



Advanced Network Security

Lecture 7: Introduction to Mobile Networks

Harald Vranken, Katharina Kohls

April 12th, 2021

Open University Nijmegen

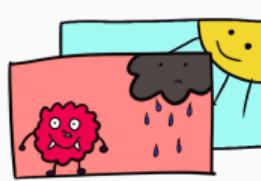
Radboud University Nijmegen

Ubiquity of Mobile Devices



Calling

Ubiquity of Mobile Devices



Media



Calling

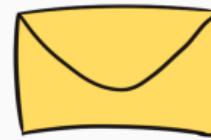
Ubiquity of Mobile Devices



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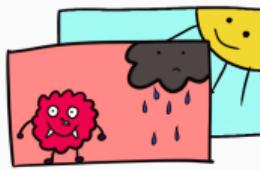


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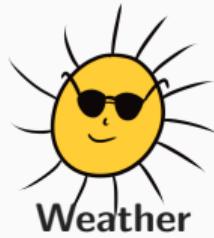


Texting

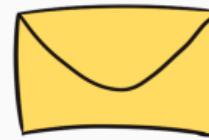
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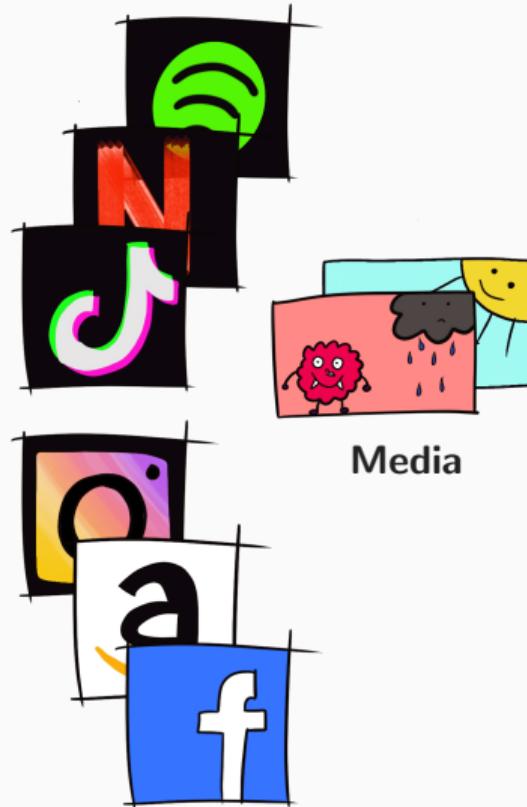
Gaming

...

Shopping

...

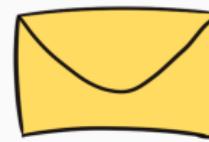
Assistants



Media

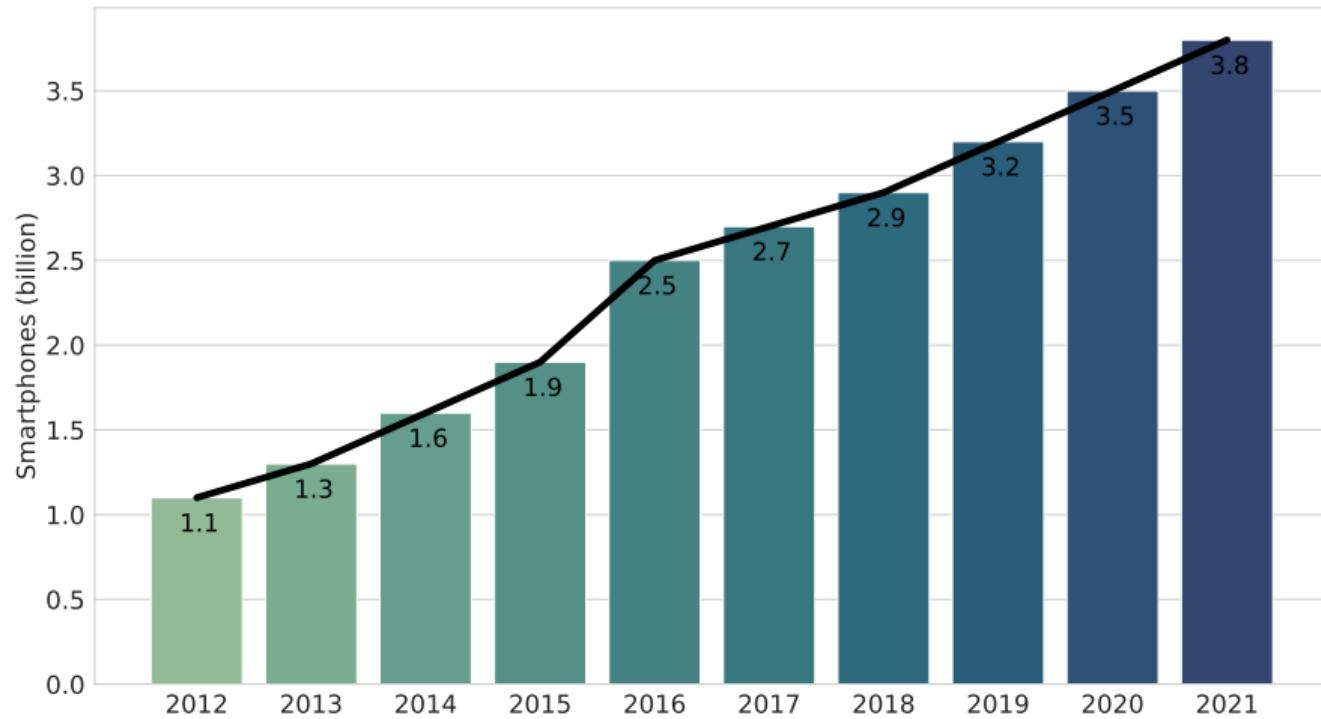


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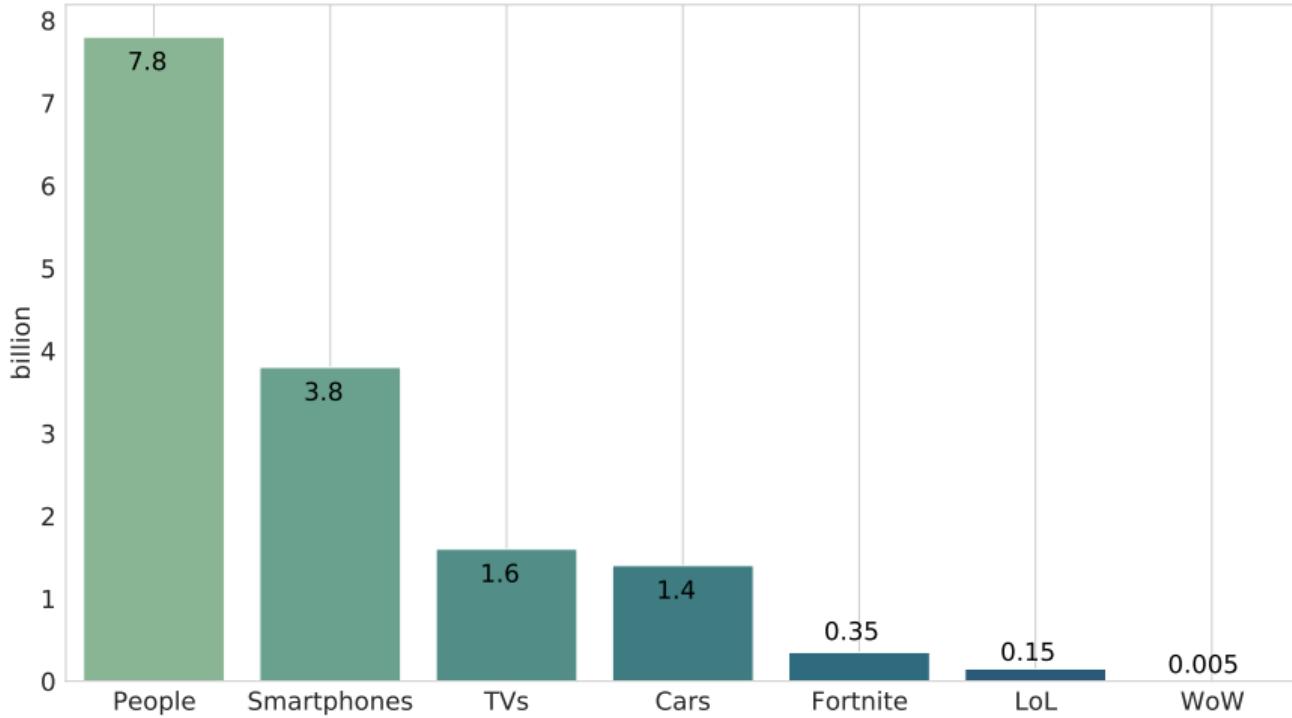


Texting

How present are smartphones?



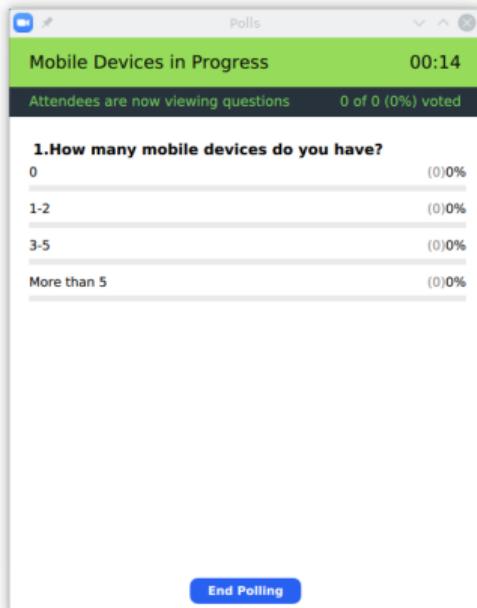
Let's put this into reference!



It's not only about smartphones!

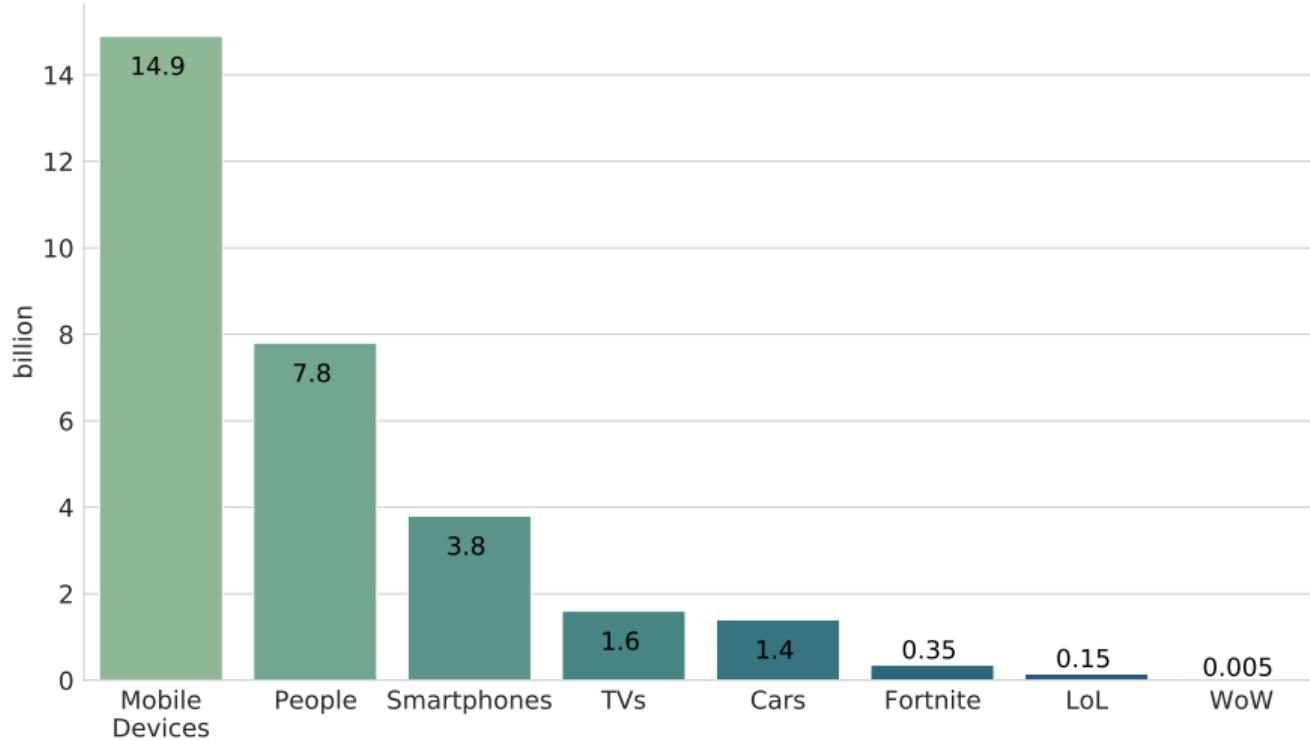


Personal Devices



**How many mobile
devices do you have?**

Let's get the real reference now!



- ▶ Critical infrastructures and emergency
 - Food and water
 - Public health
 - Transportation systems
 - Security services

Only casual?

- ▶ Critical infrastructures and emergency
 - Food and water
 - Public health
 - Transportation systems
 - Security services
- ▶ Industrial contexts
 - Sensors
 - Machines
 - Complex and automated systems



Mobile Devices

- ▶ There are tons of mobile devices
- ▶ Many of them use the cellular network
- ▶ Familiar for us: Casual use cases
- ▶ Not so familiar: Emerging use of mobile networks everywhere else

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Our Focus

- ▶ We focus on the **security** of mobile networks
- ▶ Specific attacks and the required technical background

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Look out for red slides! They provide a quick summary of a topic block and questions to test your knowledge.

Content of Course Part II

Updated content overview:

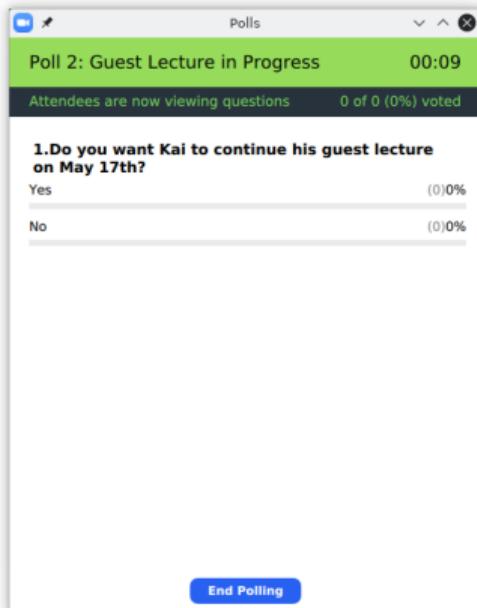
7	Mobile Networks	Introduction to Mobile Networks	April 12th
8	Attacks	Layer-2 Attacks and Requirements	April 19th
9	Impersonation Attack	Full Impersonation	April 26th
10	ReVoLTE Attack	Decrypting phone calls	May 10th
11	4G and 5G	Outlook on 5G	May 17th
12	Wrapup	Rushing through the course	May 31st

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*Option: Invite Kai again and let him continue the lecture on the OpenSky Network.
This would happen in Lecture 11 (4G and 5G).*



**Another guest lecture
on May 17th?**

Mobile Network Basics

Introducing (General) Security

Mobile (Security) Evolution

Slides 34–38 are not relevant for the exam

Mobile Security Goals

Summary

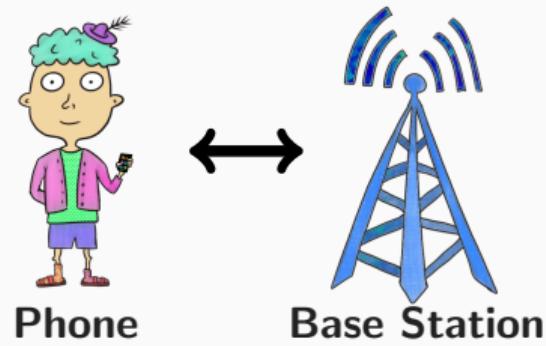
Mobile Network Basics

Basic Network

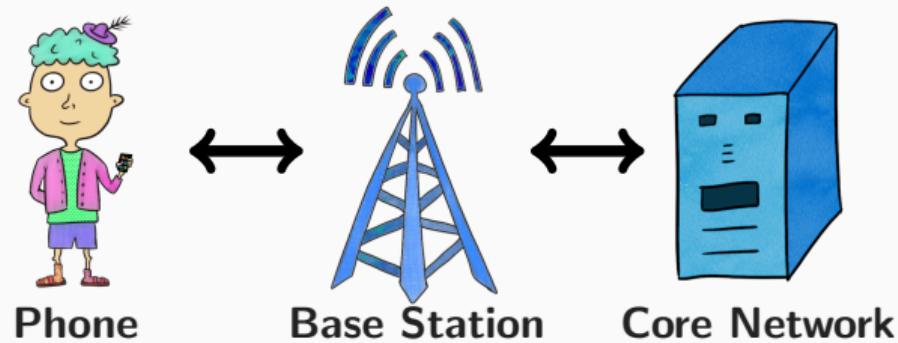


Phone

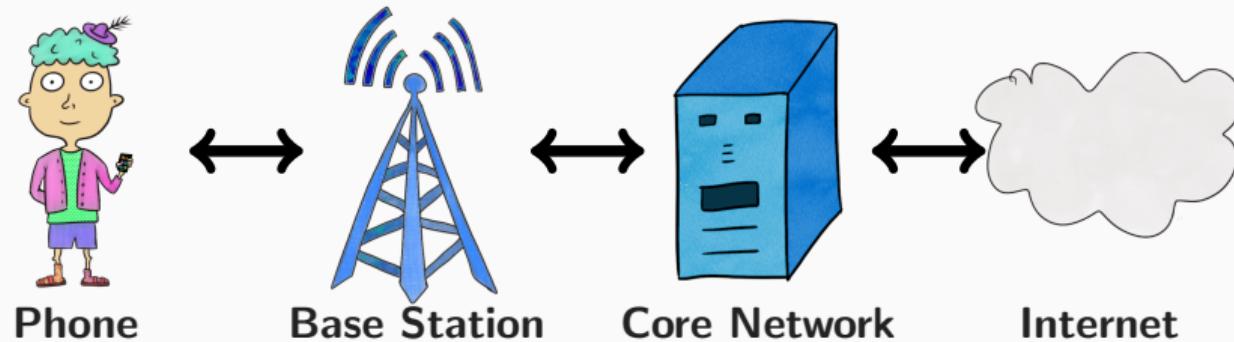
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Basic Network

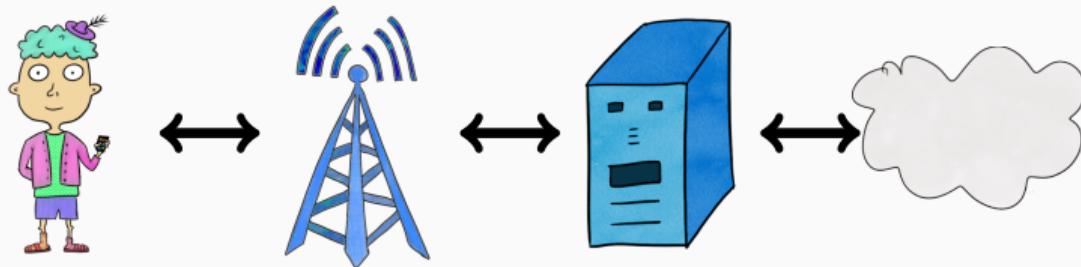


Generic Components

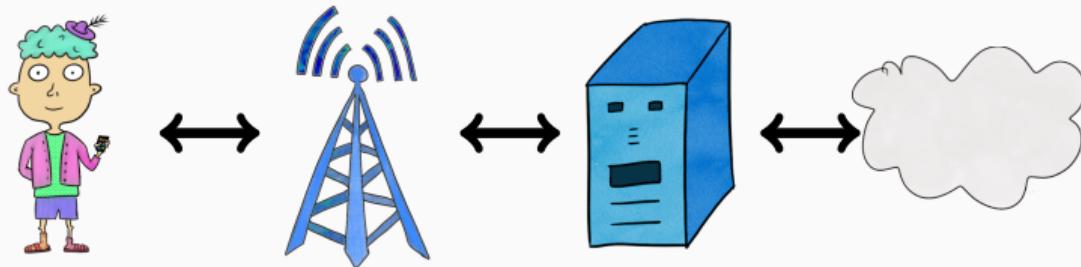
- ▶ **Phone:** Connects to the network
- ▶ **Base Station:** Provides the *radio connection*
- ▶ **Core Network:** Provides the main management
- ▶ **Internet:** Where you want to go

Component	Icon
Phone	
Base Station	
Core Network	
Internet	

LTE Network

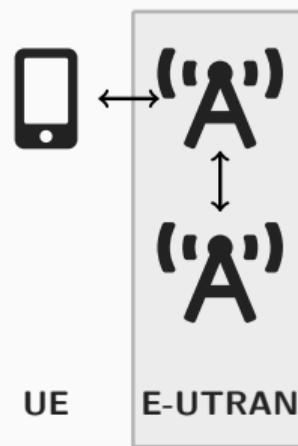
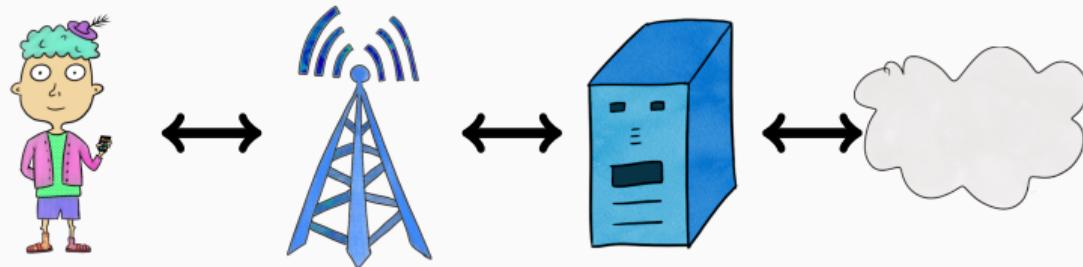


LTE Network

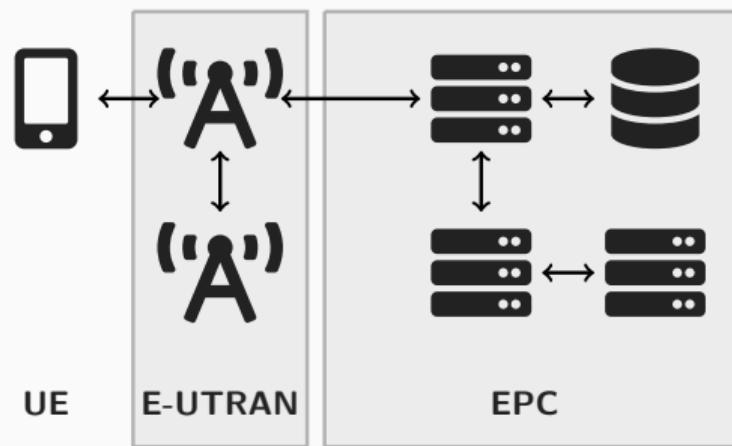
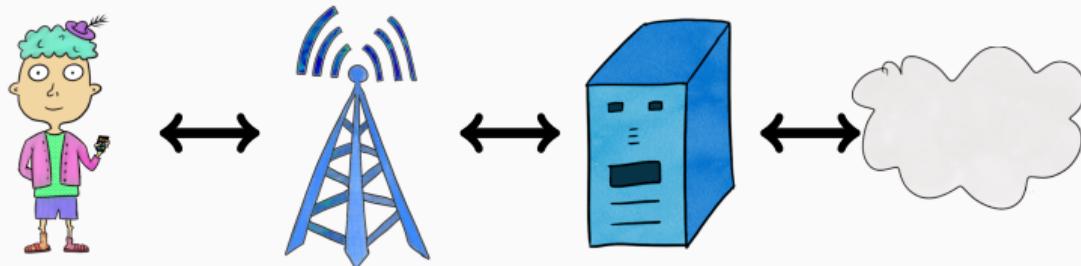


UE

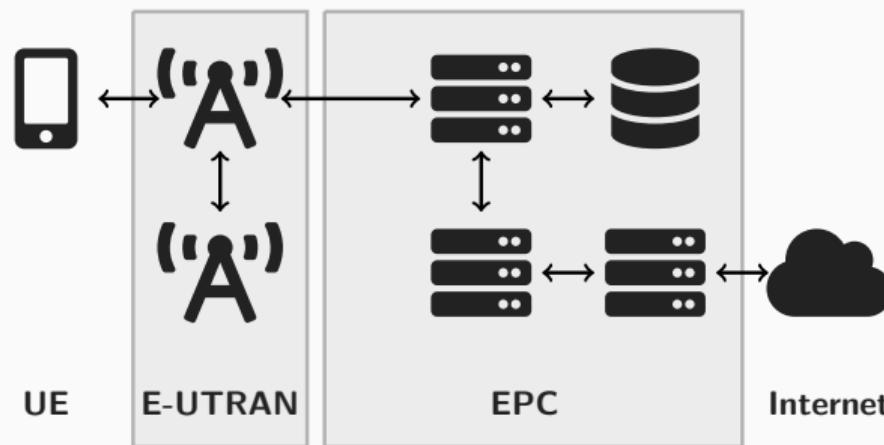
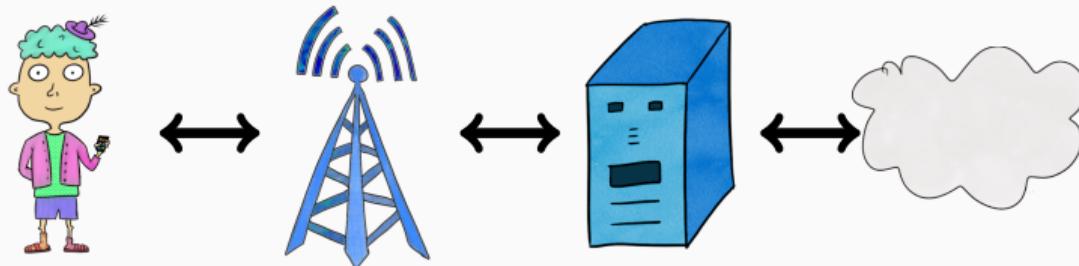
LTE Network



LTE Network



LTE Network



LTE Components

Component	LTE Acronym	LTE Component	Icon
Phone	UE	User Equipment	
Base Station	eNodeB	Evolved Node B	
Core Network	EPC	Evolved Packet Core	
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Focusing on the wireless connection:

- We focus on the **air interface**  \leftrightarrow 

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Focusing on the wireless connection:

- We focus on the **air interface**  \leftrightarrow 
- Another term for this is **radio access network**
- In LTE, the radio access network is called **E-UTRAN**

Next Step?

So far, we looked at some very basic components of a mobile network
and how they are connected.

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and how they are connected.

**We now go into detail and take a look
at the LTE protocol stack.**

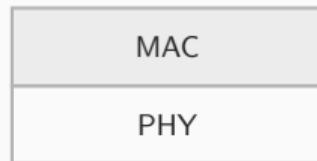
The next part is important 

LTE Protocol Stack

PHY

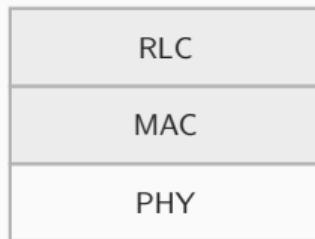
Get a better understanding: Compare this to the ISO/OSI or the TCP/IP stack

LTE Protocol Stack



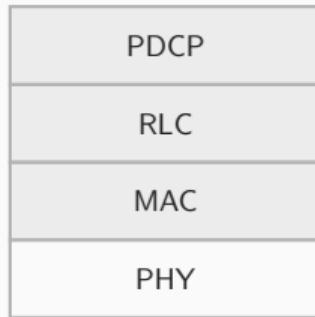
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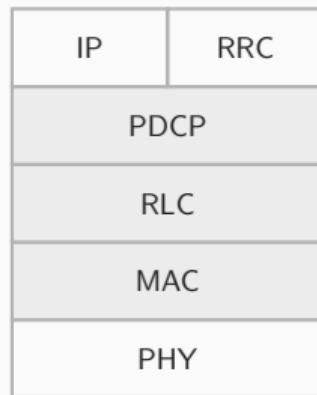
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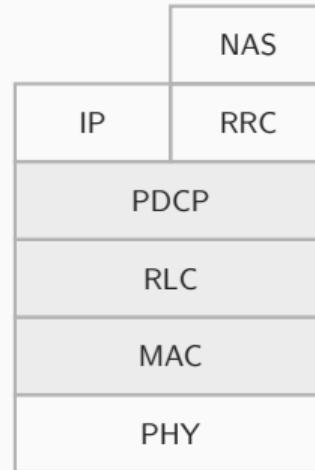
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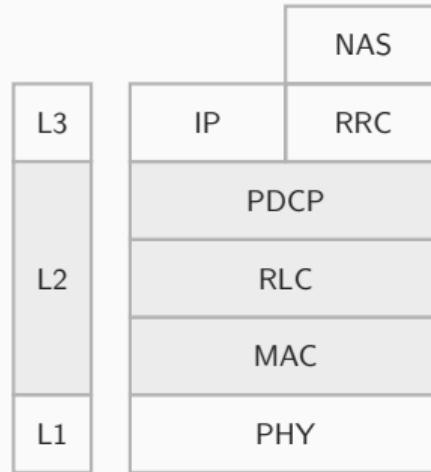
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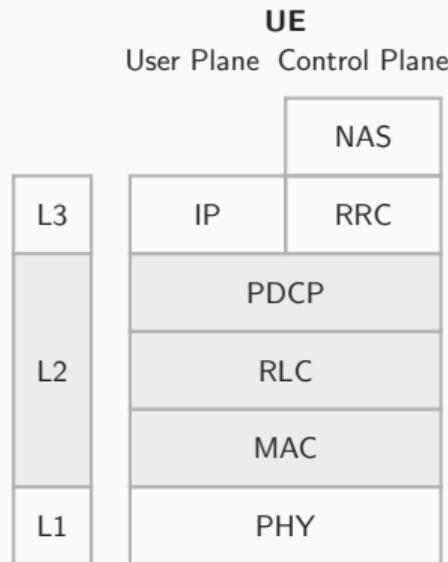
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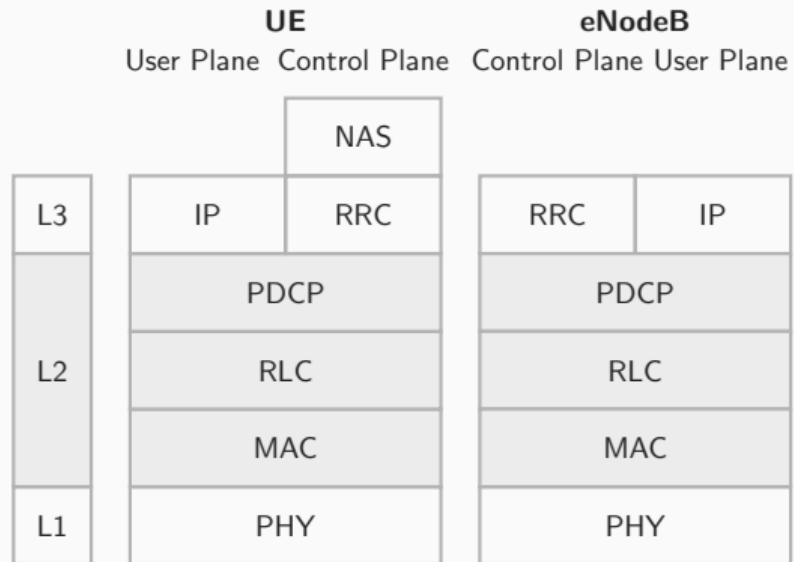
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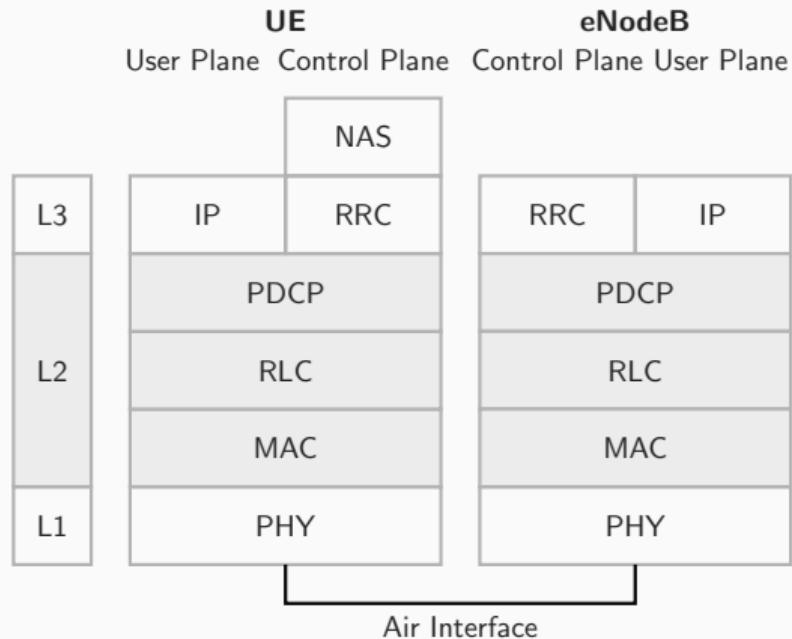
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LTE Protocol Stack Layers

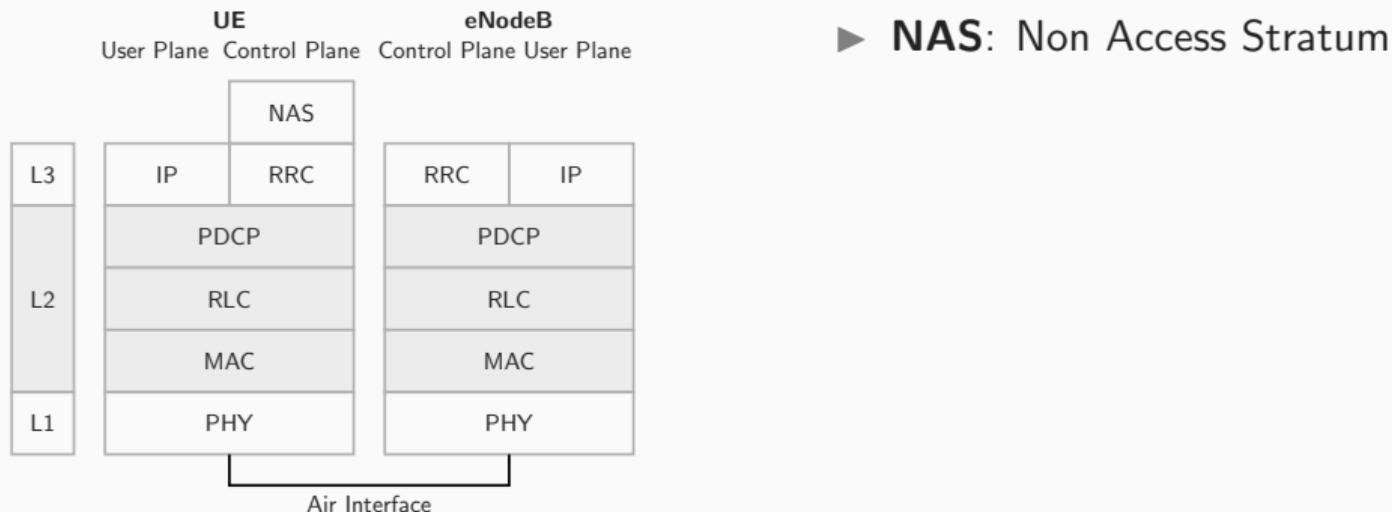
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LTE Protocol Stack Layers

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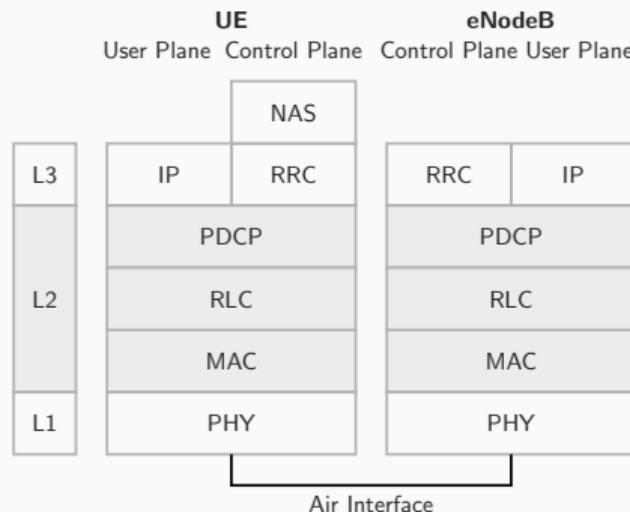
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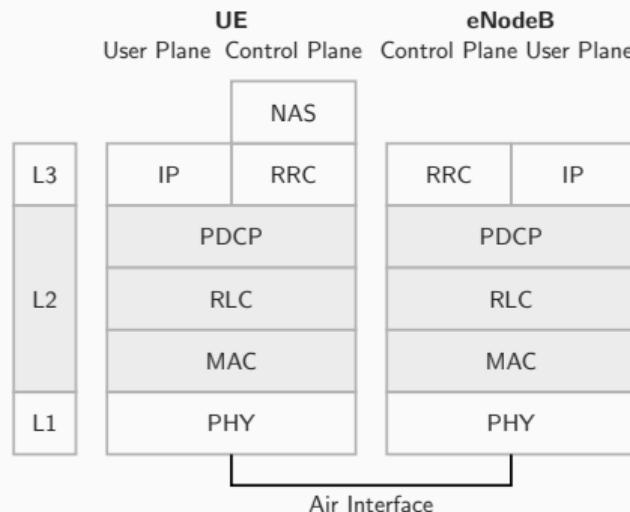
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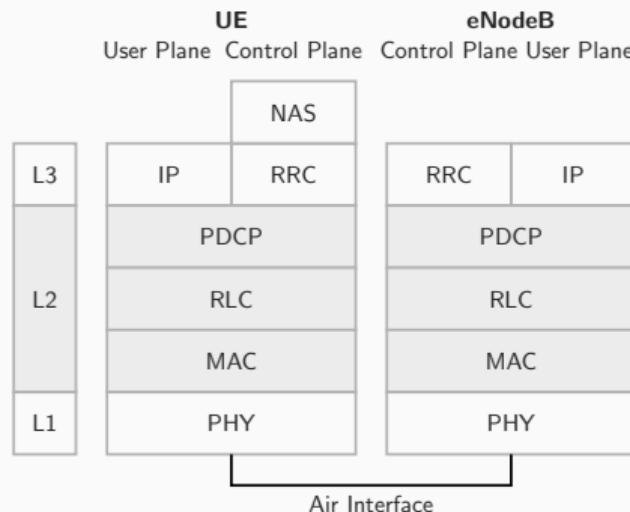
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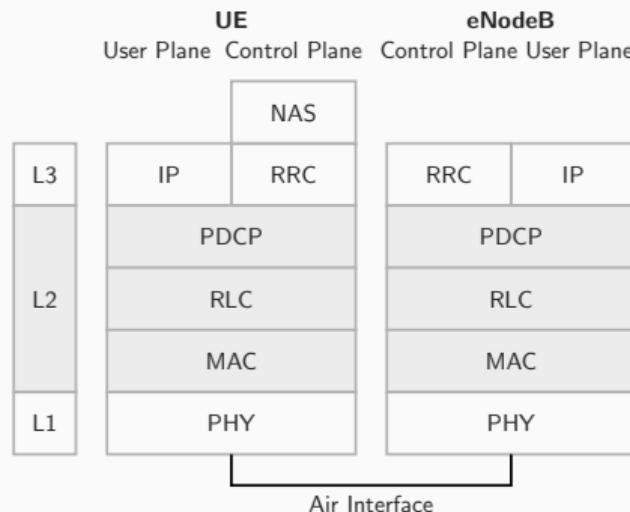
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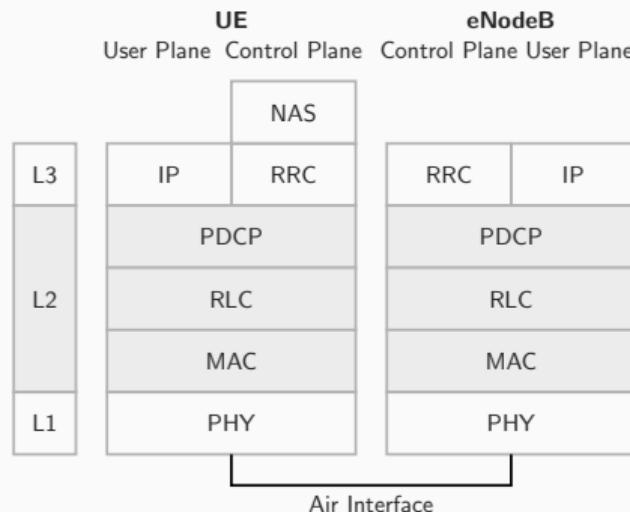
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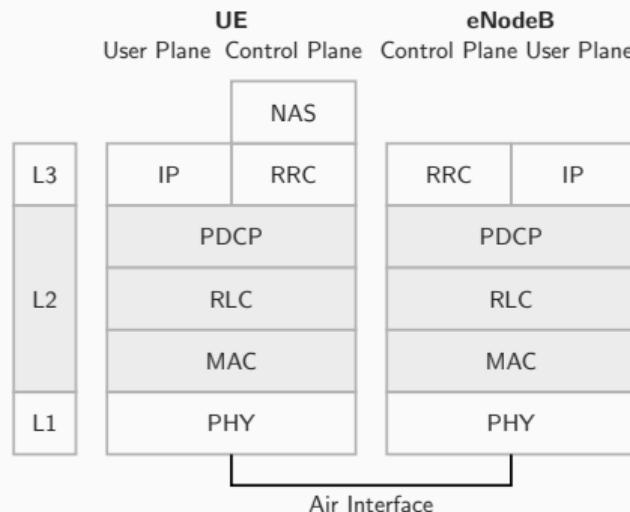
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- ▶ **MAC:** Medium Access Control
- ▶ **PHY:** Physical Layer

- ▶ **NAS:** Connects the UE *inside* the E-UTRAN with MME *outside* the E-UTRAN.
Authentication of UE, security control, paging.

Stack Layers Explained

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Stack Layers Explained

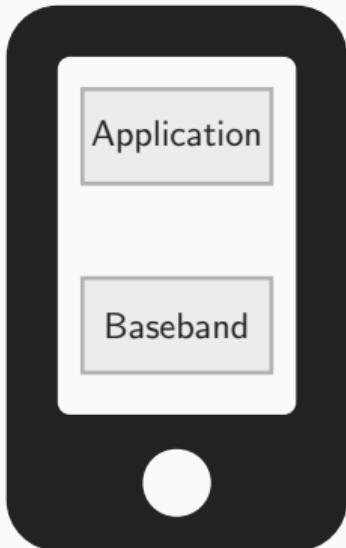
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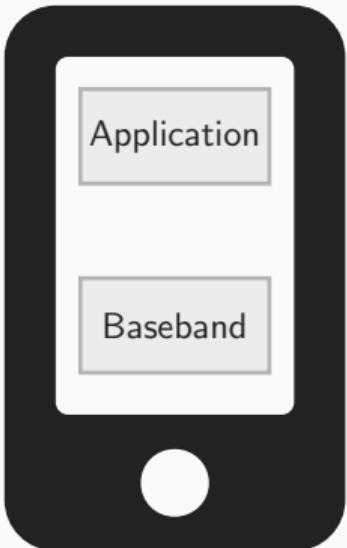
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- ▶ **PHY**: Transport data over the air interface.



Application Processor

- ▶ The OS implements the network stack
- ▶ Standard Ethernet connection like WiFi



Application Processor

- ▶ The OS implements the network stack
- ▶ Standard Ethernet connection like WiFi

Baseband Processor

- ▶ The Baseband implements the modem
- ▶ Mobile data connection

Website request:

- ▶ Browser sends request
- ▶ Goes down the network stack
- ▶ Data link and physical layer are *Ethernet*-specific

Application Processor



Baseband Processor → 'A'

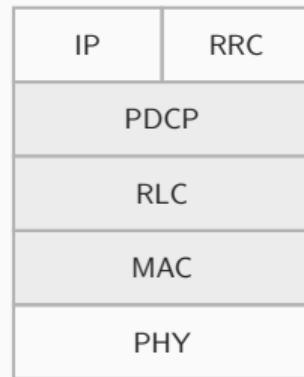
Baseband receives IP packet:

- ▶ Encapsulate in LTE-specific PDCP
- ▶ Hand down further
- ▶ Transmit via *air interface*

Application Processor

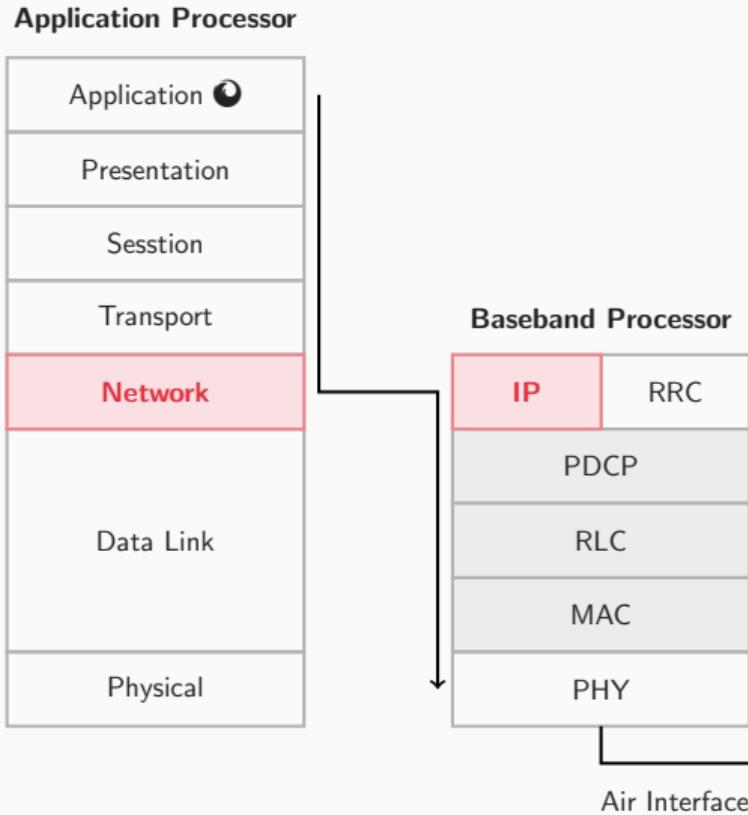


Baseband Processor



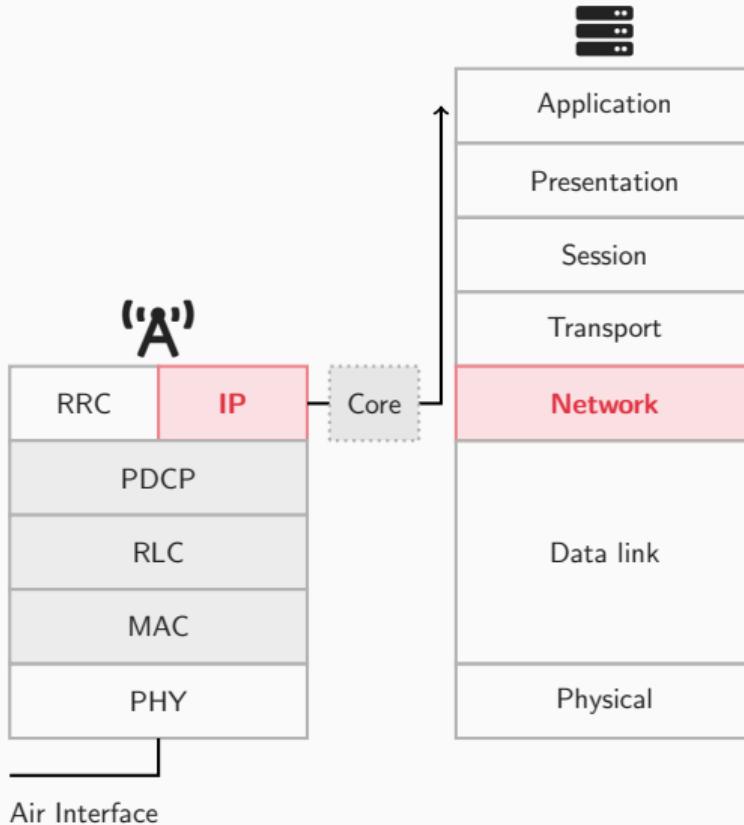
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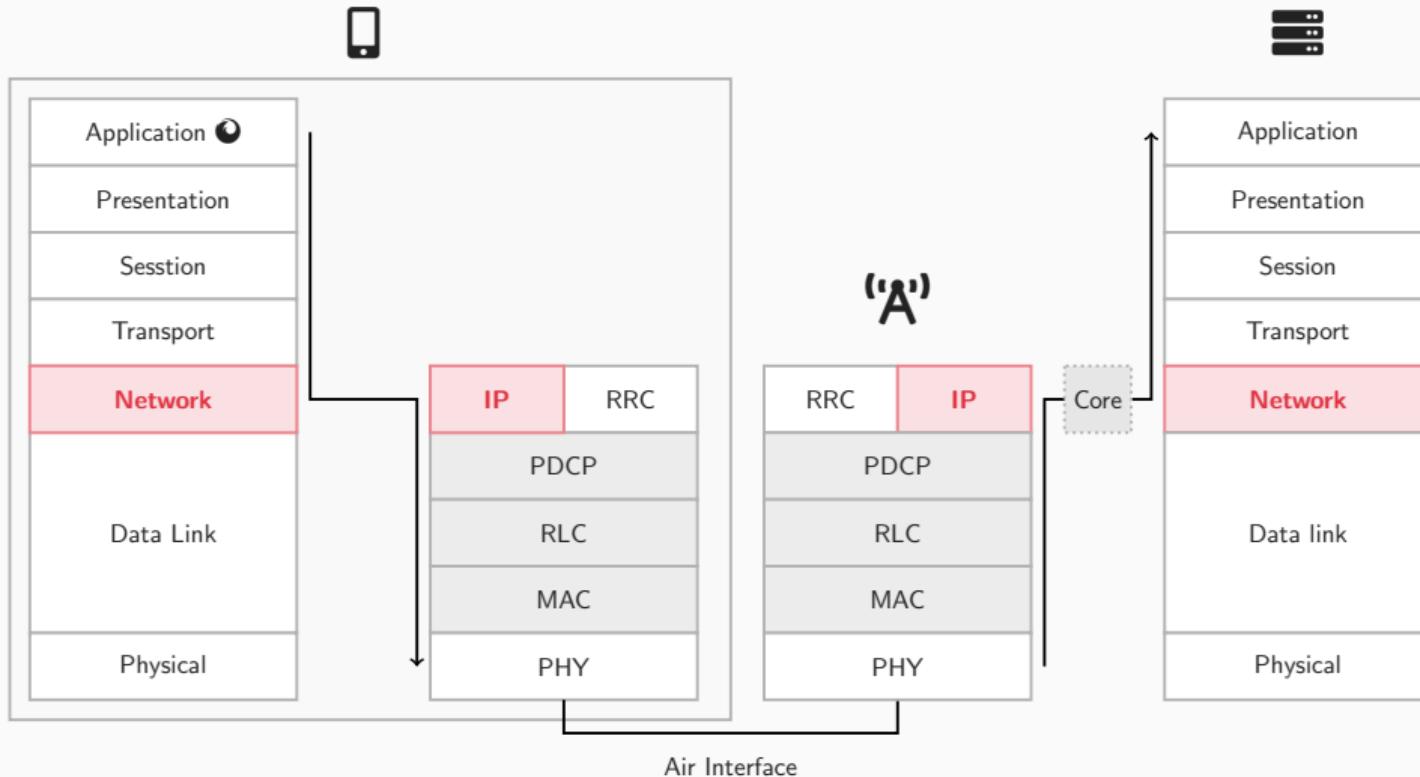


Website Request

- ▶ The eNodeB connects to the core network
- ▶ From there the requests reaches the internet
- ▶ The LTE stack represents the “Data link layer”



Combining Stacks → →



Combined Stacks (in words)

(1) Application Processor

- Browser prepares website request
- Go down the stack
- On the network layer, *Baseband* takes over

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(3) Base Station

- Receive request
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- Process packets
- Hand over to Internet

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- Hand down, send via air interface

(3) Base Station

- Receive request
- Hand up the stack

(4) Core Network

- Process packets
- Hand over to Internet

(5) Internet stack takes over again

- Go up the stack
- Server receives request

Network Setup

- ▶ A generic network consists of UE \leftrightarrow eNodeB \leftrightarrow EPC
- ▶ We focus on the air interface E-UTRAN
- ▶ LTE has its own mobile stack, comparable to the data link layer

Next Steps

- ▶ General security goals
- ▶ Security in mobile networks

Exam Preparation

- ▶ You get a cheat sheet with all acronyms.
- ▶ This only helps if you have an idea of what things do.
- ▶ If there are things you *do not* need for the exam, I'll mark them.

Example Questions (test your knowledge, no guarantees)

- ▶ What does the application processor do? What does the baseband processor do?
What is the main difference between both?
- ▶ Sketch the communication between entities when you want to fetch a website
with your phone and mobile data plan (ignore the stack for a moment).
- ▶ What is the air interface?
- ▶ Name all four layer-2 protocols of the LTE stack.

Introducing (General) Security

General Security Goals

Confidentiality

General Security Goals

Confidentiality

Privacy

General Security Goals

Confidentiality

Privacy

Integrity

General Security Goals

Confidentiality

Privacy

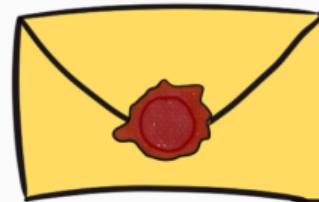
Integrity

Availability

Only authorized access allowed:

Only authorized access allowed:

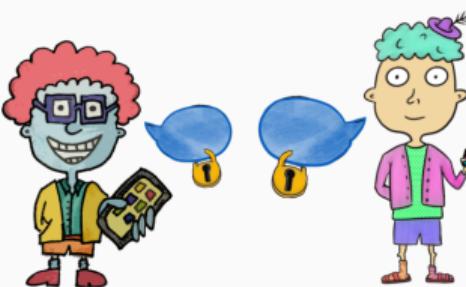
- ▶ Protect content from unwanted access
- ▶ Involve only intended communication partners



The provider knows this, but an attacker must not:

The provider knows this, but an attacker must not:

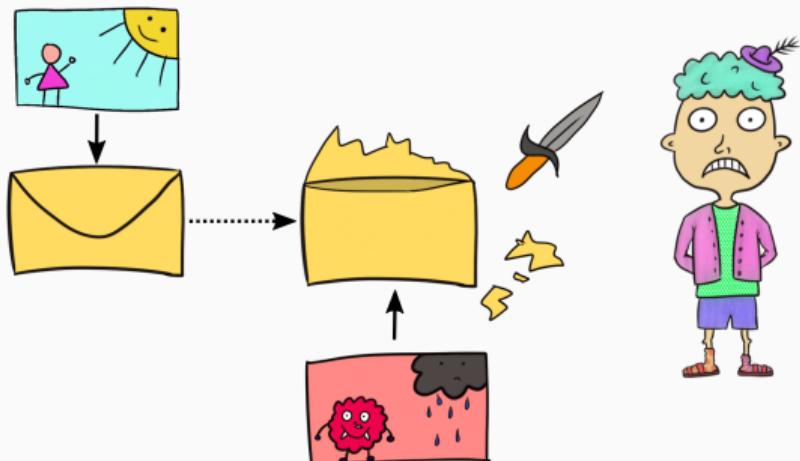
- ▶ Your geographical location
- ▶ Your temporary or even permanent identity



Nobody fiddled with the data:

Nobody fiddled with the data:

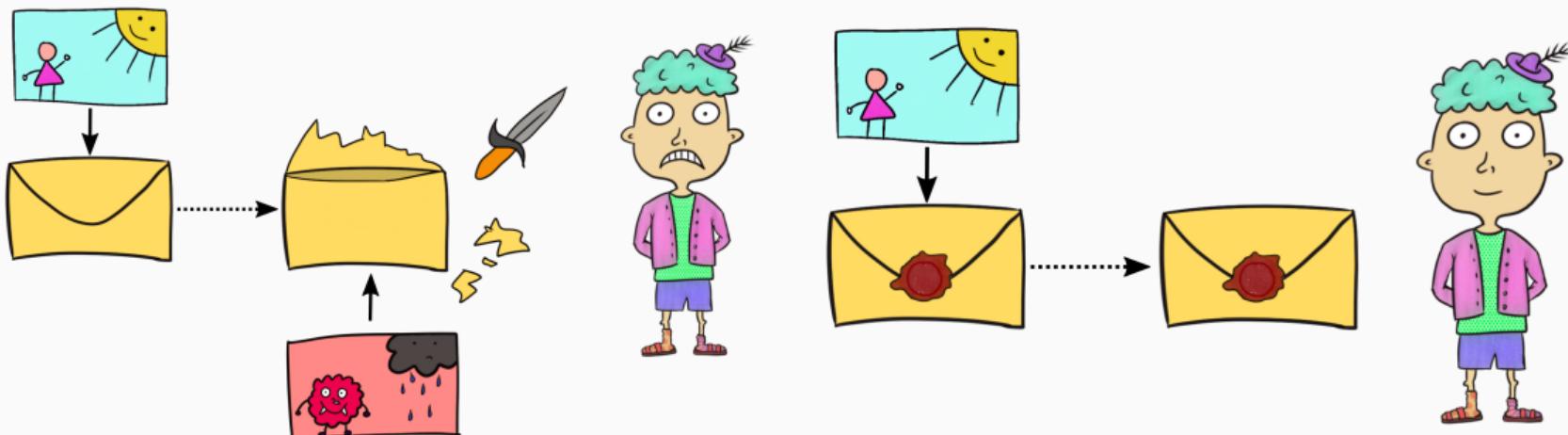
- ▶ Original message arrives at the recipient
- ▶ Not changed along the way



Data Integrity

Nobody fiddled with the data:

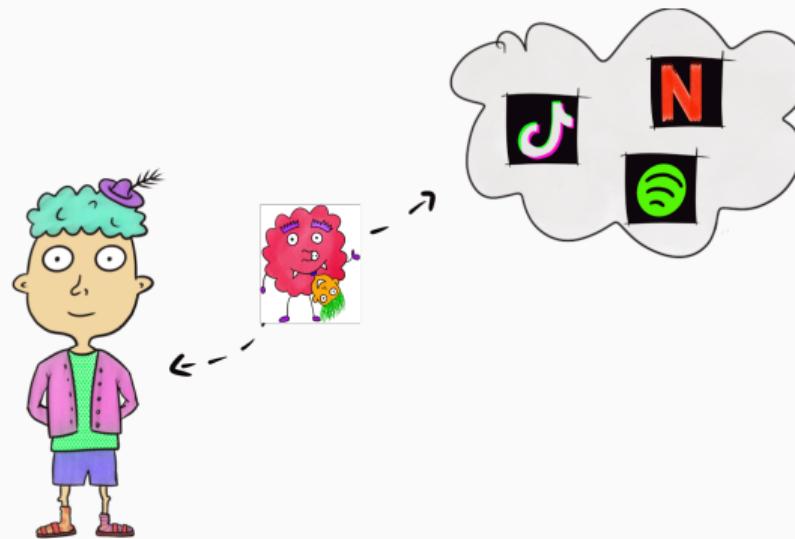
- ▶ Original message arrives at the recipient
- ▶ Not changed along the way



Being able to reach a service:

Being able to reach a service:

- ▶ Service is up and functioning
- ▶ You can reach it when needed



CIA + P

- ▶ Confidentiality, Integrity, Availability, Privacy
- ▶ These are *general* security goals
- ▶ We'll later see what this means in the context of LTE

Exam Examples

- ▶ Remember CIA + P and what this is about
- ▶ More important: Understand this in the context of LTE!

Mobile (Security) Evolution

Slides 34–38 are not relevant for the exam

Mobile Generations

90's

00's

10's

20's

Mobile Generations

2G →

90's

00's

10's

20's

Mobile Generations

3G —————→

2G —————→

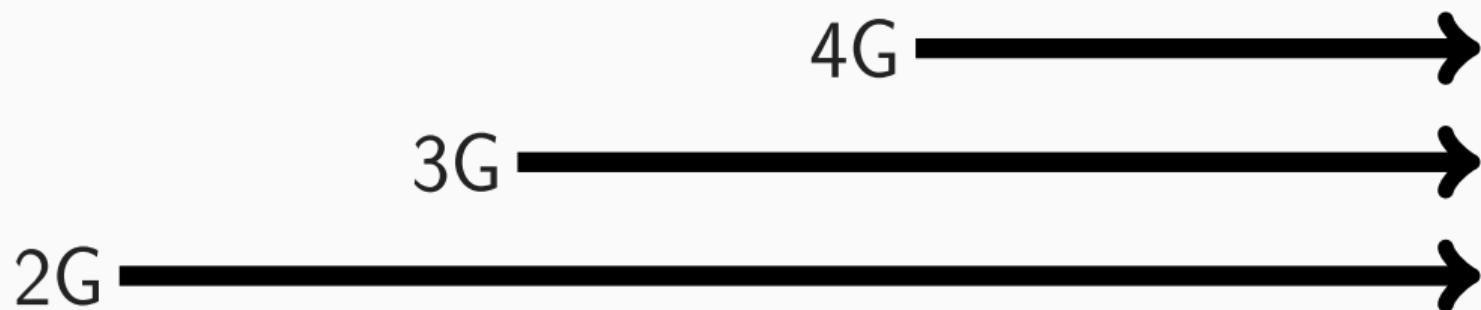
90's

00's

10's

20's

Mobile Generations



90's

00's

10's

20's

Mobile Generations



90's

00's

10's

20's

2G Vulnerabilities

90's

00's

10's

20's

2G



2G Vulnerabilities

90's

00's

10's

20's

2G



- ▶ Weak crypto Voice & data A5/1 GEA1

90's

00's

10's

20's

2G



- ▶ Weak crypto Voice & data A5/1 GEA1
- ▶ Export ciphers GEA1 A5/2 40bit

90's

00's

10's

20's

2G



- ▶ Weak crypto Voice & data A5/1 GEA1
- ▶ Export ciphers GEA1 A5/2 40bit
- ▶ Missing network authentication

90's

00's

10's

20's

2G



- ▶ Weak crypto Voice & data A5/1 GEA1
- ▶ Export ciphers GEA1 A5/2 40bit
- ▶ Missing network authentication
- ▶ Inter-core network builds upon trust (SS7)

90's

00's

10's

20's

2G



- ▶ Weak crypto Voice & data A5/1 GEA1
- ▶ Export ciphers GEA1 A5/2 40bit
- ▶ Missing network authentication
- ▶ Inter-core network builds upon trust (SS7)
- ▶ Vulnerabilities exists until 2G disappears

90's

00's

10's

20's

2G

- ▶ Weak crypto Voice & data A5/1 GEA1
- ▶ Export ciphers GEA1 A5/2 40bit
- ▶ Missing network authentication
- ▶ Inter-core network builds upon trust (SS7)
- ▶ Vulnerabilities exists until 2G disappears

Conclusion

2G/GSM is completely broken!

90's

00's

10's

20's

3G



90's

00's

10's

20's

3G



- ▶ Improved ciphers for voice and data

90's

00's

10's

20's

3G



- ▶ Improved ciphers for voice and data
- ▶ Same GSM (SS7) inter-core network

90's

00's

10's

20's

3G



- ▶ Improved ciphers for voice and data
- ▶ Same GSM (SS7) inter-core network
- ▶ IMSI catchers and downgrade attacks

90's

00's

10's

20's

3G



- ▶ Improved ciphers for voice and data
- ▶ Same GSM (SS7) inter-core network
- ▶ IMSI catchers and downgrade attacks
- ▶ Less research on 3G

90's

00's

10's

20's

3G

- ▶ Improved ciphers for voice and data
- ▶ Same GSM (SS7) inter-core network
- ▶ IMSI catchers and downgrade attacks
- ▶ Less research on 3G

Conclusion

3G is still
vulnerable to
certain attacks

90's

00's

10's

20's



90's

00's

10's

20's



- ▶ Improved ciphers for voice and data

90's

00's

10's

20's



- ▶ Improved ciphers for voice and data
- ▶ New inter-core network (Diameter) but same attacks

90's

00's

10's

20's

4G 

- ▶ Improved ciphers for voice and data
- ▶ New inter-core network (Diameter) but same attacks
- ▶ IMSI catchers and downgrade attacks

90's

00's

10's

20's

4G 

- ▶ Improved ciphers for voice and data
- ▶ New inter-core network (Diameter) but same attacks
- ▶ IMSI catchers and downgrade attacks
- ▶ Missing user plane integrity protection

90's

00's

10's

20's

4G 

- ▶ Improved ciphers for voice and data
- ▶ New inter-core network (Diameter) but same attacks
- ▶ IMSI catchers and downgrade attacks
- ▶ Missing user plane integrity protection
- ▶ More sophisticated attacks & capabilities

90's

00's

10's

20's

4G

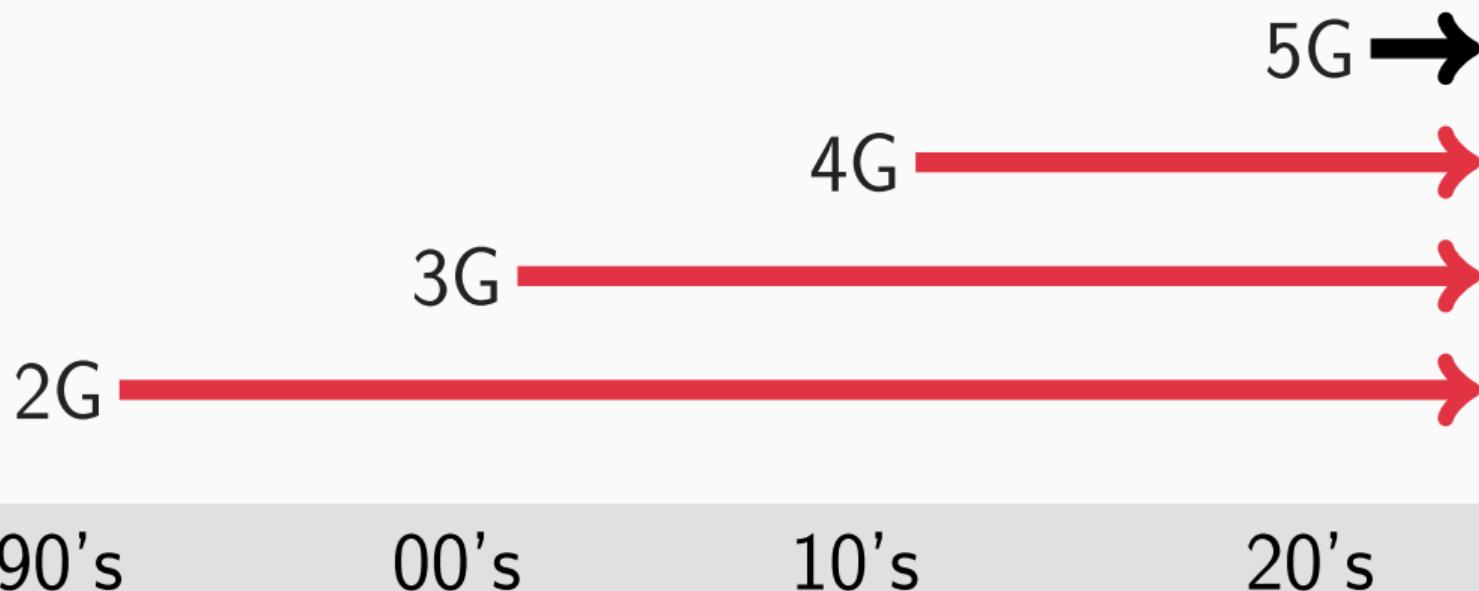


- ▶ Improved ciphers for voice and data
- ▶ New inter-core network (Diameter) but same attacks
- ▶ IMSI catchers and downgrade attacks
- ▶ Missing user plane integrity protection
- ▶ More sophisticated attacks & capabilities

Conclusion

4G improved security but not perfect

Inherited Weaknesses

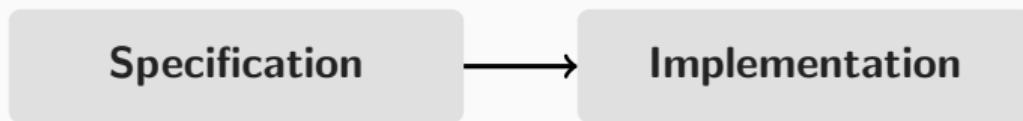


How is a new mobile generation being created?

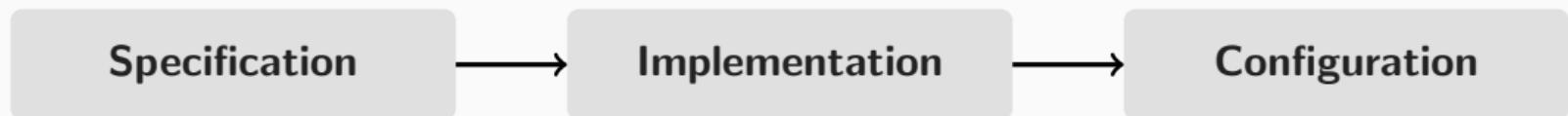
How is a new mobile generation being created?

Specification

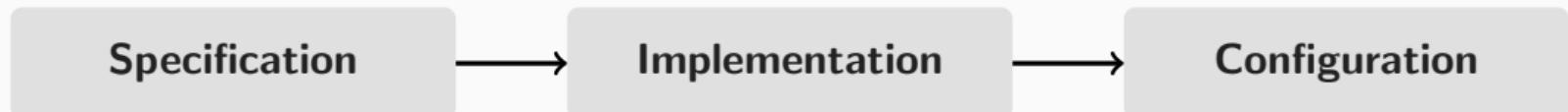
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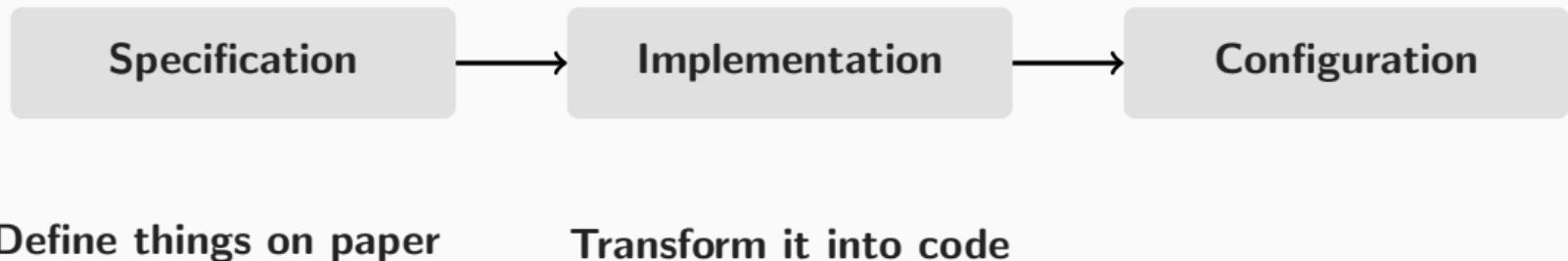


How is a new mobile generation being created?

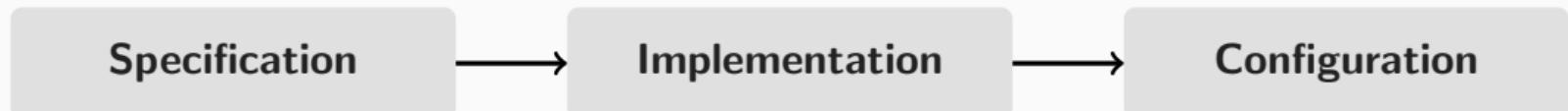


Define things on paper

How is a new mobile generation being created?



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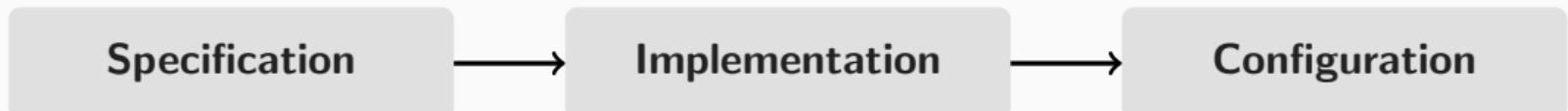


Define things on paper

Transform it into code

Fine-tune the live network

How is a new mobile generation being created?



Specification

Implementation

Configuration

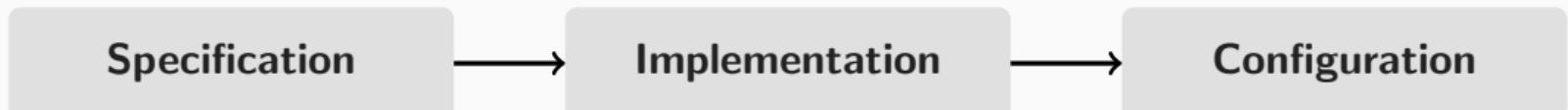
Define things on paper

Transform it into code

Fine-tune the live network

Things are flawed by
definition.

How is a new mobile generation being created?



Specification

Implementation

Configuration

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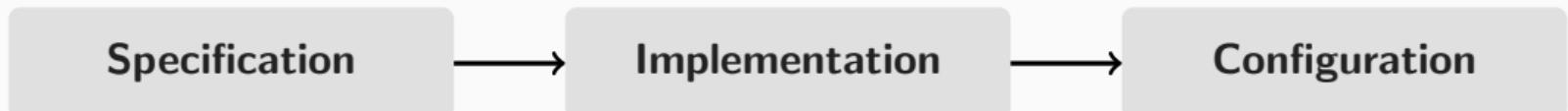
Transform it into code

Fine-tune the live network

Things are flawed by
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All devices with this
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How is a new mobile generation being created?



Specification

Implementation

Configuration

Define things on paper

Things are flawed by definition.

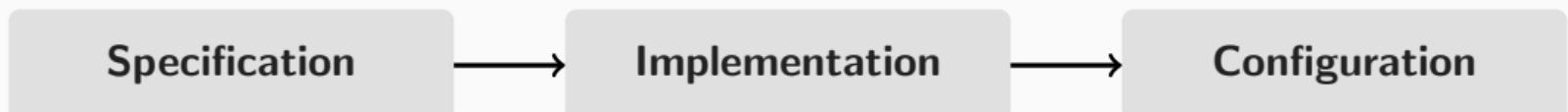
Transform it into code

All devices with this implementation are flawed.

Fine-tune the live network

Local network has a flawed configuration.

How is a new mobile generation being created?



Specification

Implementation

Configuration

Define things on paper

Transform it into code

Fine-tune the live network

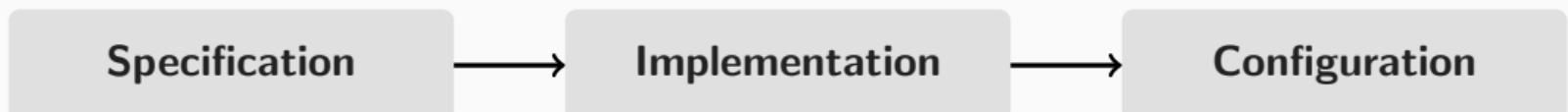
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Local network has a flawed
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Update specification ☺

How is a new mobile generation being created?



Specification

Implementation

Configuration

Define things on paper

Transform it into code

Fine-tune the live network

Things are flawed by definition.

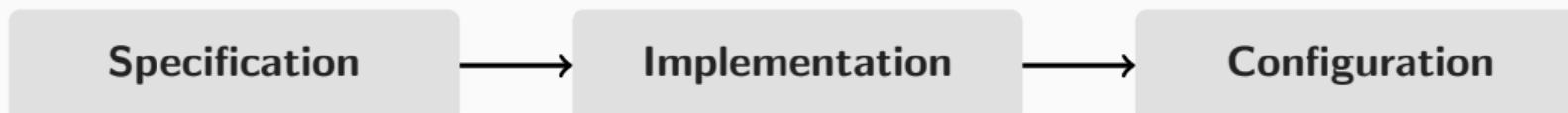
All devices with this implementation are flawed.

Local network has a flawed configuration.

Update specification ☺

Patch implementation 😞

How is a new mobile generation being created?



Specification

Implementation

Configuration

Define things on paper

Transform it into code

Fine-tune the live network

Things are flawed by definition.

All devices with this implementation are flawed.

Local network has a flawed configuration.

Update specification 😳

Patch implementation 😞

Patch configuration 😊

Who is responsible?

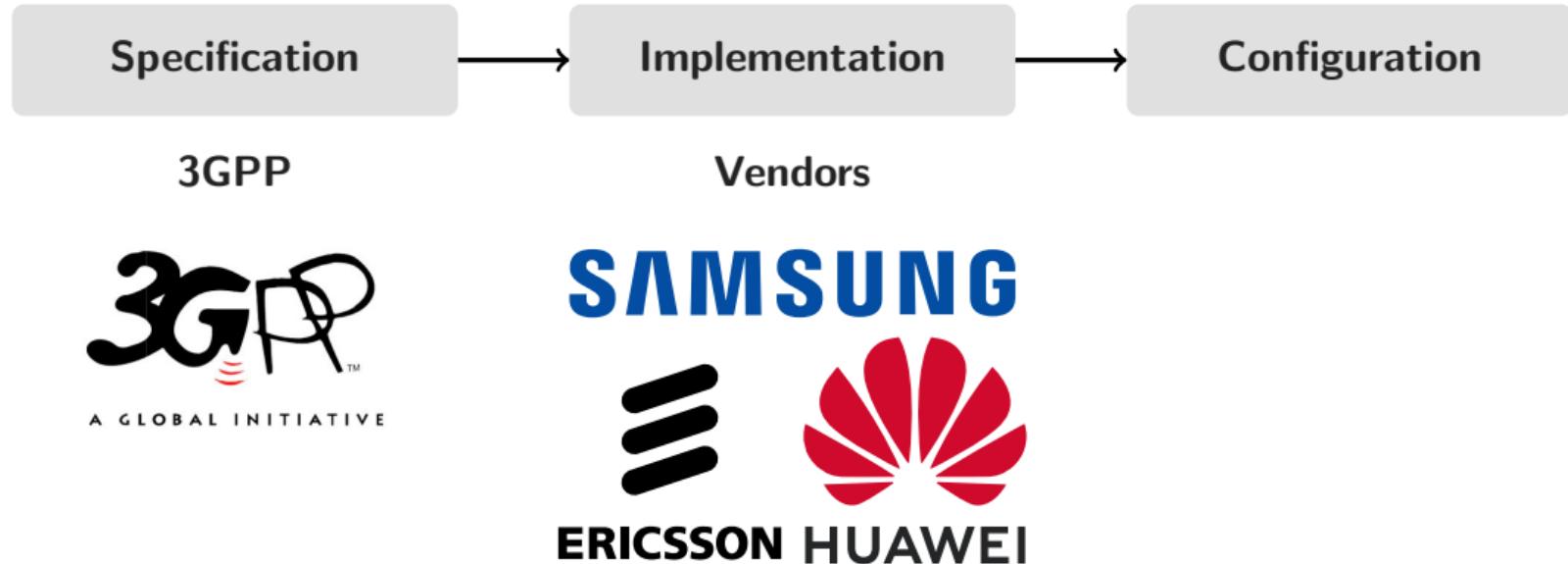
Specification → Implementation → Configuration

3GPP

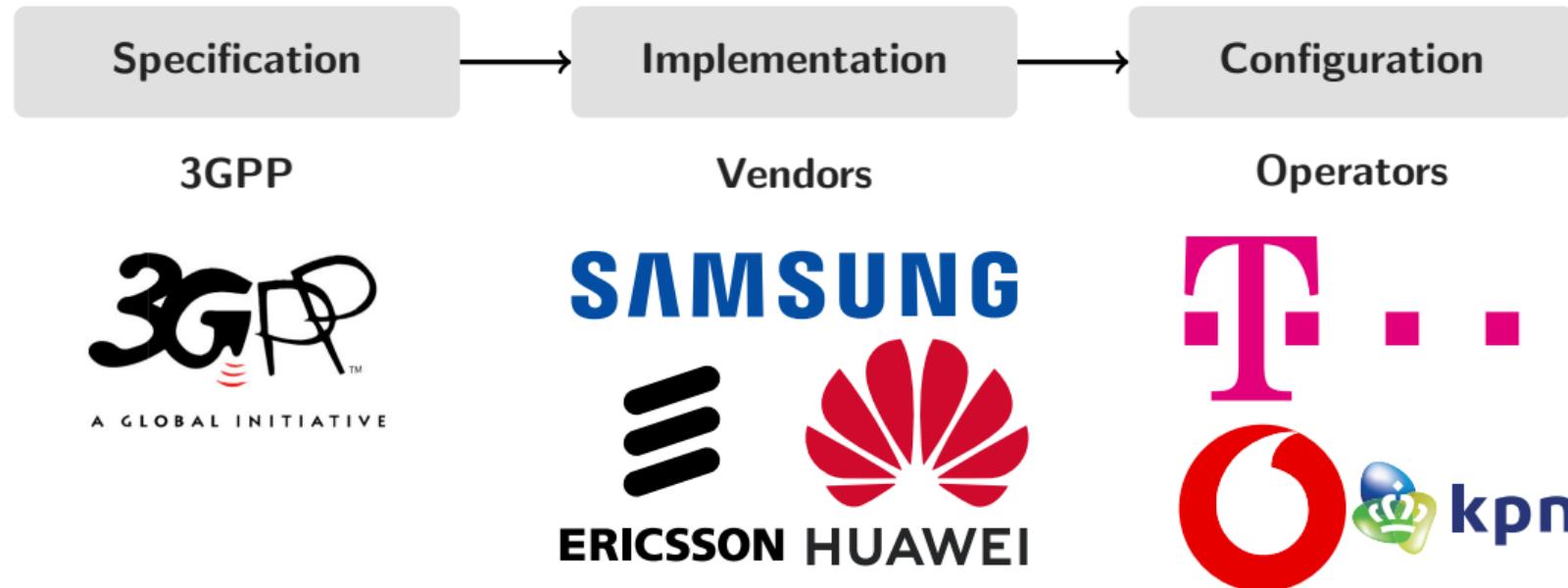


A GLOBAL INITIATIVE

Who is responsible?



Who is responsible?



2G, 3G, 4G, 5G

- ▶ Each mobile generation has their own flaws
- ▶ 4G is the current mobile generation
- ▶ Better than 3G, still not perfect
- ▶ 5G is pretty similar

Mobile Lifecycle

- ▶ Specification → Implementation → Configuration
- ▶ Flaws are inherited from one step to the next
- ▶ It's not always possible to patch a flaw
- ▶ 3GPP is responsible of the specification, vendors are responsible of implementations, operators are responsible of configurations.

- ▶ Explain why it is so difficult to remove flaws from the specification.
- ▶ What is the role of vendors? Where do we find their products?
- ▶ What is the current mobile generation?
- ▶ Who is responsible of the configuration of networks?
- ▶ Describe the most important difference between a specification flaw and an implementation flaw.

Mobile Security Goals

Security Goals in Mobile Networks

Security Category	Mobile Network Aims
Confidentiality	Confidentiality of User Data Traffic
	Confidentiality of Voice/Video Calls
	Confidentiality of text messages (SMS) / RCS
Privacy	Location Privacy
	Identity Privacy
Integrity	Correct Charging Service
	Traffic Integrity
	Mutual Authentication
	Software and Hardware Integrity
Availability	Undistributed Service

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Attack Aims versus Security Goals

Security Category	Mobile Network Aims	AttackAims
Confidentiality	Confidentiality of User Data Traffic	Interception of Internet traffic
	Confidentiality of Voice/Video Calls	Eavesdropping Phone Calls
	Confidentiality of text messages (SMS) / RCS	Interception of text messages / RCS
Privacy	Location Privacy	User tracking
	Identity Privacy	User identification User localization
Integrity	Correct Charging Service	Fraud attacks
	Traffic Integrity	Modification of traffic
	Mutual Authentication	Impersonation attack
	Software and Hardware Integrity	Malware and Hardware Trojan
Availability	Downgrade Attacks (stepping stone attack)	
	DoS of target subscribers	
	DoS of infrastructure (ransom)	

Why is the attack aim a problem for the security goal?💡

Confidentiality: Only authorized access allowed

Security Category	Mobile Network Aims	AttackAims
Confidentiality	Confidentiality of User Data Traffic	Interception of Internet traffic
	Confidentiality of Voice/Video Calls	Eavesdropping Phone Calls
	Confidentiality of text messages (SMS) / RCS	Interception of text messages / RCS

Why is the attack aim a problem for the security goal?💡

Privacy: Provider knows this, attacker must not.

Security Category	Mobile Network Aims	AttackAims
Privacy	Location Privacy Identity Privacy	User tracking User identification User localization

Why is the attack aim a problem for the security goal?💡

Integrity: Nobody fiddled with the data

Security Category	Mobile Network Aims	AttackAims
Integrity	Correct Charging Service	Fraud attacks
	Traffic Integrity	Modification of traffic
	Mutual Authentication	Impersonation attack
	Software and Hardware Integrity	Malware and Hardware Trojan

Why is the attack aim a problem for the security goal?💡

Availability: Being able to reach a service

Security Category	Mobile Network Aims	AttackAims
Availability	Undistributed Service	Downgrade Attacks (stepping stone attack) DoS of target subscribers DoS of infrastructure (ransom)

Summary

Basics and Security

- ▶ Radio Access Network: Basic features of mobile networks
- ▶ CIA + P: General security features
- ▶ Mobile Evolution: Inherited problems
- ▶ Discussion: How attack aims contradict security goals

Next Time

- ▶ Three attacks against LTE
- ▶ Website fingerprinting
- ▶ Identity mapping
- ▶ User data redirection
- ▶ ... and the required background

Acronyms

AKA	Authentication and Key Agreement
C-RNTI	Cell Radio Network Temporary Identity
eNodeB	Evolved NodeB
EPC	Evolved Packet Core
E-UTRAN	Evolved Universal Terrestrial Radio Access
EPLMN	Equivalent PLMN
GUTI	Globally Unique Temporary Identifier
HPLMN	Home PLMN
HSS	Home Subscriber Service
IMSI	International Mobile Subscriber Identity
LTE	Long Term Evolution
MAC	Medium Access Control
MCC	Mobile Country Code
MME	Mobility Management Entity
MNC	Mobile Network Code
NAS	Non-Access Stratum
P-GW	PDN Gateway
PDCP	Packet Data Convergence Protocol
PDN	Packet Data Network
PHY	Physical Layer
PLMN	Public Land Mobile Network
RAP	Random Access Preamble
RA-RNTI	Random Access RNTI
RLC	Radio Link Control
RNTI	Radio Network Temporary Identity
RRC	Radio Resource Control
S-GW	Serving Gateway
S1AP	S1 Application Protocol
SCTP	Stream Control Transmission Protocol
VPLMN	Visiting PLMN
SDR	Software Defined Radio
TMSI	Temporary Mobile Subscriber Identity
UE	User Equipment