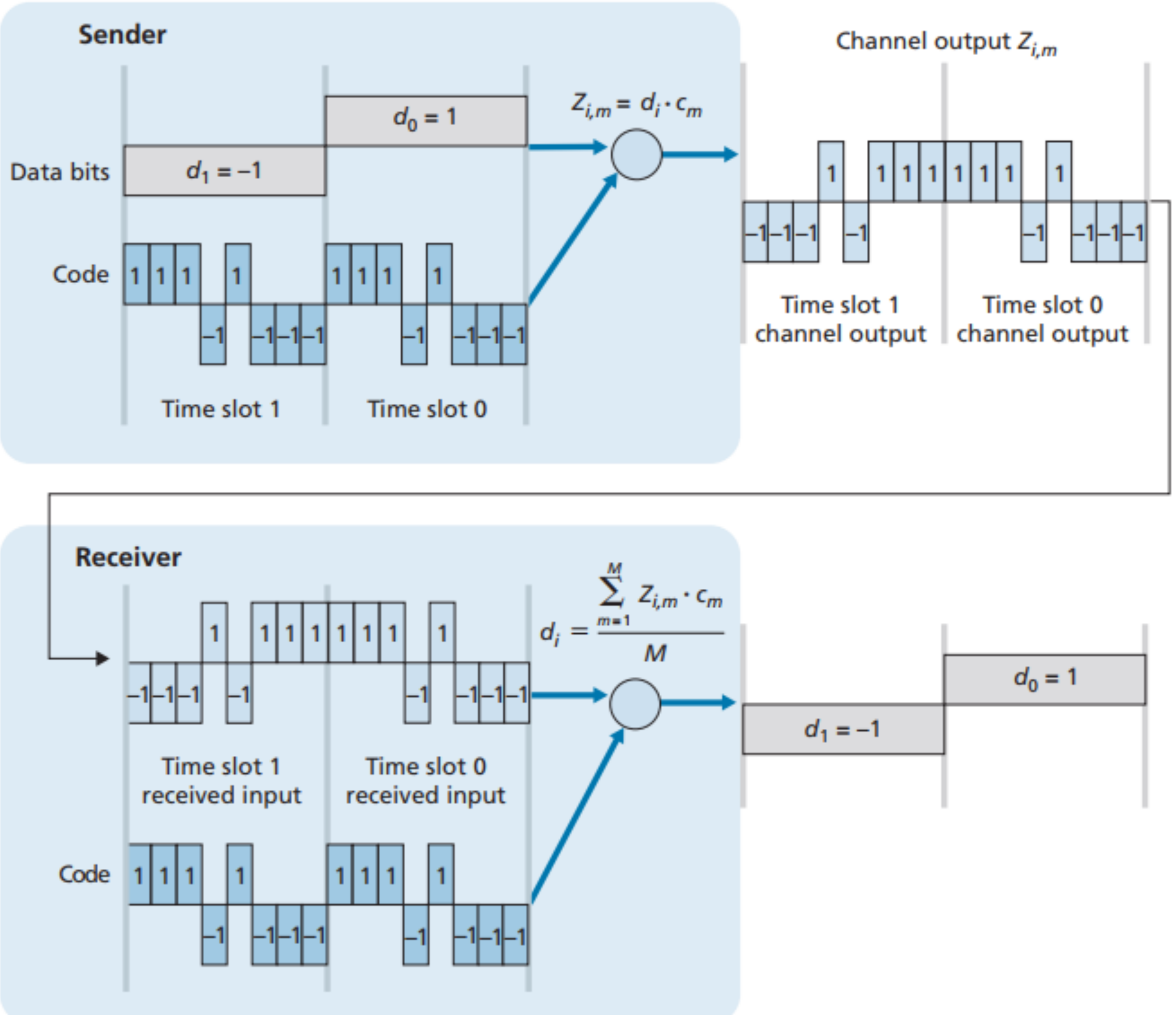




Cellular networks: the first hop

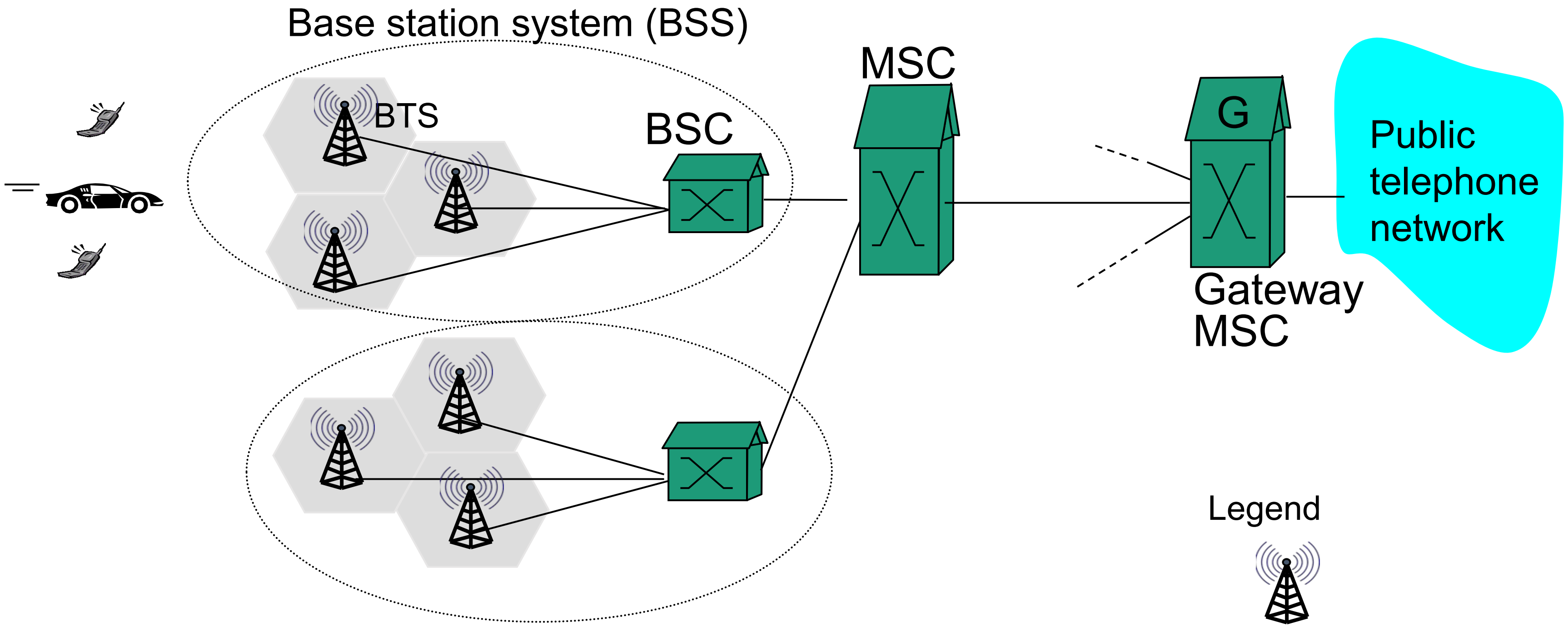
Two techniques for sharing mobile-to-BS radio spectrum

- combined FDMA/TDMA: divide spectrum in frequency channels, divide each channel into time slots
- CDMA: code division multiple access
  - Partioning the code space

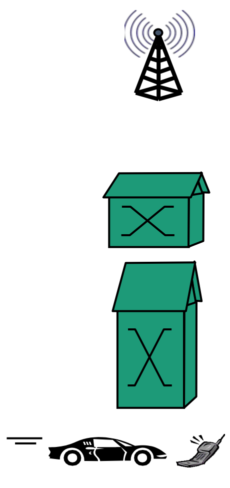


2G (voice) network architecture

call



Legend



Base transceiver station (BTS)

Base station controller (BSC)

Mobile Switching Center (MSC)

Mobile subscribers

GSM (global system for mobile communications)

- TDM+FDM: 200 Khz frequency band, each band supports 8 TDM calls

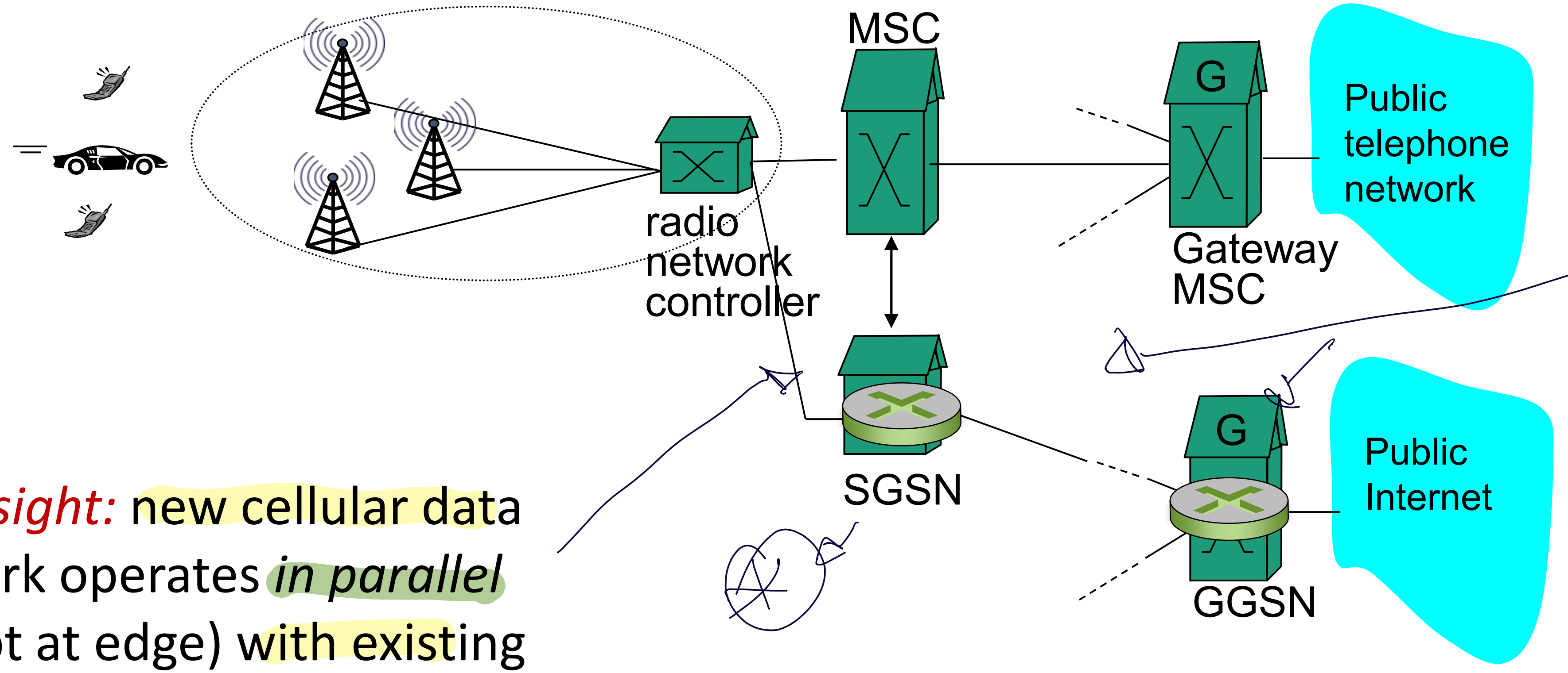
2.5G

- GPRS (2.5 G) General Packet Radio Service
  - Time slots dynamically reserved for data transfer(40-60 kbps)
- CDMA

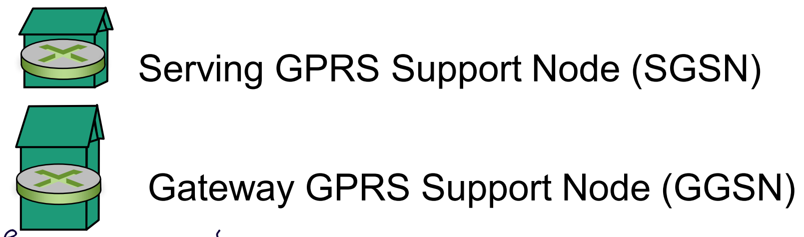
connections with public internet

3G (voice+data) network architecture

=> To not change arch.



introducing extending



Key insight: new cellular data network operates *in parallel* (except at edge) with existing cellular voice network

- voice network *unchanged* in core
  - Circuit switching
- data network operates in parallel
  - Packet switching

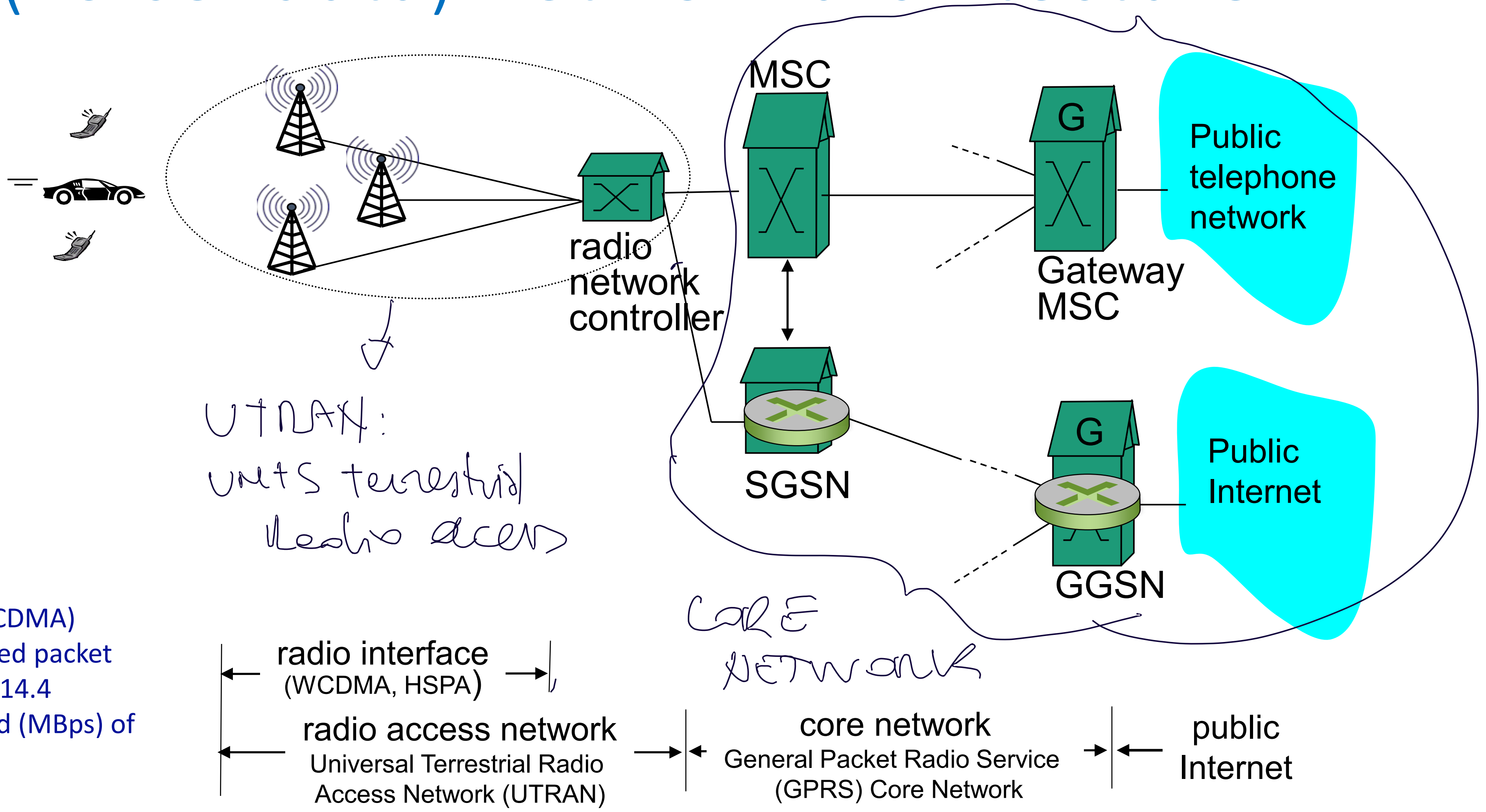
GPRS: General Packet Radio Service: realize transfer of packets from telephone network to internet

input: more analog signals & realize MULTIPLEXING using TDMA channels of GSM

on OUTPUT: 1 signal (same channel)

3G (voice+data) network architecture

NEW



WCDMA (Wideband CDMA)
HSPA: HSPA (high speed packet access): maximum of 14.4 megabytes per second (MBps) of throughput per cell

Example:
UMTS

UMTS: Universal Mobile Telecommunications System

NEW

3G (voice+data) network architecture

3G evolution of GSM uses W-CDMA for transmission on access radio to the system

s(t) will be MODULATED and transmitted on the channel

s(t) multiplexing technique: binary info • code (chip)

- UTRAN (UMTS Terrestrial Radio Access Network)
  - network and equipment that connects mobile handsets to the mobile network. It contains the base stations and the Radio Network Controllers (RNCs).
  - Radio Network Controllers: manages and controls radio resources and acts as an access point between UTRAN and the Core Network
    - Load and congestion management in the cell
    - Admission control
    - Allocation of codes
  - Base stations (Node B)
    - Participate in radio resource management
    - Channel coding
    - Rate adaptation

BS + Radio Network Controller

3G (voice+data) network architecture

NEW

- Core Network
  - Mobile Switching Center: MSC
    - voic
    - manages call setup
    - handles mobility
    - connects to public wired telephone network
  - For DATA
  - Serving GPRS Support Node (SGSN) and Gateway GPRS Support Nodes
    - Serving GPRS Support Node (SGSN): delivery of data packets from and to the mobile stations within its geographical service area
    - GGSN: inter-networking between the GPRS network and external packet data networks

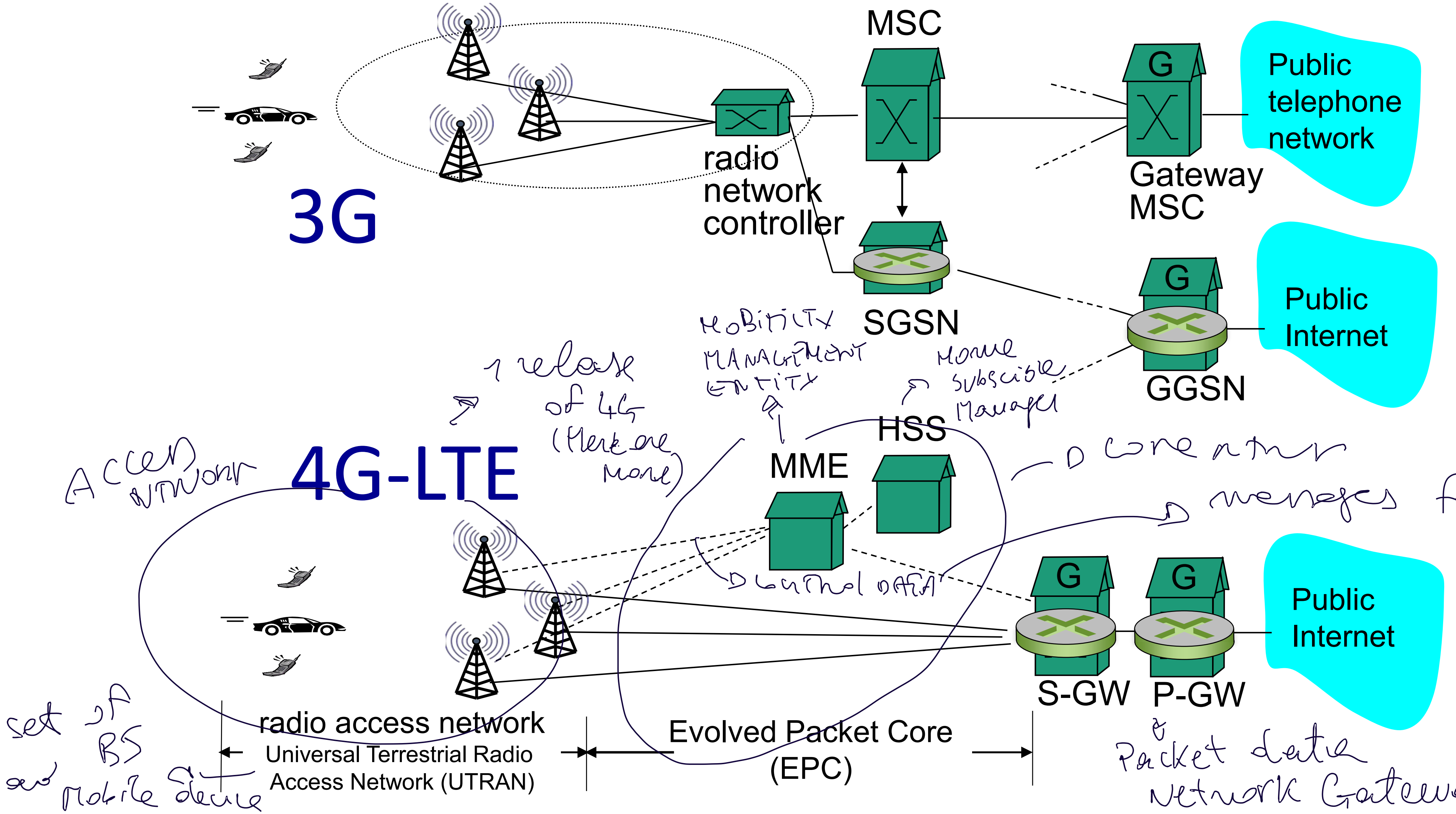
Many releases of 4G

option to switch 4/G → 5G

or

2G/3G/4G/5G
Marketing
proper
name

3G versus 4G LTE network architecture

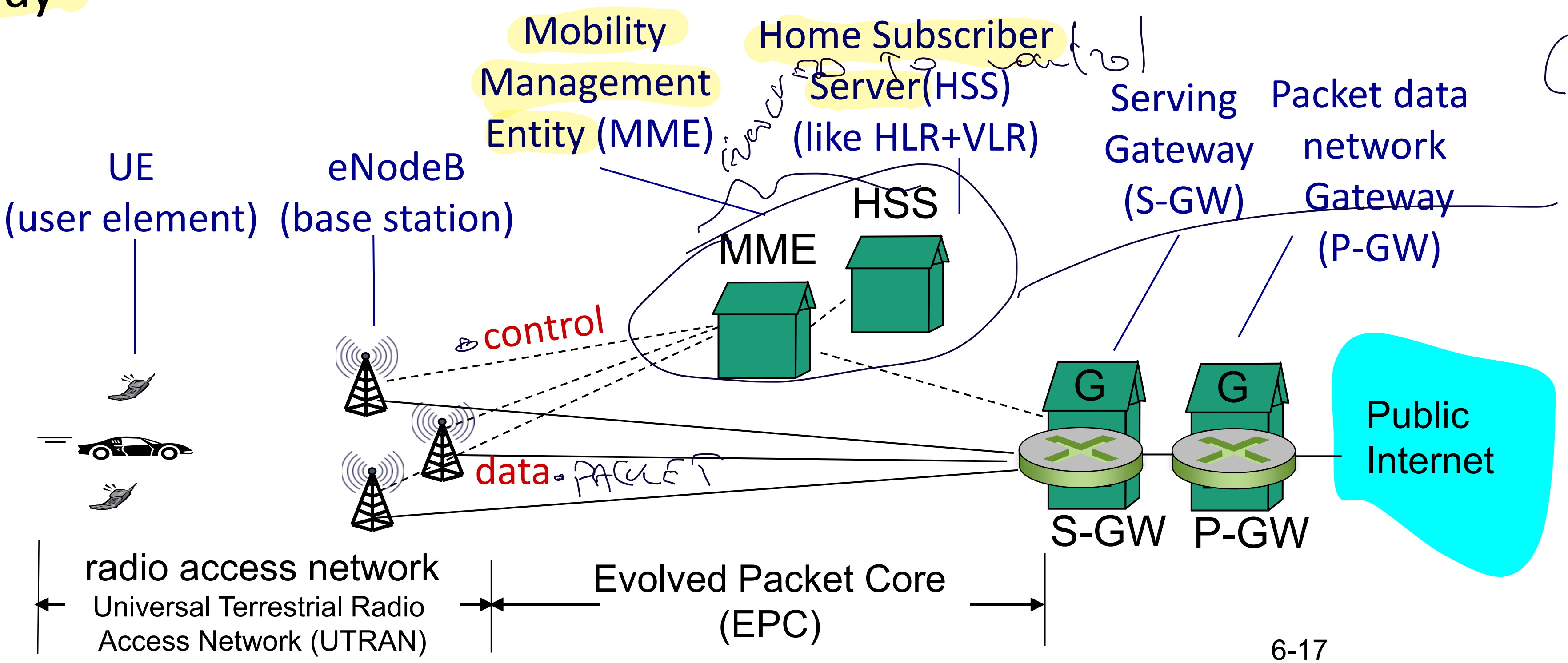


exchanges
→ messages for
Auth
attaching
mobile

4G: main differences from 3G

Turning point 3G–4G
– no circuit but
Packet switching
=> using IP in core also for voice call

- All-IP core: IP packets tunneled (through core IP network) from base station to gateway
- no separation between voice and data – all traffic carried over IP core to gateway



(BIG TURNING POINT)
PACKET & VOICE
PACKET FOR VOICE SERVICES

4G/5G cellular networks

monetized ip PACKET

- the solution for wide-area mobile Internet
- widespread deployment/use
- transmission rates up to 100's Mbps
- technical standards: 3rd Generation Partnership Project (3GPP)
  - wwww.3gpp.org
  - 4G: Long-Term Evolution (LTE) standard

when access mobile network in dev. SIM card ID of subscriber → you access to all the services and recognise to refine services → change operator

4G/5G cellular networks

MOBILE/WIRED => IP to forward PACKETS

similarities to wired Internet

still diff.

- edge/core distinction, but both below to same carrier

  → forward PACKET, AUTH BY OPERATOR

  devices

- global cellular network: a network of networks

  CO-OPERATION
  Moving in country → network of network operators agreements

- widespread use of protocols we've studied: HTTP, DNS, TCP, UDP, IP, NAT, separation of data/control planes, SDN, Ethernet, tunneling

  DHCP: assigning dynamically IP address

- interconnected to wired Internet

differences from wired Internet

- different wireless link layer
- mobility as a 1st class service
- user "identity" (via SIM card)
- business model: users subscribe to a cellular provider
  - strong notion of "home network" versus roaming on visited nets

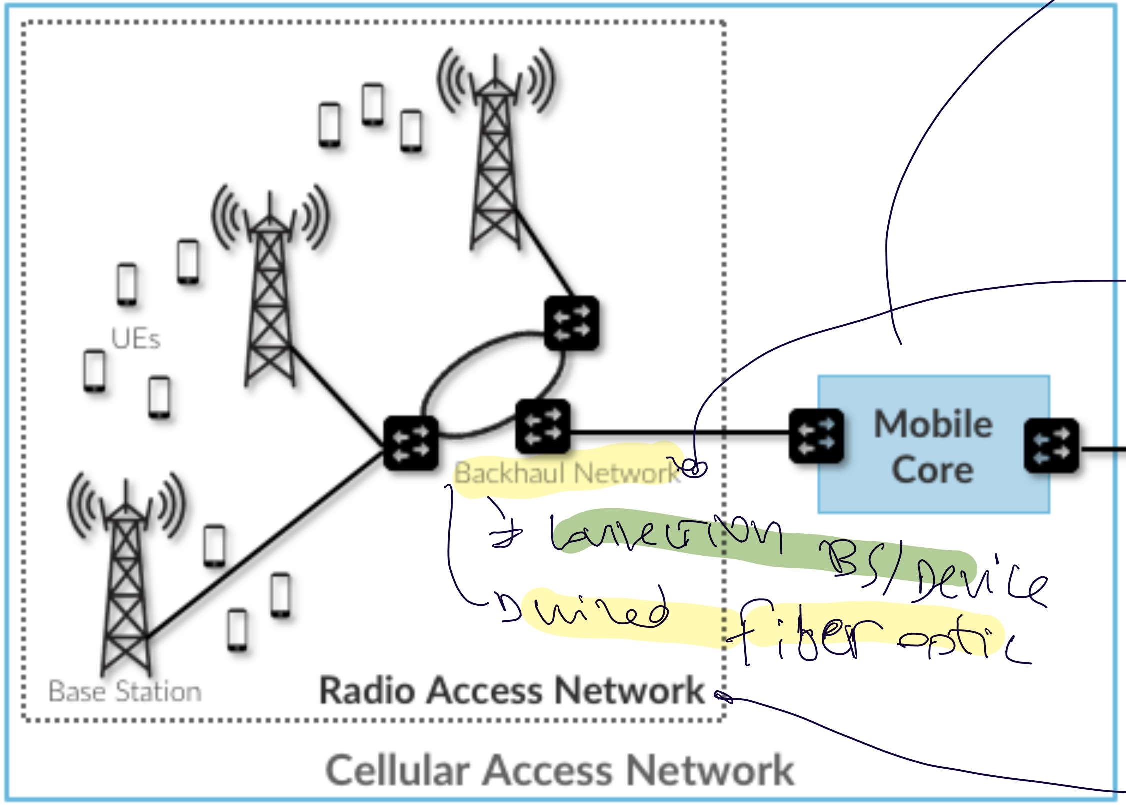
    IN MOBILE
  - global access, with authentication infrastructure, and inter-carrier settlements

in common separation with radio access ntw/ mobile network

4G/5G cellular network architecture

(In 3G we had radio ntw controller (control BS and CDMA)

=> here no radio ntw controller



Mobile Core
- Provides Internet (IP) connectivity for both data and voice services
- Ensures QoS requirements
- Tracks user mobility to ensure uninterrupted service
- billing and charging

Backhaul Network
- interconnects the RAN with the Mobile Core
- Wired network (e.g. fiber-optic)
- Emerging wireless solution (Integrated Access Backhaul – IAB)

Radio Access Network (RAN)
- distributed collection of BSs
- manages the radio spectrum

split by BS

• Voice call or packet need
A DATA PATH: dev<BS- service gateway - MME - getting up this data path

3rd party between home subscriber - BS

Elements of 4G architecture

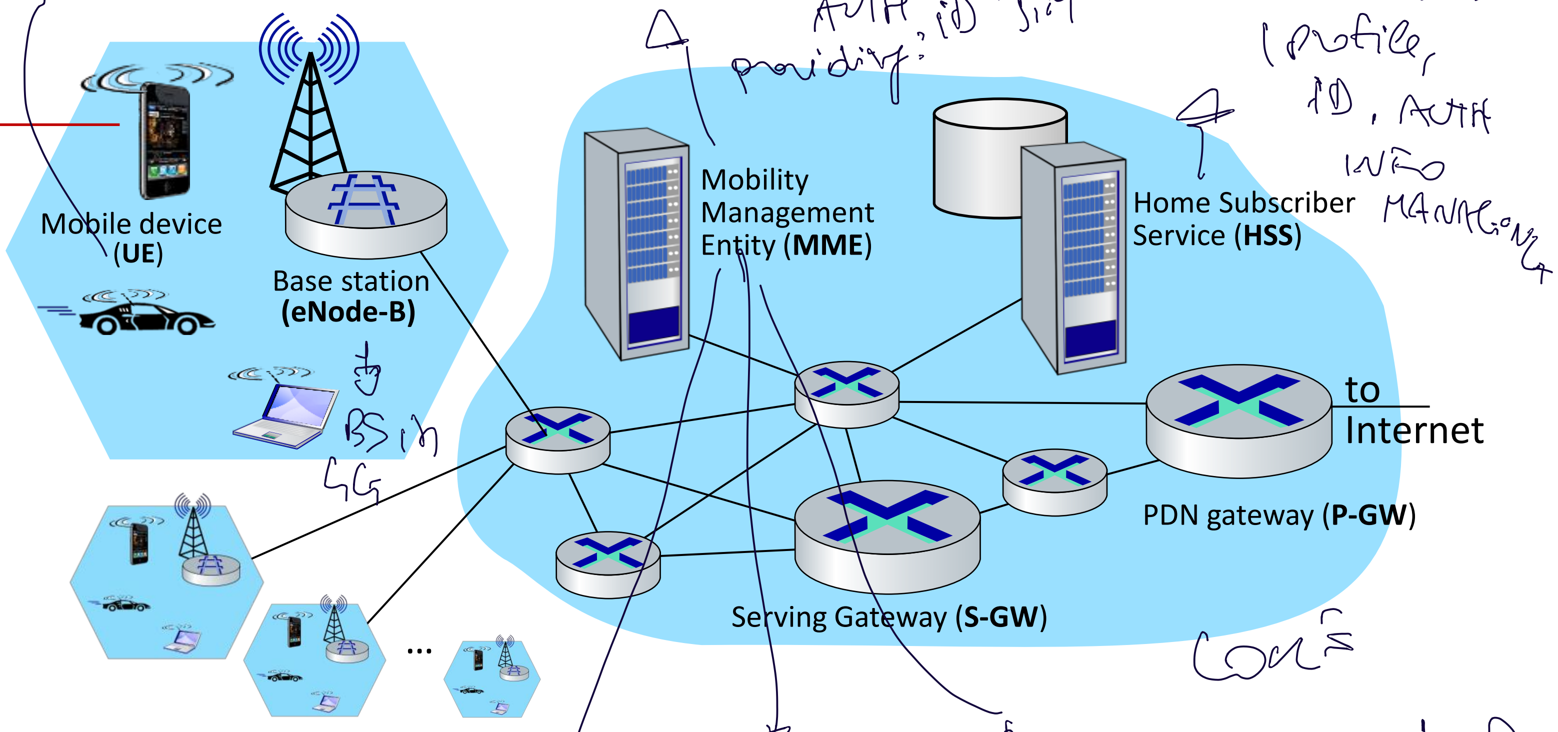
dev -> cell -> bs -> has to auth providing: ID in sim

DB contains info about subscribers (profile, ID, auth info management)

-> user equipment

Mobile device:

- smartphone, tablet, laptop, IoT, ... with 4G LTE radio
- 64-bit International Mobile Subscriber Identity (IMSI), stored on SIM (Subscriber Identity Module) card
- LTE jargon: User Equipment (UE)



BS in 4G

core

trace movement of device

Base station:

- at "edge" of carrier's network
- LTE jargon: eNode-B

radio access network

all-IP Enhanced Packet Core (EPC)

manages mobility of dev. changing BS or mobility operator

tracks
forward info to HSS

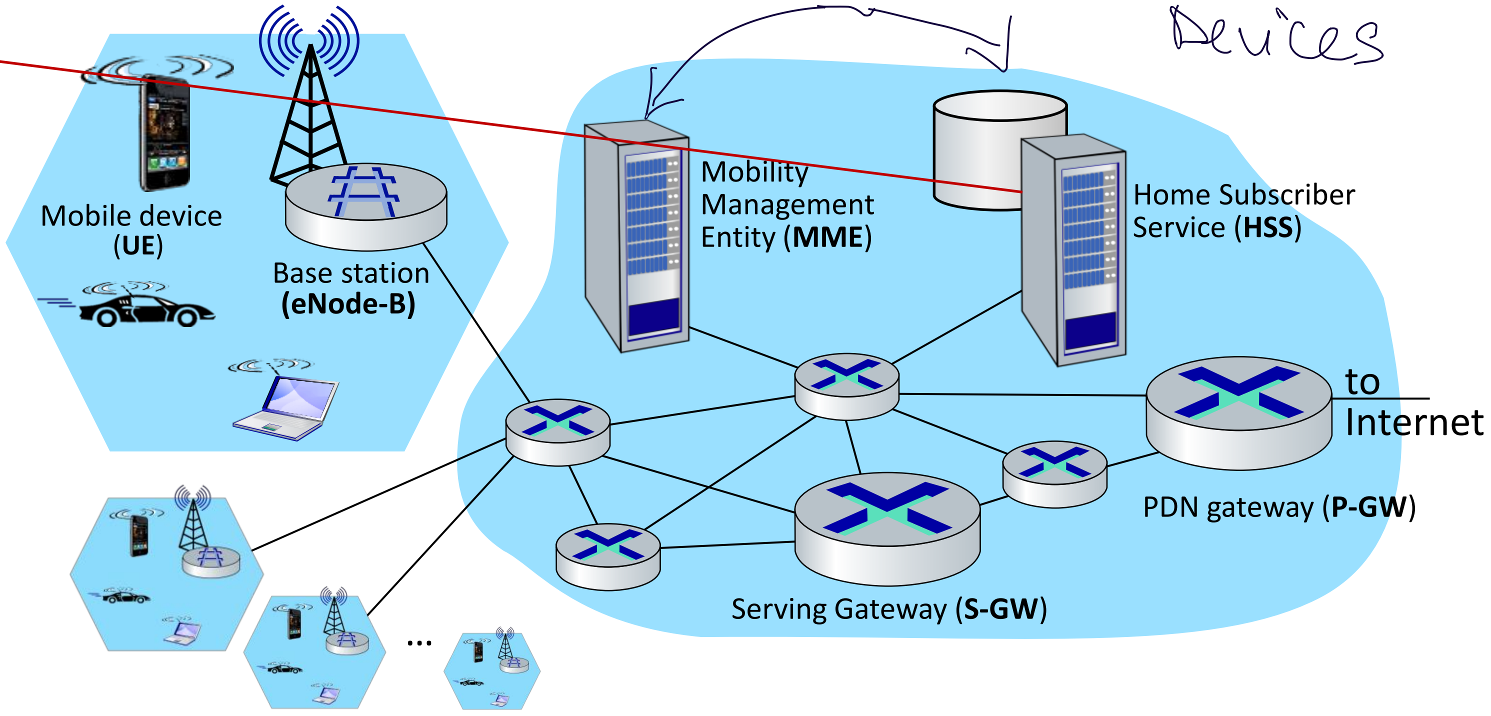
if attached time a device was connect/disconnect

Elements of 4G architecture

works together
For authenticating
Devices

Home Subscriber Service

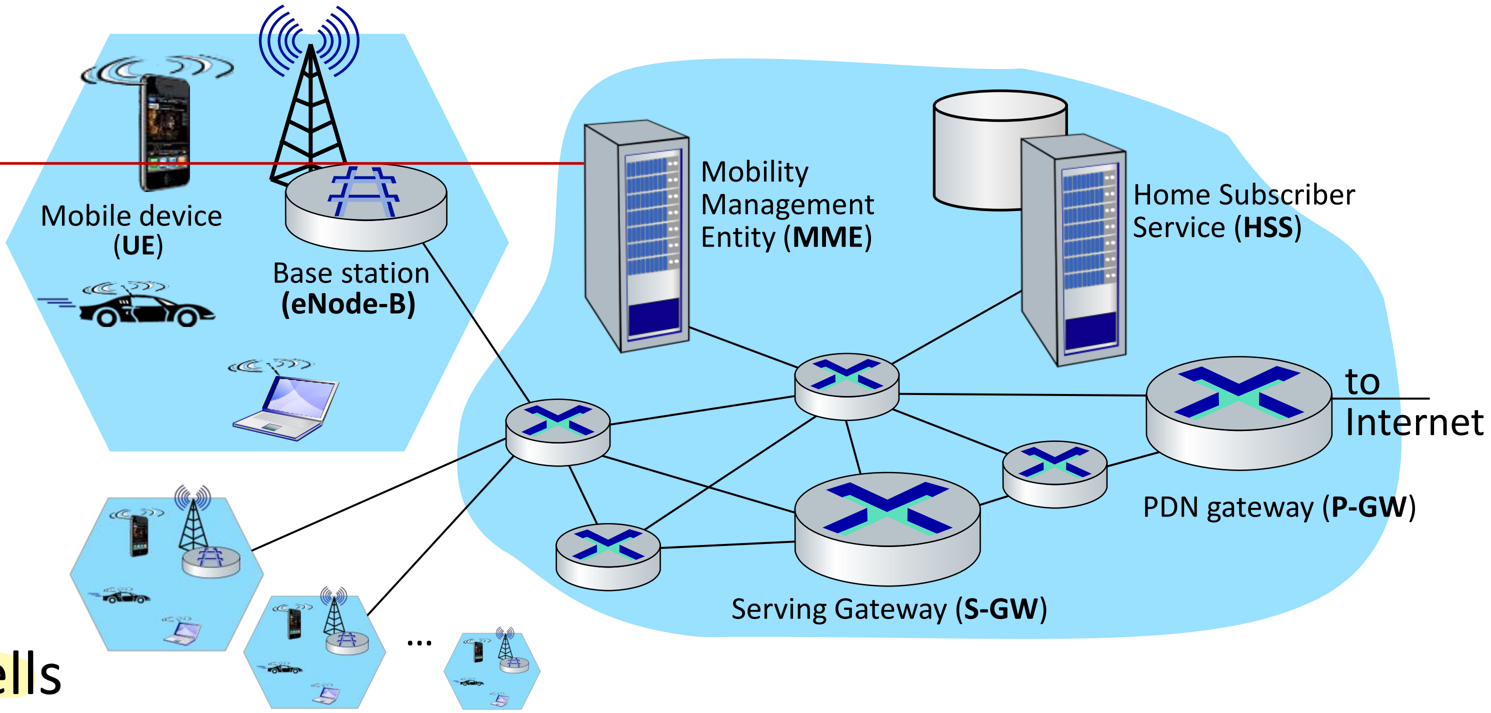
1) - A database that contains all subscriber-related information
2) - stores info about mobile devices for which the HSS's network is their "home network"
3) - works with MME in device authentication



Elements of 4G architecture

Mobility Management Entity

- device authentication (device-to-network, network-to-device) coordinated with mobile home network HSS
- mobile device management:
  - device handover between cells
  - tracking/paging device location
- path (tunneling) setup from mobile device to P-GW

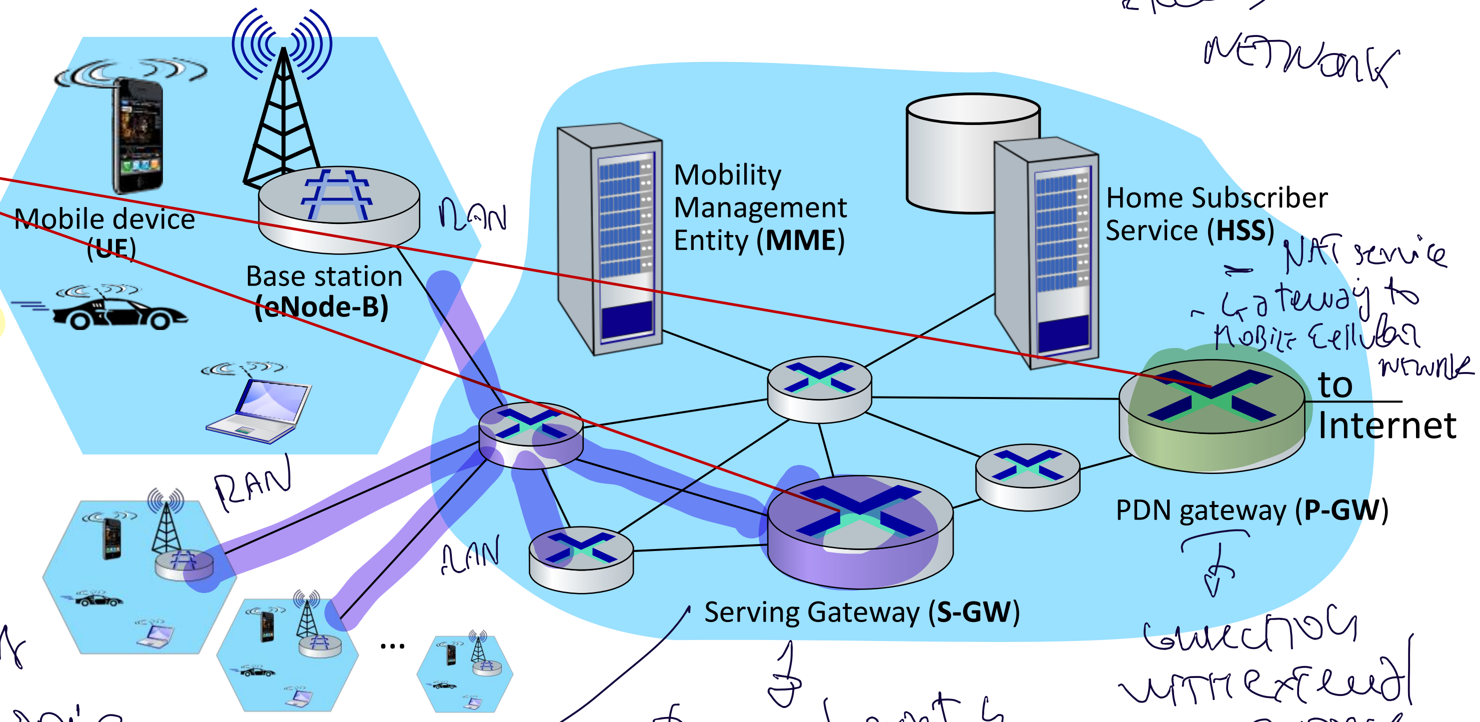


Elements of 4G architecture

receive DATA packets from BS, forward pack to/from RADIO ACCESS NETWORK

Serving Gateway (S-GW), PDN Gateway (P-GW)

- on data path from mobile to/from Internet
- S-GW: forwards IP packets to and from the RAN → RADIO ACCESS NETWORK: BACKHOLE & BS
- P-GW
  - a gateway to mobile cellular network
  - looks like any other internet gateway router
  - provides NAT services
  - supports additional access-related functions, including policy enforcement, traffic shaping, and charging.
- other routers: forwarding packets



The S-GW is also responsible for inter-eNB (BS) handovers and provides mobility between 4G and other types of networks, such as between 2G/3G and P-GW.

other over change BS service gateway is involved if core network

if packet needs to go outside → they go

4G Architecture

Cloud / virtualisation To have high degree of flexibility

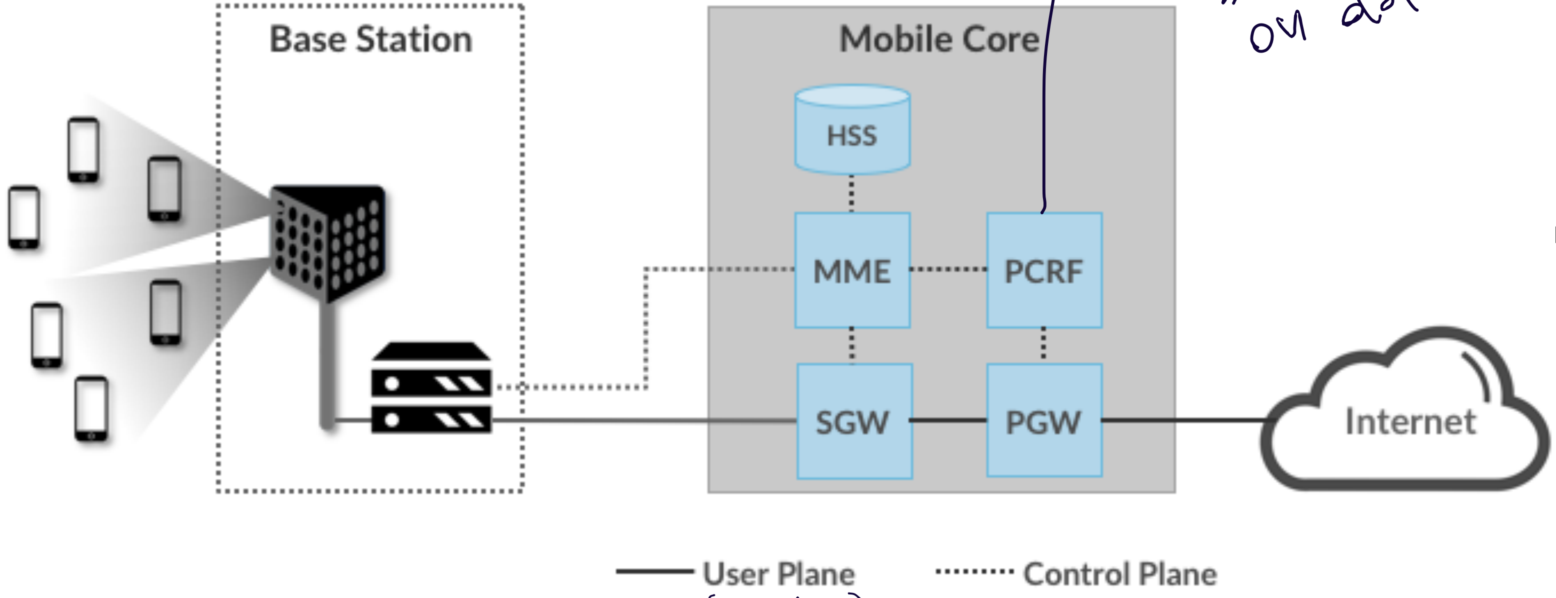
- Mobile Core components can be flexibly deployed to serve a geographic area

involved

serve a metropolitan area each serve ≈ 10 BS

- For example, a single MME/PGW pair might serve a metropolitan area, with SGWs deployed across ~10 edge sites spread throughout the city, each of which serves ~100 base stations
- alternative deployment configurations are allowed by the specifications (3GPP)

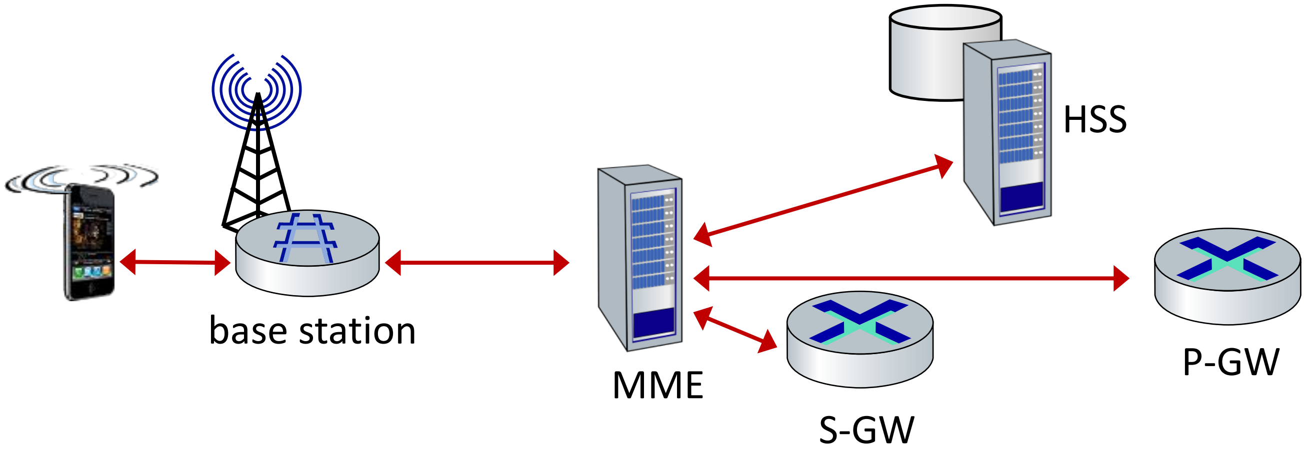
Decisions for checking
- policies
- billing
based on data flow



(Data)

4G: data plane control plane separation

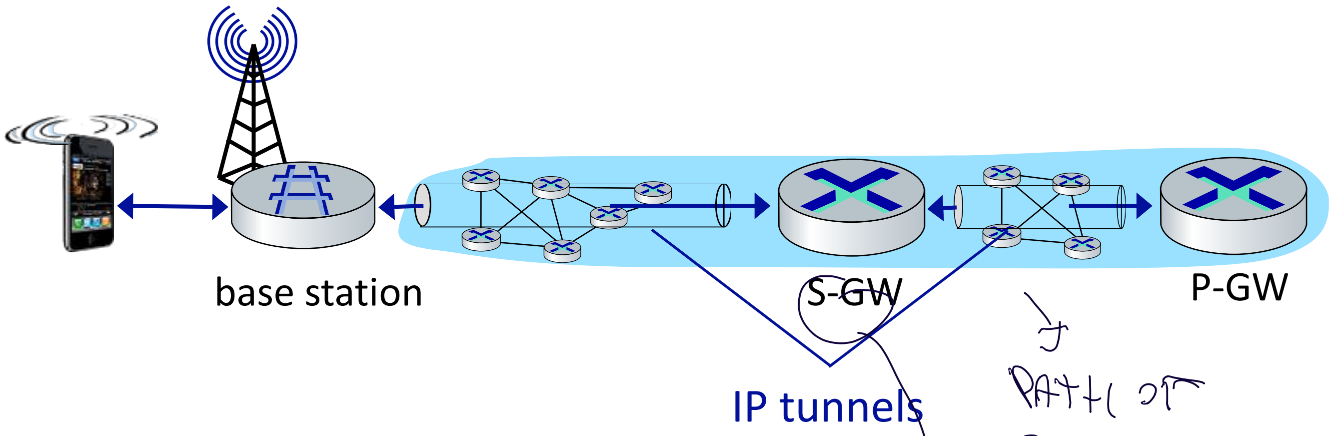
1) Mobility
2) Management
3) Security
4) Auth



control plane

- new protocols for mobility management (later), security, authentication

→ entities involved



PATH OF PACKETS

data plane

- new protocols at link, physical layers
- extensive use of tunneling to facilitate mobility

cell → packets to video youtube

→ DATA PATH is setup 2 TUNNEL

1 → BS → SGW / → PGW

Service GATEWAY

?

Have you already heard about control and data plane separation? Where?

NETWORK LAYER SMTP

4G: data plane/control plane separation

uses Different protocol

- The BS forwards both control and user plane packets between the Mobile Core and the UE.
- Control plane: packets are tunneled over SCTP/IP
  - SCTP (Stream Control Transport Protocol) is an alternative reliable transport to TCP, tailored to carry signaling (control) information for telephony services.
  - UE authentication, registration, and mobility tracking

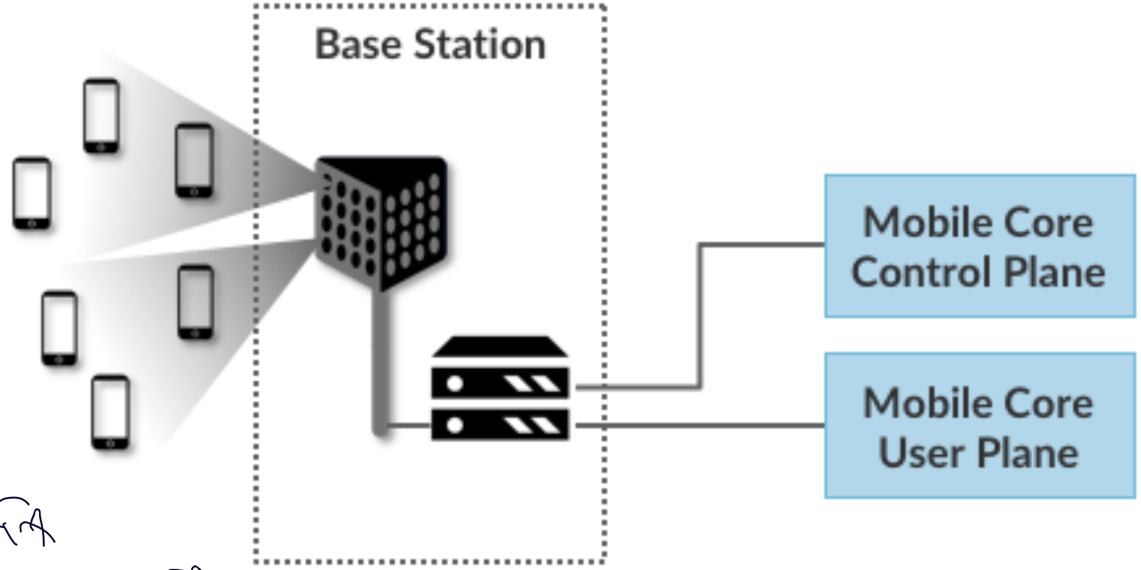
to deliver control/signal info

DATA

- User Plane: packets are tunneled over GTP (General Packet Radio Service) Tunneling Protocol)
  - GTP is a 3GPP-specific tunneling protocol designed to run over UDP

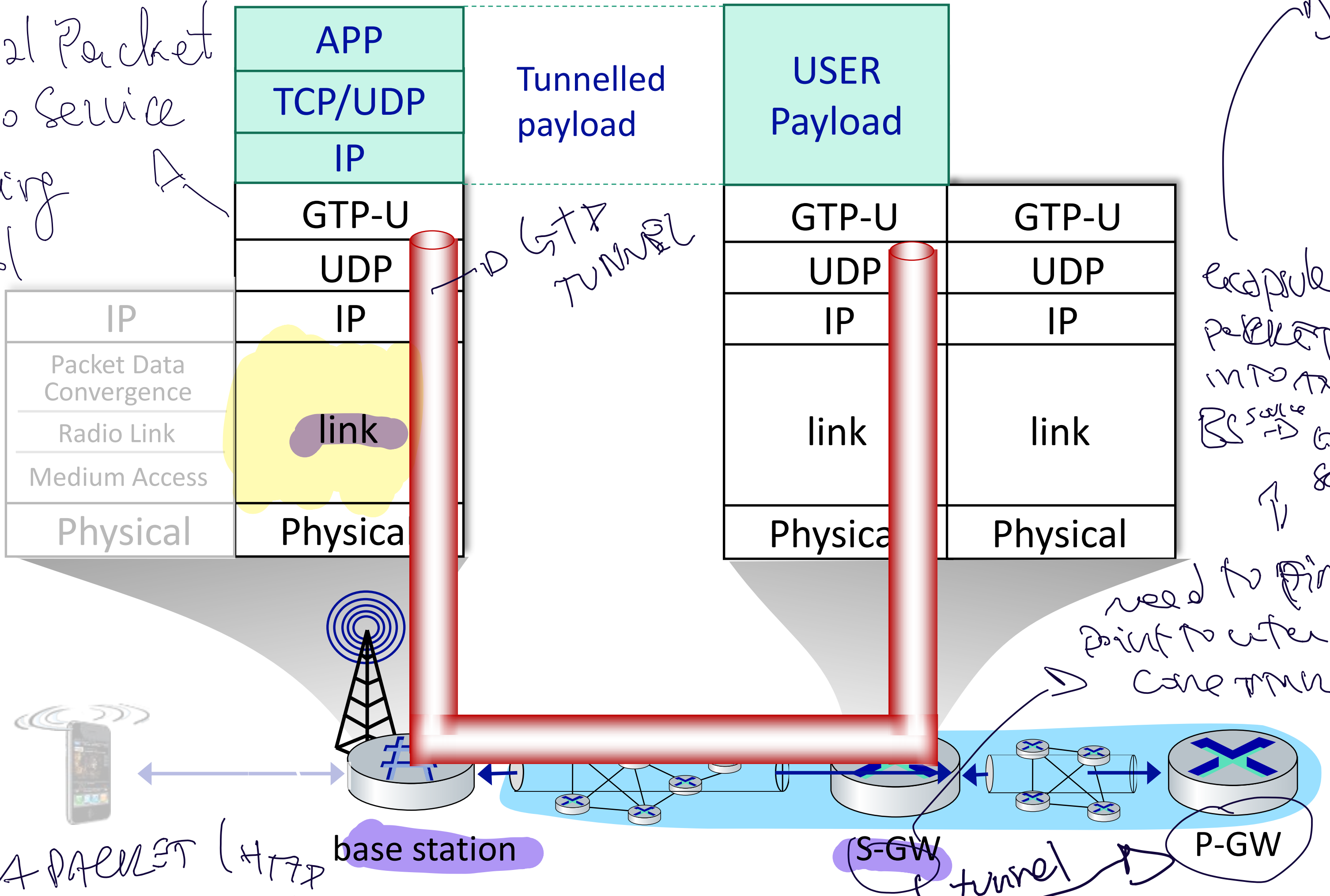
DATA PACKETS

TO DO THAT



LTE data plane protocol stack: packet core

General Packet Radio Service Tunnelling Protocol



-> useful cuz BS -> GTW -> mobile gateway is a fixed point if dev change BS -> change just 1 tunnel

encapsulate packet into another BS source -> dest gateway scum

need to find point to enter in core network

tunneling:

- mobile datagram encapsulated using GPRS Tunneling Protocol (GTP), sent inside UDP datagram to S-GW
- S-GW re-tunnels datagrams to P-GW
- supporting mobility: only tunneling endpoints (gateway) change when mobile user moves

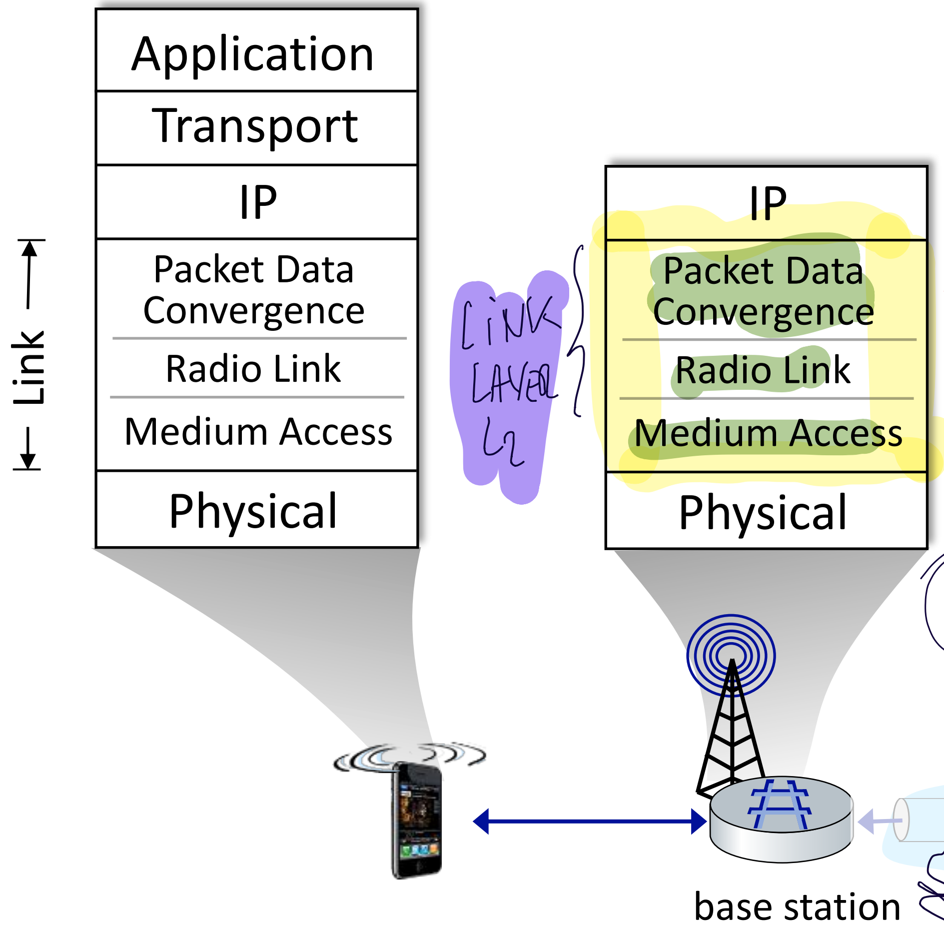
not tunneling of original

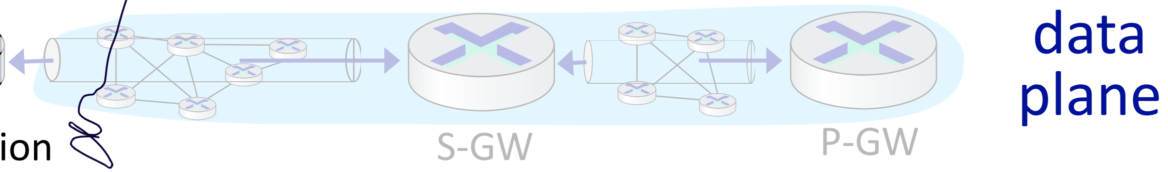
S-GW will set another address BS

A packet (HTTP generated) -> incapsulate in UDP -> source add / dest address -> endpoint (HTTP server)

LTE data plane protocol stack: first hop

initial exchange of msgs
↳ FROM physical to link layer
may be encrypted





LTE link layer protocols:

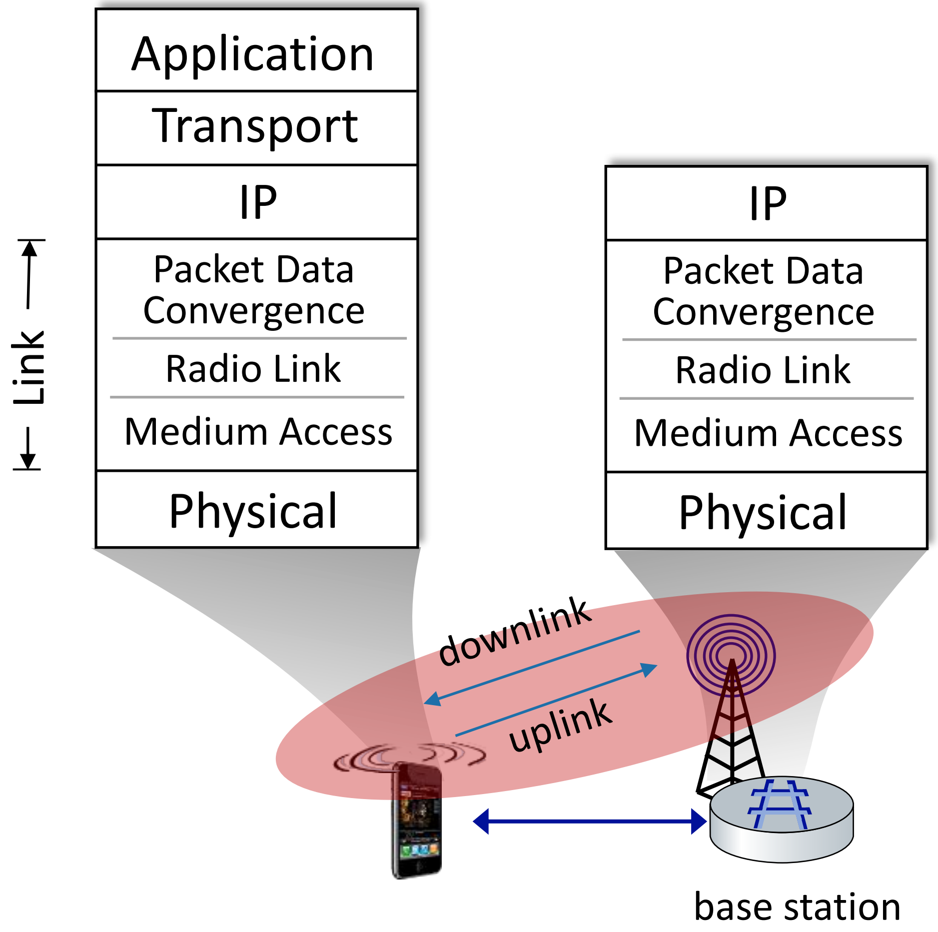
1. ▪ Packet Data Convergence: header compression/decompression, encryption/decryption
2. ▪ Radio Link Control (RLC) Protocol: fragmentation/reassembly, reliable data transfer
3. ▪ Medium Access: requesting and use of radio transmission slots

access to physical medium

Provide reliable data transfer

LTE data plane protocol stack: first hop

frequency time division MULTIPLEXING

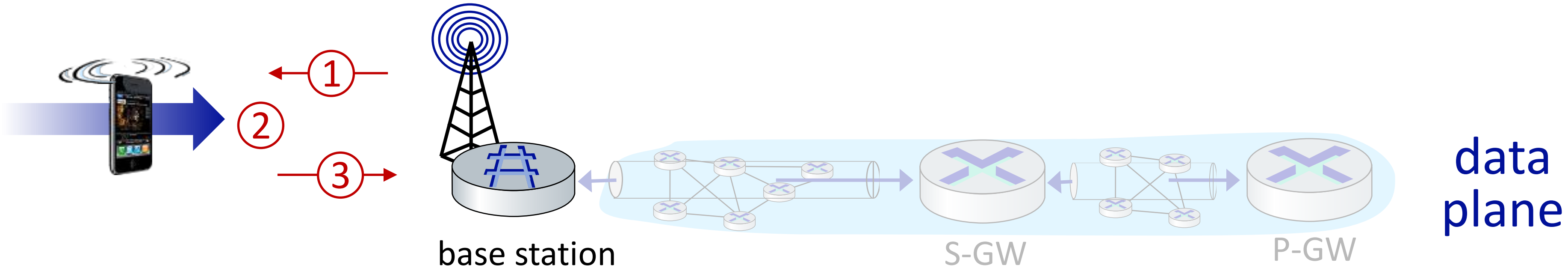


LTE radio access network:

- downstream channel: combination of FDM and TDM within frequency channel (OFDM - orthogonal frequency division multiplexing)
  - "orthogonal": minimal interference between channels
- upstream: FDM, TDM similar to OFDM combination
- each active mobile device allocated two or more 0.5 ms time slots in or more channel frequencies
  - scheduling algorithm not standardized – up to operator
  - 100's Mbps per device possible

LTE data plane: associating with a BS

HOW TO ATTACH



SINCRONIZ SIGNAL FROM BS

1. BS broadcasts primary synch signal every 5 ms on all frequencies
   - BSs from multiple carriers may be broadcasting synch signals

ON A GIVEN FREQUENCY, HAS TO BE NEW SYNC SIGNALS

2. mobile finds a primary synch signal, then locates 2nd synch signal on this freq.
   - mobile then finds info broadcast by BS: channel bandwidth, configurations; BS's cellular carrier info

MUTUAL AUTH

→ BUT THEN SELECT 1, HEADQUARTER SOUN PROVIDER IN MANY

MOBILITY MANAGEMENT SERVICE

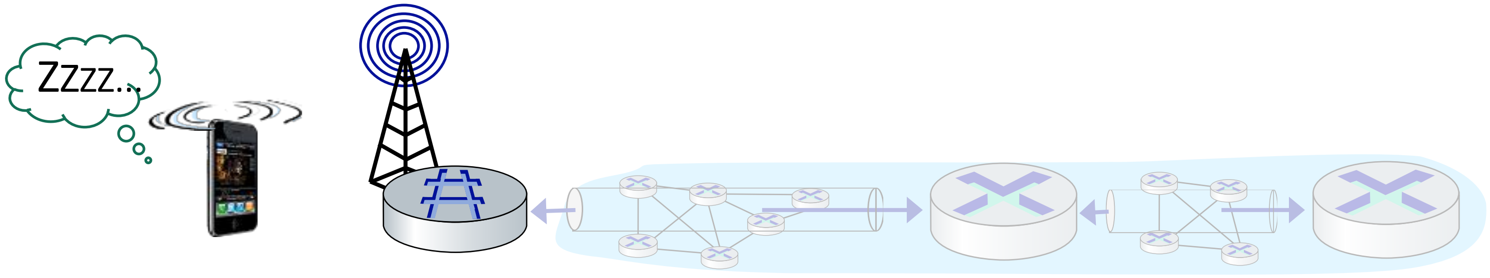
   - mobile may get info from multiple base stations, multiple cellular networks

HOME SUBSCRIBER

3. mobile selects which BS to associate with (*e.g.,* preference for home carrier)
4. more steps still needed to authenticate, establish state, set up control plane

LTE mobiles: sleep modes

SAVE ENERGY OF MOBILE DEVICES => sleepy MODE



data plane

as in WiFi, Bluetooth: LTE mobile may put radio to "sleep" to conserve battery:

very important

- light sleep: after 100's msec of inactivity

  if there are transmission: voice msg

  - wake up periodically (100's msec) to check for downstream transmissions
- deep sleep: after 5-10 secs of inactivity
  - mobile may change cells while deep sleeping – need to re-establish association

  CAN ALSO MOVE, BS LOSE CONNECTION TO device

  MOBILE REMAIN SERVICE

On to 5G!

- goal: 10x increase in peak bitrate, 10x decrease in latency, 100x increase in traffic capacity over 4G

  innovations: new radio; new freq. range
- 5G NR (new radio):
  - two frequency bands: FR1 (450 MHz–6 GHz) and FR2 (24 GHz–52 GHz): millimeter wave frequencies
  - not backwards-compatible with 4G
  - MIMO: multiple directional antennae

    → multiple input / multiple output
- millimeter wave frequencies: much higher data rates, but over shorter distances

  SMALLER cells
  - pico-cells: cells diameters: 10-100 m
  - massive, dense deployment of new base stations required

    • MORE BS needed IN 5G

5G use cases

+ speed
- latency

} to support 'many' secure domain

-> streaming need capacity

-> want no delay in streaming

- Support critical M2M communication (industry)

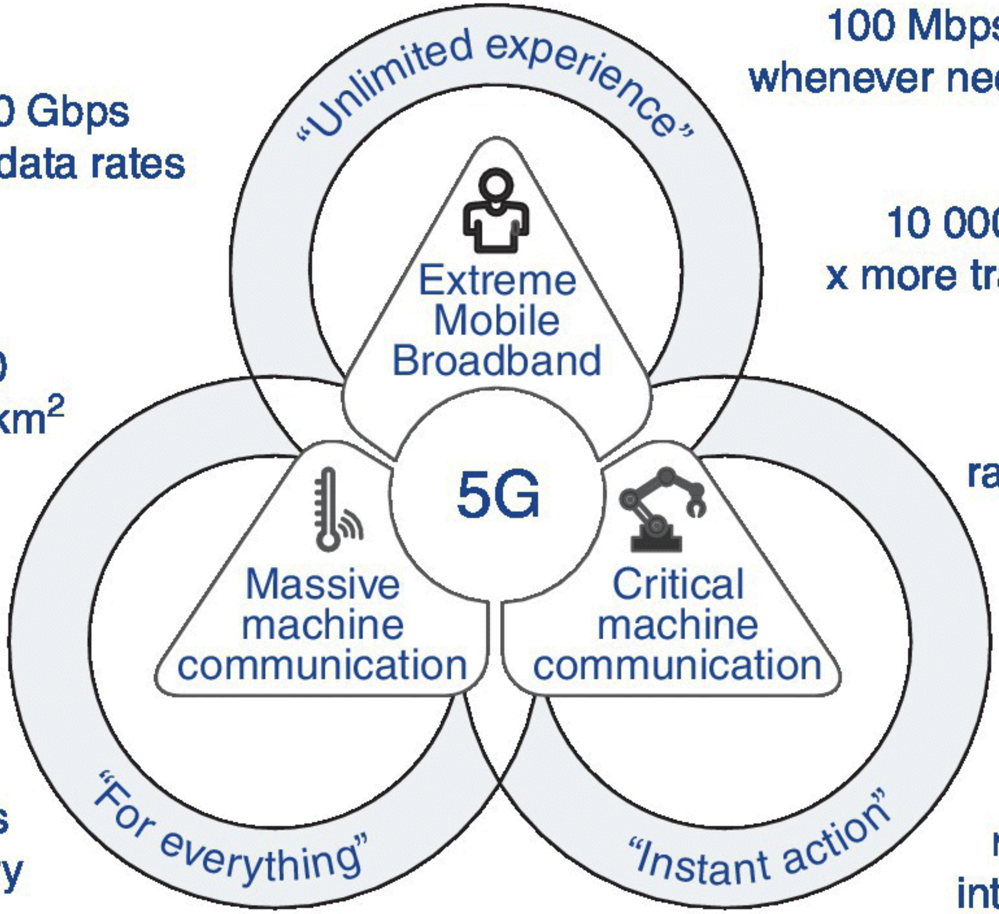
Capacity

>10 Gbps
peak data rates

100 Mbps
whenever needed

10 000
x more traffic

1,000,000
devices per km^2



Latency

-> low latency to control realtime

<1 ms
radio latency

Ultra low cost
for massive
machine coms.

Ultra
reliability
< 10^{-5} E2E outage

-> highly reliability

Connectivity

10 years
on battery

Zero
mobility
interruption

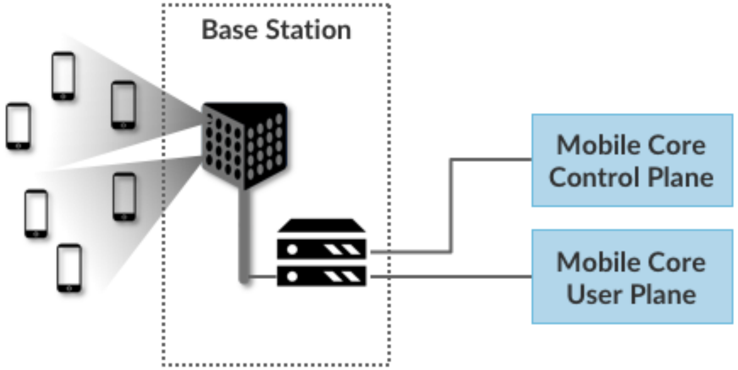
Reliability

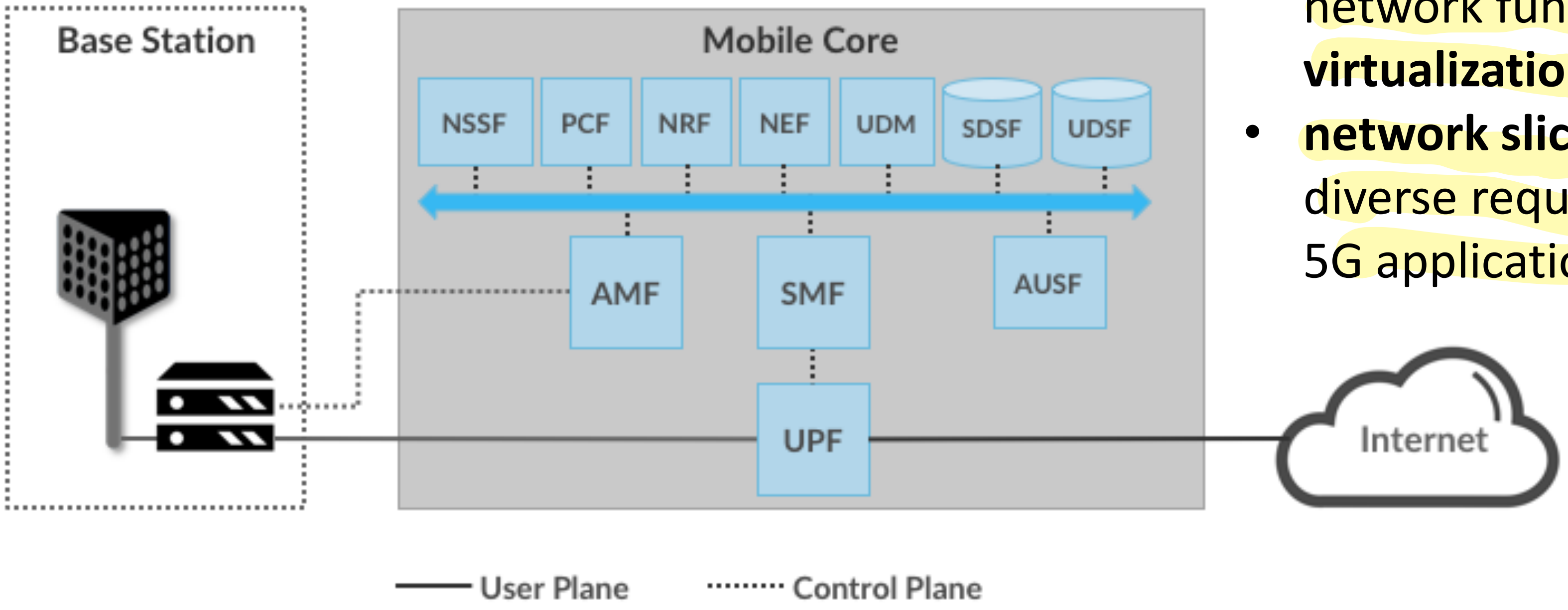
-> support IoT (connect # of sensors) save battery

don't care if loose some packet (media)

AUTH DEV.
MOBILITY OF DEV.

5G Architecture





The 5G Core network

- redesigned to better integrate with the Internet and cloud-based services
- Complete control and user plane separation
- distributed servers and caches across the network to reduce latency
- Consists of virtualized software network functions (**network function virtualization**)
- **network slicing** to flexibly meet the diverse requirements of the different 5G applications

next lectures

(Ex)

~~xx~~ user function like micros
→ packet inspection
– QoS
– usage of resource
⇒ realise these as set of MS
to have replica scalability
deploy

5G Architecture - User Plane

• separation control / DATA PLANE

DISTRIBUTE

UPF (User Plane Function)

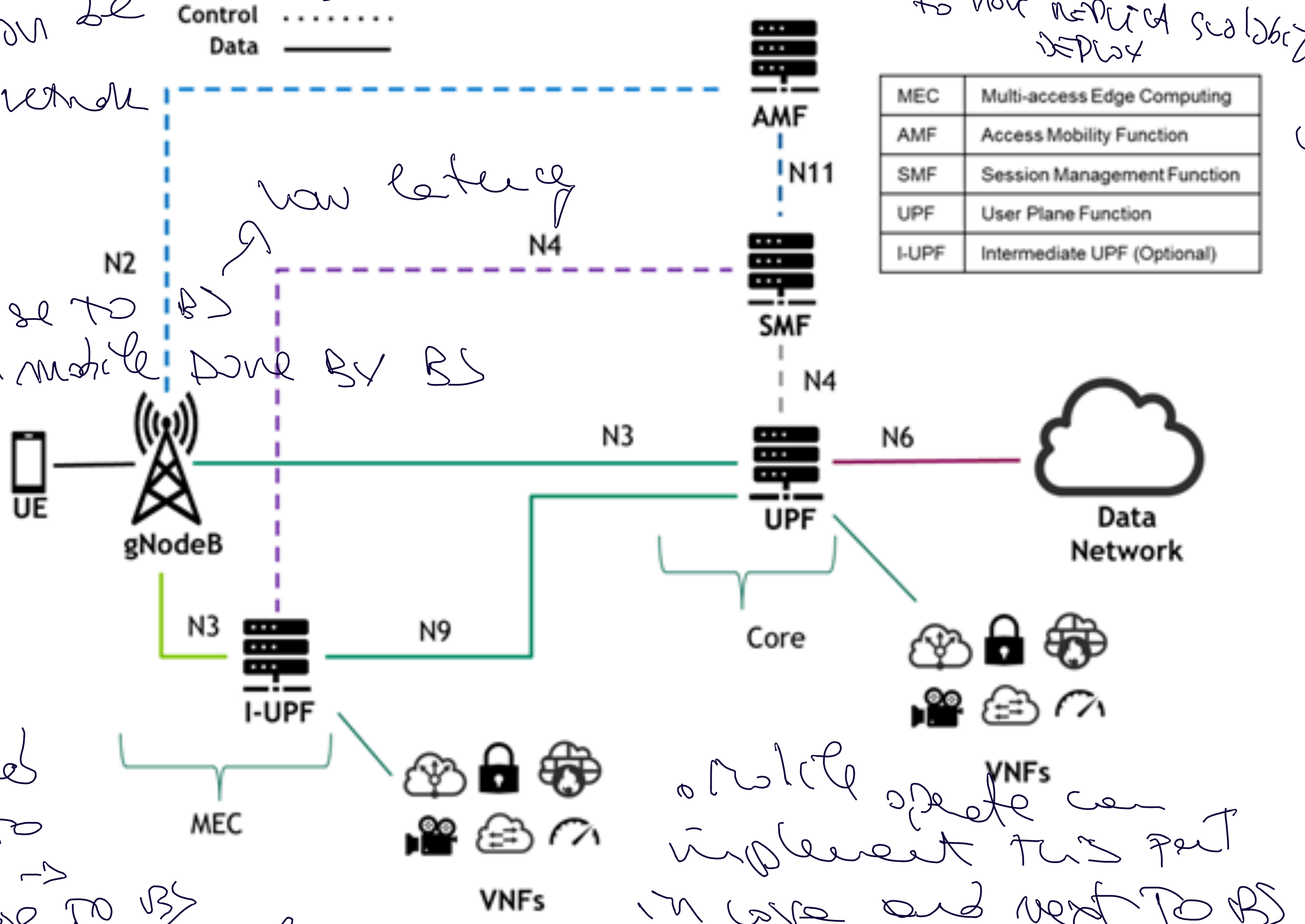
function, can be
→ RADIO ACCESS NETWORK

- forwards traffic between RAN and the Internet, corresponding to the S/PGW combination in EPC. It also is responsible for:
  - Packet inspection & application detection
  - QoS management
  - traffic usage reporting

low latency

moving app close to BS
(edge computing in mobile) Done by BS

- flexibility to deliver user plane functionality at the edge as well as the network core.
  - UPF can be co-located with edge and central data centers at both locations
  - Multi-Access Edge Computing (MEC)



DISTRIBUTE TRAFFIC MANAGED AT THE EDGE

next lectures

if needed functions to analyse data → put and close to BS
and UPF

short PATH → lower latency

• mobile operator can implement this part in core and next to BS

Image from: https://developer.nvidia.com/blog/accelerating-iva-using-ultra-efficient-5g-core-with-mavenir-and-nvidia-edge-ai/

דגשים

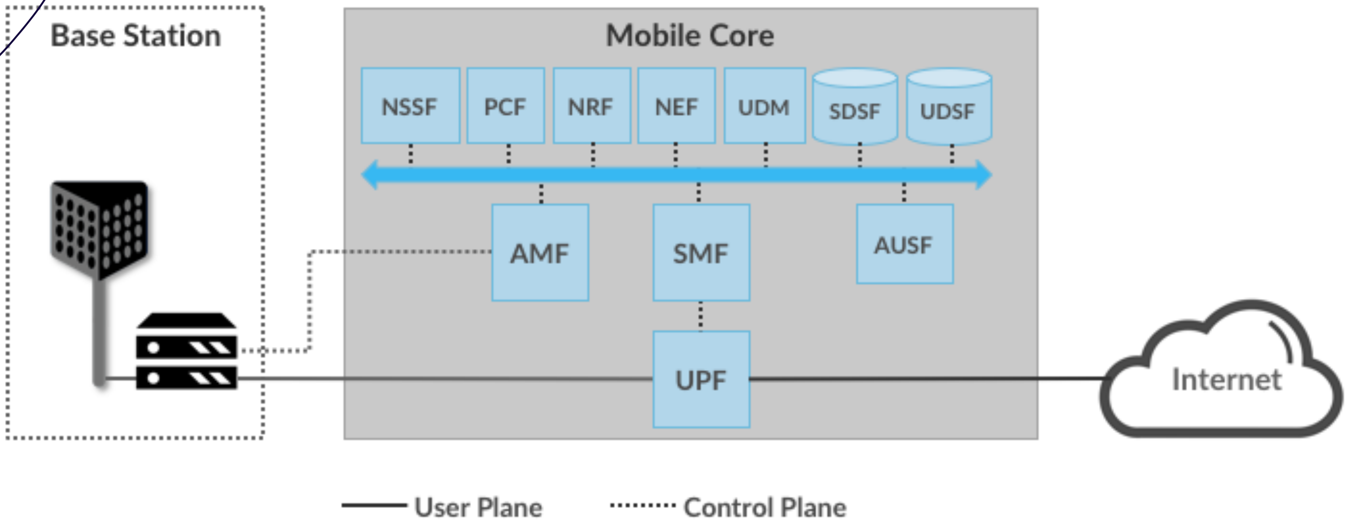
5G Architecture - Control Plane

(inheriting from 4G)

- AMF (Core Access and Mobility Management Function): connection and reachability management, mobility management, access authentication and authorization, and location services ->MME (corresponding name in 5G

Mobility Management Entity

- SMF (Session Management Function): manages each UE session, including IP address allocation, selection of associated UP function, control aspects of QoS, and control aspects of UP routing. -> MME and the control-related aspects of PGW.
- PCF (Policy Control Function): manages the policy rules that other CP functions then enforce. -> PCRF.
- UDM (Unified Data Management): Manages user identity, including the generation of authentication credentials. -> HSS.
- AUSF (Authentication Server Function): Essentially an authentication server. -> HSS.



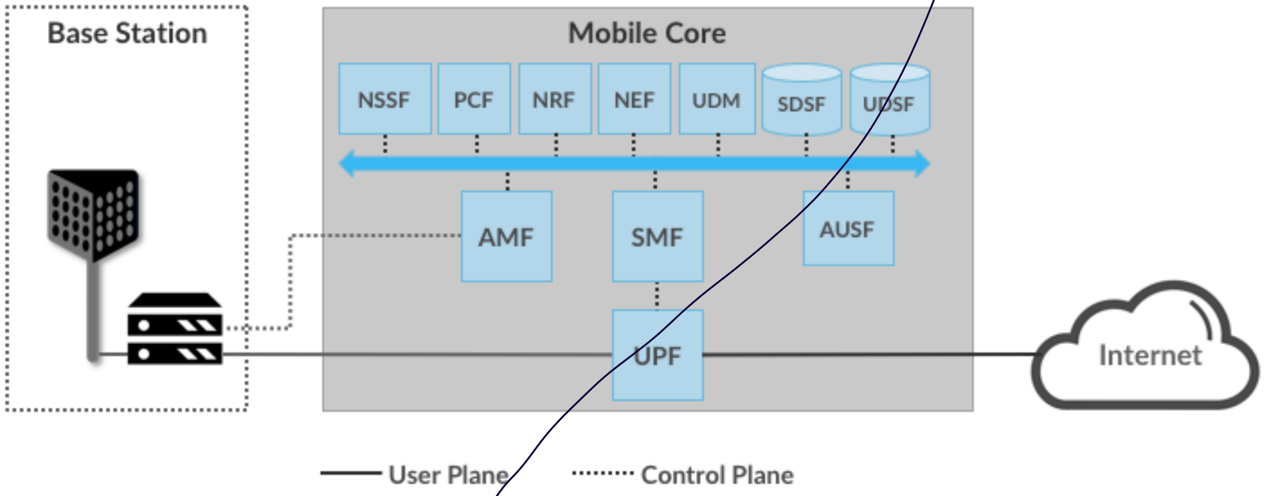
5G Architecture - Control Plane

idea to separate data from application logic

Control Plane (not existing in from 4G)

- SDSF (Structured Data Storage Network Function): a "helper" service used to store structured data.
- UDSF (Unstructured Data Storage Network Function): A "helper" service used to store unstructured data.
- NEF (Network Exposure Function): A means to expose select capabilities to third-party services
- NRF (NF Repository Function): A means to discover available services.
- NSSF (Network Slicing Selector Function): A means to select a Network Slice to serve a given UE. Network slices are essentially a way to partition network resources in order to differentiate service given to different users.

applying



MS concept, applying container to do this

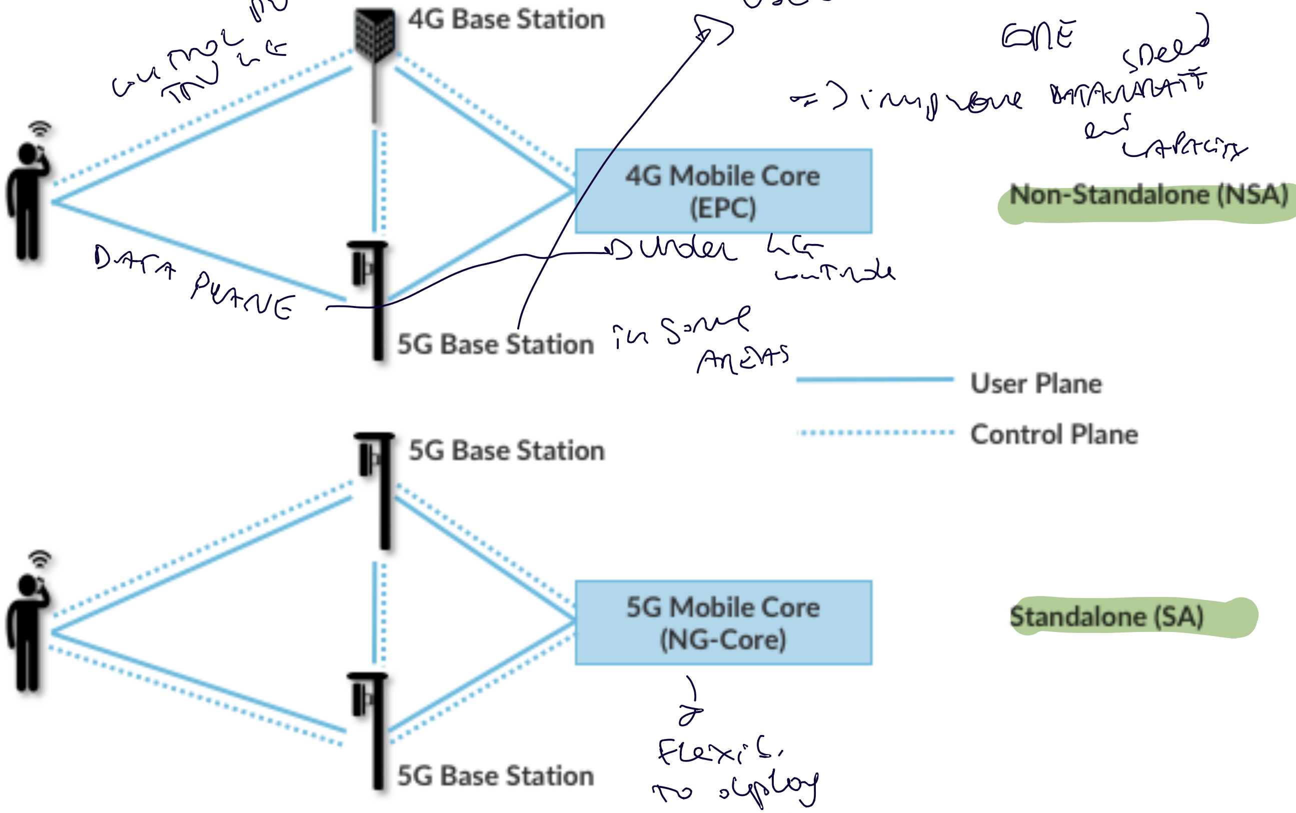
- cloud native solution
- distinct storage services means that all the other services can be stateless, and hence, more readily scalable.

Deployment Options

~ 4G

- Standalone 4G / Stand-Alone 5G
  of 5G in ITALY
- Non-Standalone (4G+5G RAN) over 4G's EPC
  - 5G base stations being deployed alongside the existing 4G base stations in a given geography to provide a data-rate and capacity boost. => not really delivered 5G
  - In NSA, control plane traffic between the user equipment and the 4G Mobile Core utilizes (i.e., is forwarded through) 4G base stations, and the 5G base stations are used only to carry user traffic
- Non-Standalone (4G+5G RAN) over 5G's NG-Core

ITALY



control plane thru 4G

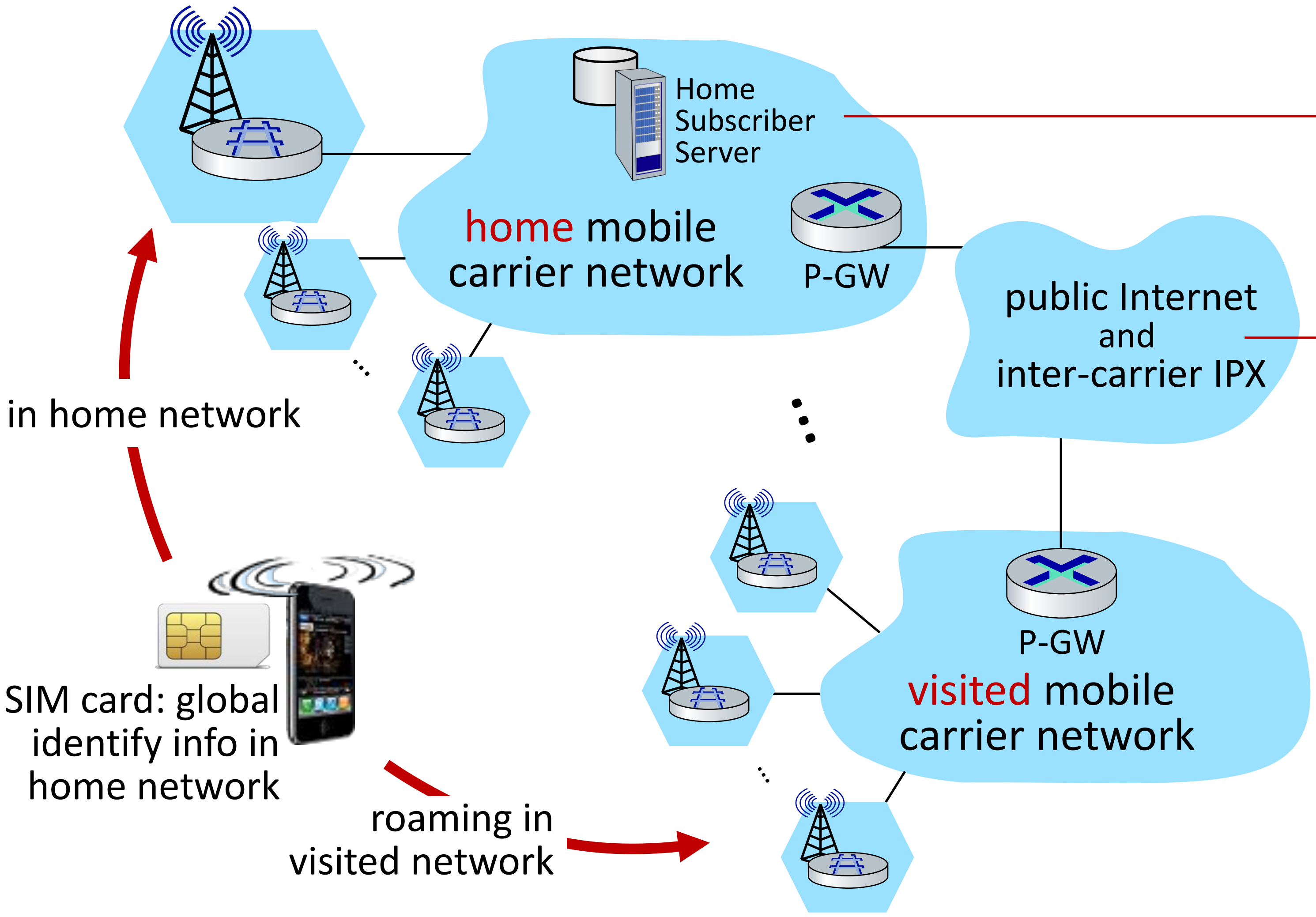
Data plane

uses 4G mobile core => improve datarate speed and capacity

=> under 4G control in some areas

flexible to deploy app to BS ... scale

Global cellular network: a network of IP networks



home network HSS:

- identify & services info, while in home network and roaming

all IP:

- carriers interconnect with each other, and public internet at exchange points
- legacy 2G, 3G: not all IP, handled otherwise

VoIP

Outline

- Cellular networks
  - Cellular network evolution (1G, 2G, 3G)
  - 4G and 5G networks
- Mobility
  - Mobility management: principles
  - Mobility management: practice
    - Mobility management in 4G/5G networks
    - Mobile IP
  - Impact on higher-layer protocols

What is mobility?

different;

- spectrum of mobility, from the network perspective:

no mobility — high mobility

different operators

1. device moves between networks, but powers down while moving
2. device moves within same AP in one provider network
3. device moves among APs in one provider network

device moves among multiple provider networks, while maintaining ongoing connections

maintaining ongoing connection

We're interested in these!

dev → phone
→ university
(dynamic joining of dev → temporary IP

Contacting a mobile friend:

Consider friend frequently changing locations, how do you find him/her?

- search all phone books?
- expect her to let you know where he/she is?
- call his/her parents?
- Facebook!

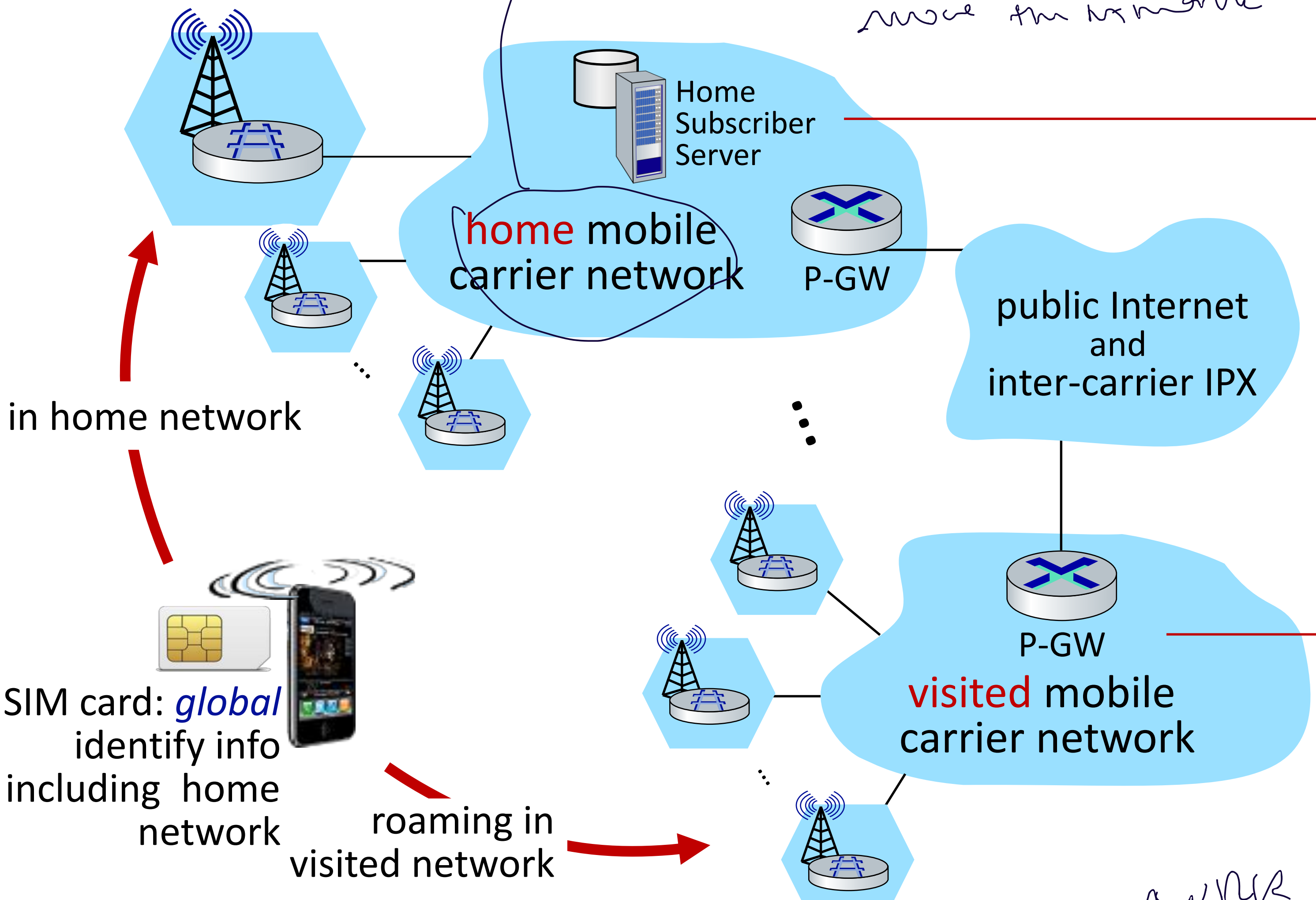
Home network

The importance of having a "home":

- a definitive source of information about you
- a place where people can find out where you are

Home network, visited network: 4G/5G

so with wireless, devices can move the network



Better covering the concept;

home network:

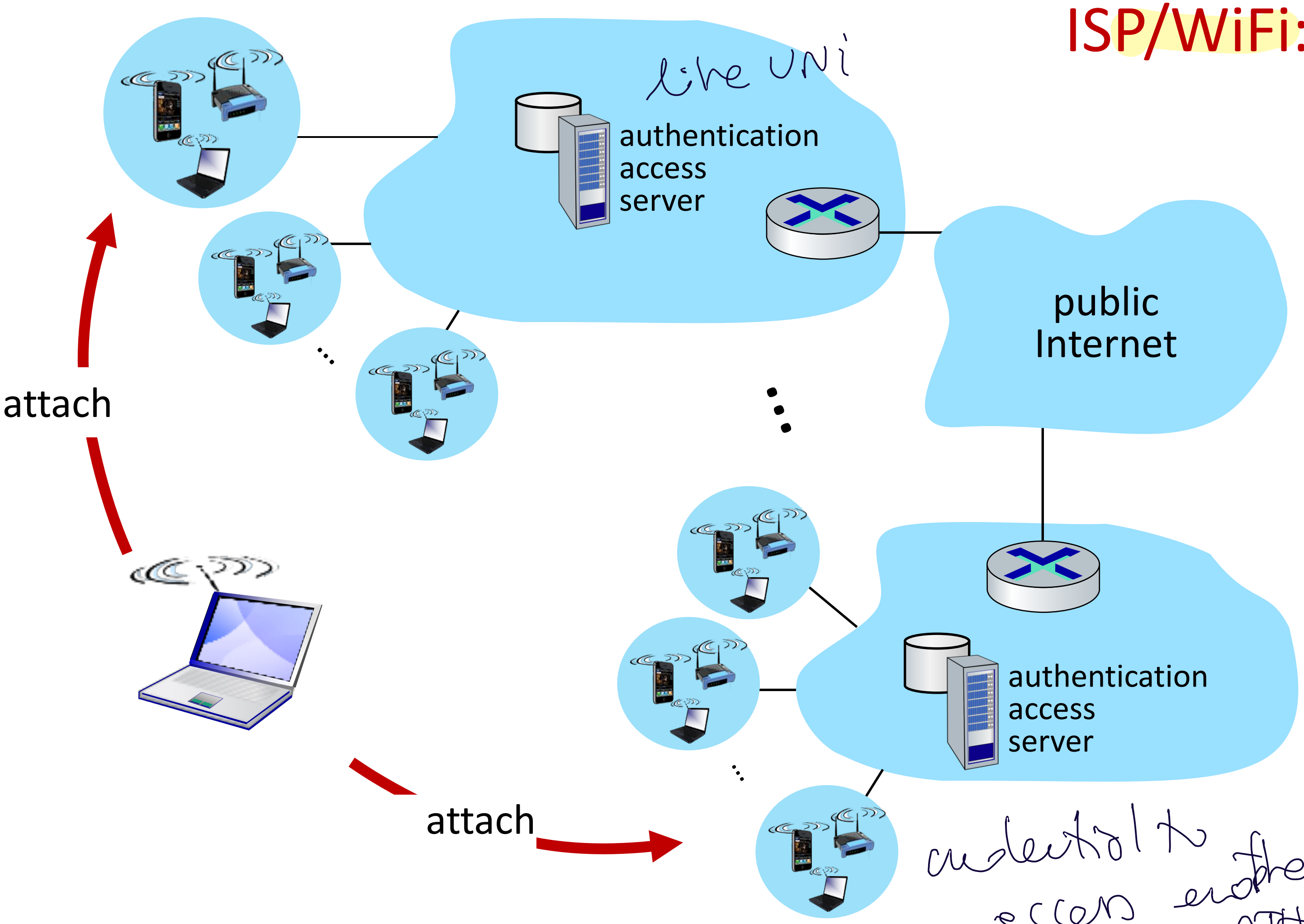
- (paid) service plan with cellular provider, e.g., Verizon, Orange
- home network HSS stores identify & services info

visited network:

- any network other than your home network
- service agreement with other networks: to provide access to visiting mobile

mobile attached to new network (visited mobile home network carrier)

Home network, visited network: ISP/WiFi



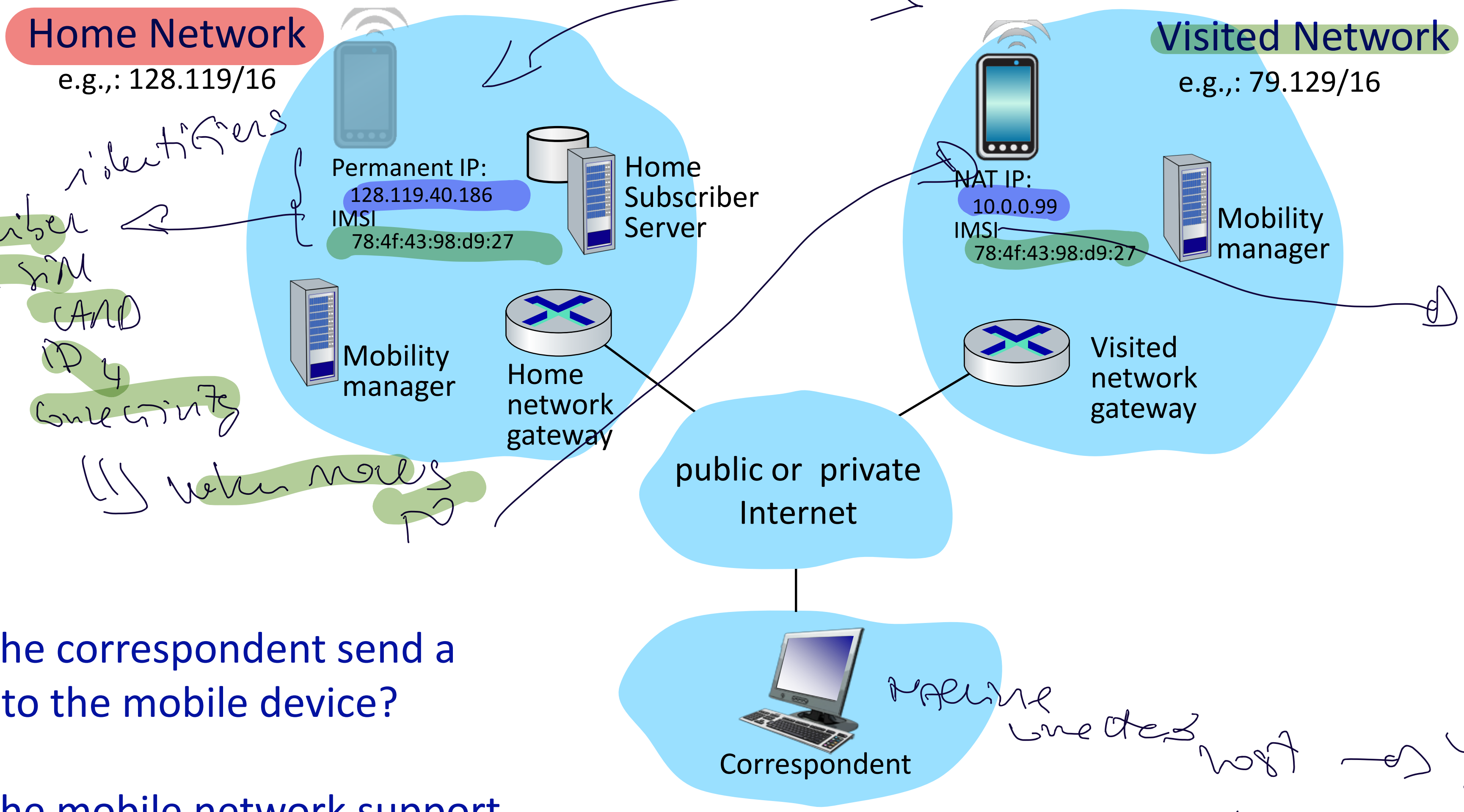
ISP/WiFi: no notion of global "home"

- credentials from ISP (e.g., username, password) stored on device or with user
- ISPs may have national, international presence
- different networks: different credentials
  - some exceptions (e.g., eduroam)
  - architectures exist (mobile IP) for 4G-like mobility, but not used

credential to access another
share AUTH service

← Federated identity (like eduroam)
AUTH MANAGEMENT

Home network, visited network: generic



How can the correspondent send a datagram to the mobile device?

How can the mobile network support device's mobility?

problem: statelessness to mobility

device move from/to

identifiers

Subscriber ID in SIM card & ID 4 connectivity

(1) when moves to

dynamics ID
ip can be same on another IP or NAT
→ network problems

machine wanted host → want to communicate with mobile device

roaming visited network

Mobility approaches

like internet → set of net, routers interconnected

- let network (routers) handle it:
  - routers advertise well-known name, address (e.g., permanent 32-bit IP address), or number (e.g., cell #) of visiting mobile node via usual routing table exchange
  - Internet routing could do this already *with no* changes! Routing tables indicate where each mobile located via longest prefix match!

→ update R TABLES → IP reached the given path

⇒ Changing FT of routers

→ in routers use aggregate address

→ don't want 1000...00 of entries in RT

⇒ not scalable

Mobility approaches

idea: manged by mobile ntw (node (user?)) at the edge

2

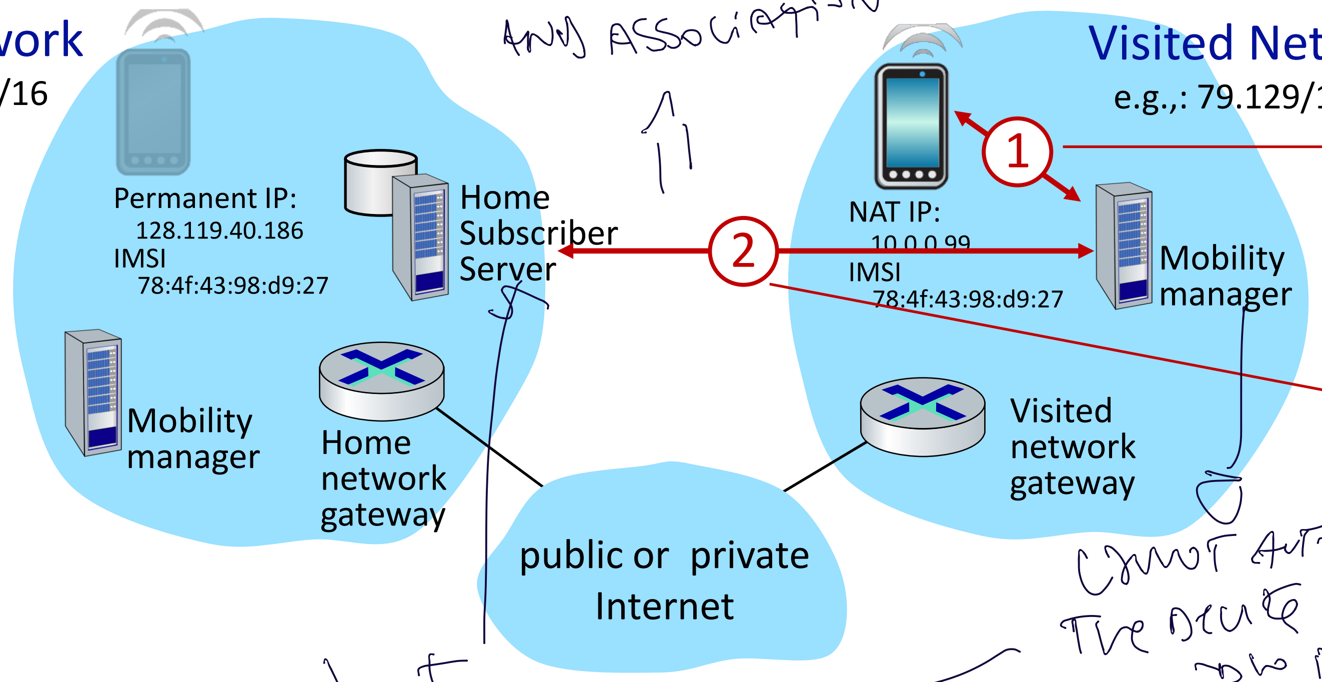
- let network (routers) handle it:
  - routers advertise well-kn address (e.g., permanent 32-bit IP address), or numb) of visiting mobile node via usual routing table exch
  - Internet routing could do dy *with no* changes! Routing tables indicate where each mobile located via longest prefix match!

not scalable to billions of mobiles

the home ntw

- let end-systems handle it: functionality at the "edge"
  - *indirect routing:* communication from correspondent to mobile goes through home network, then forwarded to remote mobile
  - *direct routing:* correspondent gets foreign address of mobile, send directly to mobile → contact HN when mobile reside and who to contact visited ntwk

Registration: home needs to know where you are!



mobile *associates* with visited mobility manager

visited mobility manager *registers* mobile's location with home HSS

end result:

- visited mobility manager knows about mobile
- home HSS knows location of mobile

The mobile device needs an IP address in the visited network

1. permanent address associated with the mobile device's home network
2. new address in the address range of the visited network
3. IP address via NAT

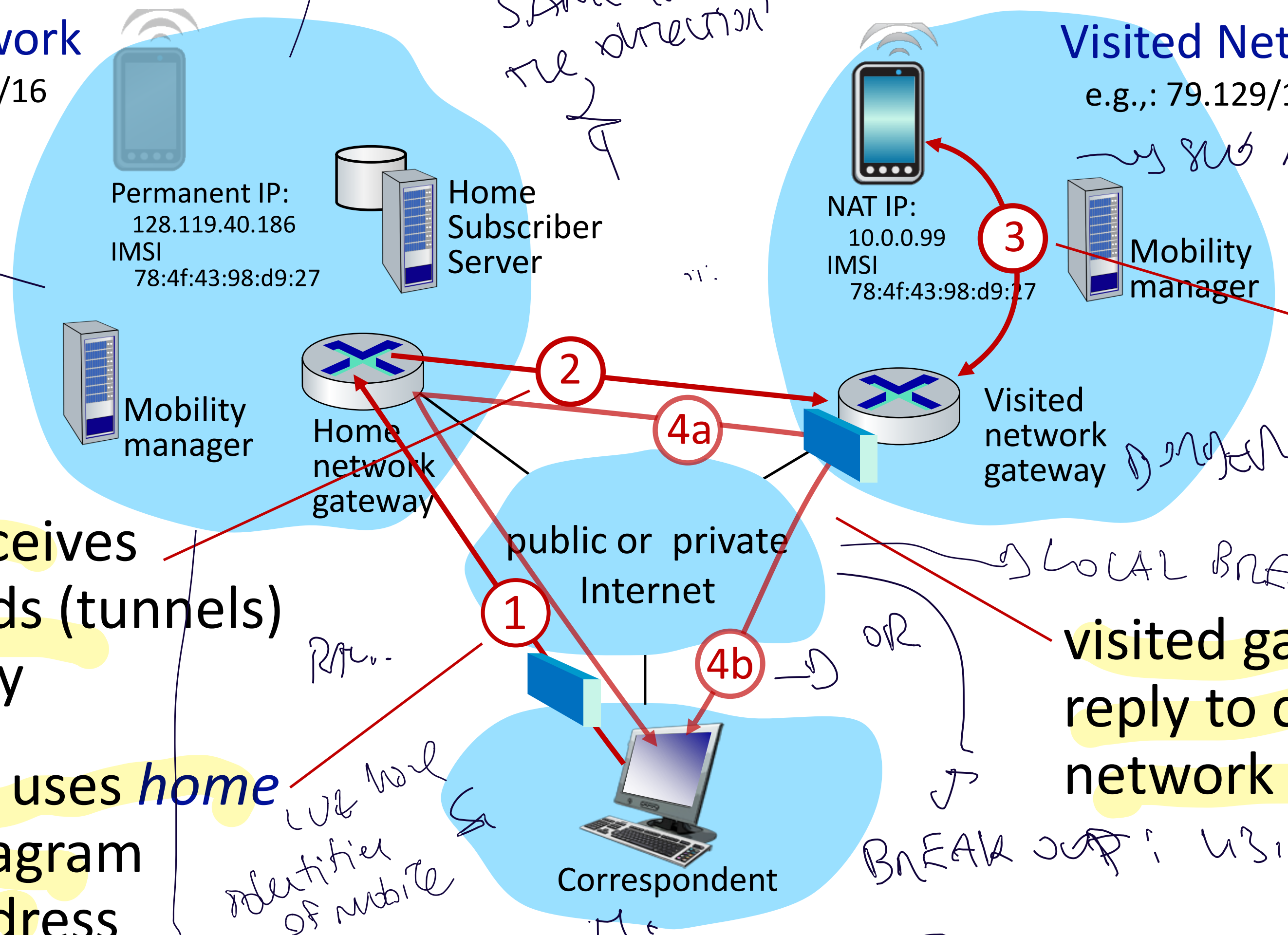
Transient identifiers

5G approach ... -ity

this data plane → need control plane to make this get

→ need exchange info to home who know IMSI to visited network

Mobility with indirect routing



Border gateway → communication per. kept

Path are same in the direction

→ send back response

home gateway receives datagram, forwards (tunnels) to remote gateway

correspondent uses *home* address as datagram destination address

use home identifier of mobile

always go to HNet to forward packet

visited gateway router forwards to mobile

, forward packet to end device

→ LOCAL BREAK OUT

OR

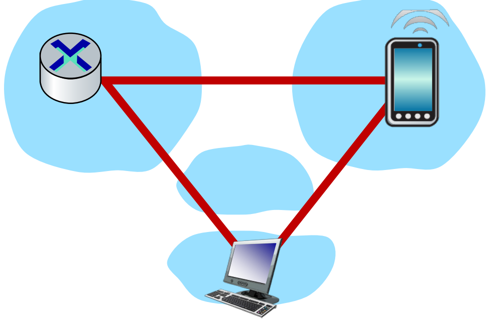
visited gateway router forwards reply to correspondent via home network (4a) or directly (4b)

BREAK OUT: visited network bypass home network

An indirect routing approach is used in 4G LTE networks and in the mobile IP standard

Mobility with indirect routing: what is required?

(CONTROL PLANE) to manage real traffic



- A mobile-device–to–visited-network association protocol
  - (1) The mobile device will need to associate with the visited network, and will similarly need to disassociate when leaving the visited network
- visited-network–to–home-network-HSS registration protocol
  - (2) The visited net-work will need to register the mobile device's location with the HSS in the home network

→ Reg protocol visited/Home net can dialog to AUTH dev. and service that mobile subscribe can consume & update DB

→ need setup some ~~Potential~~ Tunnel to manage this mobility

- A datagram tunneling protocol between in the home network gateway and the visited network gateway router
  - (3) The home gateway performs encapsulation and forwarding of the correspondent's original datagram
  - (4) On the receiving side, the gateway router performs decapsulation, NAT translation, and forwarding of the original datagram to the mobile device

Tunnel is encapsulation → a packet can take original datagram and change source/dest addresses

GENERAL

Mobility with indirect routing: comments

considerations

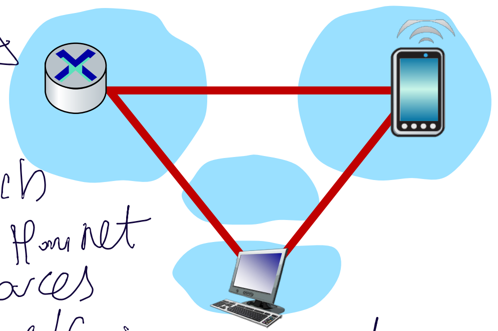
"v – "

(mobile on wireless conditions)

- triangle routing:
  - − inefficient when correspondent and mobile are in same network

    Involve: home gateway

    ⇒ too much
    1) consume Home Net resources
    2) latency c/s is increased



- + mobile moves among visited networks: transparent to correspondent!

  → external host (correspondent) don't need to know mobile device is (just address)

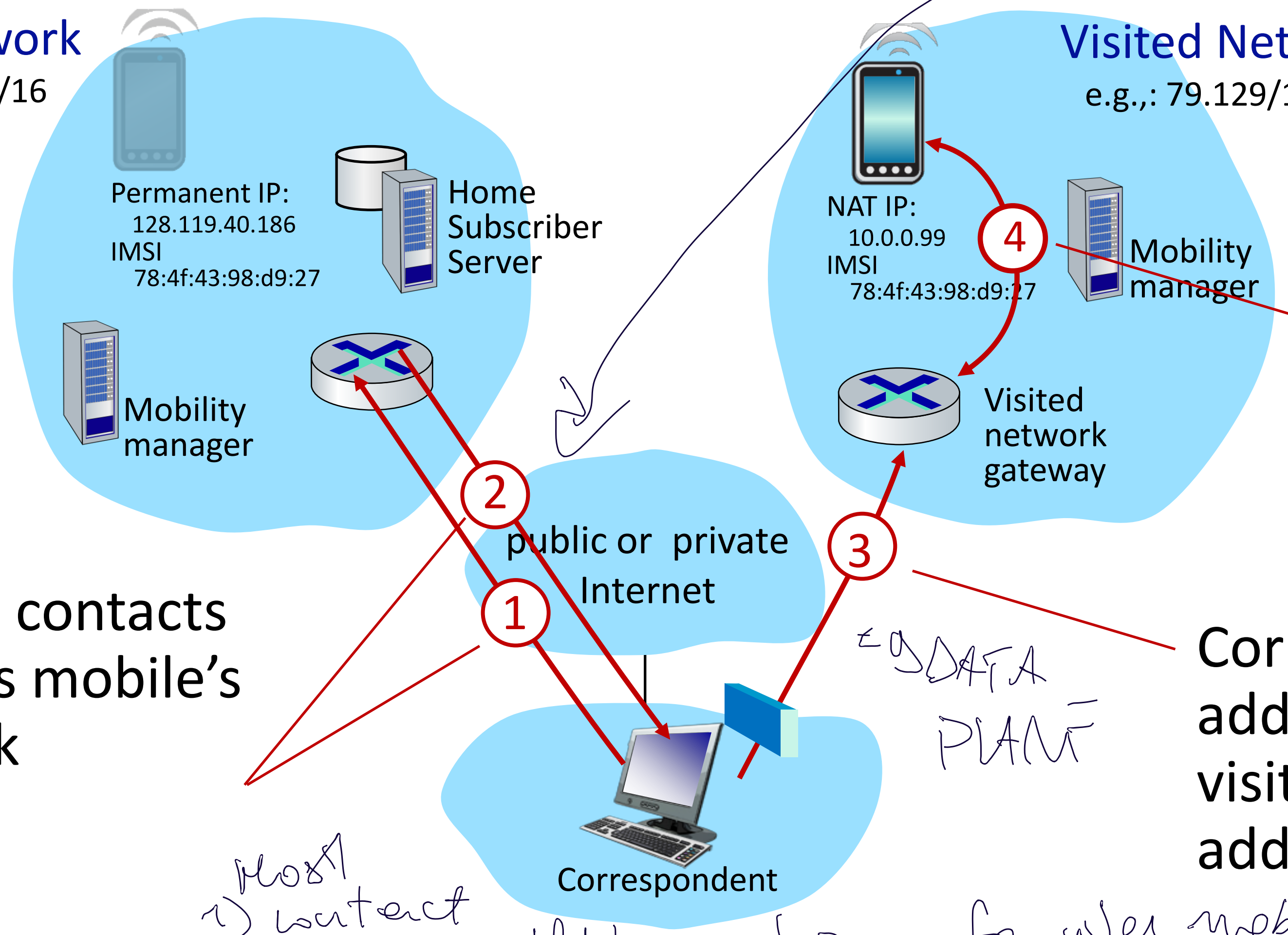
  - associates in new visited network
  - new visited network registers with home HSS → everything managed by Home Net
  - datagrams continue to be forwarded from home network to mobile in new network
- But will the mobile device see an interrupted flow of datagrams as it moves between networks?
  - *A few datagrams may be lost but…*
  - *on-going (e.g., TCP) connections between correspondent and mobile can be maintained!*

⇒ need ~~[illegible]~~ control message to manage mobility: reliable transport services

TCP
UDP ⇒ reliability at app level

Mobility with direct routing

→ more control msg exchanged to locate host



visited gateway router forwards to mobile

correspondent contacts *home* HSS, gets mobile's visited network

← DATA PLANE

Correspondent addresses datagram to visited network address

Host
1) contact 1 time HN to retrieve info where mobile device is
2) with this info, send packet to visit net gateway → mobile
address

Mobility with direct routing: comments

INDIRECT: inefficient but simple

DIRECT: cost of movements

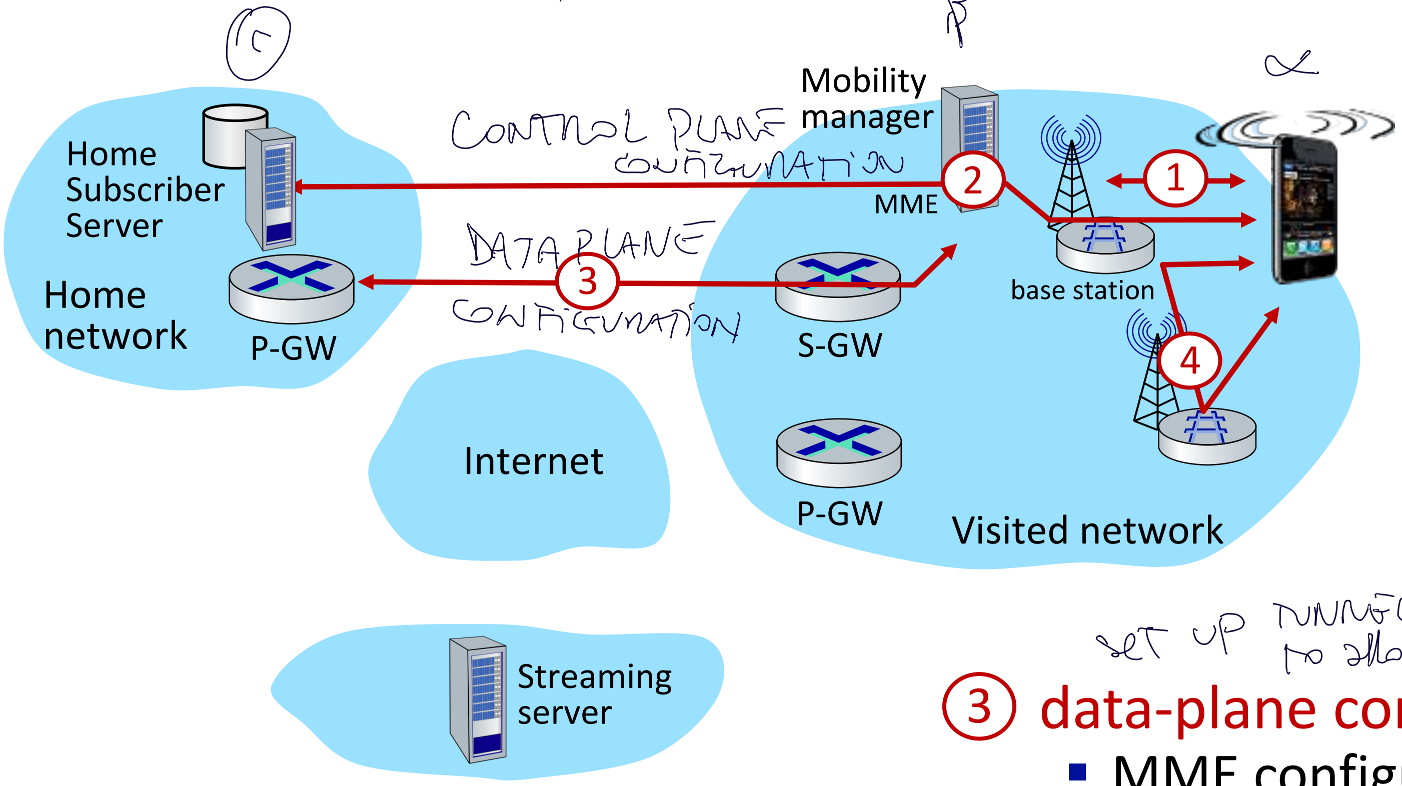
- (+) overcomes triangle routing inefficiencies
- (−) *non-transparent to correspondent:* correspondent must get care-of-address from home agent
  here: corresp contact 1 time home pt → retrieve IP address of device associated to visited → ex chay
- what if mobile changes visited network?
  - In case of indirect routing: easily solved by
    - 1ST updating the HSS in the home network → From 1 visited NET GATEWAY TO ANOTHER
    - changing the tunnel endpoint to terminate at the gateway router of the new visited network
      MOBILITY HERE IS SIMPLE
      if device moves → served by different NET
      IT'S IP changes
  - In case of indirect routing: can be handled, but with additional complexity
    - the HSS is queried by the correspondent only at the beginning of the session

to know the movements of end device ← periodically ... need to have control

INDIRECT IN 4G
implemented

Mobility in 4G networks: major mobility tasks

α|β|c: exchange info to AUTH device



1 base station association:

owners in a visited NET

- mobile device associates with a BS in the visited network (association with BS)
- mobile provides IMSI – identifying itself, home network

international mobility ~~LAT~~ from subscribe info

2 control-plane configuration:

- MME, home HSS establish control-plane state - mobile is in visited network

set up TUNNEL to allow communication WITH MME visited CONTACT HSS of HOME TO AUTH THE Device

3 data-plane configuration:

- MME configures forwarding tunnels for mobile
- Visited and home networks establish tunnels from home P-GW to mobile

INDIRECT TUNNEL

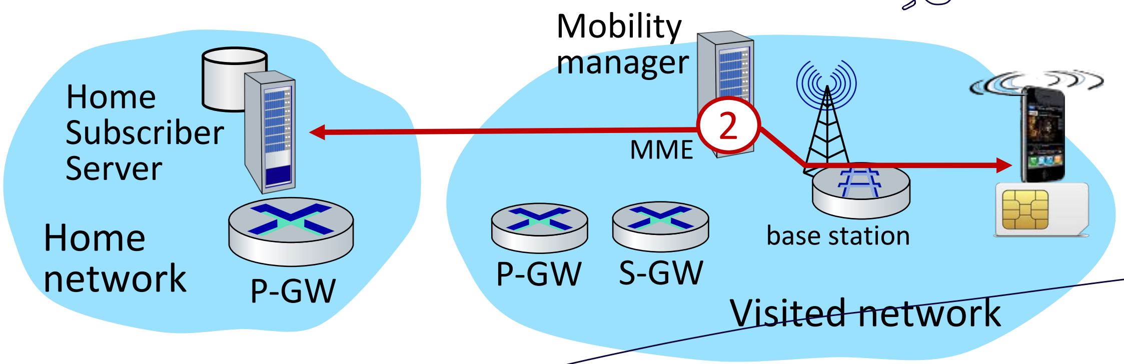
4 mobile handover:

Mobile change BS of same VISITED NET → manage this mobility change Termination of tunnel

- mobile device changes its point of attachment to visited network
- A handover occurs when a mobile device changes its association from one BS to another

2. Configuring LTE control-plane elements

MM
seed id of dev.
→ update DB
— AUTH part mobile device @ HSS
if ok AUTH



- Mobile communicates with local MME via BS control-plane channel
- MME uses mobile's IMSI info to contact mobile's home HSS
  - retrieve authentication, encryption, network service information
  - home HSS knows mobile now resident in visited network
- BS and mobile select parameters for BS-mobile data-plane radio channel

link between BS and device

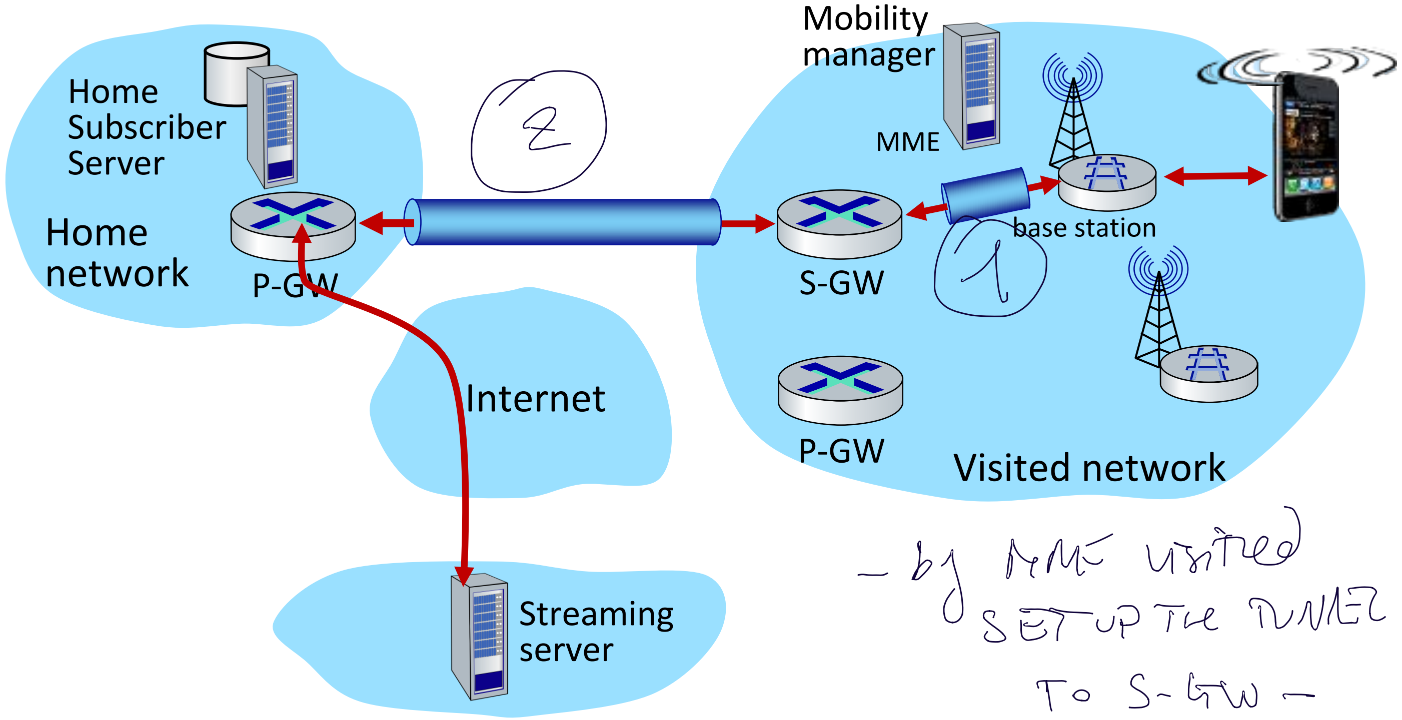
set ⇒ utilize routing: path that dev. home connection to packet gateway on its from rei

3. Configuring data-plane tunnels for mobile

- The MME configures the data plane for the mobile device
- all traffic to/from the mobile device will be tunneled through the device's home network
- Two tunnels established
  1. S-GW to BS tunnel

     when mobile changes base stations, simply change endpoint IP address of tunnel
  2. S-GW to home P-GW tunnel

     implementation of indirect routing



- by MME visited SET UP THE TUNNEL To S-GW - P-GW

(video) ⇒ send packet To HOME NET and FORWARDED

- tunneling via GTP (GPRS tunneling protocol): mobile's datagram to streaming server encapsulated using GTP

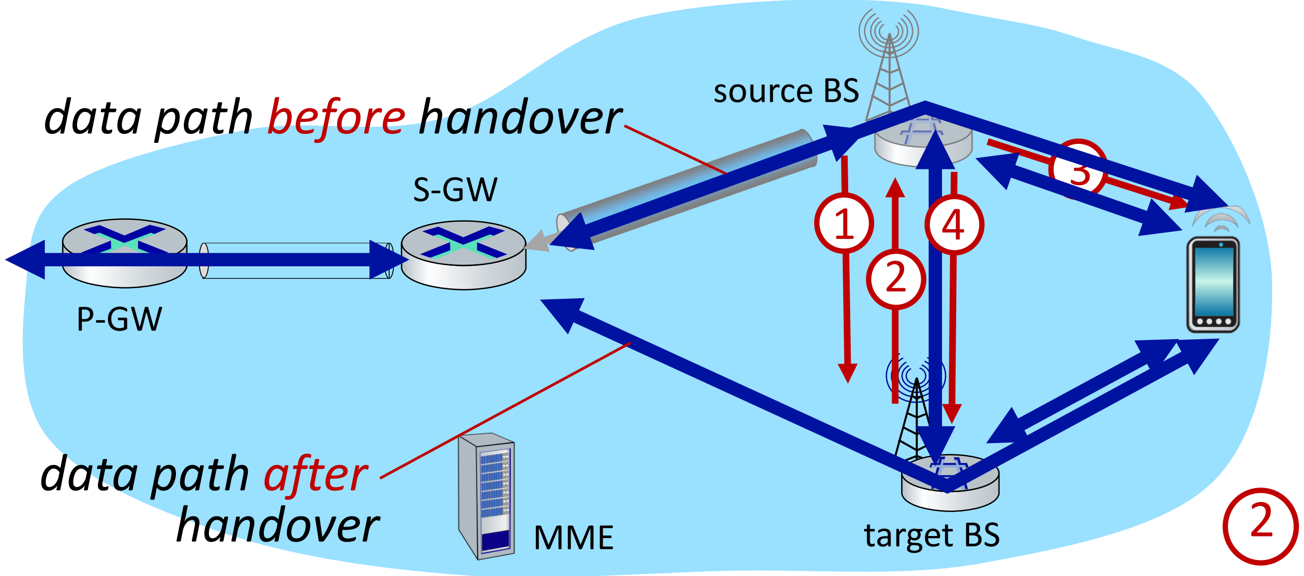
ID of tunnel

~~Port~~: - ext header

- encapsulate packet with different source/address IP

4. Handover between BSs in same cellular network

- change termination point of tunnel



1. current (source) BS chooses to select a handover whose handling device

   (e.g. due to cell overloading, signal deterioration between mobile and BS)

   selects target BS, sends *Handover Request message* to target BS
   To inform to handle mobile device

   BS periodically monitors quality => if change to another BS (like signal strength)

2. target BS pre-allocates radio time slots, responds with HR ACK with info for mobile
   ack reply

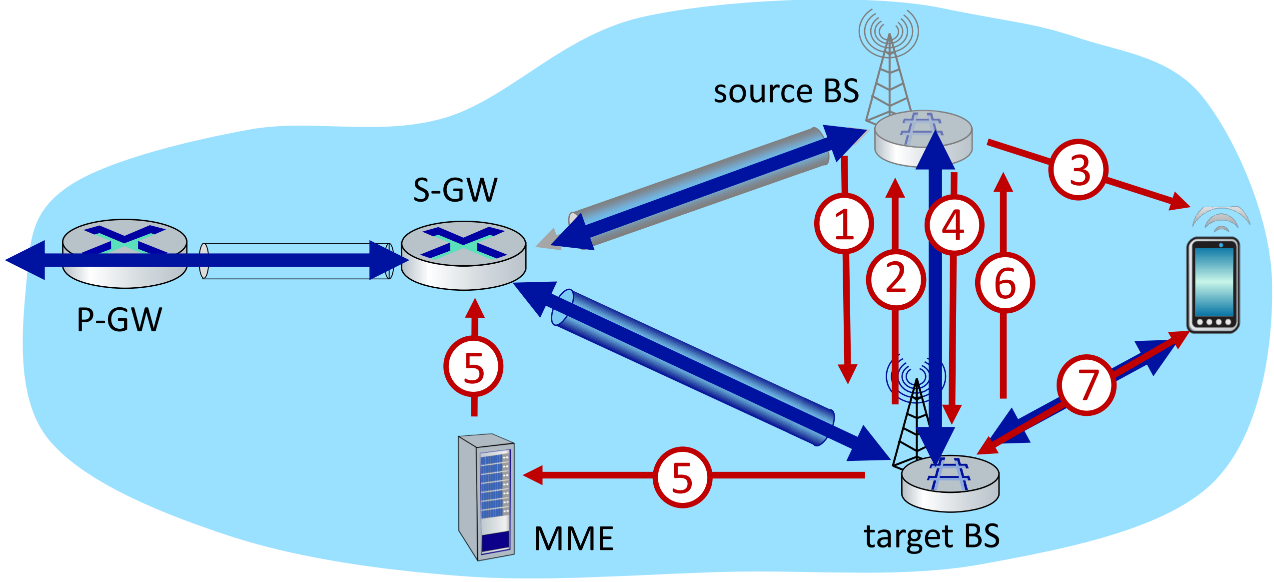
=> have to choose best BS for device

3. source BS informs mobile of new BS To change radio link
   - mobile can now send via new BS - handover *looks* complete to mobile

mobile communicate with target BS => don't have the tunnel

4. source BS stops sending datagrams to mobile, instead forwards to new BS (who forwards to mobile over radio channel) • For a while, tunnel not configured => packet arrived ~~sent~~ TMA to 2 BS

4. Handover between BSs in same cellular network



MME change TUNNEL config

⑤ target BS informs MME that it is new BS for mobile

- MME instructs S-GW to change tunnel endpoint to be (new) target BS

⑥ target BS ACKs back to source BS: handover complete, source BS can release resources source BS forward just remaining packet

⑦ mobile's datagrams now flow through new tunnel from target BS to S-GW another approach to handle mobility: with internet

Mobile IP

to handling address device when move

- mobile IP architecture standardized ~20 years ago [RFC 5944]
  - long before ubiquitous smartphones, 4G support for Internet protocols
  - did not see wide deployment/use
  - perhaps WiFi for Internet, and 2G/3G phones for voice were "good enough" at the time
- mobile IP architecture: . also implementation to direct routing
  - indirect routing to node (via home network) using tunnels
  - mobile IP home agent: combined roles of 4G HSS and home P-GW
  - mobile IP foreign agent: combined roles of 4G MME and S-GW
  - protocols for agent discovery in visited network, registration of visited location in home network via ICMP extensions

Wireless, mobility: impact on higher layer protocols

may loose some packets supporting mobility

=> TCP/UDP can run seamlessly over Network

=> ≠ performance

- UDP doesn't care losses
- TCP performance change with packet lost

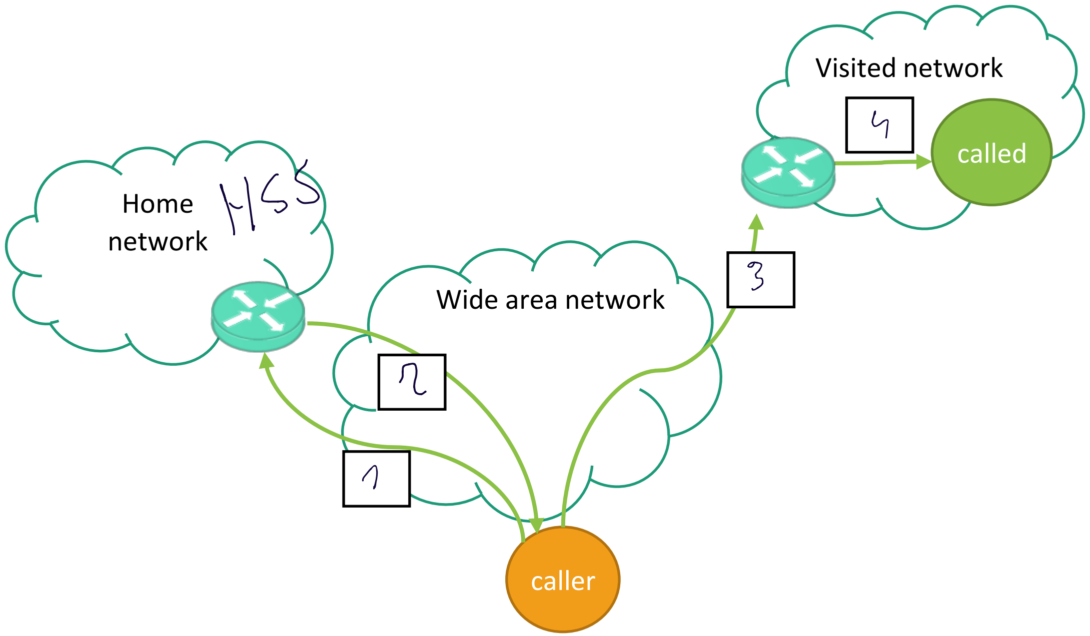
- logically, impact *should* be minimal …
  - best effort service model remains unchanged
  - TCP and UDP can (and do) run over wireless, mobile
- … but performance-wise:
  - packet loss/delay due to bit-errors (discarded packets, delays for link-layer retransmissions), and handover loss
  - TCP interprets loss as congestion, will decrease congestion window un-necessarily (side effect of handling mobility)
  - delay impairments for real-time traffic
  - bandwidth a scare resource for wireless links

Quiz

1. When a mobile device is handed over from one base station to another in a 4G/5G network, which network element makes the decision to initiate that handover? BS
2. Which network element chooses the target base station to which the mobile device will be handed over? Source BS

Question

Considering the following picture which represents the interactions (with arrows) necessary to set up a communication between two terminals with **direct routing**, number the arrows in order of time of occurrence and explain, for each interaction (arrow), what is its purpose.



References

Title: 5G Mobile Networks: A Systems Approach

Authors: Larry Peterson and Oguz Sunay

Source: https://github.com/SystemsApproach/5G