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Wireless Security (Cellular Networks)

Dr. Ravishankar Borgaonkar

DAT-610

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Outline

- Cellular wireless network threats
- Authentication & Encryption in 4G/5G networks
- Security issues in 4G/5G

Concepts used to secure your mobile phone calls and Internet connections!

Is your data transmitted from mobile phone 100% secured?

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Note : References for the research figure and tables can be found at the last slide number 58.
Some un-referenced pictures are used from Internet to show the subject over online-form of the lecture.

Magic of wireless telecommunication

- First demonstration in 1877 – Stockholm, Sweden
- “Telephone is the instrument of Devil” **
- Innovations - wireline (1877) to wireless (2017)
- Foundation – seamless connectivity and low latency
- Features - quality of service & availability
- Fear and hope

figure- Ericsson History

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1G Networks – wireless era

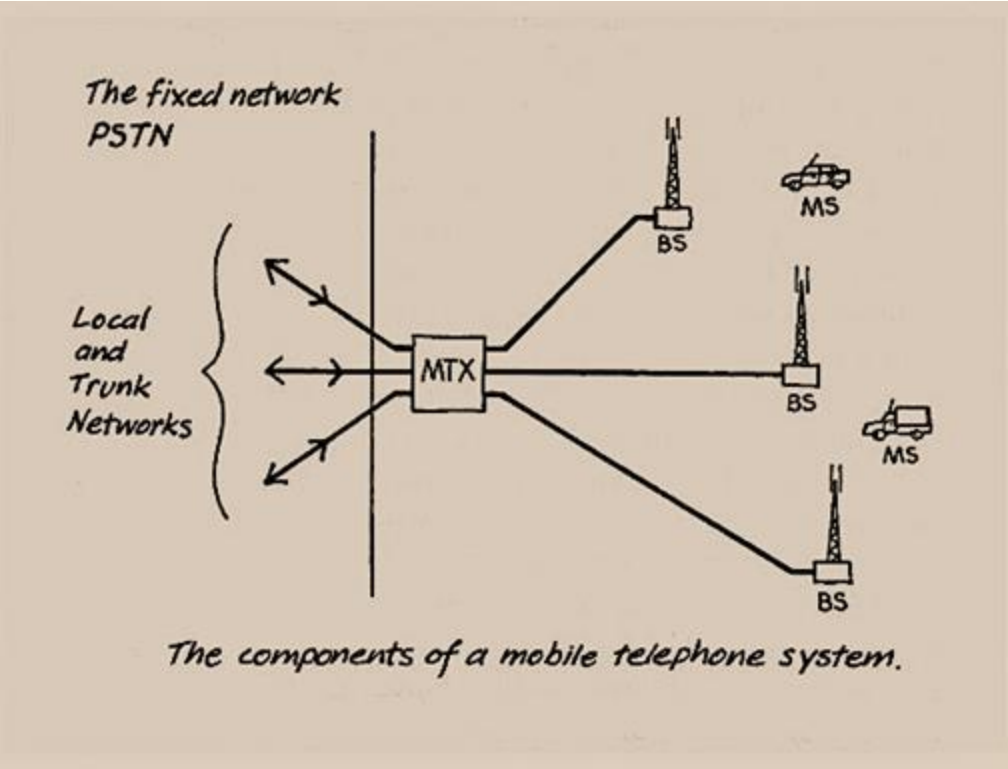

figure- Ericsson History

Problems with 1G

- No authentication & encryption
- Heavy devices
- No roaming – international calls
- But still luxury of talking to loved ones

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Stakeholders & Roles

- Cellular network providers
- End-user equipment vendors
- Standard organizations
- Infrastructure & support services
- OTT services

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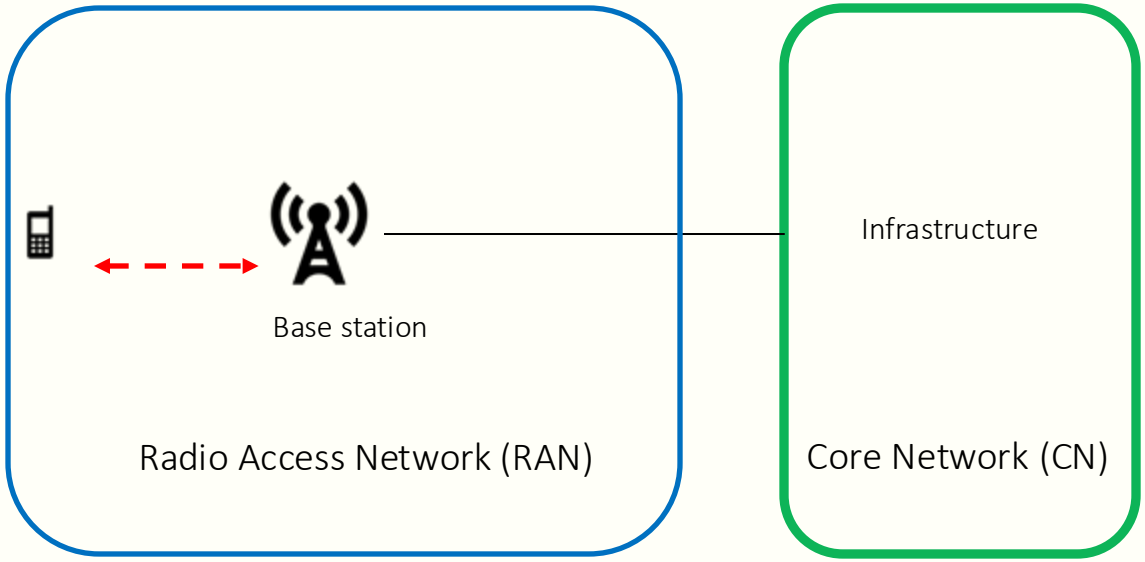
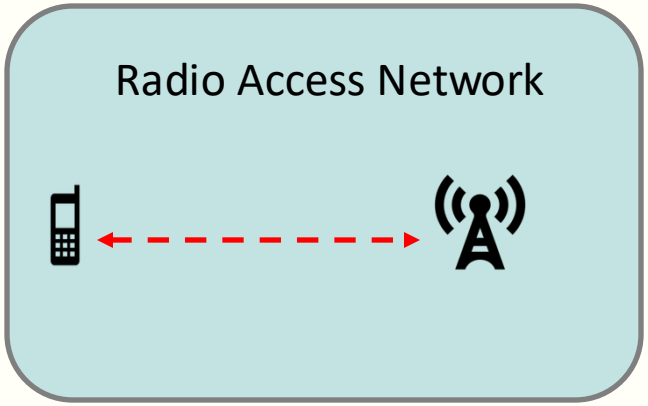
General Cellular Network Architecture



Note: picture provides an abstract view only

Threats to RAN

- Interception
- Location tracking
- Man-in-the-middle attacks
- Denial of Service attacks
- Device and identity theft



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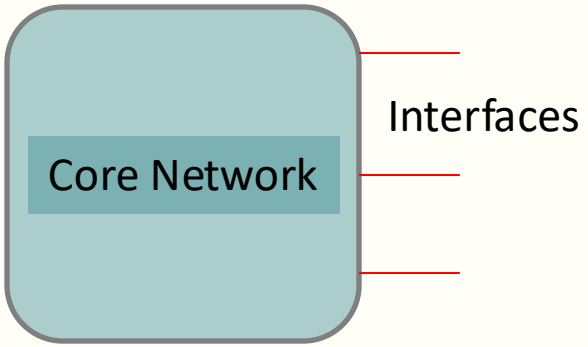
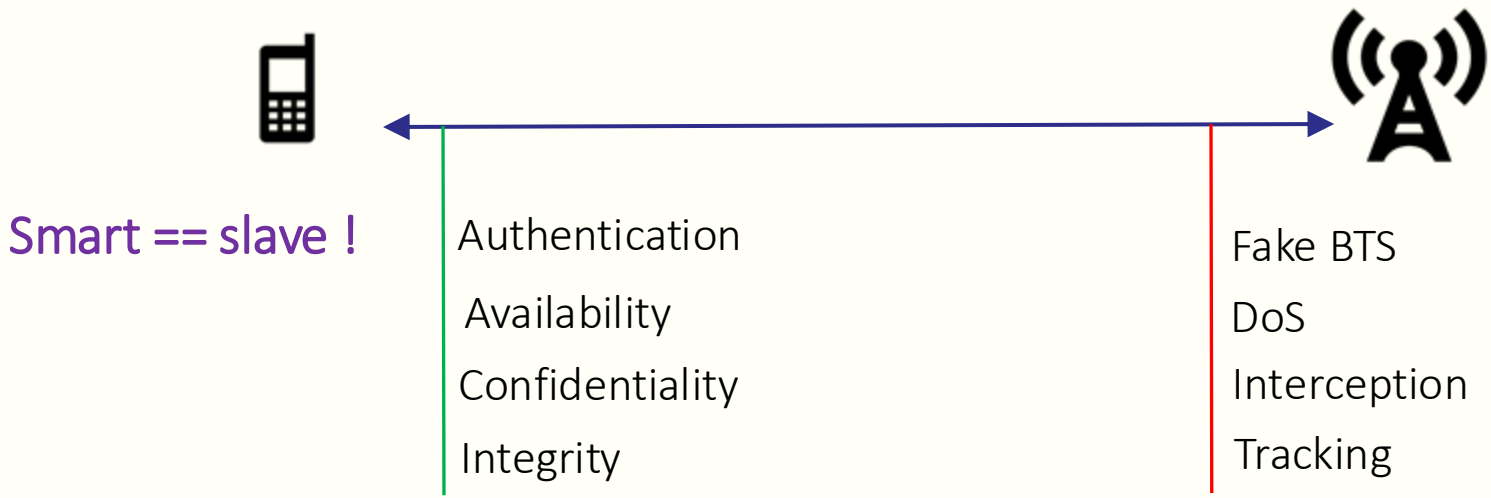
Threats to Core Network

- Espionage
- Insider attacks
- Location tracking
- Billing frauds
- Denial of service



Security aspects

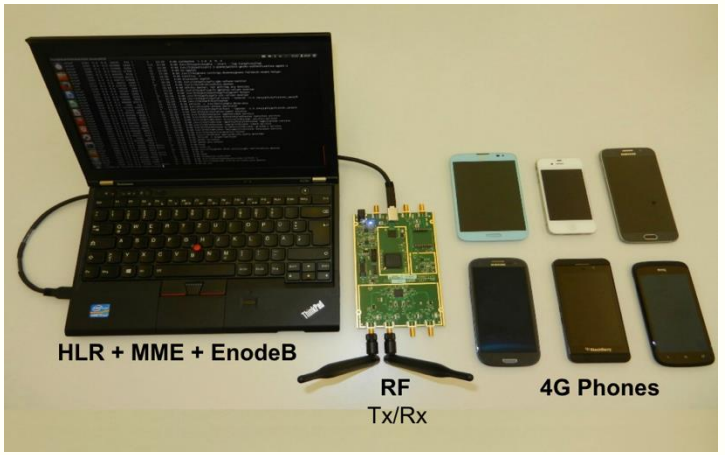
Security aspects & threats



Security tradeoffs play essential role in protocol design!

Low cost attacking infrastructure

- 2G/3G/4G* network setup cost < 1000 USD
  - Open source software & hardware
  - USRP, Osmocom, OpenBTS, OpenLTE, etc
- IMSI catcher device problem
- Targeted attacks from illegal actors
- Almost no detection capabilities for the end-users



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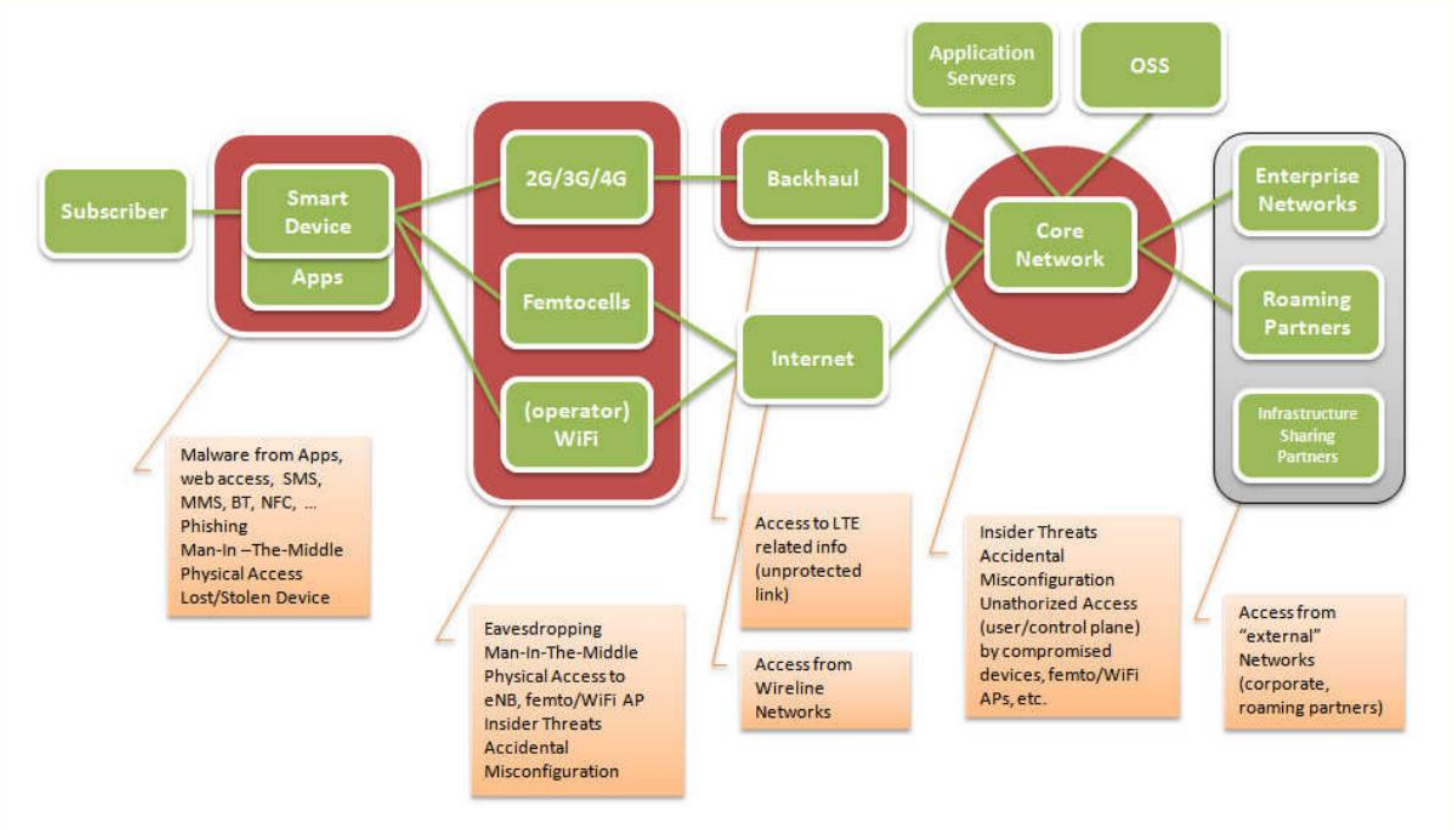
Threat Landscape



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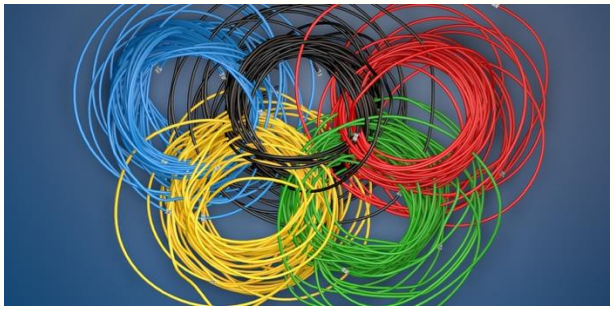
Attackers

- Fraudsters
- Cyber criminals
- Hackers
- Insider threats
- Cyber warfare actors (arguable)



POSTED BY: TOR INGAR OESTERUD 22. FEBRUARY 2016

Misinterpretation of data from another international operator lead to about 1 million Telenor customers being without mobile coverage for several hours Friday, the company said.

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Security Principles

- Authentication
  - Symmetric
  - Asymmetric
- Availability
  - Trade-offs
- Integrity
  - Exit points
- Confidentiality
  - Key sizes
  - Choice of encryption algorithms

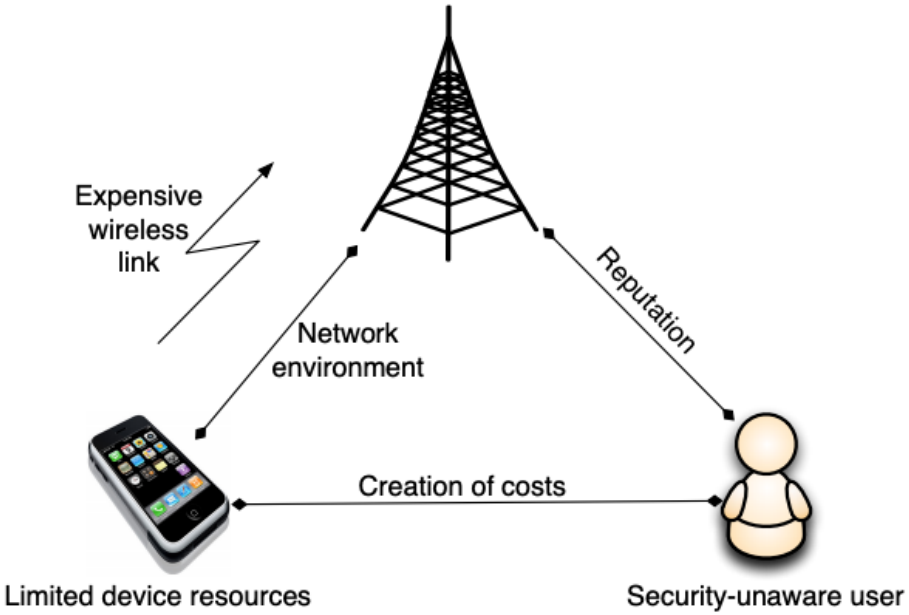

Figure 1. Specifics of Mobile Devices

Transition from 1990 to 2017

- New interfaces – opening up the traditional perimeter
- Low cost hardware/software
- Towards all IP architecture
- backword compatibility – fundamental issues persist
- Increased security level
- Less privacy - daily part of the life!

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Take Aways

- Complex wireless communication network system
- Network architecture evolved but security add-on
- Necessity of legacy system support
- Many standardized features from 1990 are not necessary in 2017
  - Easy to exploit and not maintained for the updates
- Moore's law principle for open-source development of telco infrastructure

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Authentication in Cellular Networks

SIM – pillar for authentication

- Subscriber Identity Module

- Universal Integrated Circuit Card (UICC)
  - In GSM, refers as SIM
  - In UMTS system, runs USIM software (entire card is not the USIM)
  - In 4G system, USIM
  - In 5G USIM/eSIM

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SIM Data (1)

- Integrated Circuit Card ID (ICC-ID) (aka SIM Serial Number - SSN)
  - Uniquely identifies a SIM card (hardware)
- International Mobile Subscriber Identity Module (IMSI)
  - Uniquely identifies the mobile subscriber (15 digits, ITU E.212 standard)
  - MCC (3 digits), MNC (2 or 3 digits), MSIN (9 or 10 digits)
- Authentication Key (K_i)
  - Key shared with provider
  - Never leaves the SIM in any computation
- Authentication algorithms performed on-chip

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SIM Data (2)

- Location Area Identity (LAI)
  - Stores the last known location area (saves time on power cycle)
- Address book and SMS messages
  - Higher capacity in more advanced cards
  - Have you seen “Inbox full message” in old phones?
- And more …
  - SMSC number
  - Service Provider Name (SPN)
  - Service Dialing Numbers (SDN)
  - value-added-services

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SIM Application Toolkit

- Before smart phones became popular, the SIM Application Toolkit (STK) was a popular method of deploying applications on mobile phones
  - Allowed for mobile banking applications (and other value added services) to run off the SIM (no handset hardware/OS dependence)
  - Commonly written in Java (for JavaCard) using predefined commands (applications are menu driven)
  - Send data to remote application using SMS
  - OTA update method were eventually incorporated

Security in SIM cards

- Identity and Access control (IMSI, PIN1/PIN2, PUK code)
- Authentication to network operator (Ki, A3)
- Confidentiality (Kc, A8)
- Anonymity (TMSI)
- SIM application toolkit

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SIM security issues

SIM Cloning (1998)

- Comp128 algorithm leaked
- Reverse engineered & cryptanalyzed

SIM toolkit attacks

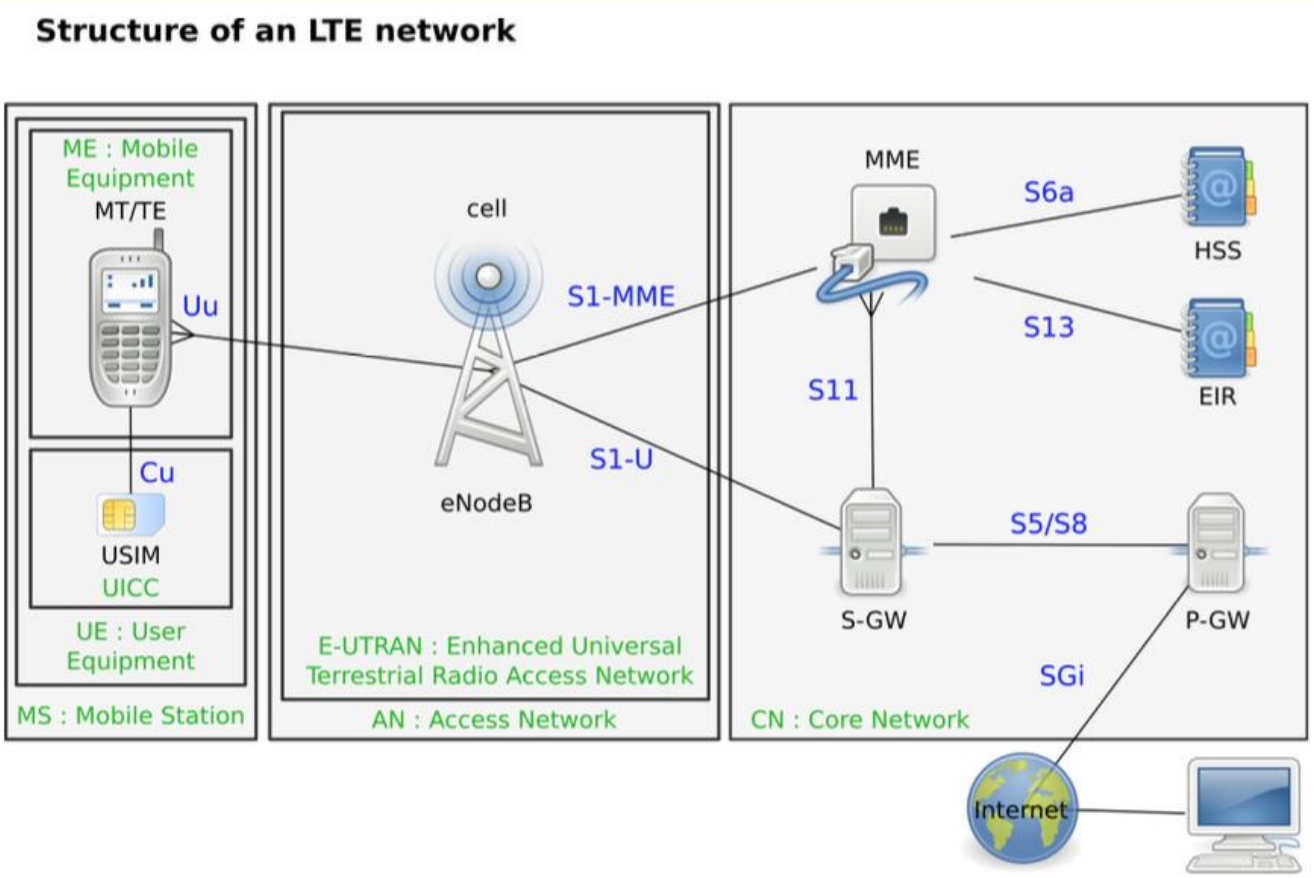
- Fuzzing SMS
- Send premium SMS

Cracking SIM Update keys

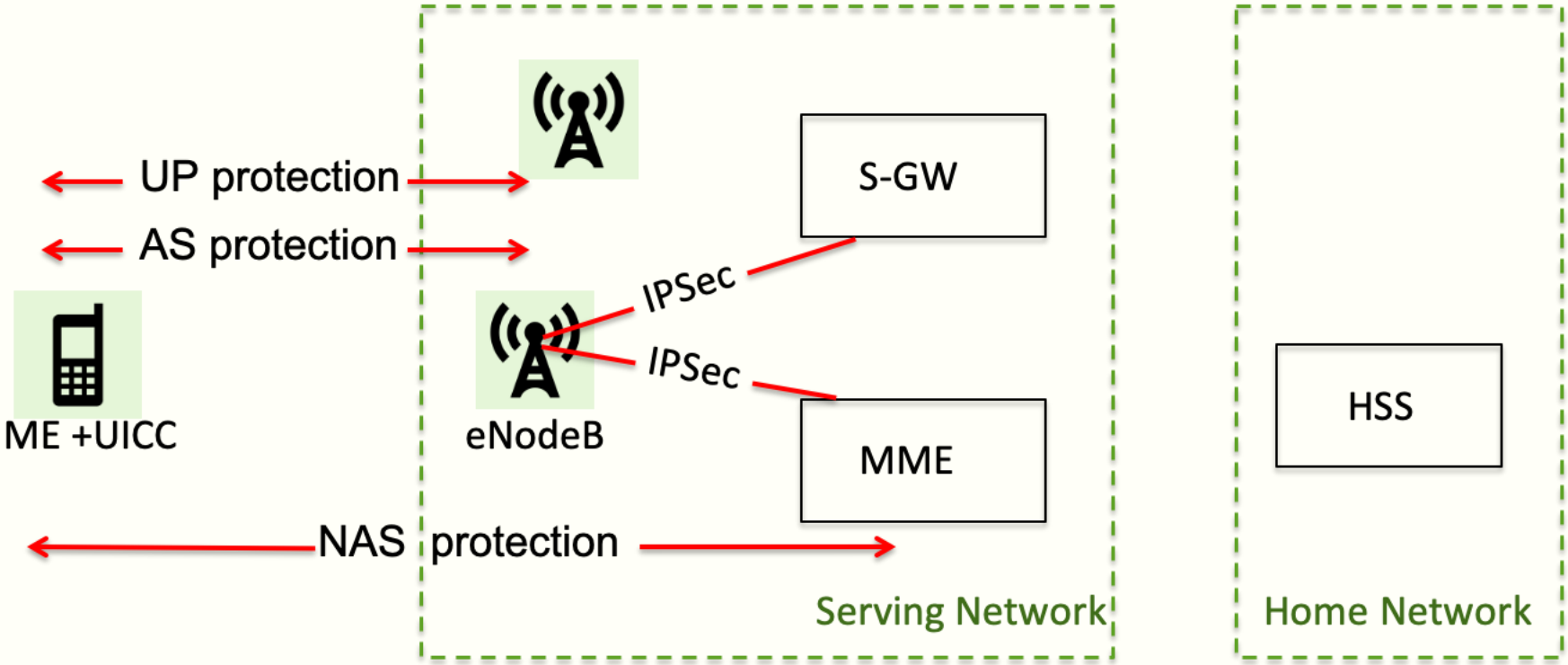
- Recover DES OTA keys
- Singed malicious applets with key

https://www.dn.no/staticprojects/special/2019/mobilkapring/

4G/LTE Network Architecture



4G security architecture



ME Mobile Equipment
UICC Universal Integrated Circuit Card
eNodeB Evolved NodeB
AS Access Stratum
UP User Plane

S-GW Security Gateway
MME Mobility Management Entity
HSS Home Subscriber Server
NAS Non Access Stratum

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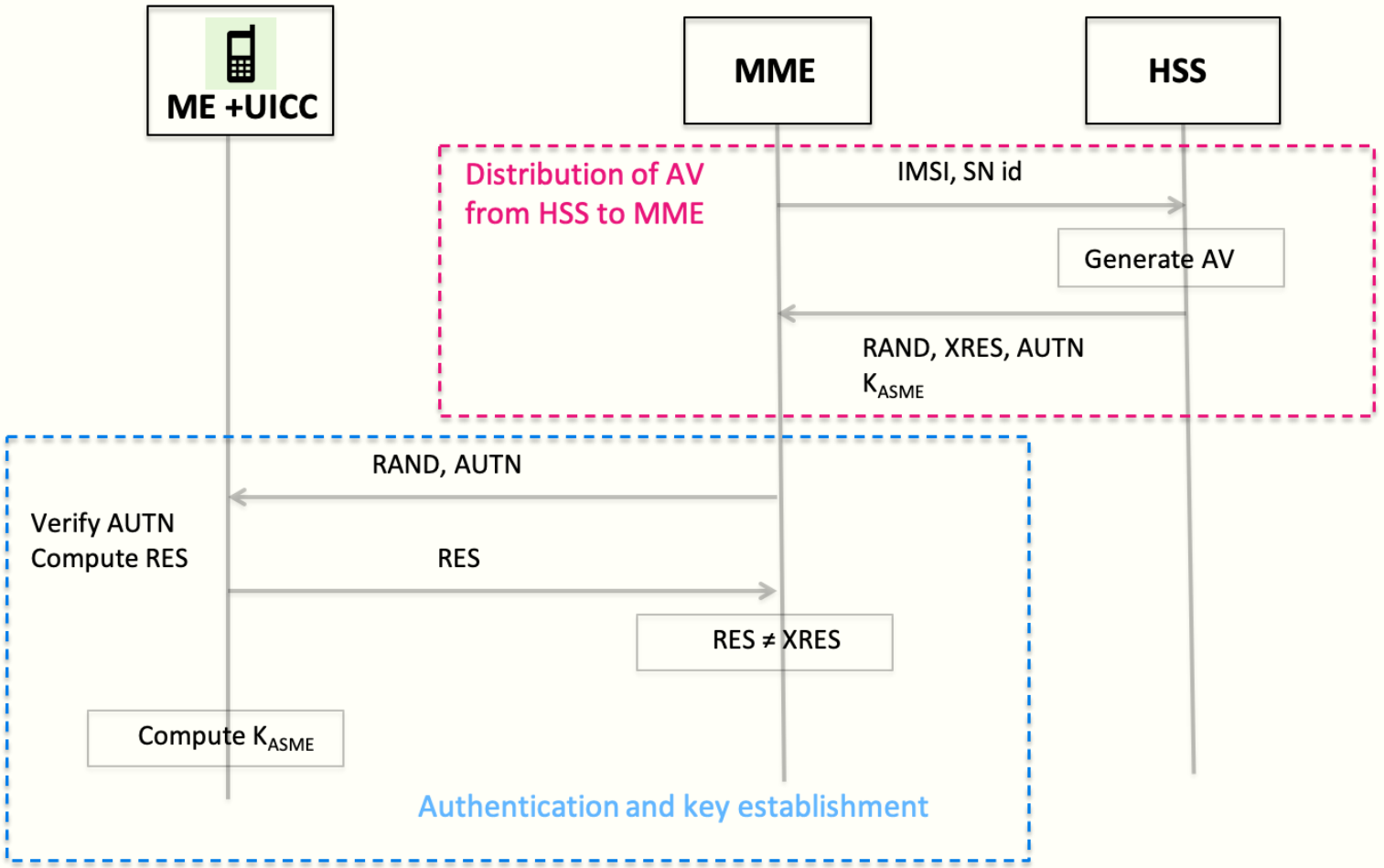
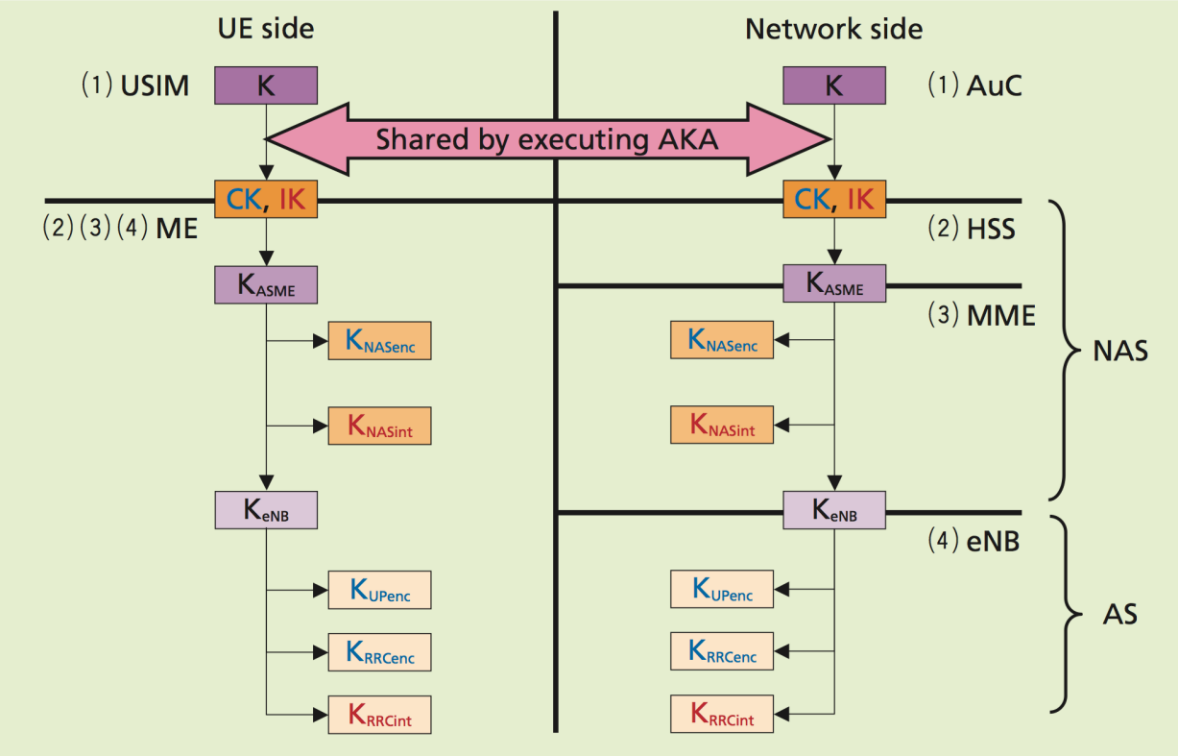
4G AKA protocol (simplified)



Key hierarchy



- Cryptographic key separation
- Key renewal
  - Minimize distribution of same key elements
  - Key freshness is important

Source: NTT Docomo Whitepaper

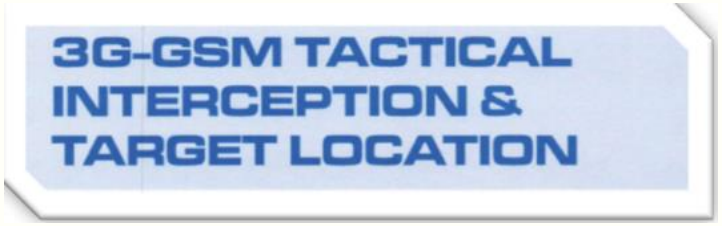
Motivation for Key Hierarchy

- Cryptographic key separation
  - Keys from one context can not be used in other
- Key renewal
  - Minimize distribution of same secret key elements
  - Key freshness is important for secured systems

Emerging attack examples

IMSI catchers (1)

- Exploit weakness in authentication methods
- Location tracking and interception
- Protection for ‘active attacks’ not considered
- Lack of security indicator implementation



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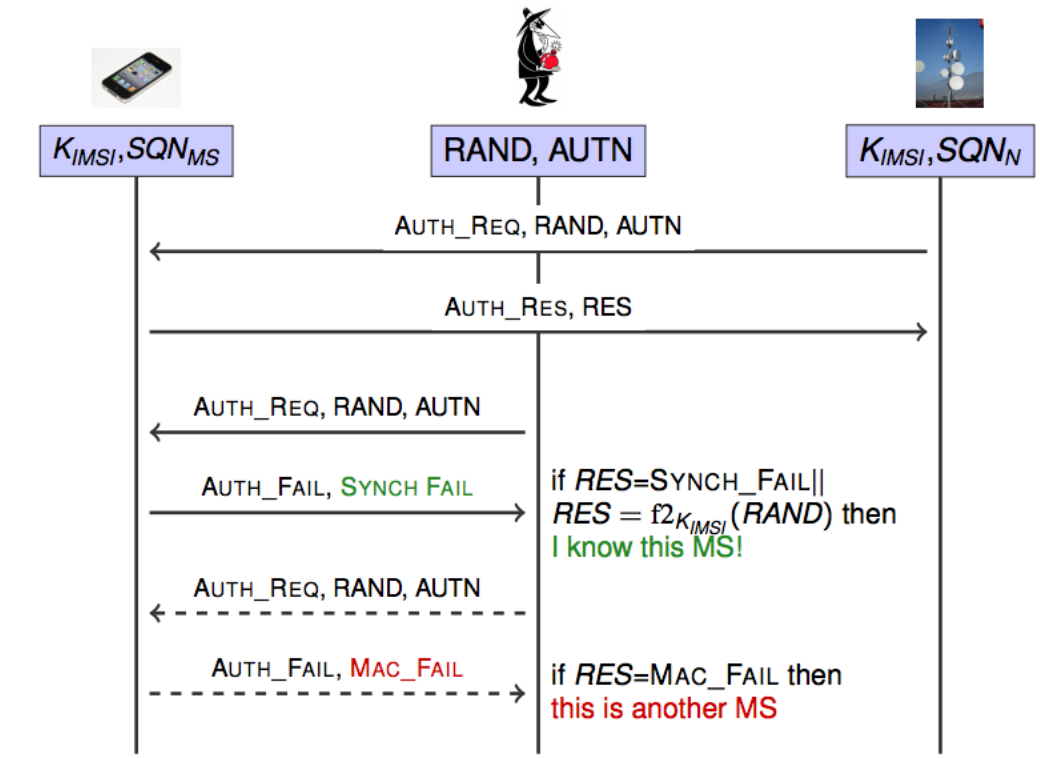
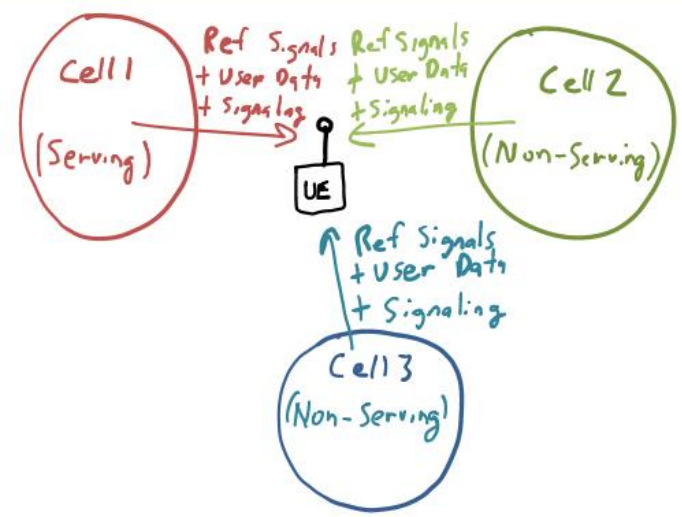
3G/4G AKA vulnerability

- Linkability attack by Arpanis et al
- Affects in 4G as well
- IMSI catcher type attacks



3GPP Specification issues

- RRC protocol – 3GPP TS 36.331
- 'UE Measurement Report' messages
- Necessary for handovers & troubleshooting
- No authentication for messages
- Reports not encrypted



MeasurementReport	+	-	-	Justification for case "P": RAN2 agreed that measurement configuration may be sent prior to security activation

P…Messages that can be sent (unprotected) prior to security activation

A - I…Messages that can be sent without integrity protection after security activation

A - C…Messages that can be sent unciphered after security activation

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Vulnerabilities in the feature

Specification

UE measurement reports

- Requests not authenticated
- Reports are not encrypted

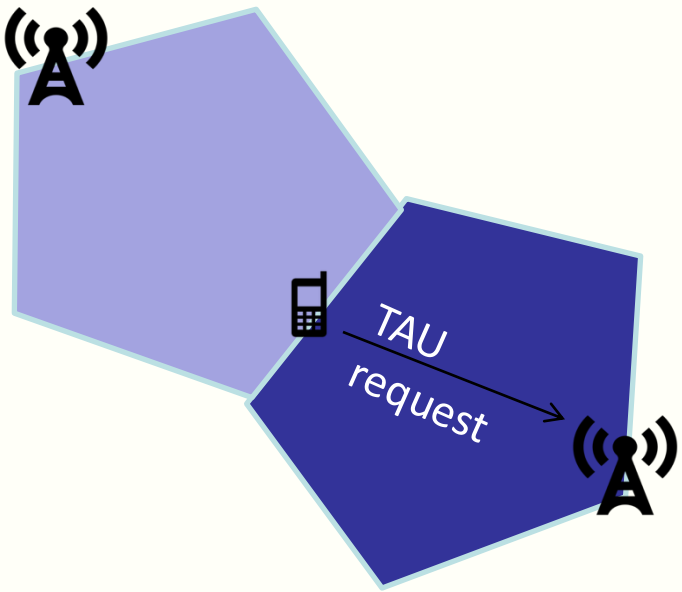
Implementations

RLF reports

- Requests not authenticated
- Reports are not encrypted
- All baseband vendors

4G Feature: Mobility Management

EMM protocol – 3GPP TS 36.331



Tracking Area Update (TAU) procedure

- During TAU, MME & UE agree on network mode (2G/3G/4G)
- "TAU Reject" used to reject some services services (e.g., 4G) to UE

Specification vulnerability: Reject messages are not integrity protected

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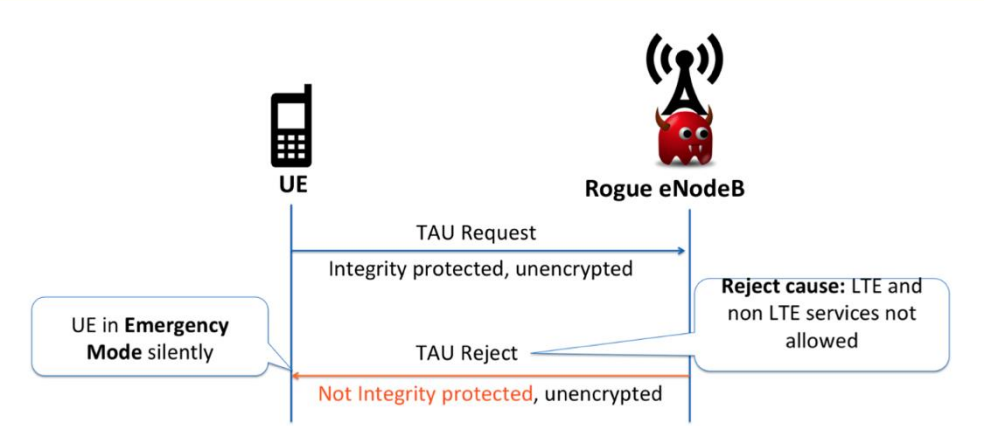
DoS Attacks

Exploiting specification vulnerability in EMM protocol!

- Downgrade to non-LTE network services (2G/3G)
- Deny all services (2G/3G/4G)
- Deny selected services (block incoming calls)
- Persistent DoS
- Requires reboot/SIM re-insertion



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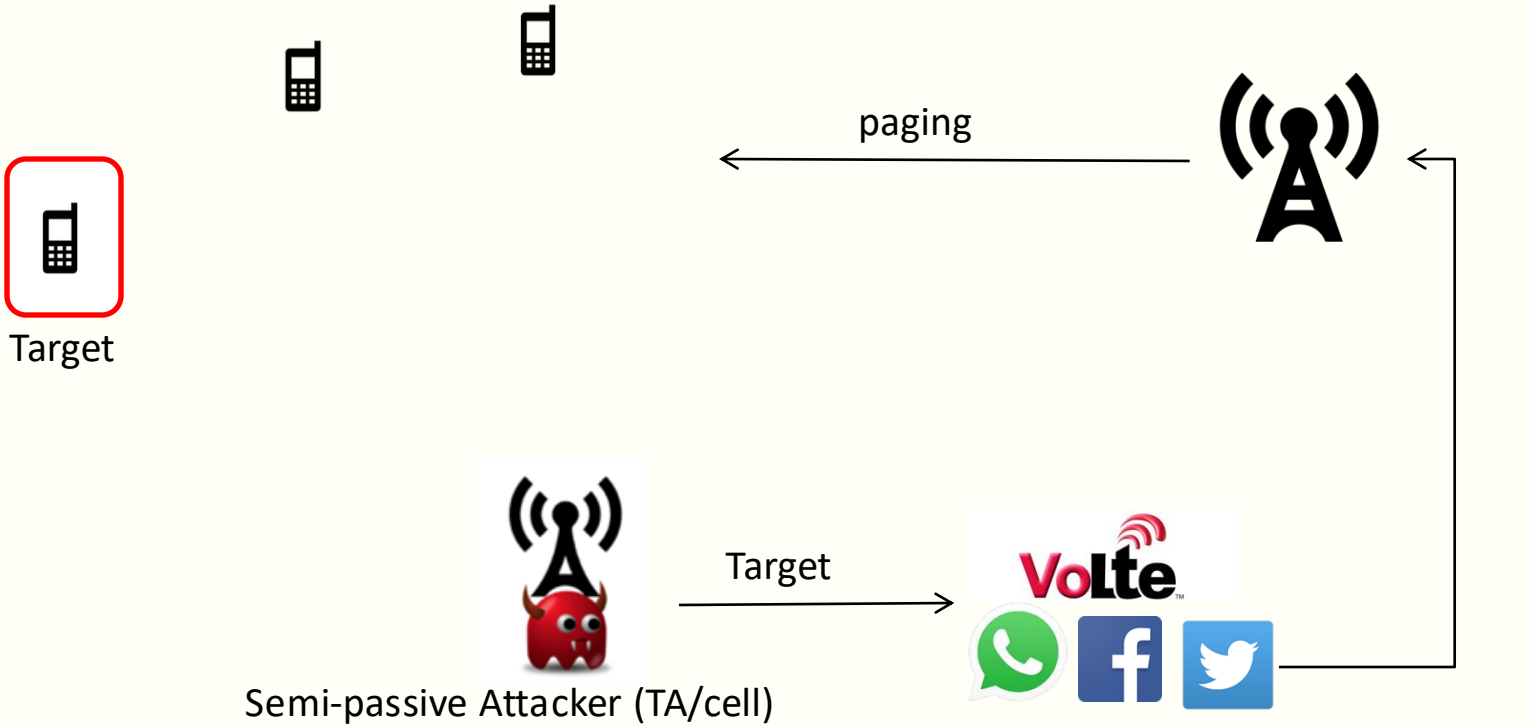
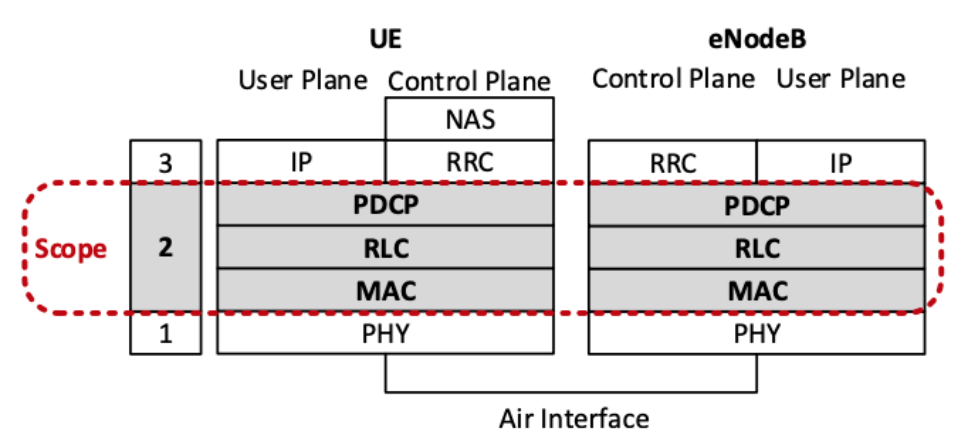
Location Leaks: tracking subscriber coarse level

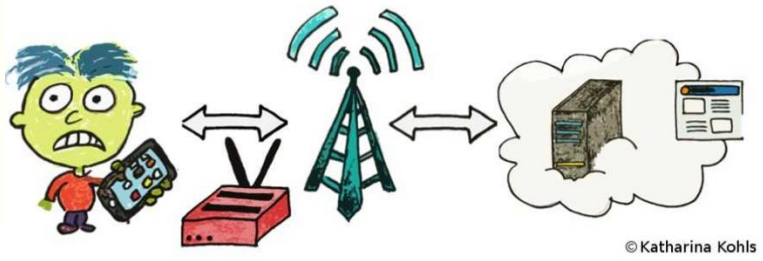


Location Accuracy: 2 Sq. Km

Attacks on Data Link Layer 2

- Passive attacks
  - Identity mapping attack
  - Website Fingerprinting
- Active attack: aLTEr
  - DNS Spoofing attack
  - Man-in-the-middle to intercept communications
  - Redirects to a malicious website





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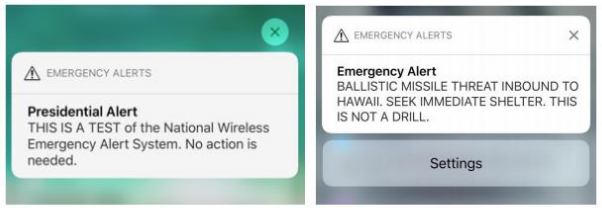
SMS spoofing Attacks

- National Alerts
  - Not used in every countries
  - USA – presidential alerts
  - brodcast
- Normal SMS
  - Many tools over Internet
  - But why this is possible?



(a) Presidential alert (b) Imminent threat alert

Figure 1: Snapshots of real WEA alerts received by cell phones: (a) the first national test of the Presidential Alert performed on Oct. 3, 2018 in the US, and (b) a false alert sent in Hawaii on Jan. 13, 2018.

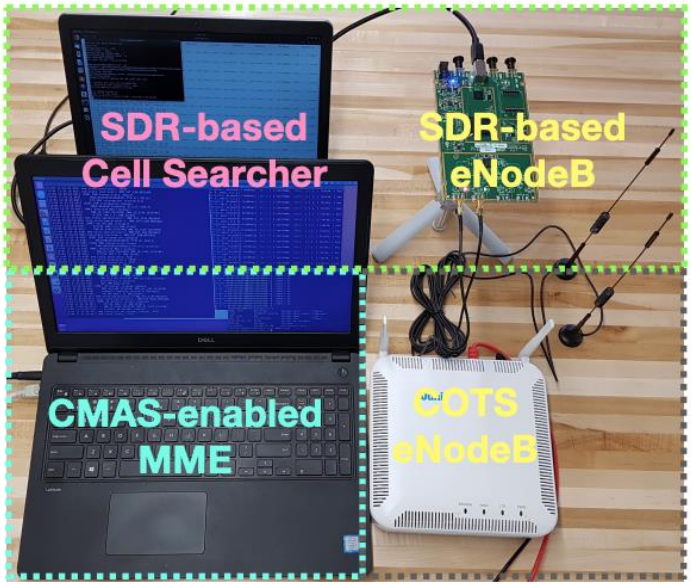


Figure 9: The Presidential Alert Spoofer scans for an eNodeB, gathers operator information, and sends a fake Presidential Alert to both idle and active UEs. The UEs may be FDD or TDD. This setup consists of one SDR device, one COTS LTE eNodeB, and 2 laptops.

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Popular Security tools

Security Research tools - software

- **Network setup cost < 1500 USD**
  - Open source software & hardware

- **Network tools**
  - Osmocom Project (2G)
  - OpenBTS-UMTS (3G)
  - OpenAirInterface/openLTE /Amarisoft (4G)
  - SRSRAN (4G/5G)
  - Amarisoft/OpenAirInterface (5G)

- **Mobile side tools**
  - Osmocombb (2G)
  - SRSRAN (4G/5G)

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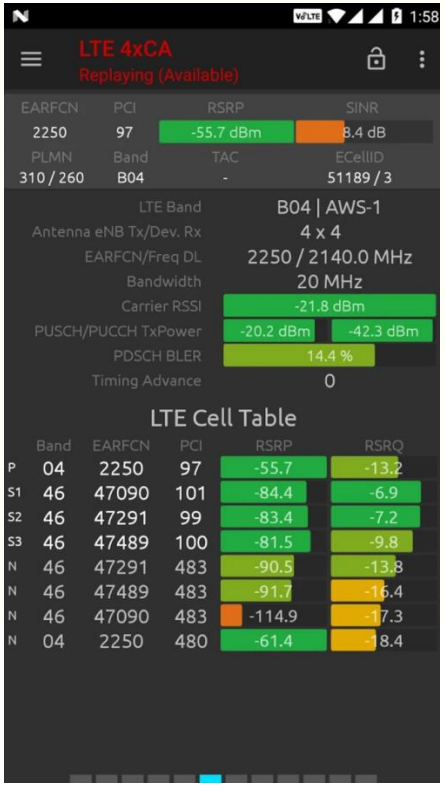
Security Research tools - hardware

- Software defined radios
  - Ettus Research
  - Myriad RF - LimeSDR

- Network monitoring software
  - Network Signal Guru (on mobile)
  - Wireshark



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Reasons for vulnerabilities

Trade of between security and

- Performance
  - Phone restricts to connect to network- saving power
  - Saving network signaling resources (avoid unsuccessful attach)
  - Operator do not refresh temporary identifiers often
- Availability
  - Operators require unprotected reports/specific information for troubleshooting
- Functionality
  - Smartphone apps on generic platforms not mobile-network-friendly
- Attacking cost
  - Active type of IMSI catcher attacks thought to be expensive

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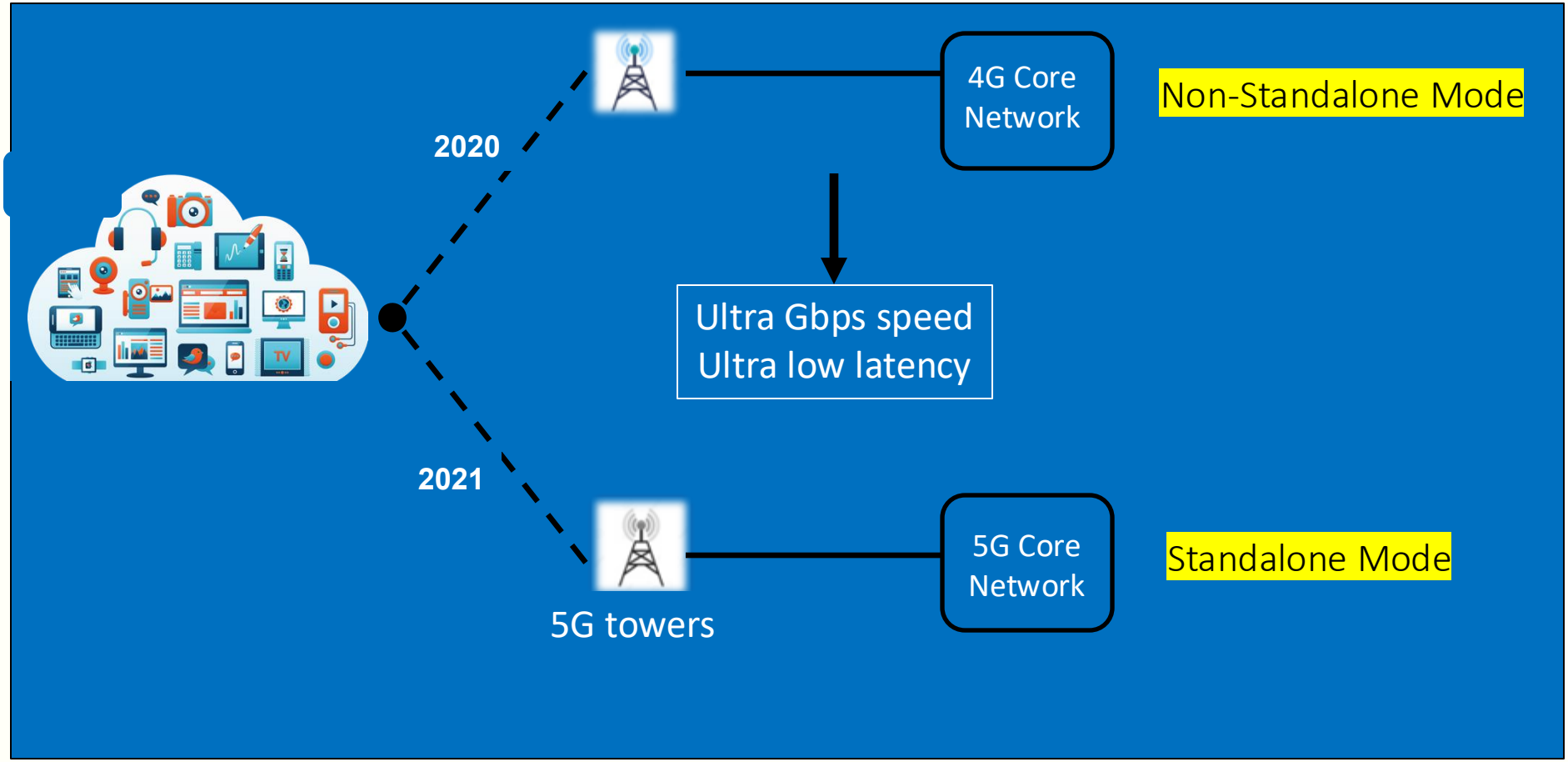
5G Deployment Types

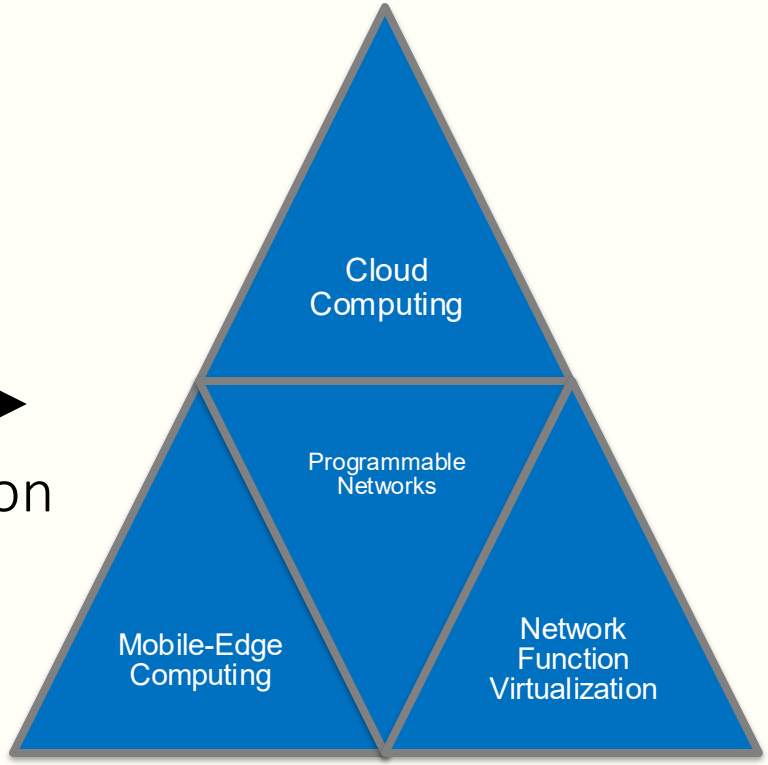


5G Architecture

5G Core Network Infrastructure

Technology

Transformation



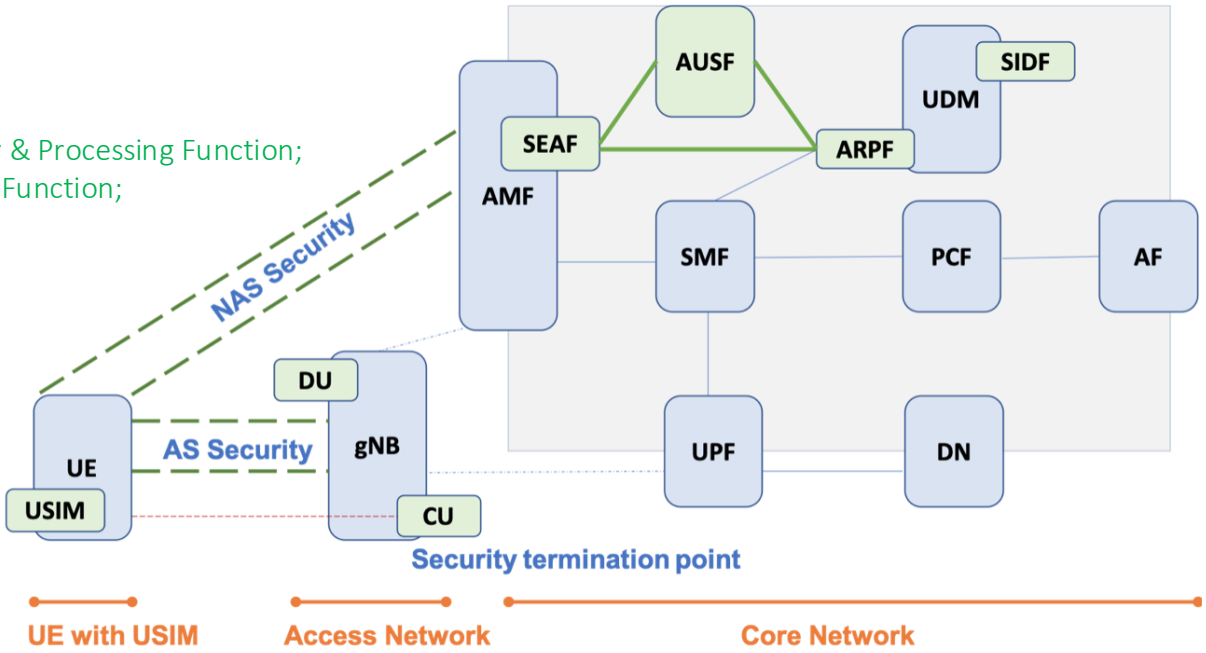
5G Architecture

gNB - NodeB
DU - Distributed Unit
CU - Central Unit

AUSF - AUthentication Server Function;
ARPF - Authentication credential Repository & Processing Function;
SIDF - Subscription Identifier De-concealing Function;
SEAF - SEcurity Anchor Function

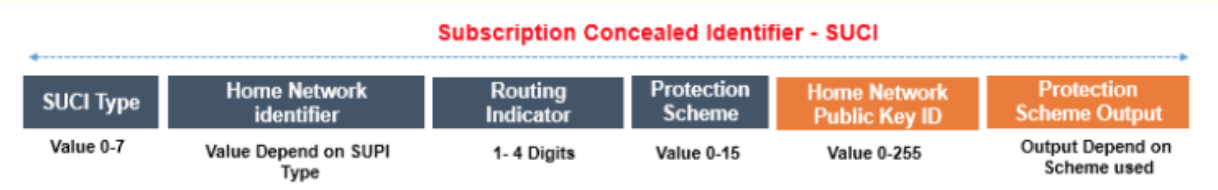
AMF - Access Management Function
SMF - Session Management Function
UDM - Unified Data Mandagement
PCF - Policy Control Function
AF- Application Function
UPF - User Plane Function
DN - Data Network

AS – Access Stratum
NAS – Non-access Stratum

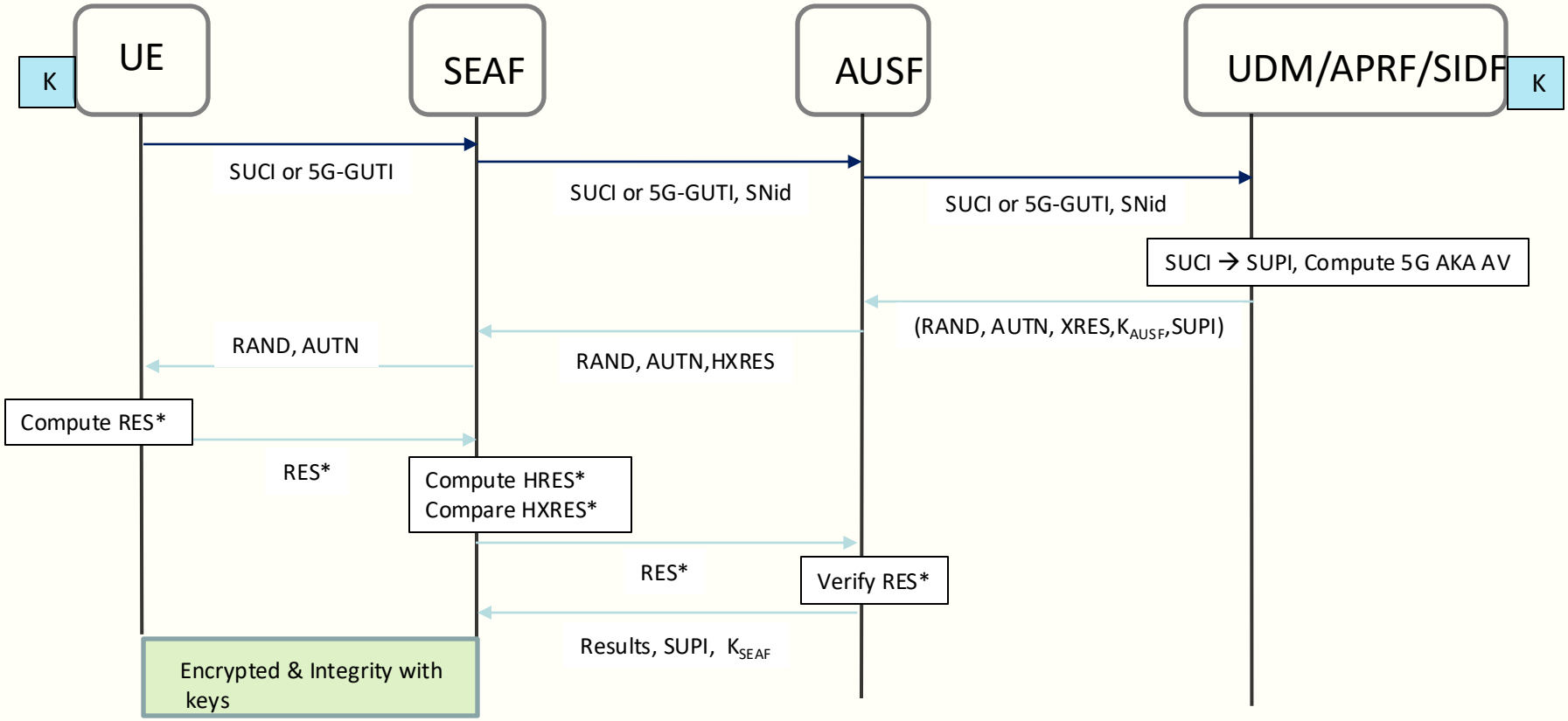


New Identifiers

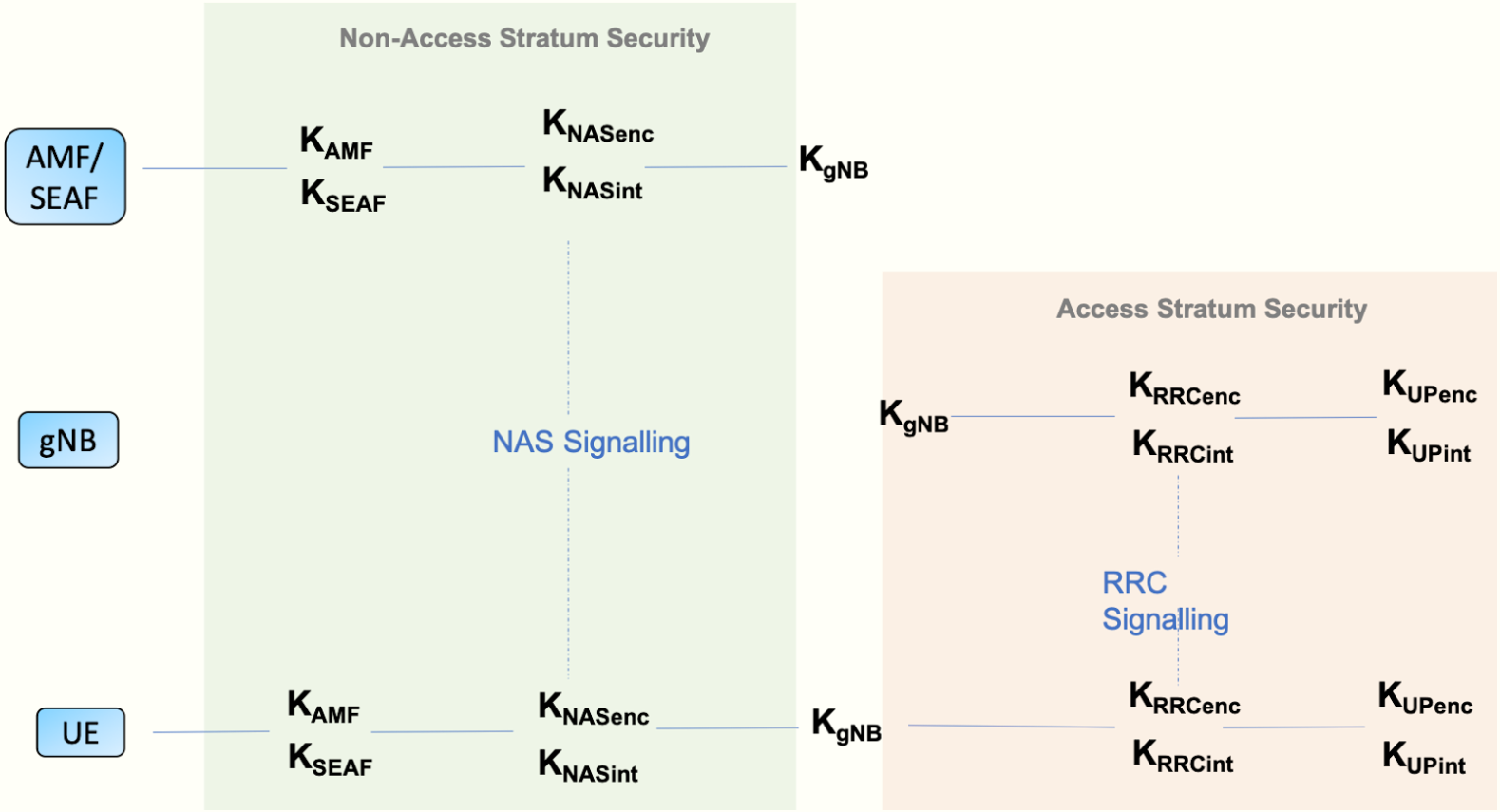
- SUCI – Subscription Concealed Identifier
- SUPI – Subscription Permanent Identifier
- Public key of the home network operator



5G Authentication Protocol - AKA



5G Authentication Protocol – Key Hierarchy



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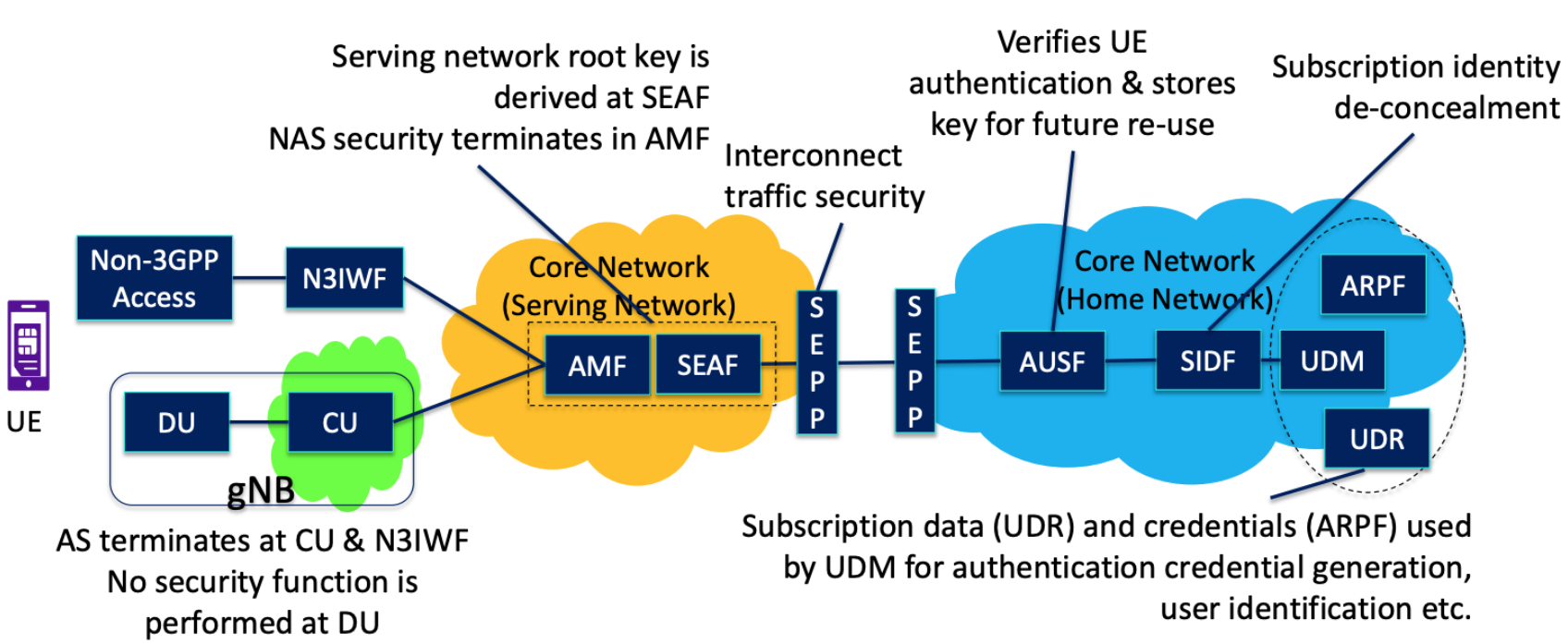
Security Functions in 5G Architecture



Source: Anand Prasad, RSA 2019

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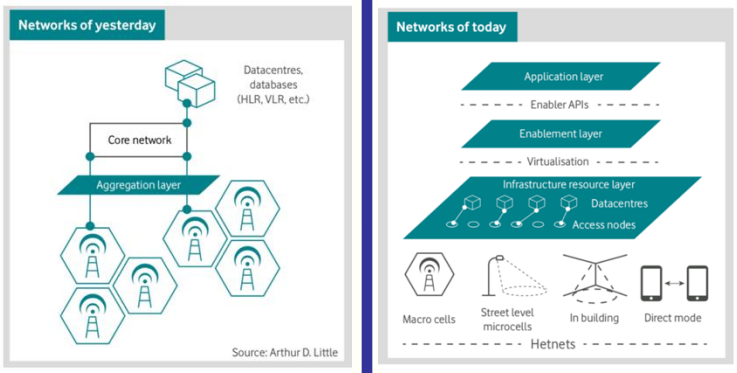
5G Security Issues

Comparison with previous generations

- Separated CN & RAN
- Dedicated IT hardware/software
- Propriety signalling protocols (Diameter/SS7)
- Difficult to modify for new services



- Less separated CN & RAN
- Configurable Software/hardware
- Web based signalling protocols (HTTP, TLS, REST)
- APIs for creating new services

figure- Vodafone Whitepaper

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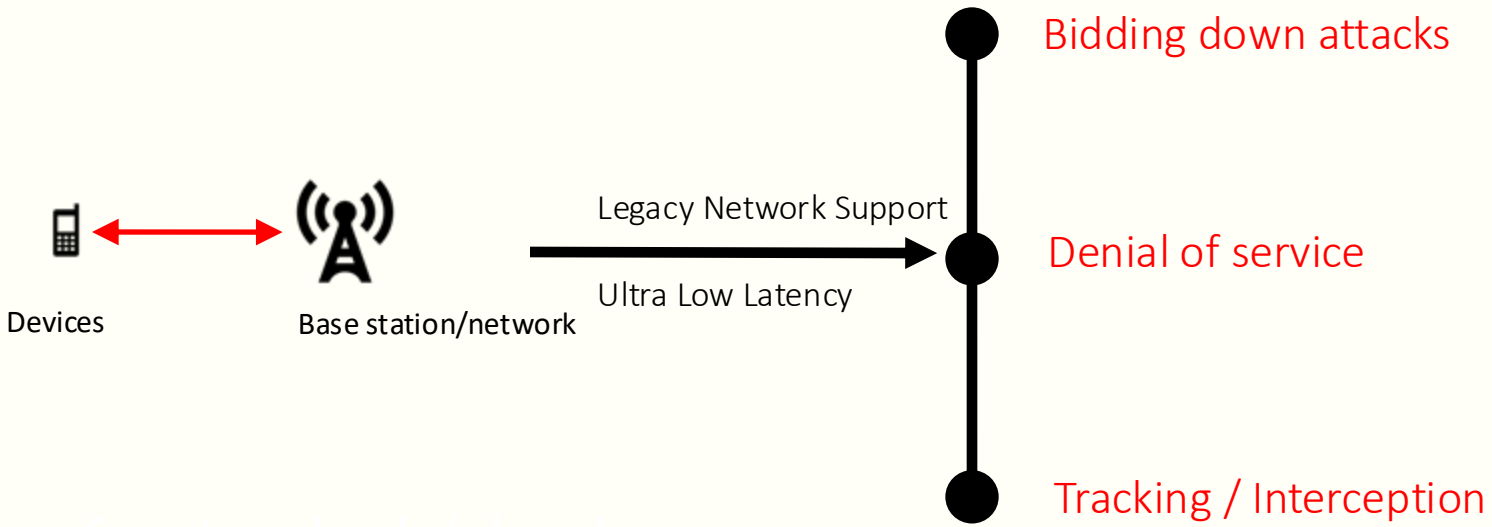
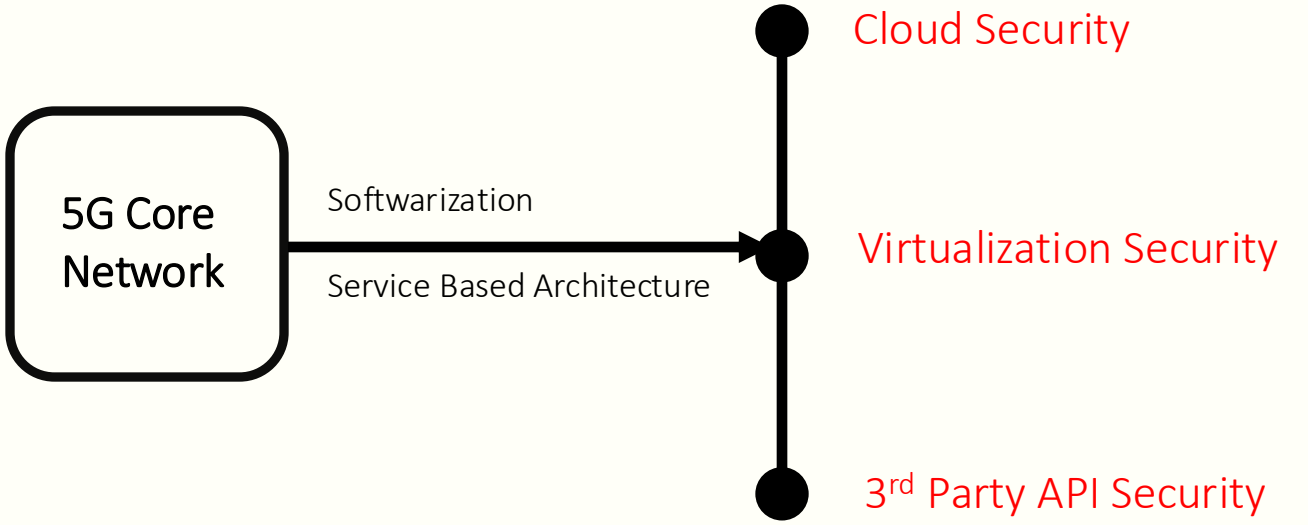
Increased Attack Surface



Increased Attack Surface



Security challenges..

Denial of Service / Distributed Denial of Service attack protection

Botnet?

21 billion by 2020

Bandwidth per device

5 Gbps

Average wired broadband speed

Rank	Country	Average Download Speed (Mbps)	Total Tests	Time To Download HD Movie (5GB)
1	Singapore	**60.39**	524,018	11 Mins, 18 Secs
2	Sweden	**46.00**	367,241	14 Mins, 50 Secs
3	Denmark	**43.99**	150,529	15 Mins, 31 Secs
4	Norway	**40.12**	86,920	17 Mins, 01 Secs
5	Romania	**38.60**	175,948	17 Mins, 41 Secs

Source: Fastmetrics

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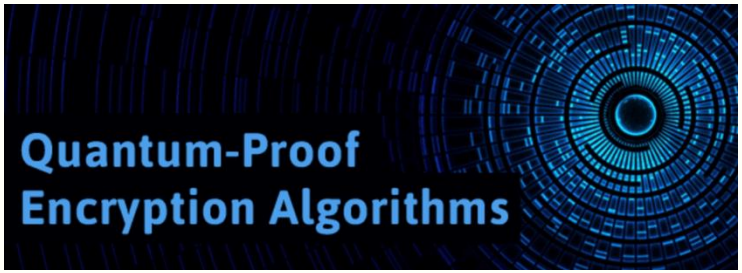
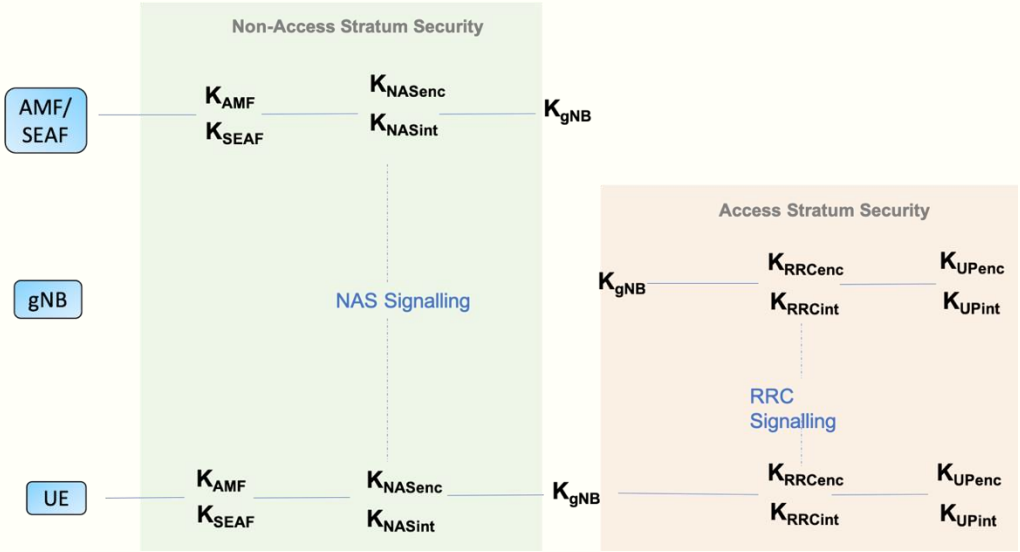
Security challenges..

Cellular encryption algorithms and techniques





Meanwhile in Norway -

Country			Spain			France	United States				Beijing			Norway				
Operator			A	B		A	A		B	C	A	B	C	1	2	3	3	4
Deployment type: SA vs. NSA			NSA	NSA		NSA	SA	NSA	NSA	NSA	SA	SA	SA	NSA	NSA	NSA	SA	Priv. SA
Subscriber Identifiers	Ciphering of Permanent Identifiers																	
	GUTI Refresh	After Registration																
		Periodic Registration									—	—	—					
		After Service Request (Paging)																—
Authentication Procedure	5G AKA										—	—	—					
Control Plane Data (CP)	Confidentiality	NAS	EEA2	EEA2/1	EEA2/1	EEA2	NEA2	EEA2	EEA2	EEA3				EEA1	EEA2	EEA2	5G-EA0	5G-EA1
		RRC	EEA2	EEA2/1	EEA2/1	EEA2	NEA2	EEA1	EEA2	EEA2				EEA2	EEA2	EEA2	NEA2	NEA0
	Integrity	NAS	EIA2	EIA2	EIA2	EIA2	NIA2	EIA2	EIA2	EIA3				EIA1	EIA2	EIA2	5G-IA2	5G-IA1
		RRC	EIA2	EIA2	EIA2	EIA2	NIA2	EIA2	EIA2	EIA2				EIA2	EIA2	EIA2	NIA2	NIA2
User Plane Data (UP)	Confidentiality		NEA2	NEA2	NEA2	NEA2	NEA2	NEA2	NEA2	NEA2								
	Integrity						NIA2		NIA2									
Initial NAS message	Protection																	
UE Radio Capabilities Transmission after RRC SMC											—	—	—	—	—	—	—	—

5G Compliant | 4G Compliant | No security | Not observed

Figure F.1: Extension of Related Works Table Full Size

Thank You.

Questions?

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