Ain't Nothin' but a G Thang

The Evolution of Cellular Networks

Tracy Mosley

hackerpinup

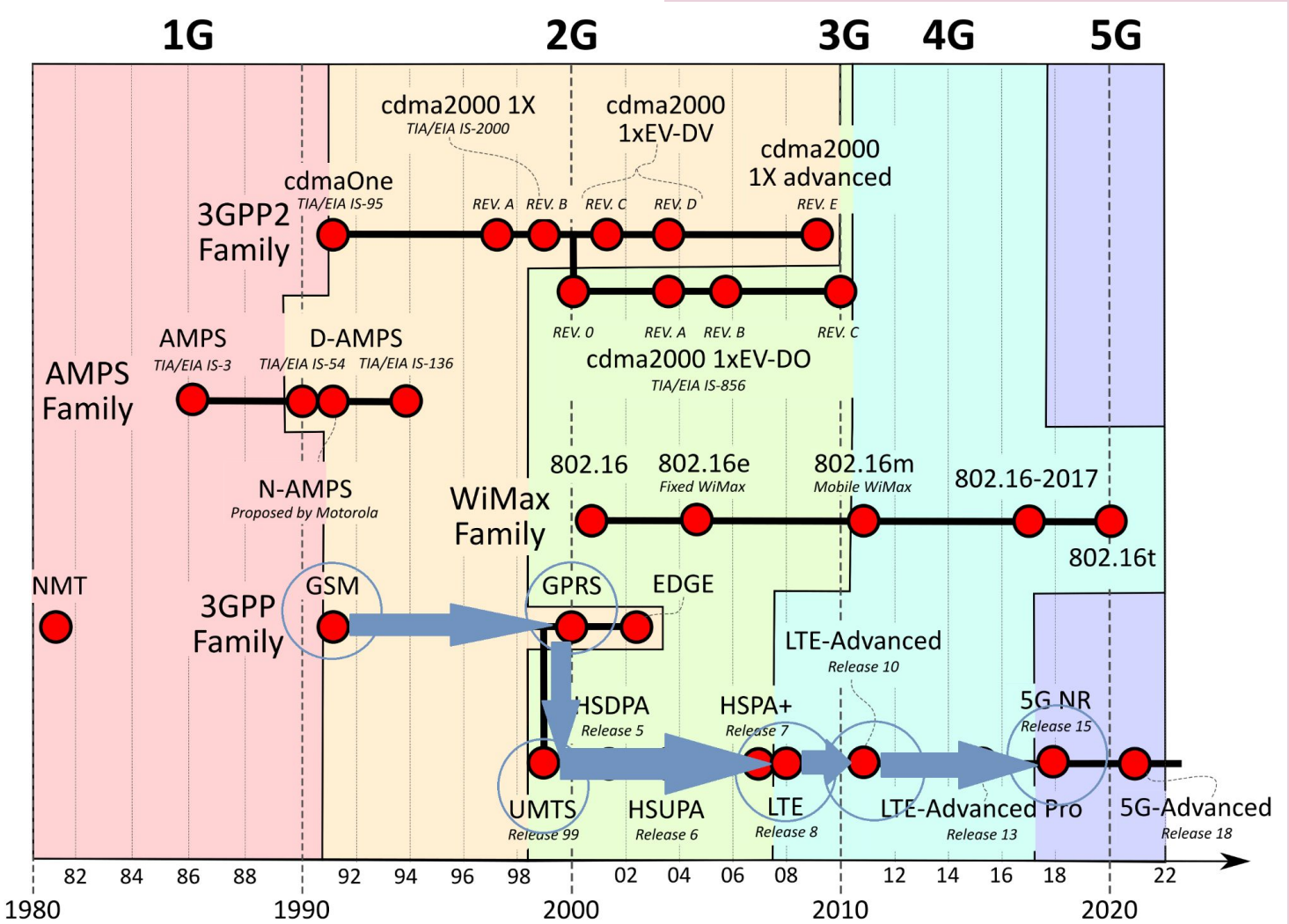
hackerpinup@infosec.exchange

Who am I?

- Vulnerability Researcher at Trenchant
- RE and embedded dev
- Telco focused
- ~10 years of experience
- Computer Engineering Degree

What to cover

- 2G: GSM. Digital Technology! Voice and Data. Circuit Switched.
- GPRS: Both Circuit and Packet Switched!
- 3g: UMTS.
- LTE: Evolved packet core!
- 4G: LTE Advanced. VoLTE, IPv6, IMS.
- 5G: NR. Virtualization. Network slicing. Functionality generally split into “functions” instead of devices.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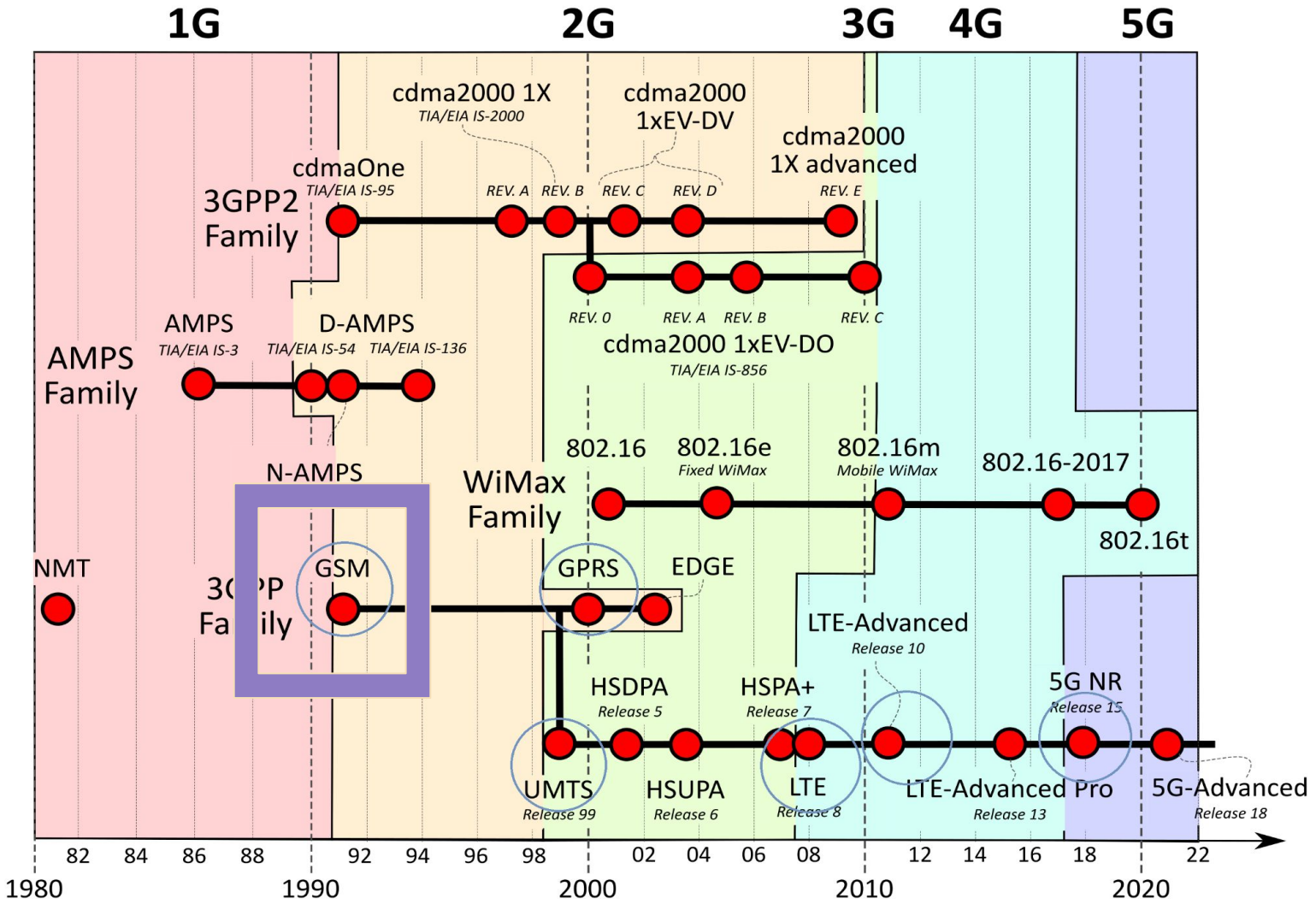
Basic Cellular Concepts

- **POTS**
  - Plain Old Telephone Service
- **PSTN**
  - Public Switched Telephone Network
- Circuit Switched
- **PDN**
  - Public Data Network
- **RRC**
  - Radio Resource Control
- **RAB**
  - Radio Access Bearer

Rachel Brosnahan stars as Midge in Amazon Studios' *The Marvelous Mrs. Maisel*. (Amazon Studios)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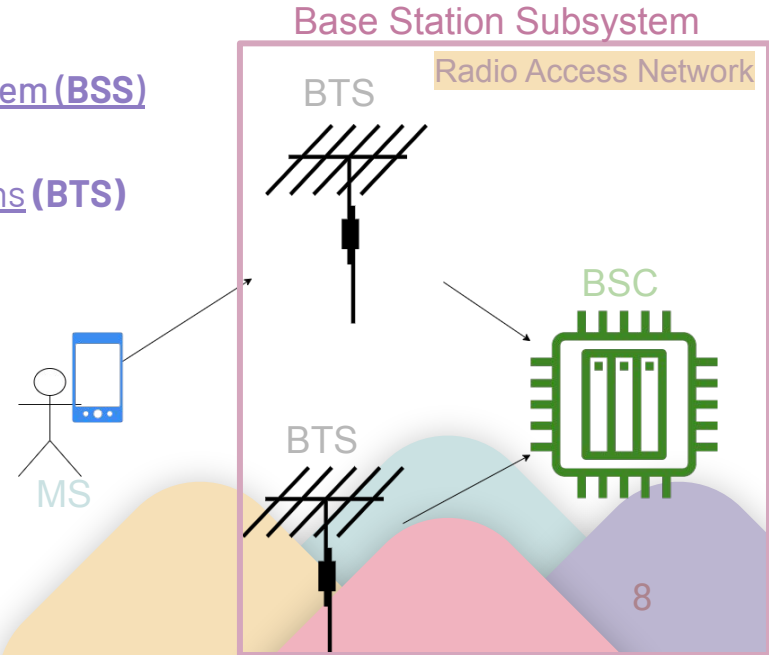
2G

GSM

- Calls
- SMS
- ETSI and GSM standardizing!
- SS7 for signaling

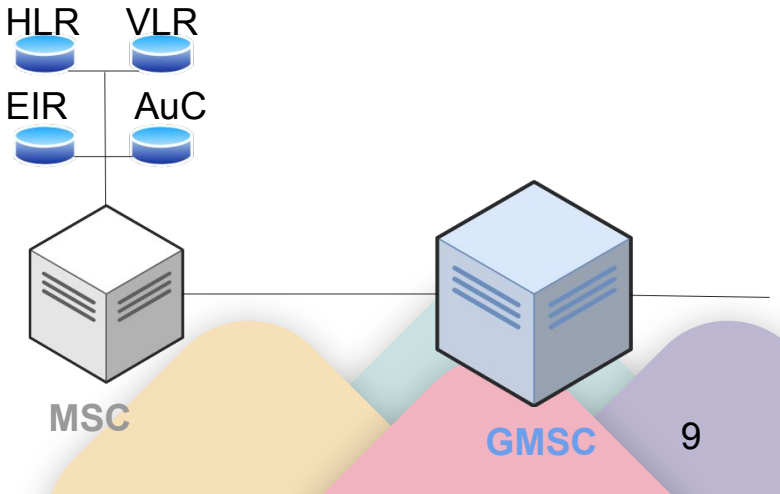
2G - GSM - Network Architecture

- Mobile Equipment **(ME)** or Mobile Station **(MS)**
  - This is usually the whole device in your hand when you're making a call.
- Radio Access Network **(RAN)**
  - In GSM it is the same as the Base Station Subsystem **(BSS)**
    - **BSS** contains
      - One or more Base Transceiver Stations **(BTS)**
      - Base Station Controller **(BSC)**



2G - GSM - Network Architecture

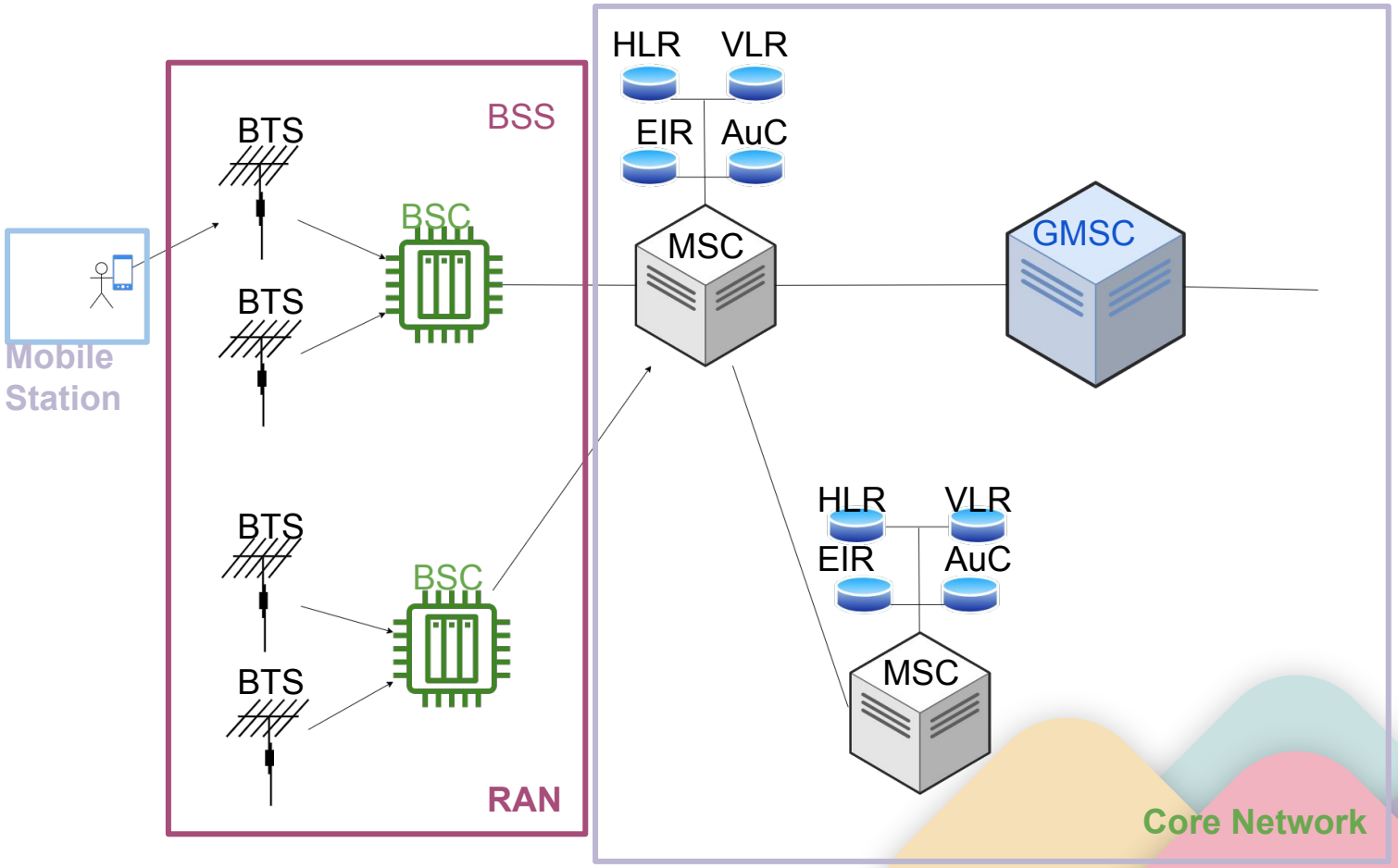
- Mobile Switching Center **(MSC)**
  - Handles the call switching, handover, registration, authentication.
- Home Location Register **(HLR)**
  - Large DB of user information for “local” users
- Visitor Location Register **(VLR)**
  - Large DB of user info for visiting users
- Authentication Center **(AuC)**
  - **Secret keys stored here**
- Equipment Identity Register **(EIR)**
  - Large DB of valid equipment on the network.
- Gateway Mobile Switching Center (GMSC)




NOKIA


Flexi BSC
Nokia Siemens Networks

2G - GSM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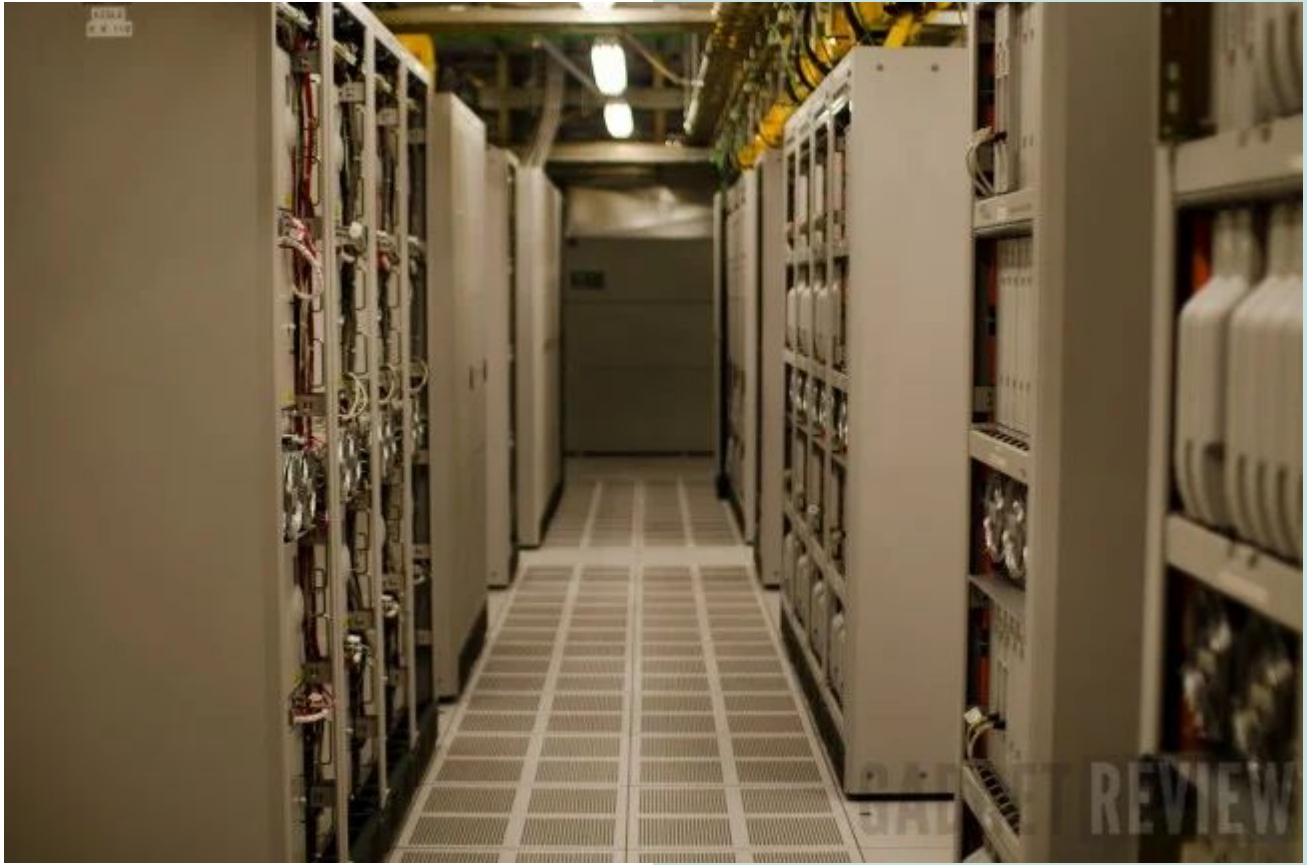
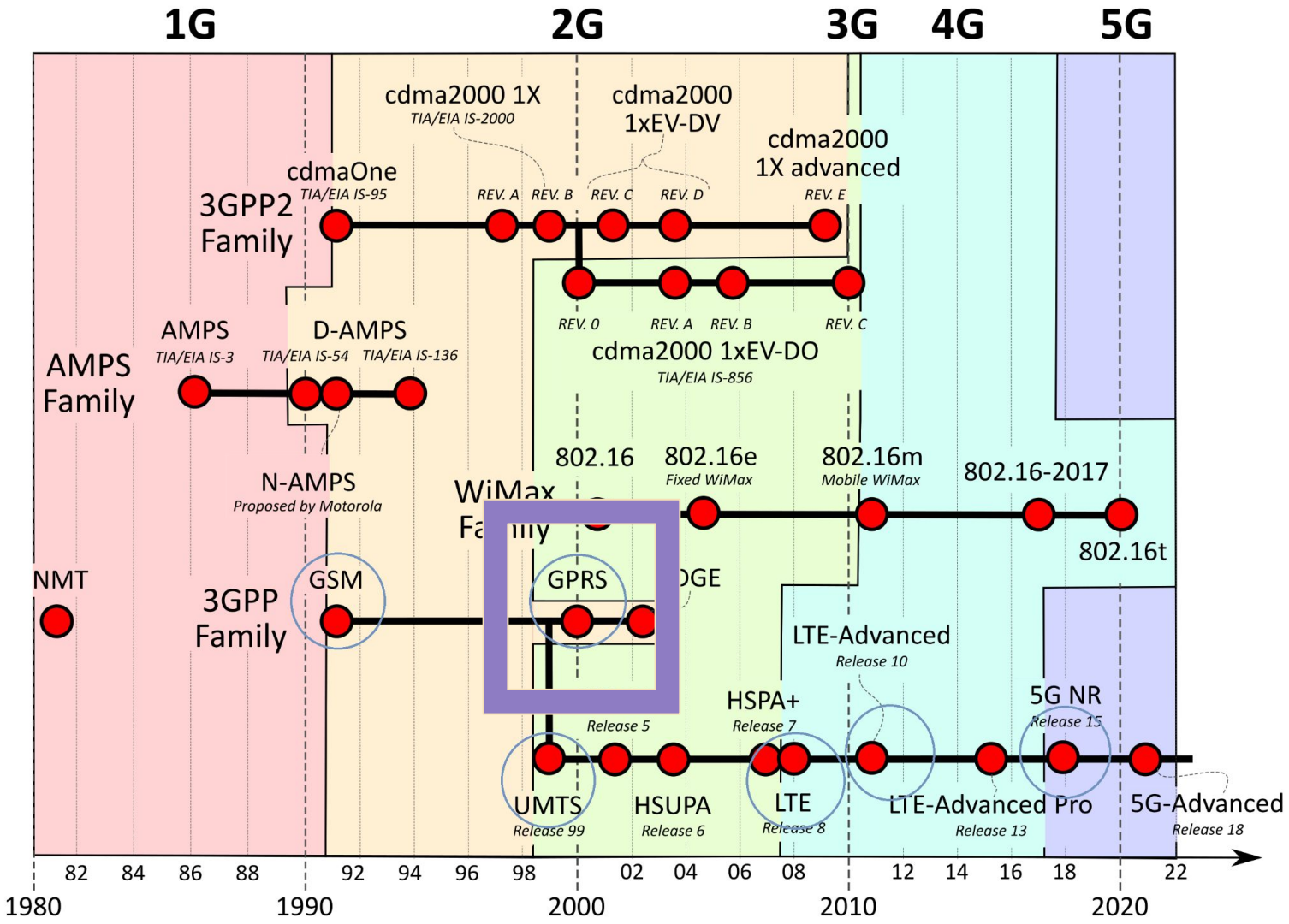
RAN



2G - GSM - Attack Vectors

- No mutual Authentication
  - IMSI-catchers / Stingray attacks
    - Rogue BTS
  - BTS determines encryption scheme!
- A5/1 is easily broken. A5/2 slightly harder but still weak.
- Jamming
- Network based attacks based on outbound signaling protocol
- Clear text tx after BTS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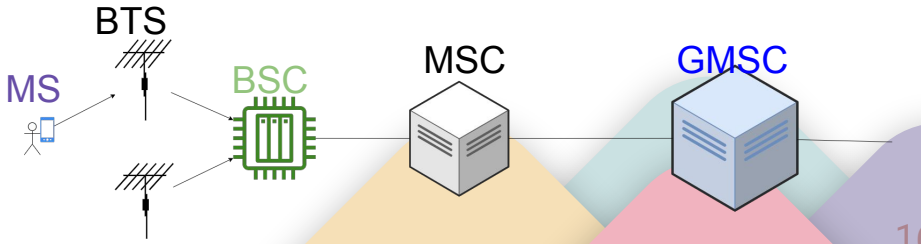
2.5G

GPRS

- Packet Switched + Circuit Switched
  - GSM + IP
- More Services!
  - MMS
  - Push-To-Talk over cellular
  - 4+1 or 3+2 timeslots

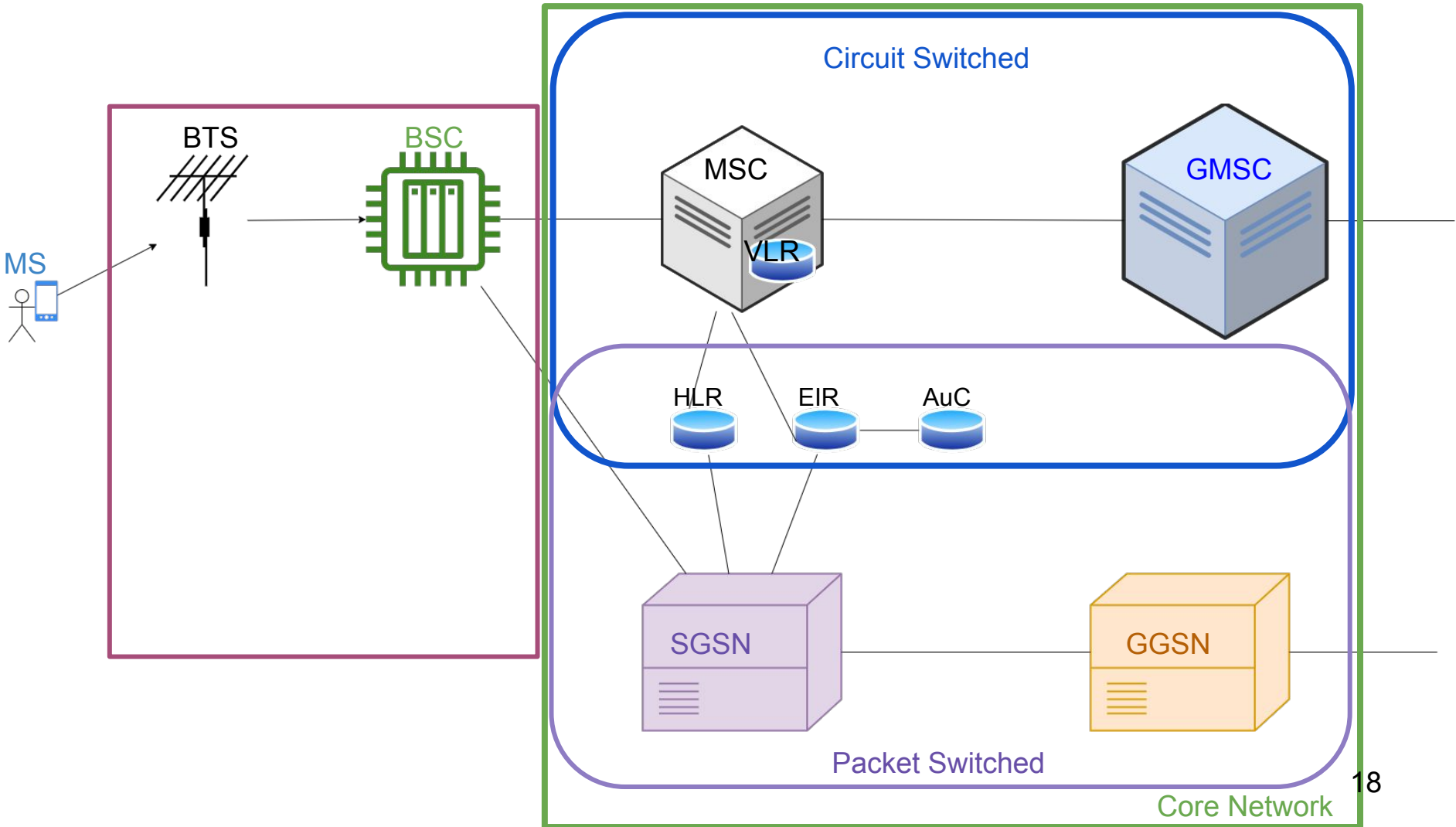
2.5G/GPRS - Network Architecture

- Front part mostly the same
  - Mobile Station **(MS)** / User Endpoint **(UE)**
    - Same thing. Now we also consider the Mobile Equipment **(ME)**.
  - BSS remains the same
    - **BTS** and **BSC** still there
- Circuit Switched Mobile GateWay **(CS-MGW)**
  - Hands it off to the known MSC.
- **MSC** functionality of before is needed for both portions of the network
  - Still feeds into the GMSC



2.5G/GPRS - Network Architecture

- GPRS Support Nodes
  - Serving GPRS Support Node (SGSN)
    - location, sec and access controls, mobility management and charging
    - communicates with other **SGSN** or **MME** (mobility management Entities) in same network and/or reaches out to the **GGSN**.
  - GPRS Gateway Support Note (GGSN)
    - a router in the subnetwork.
    - Converts incoming IP traffic into GSM and hands that off to the **SGSN**.
- Border Gateway and/or Charging Gateway
  - GGSN often contains this functionality


Circuit Switched
BTS
BSC
MSC
VLR
GMSC
MS
HLR
EIR
AuC
SGSN
GGSN
Packet Switched
Core Network

Mitigations from 2G

- Mutual Authentication for Packet Switched Portion
- Authentication between MS and SGSN
- Some level of Ciphering algorithm for SGSN.
  - PDU still transmitted in plain text.
- SGSN identity verification.

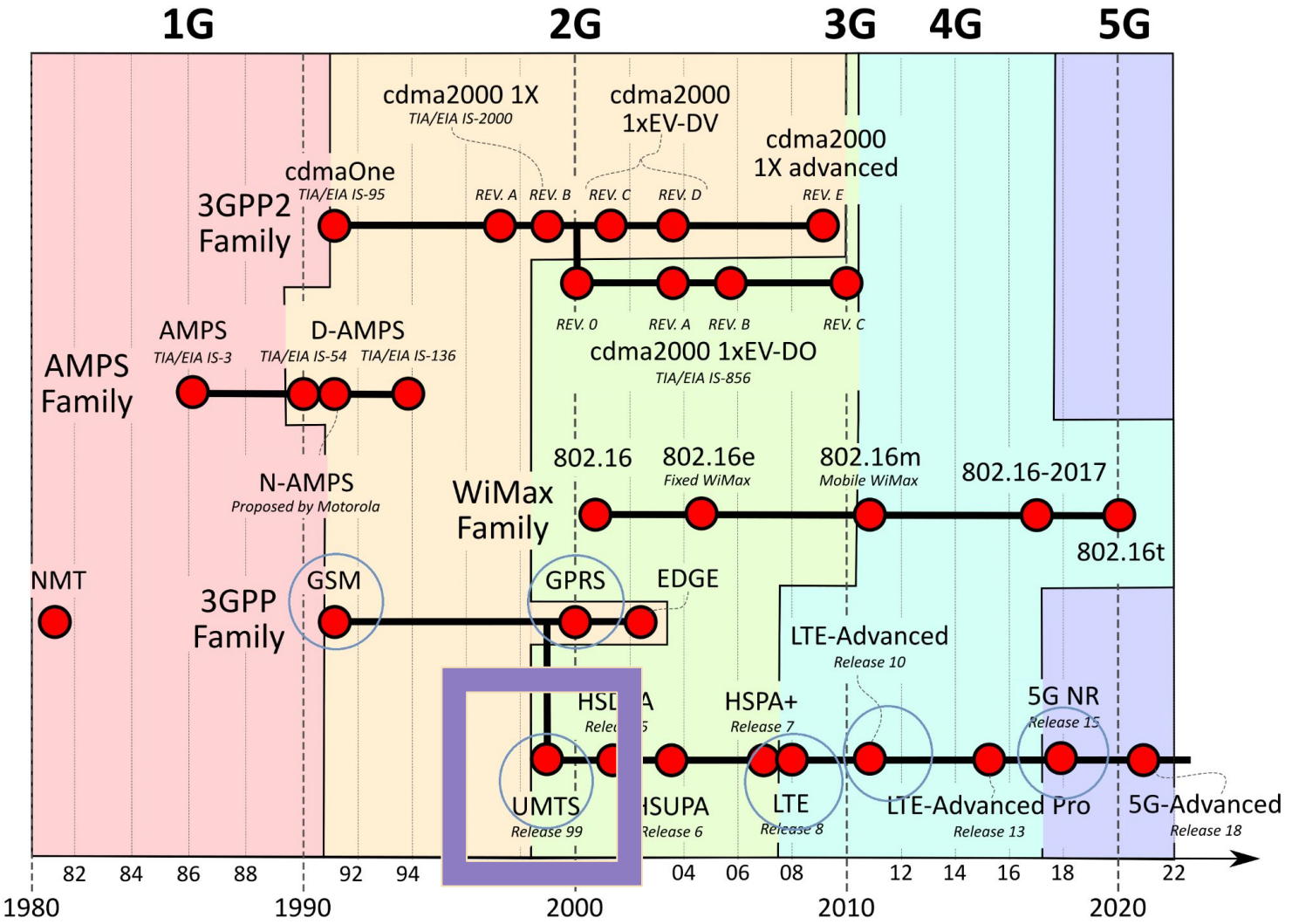
2.5G/GPRS Attack Vectors

- Same known rogue BTS flaws
- Some implementations without any encryption
  - Italy and Denmark according to P1
- Nokia GGSN attack
  - non-standard IP options in a packet over the Gi interface
- GTP weaknesses
  - GPRS Tunnelling Protocol has no encryption for User Plane or Control Plane.
  - Infra attacks, overbilling, protocol anomaly attacks
- Cisco GGSN ASR 5000
  - Improper Wireless Session Protocol (WSP) packet handling
    - Portal Page bypass
  - Improper HTTP packet handling
    - Send requests through GGSN without Verifying!

3G

UMTS

- More internet functionality!
- Video Chat!
- Mobile Broadband!
- SIGTRAN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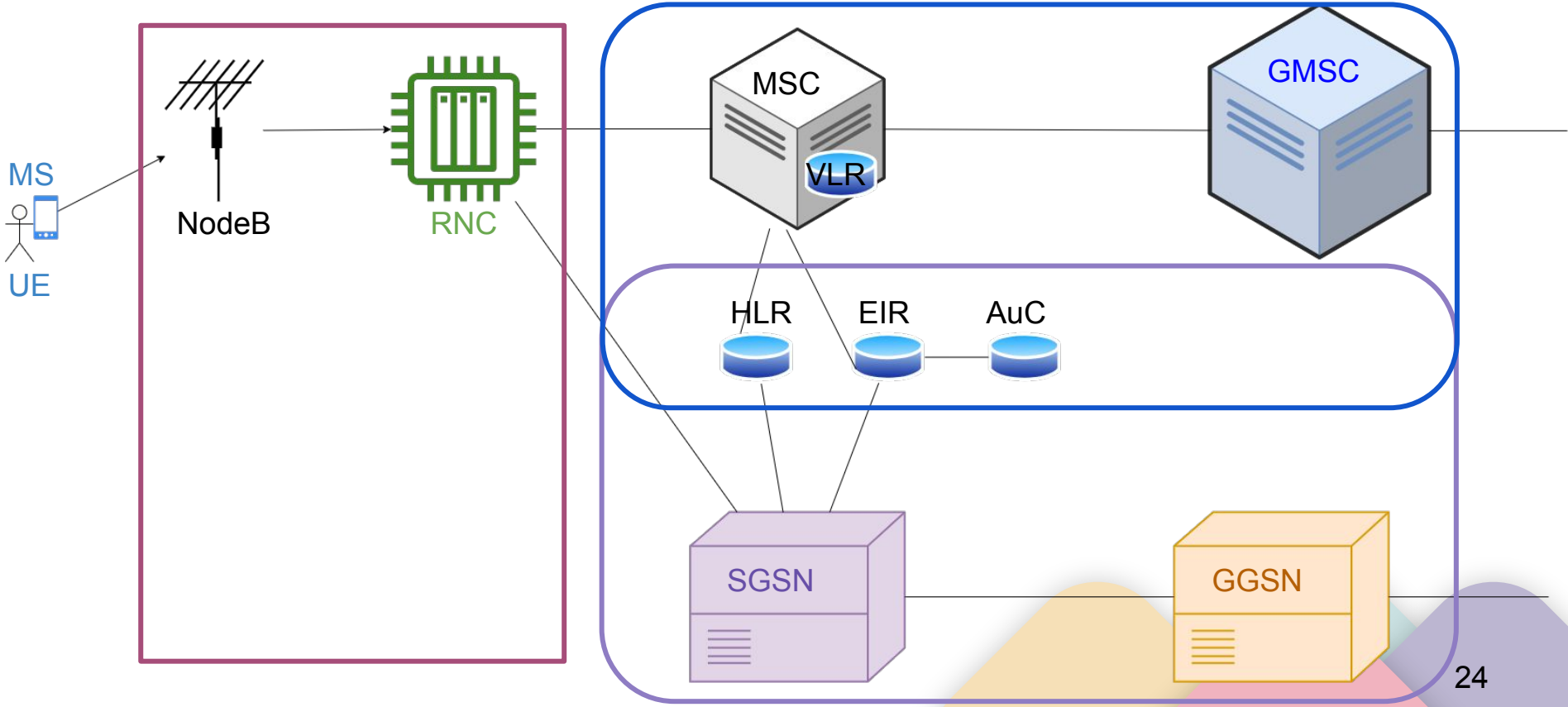
3G - UMTS -Network Architecture

- Kept most of GPRS
- RAN is now called UTRAN **(UMTS terrestrial Radio Access Network)**
- NodeB
    - This is literally the same basic placement in the network and functionality as the
- Radio Network Controller **(RNC)**
    - In charge of all NodeBs for radio management.
    - Some Mobility Management
    - User data encryption

3G - UMTS - Architecture

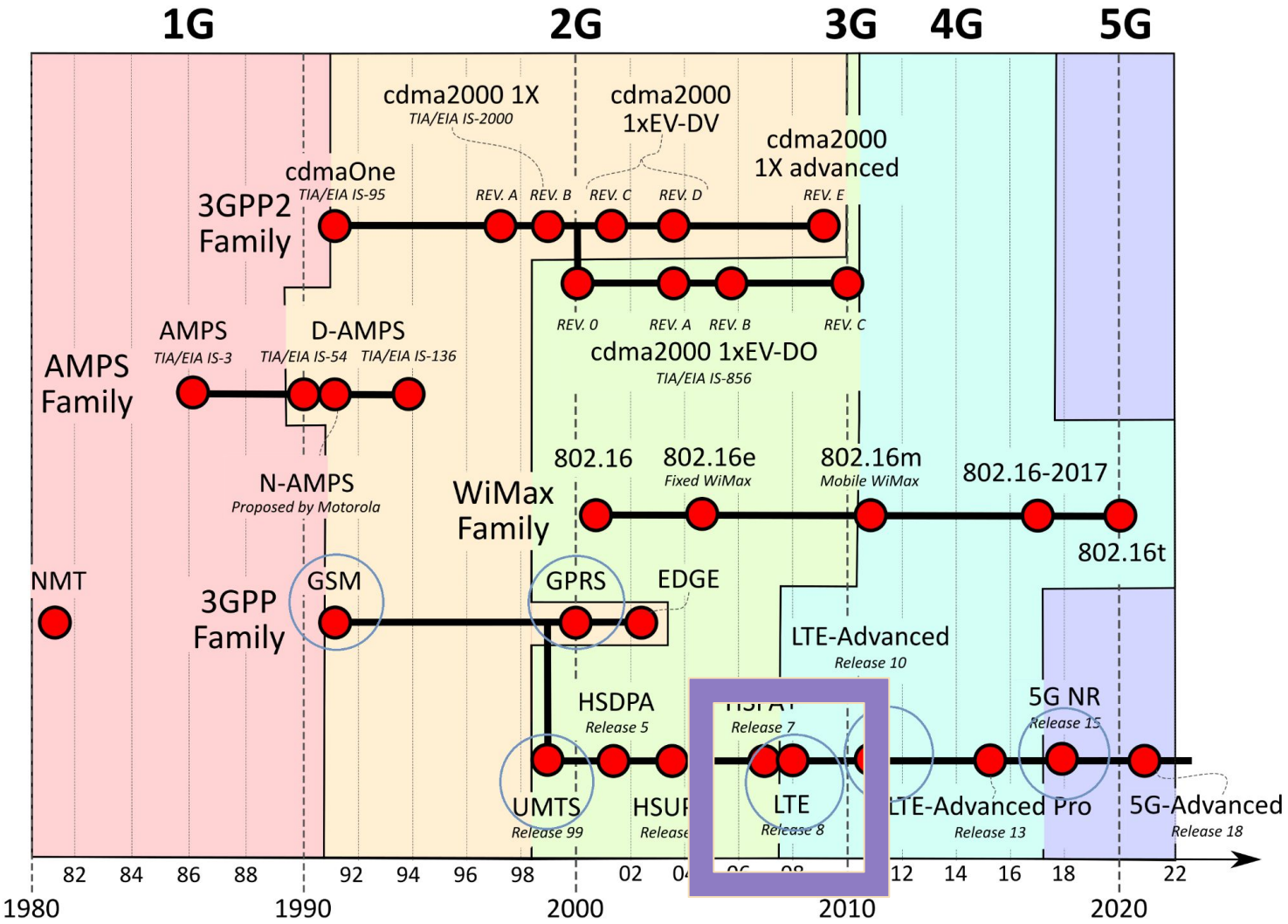


Mitigations from 2.5G

- (Attempts at) IMSI catcher mitigation
- Radio Access Link preserves IMSI confidentiality
- User Location confidentiality
- Signaling plane and user plane now have confidentiality requirements in the specs!
- Security should now be shown to the user
    - eg when hand off occurs to 2G
- True Mutual Auth!?

3G - UMTS - Attack Vectors

- Rogue **NodeB** (BTS) can still happen
- Remote IMSI Attack
  - Integrity keys between **UE** and **RNC** are generated in the Core Network and tx unencrypted to RNC, and sometimes between RNCs
  - Integrity of user data is not defined
- Signaling Plane **RAB**
- Mobile Network Operators receiving **UE** capabilities plain-text
- **HLR** overloading using SQN
- Cisco ASR 5000 Series GGSN
  - Not properly handling TCP packets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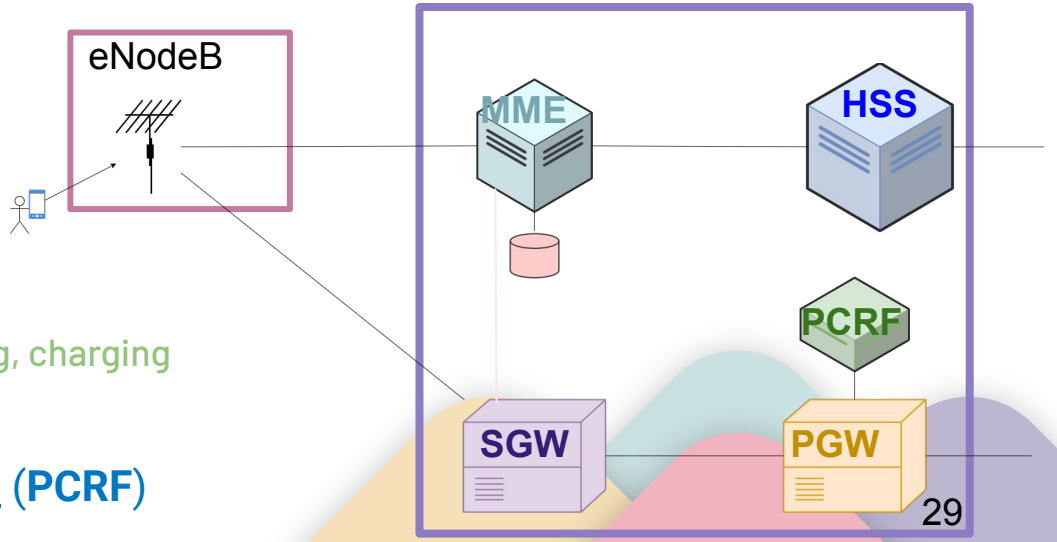
LTE

- 3.95G? 4G? Guess it’s called 4G now?
- Core network is now Evolved Packet Core aka System Architecture Evolution
- VoLTE, carrier adopted improvements
- Diameter

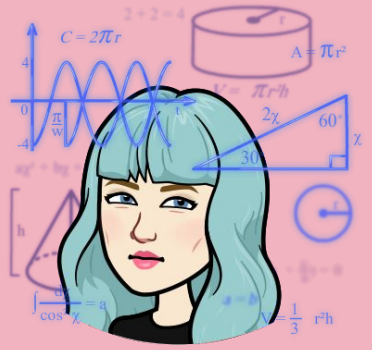
LTE - Network Architecture

- eNodeB
- Mobility Management Entity (**MME**)
  - replaces the RNC
  - Directs to appropriate SGW.
- Home Subscriber Server (**HSS**)
  - HLR and AuC combined
- Signal Gateway (**SGW**)
  - Routes and Forwards packets.
- PDN Gateway (**PGW**)
  - policy enforcement, packet filtering, charging
  - Gateway to the outside
- Policy and Charging Rules Function (**PCRF**)



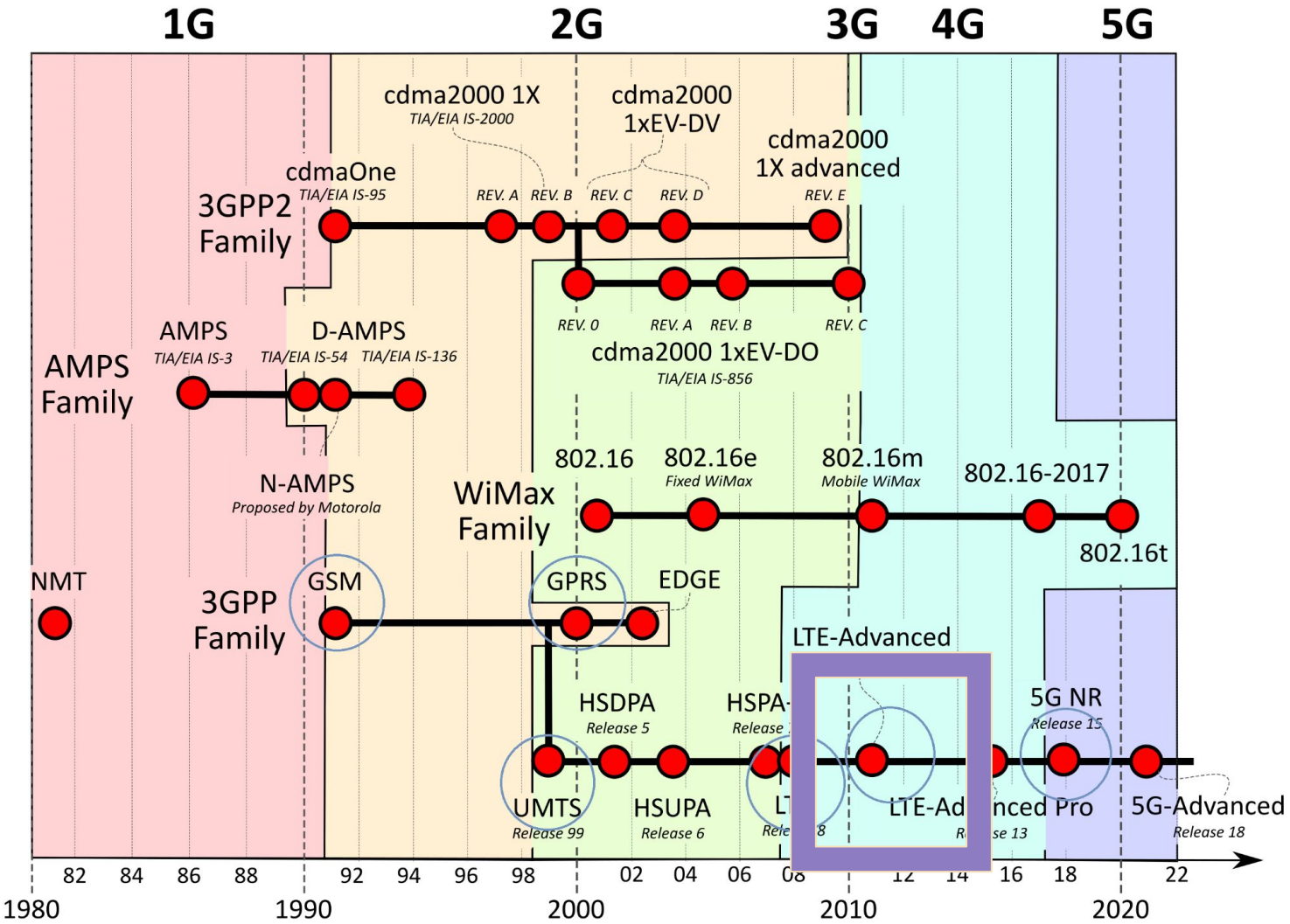
Mitigations

- eNodeB security?!
- IMEI is not sent to eNodeB until NAS (non-access stratum) security established
- EEA0
  - Null X algorithm (Null ciphering algorithm, Null integrity protection algorithm
- Mobility Management is now split apart and in its own entity for MME



LTE - Attack Vectors

- LTEinspector
  - LTEInspector: A Systematic Approach for Adversarial Testing of 4G LTE by Hussain, Chowdhurry, Mehnaz and Bertino paper on these attacks.
    - Authentication Relay Attacks
    - Paging Channel Hijacking Attack
    - Panic Attack
- Bidding Down Attacks
  - Capabilities downgraded in quality.
  - Service can be downgraded to 3g or 2g
- Actual Implementation Errors for Identifiers
- Cisco PGW 2200 Remote DOS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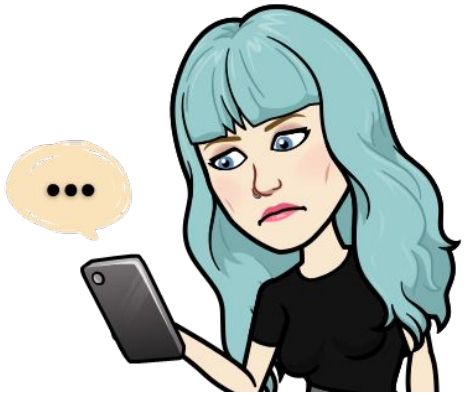
4G

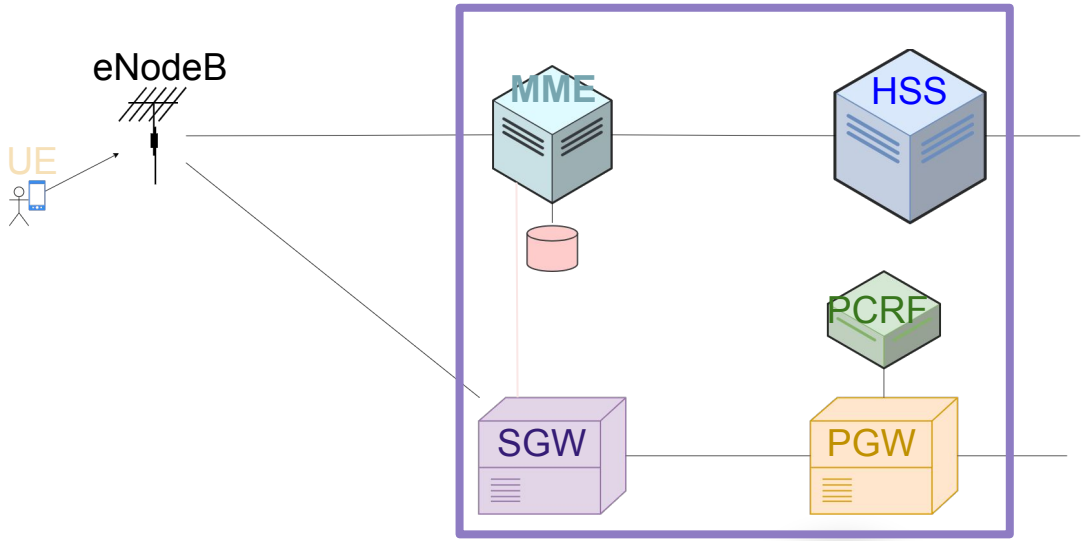
LTE Advanced, LTE Advanced Pro



- IPv6 expansions
- Adaptive modulation
- Time varying channel
- Voice over LTE
- Carrier Aggregation (LTE Advanced) and enhanced carrier aggregation (LTE Advanced Pro)
- IP Multimedia Subsystem

4G - LTE Adv - Network Architecture

- Same as 3.95G
- UE
- eNodeB
- MME
- HSS
- SGW
- PGW
- PCRF



Mitigations from LTE and Prior

- All radio interface data shall be encrypted
- AKA procedure for mutual auth between **UE** and **EPC**
- Different session keys for encryption and integrity protection
- CU-DU to make up eNodeB possible
- MNO may provide confidentiality in Radio Resource Control (RRC) signaling.
- Secondary authentication (for data network outside MNO)

4G - LTE Adv - Attack Vectors

- Still have IMSI catchers!
- Signaling vulns of Diameter
- VoIP SPIT Flooding
  - Syn flooding
  - UDP flooding
  - P2P/M2M attacks
- Router Vulns

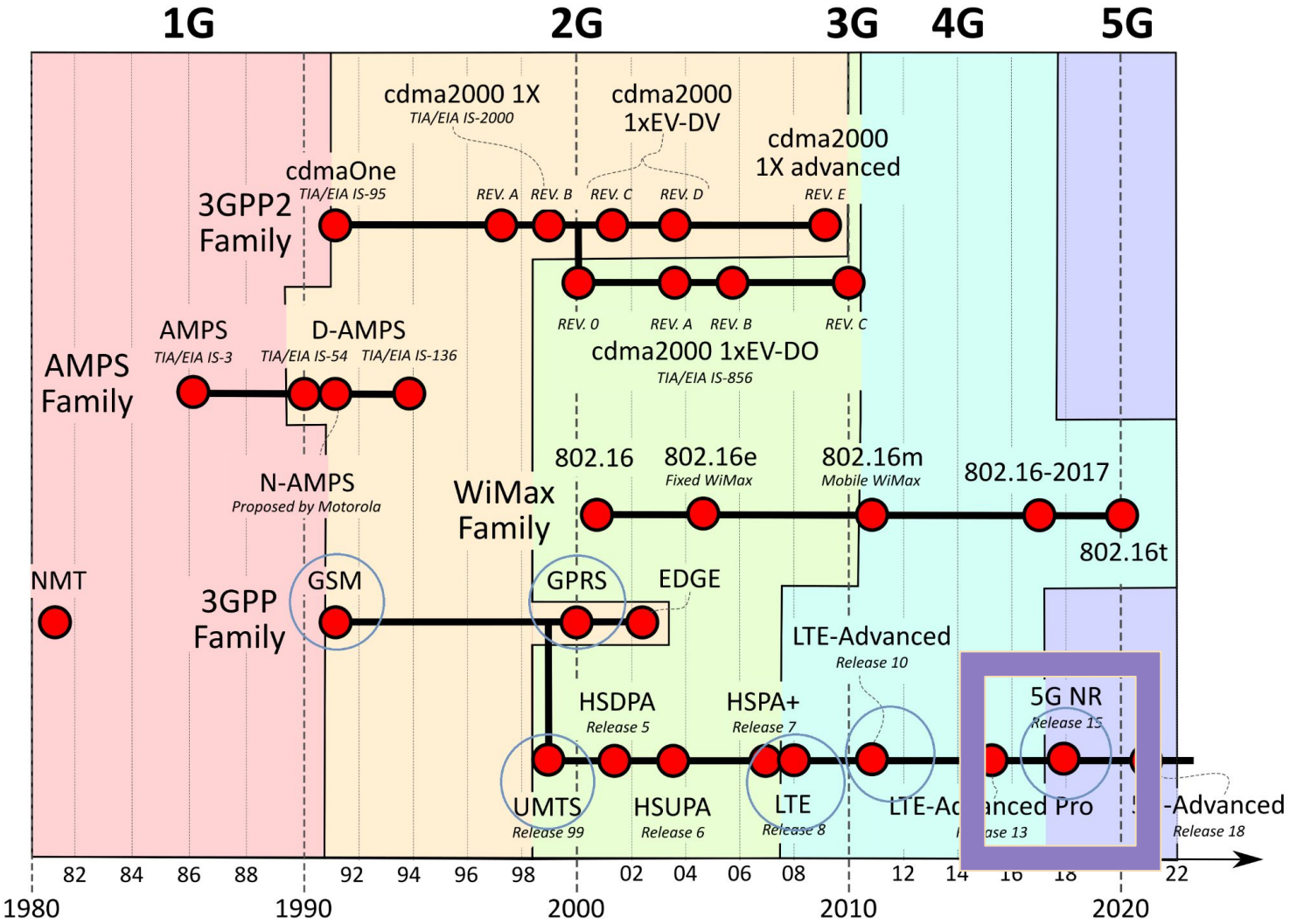
4G - LTE Adv - Attack Vectors

- Cisco ASR 5000 PGW DoS
- MME vuln
  - P1 HITB talk on keys being hardcoded
- MML Interface exposed to the wide internet on some routers
- Bidding down attacks
  - VoLTE can be denied

5G

Not just for telephony!

- Network Function Virtualization
- Management and Orchestration is now officially part of the core network
- New concept of Network Slicing
  - Different devices have different needs!
- Renaming the eNodeB to **gNodeB** just cuz!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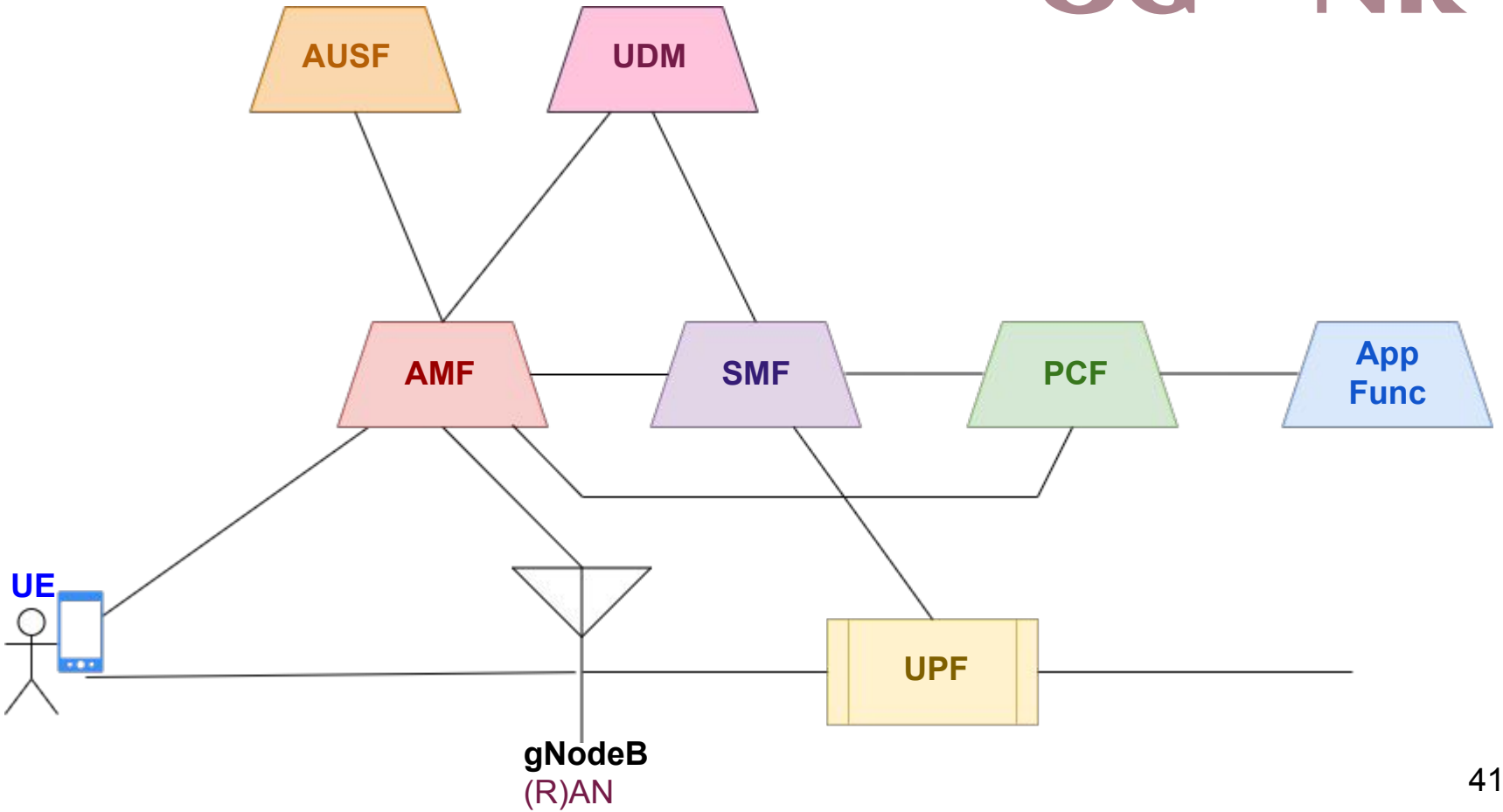
NMT
GSM
GPRS
EDGE
3GPP
Family
LTE-Advanced
Release 10
HSDPA
Release 5
HSPA+
Release 7
5G NR
Release 15
UMTS
Release 99
HSUPA
Release 6
LTE
Release 8
LTE-Ad
ase 13
anced Pro
-Advanced
Release 18
82
84
86
88
92
94
96
98
02
04
06
08
12
14
16
18
22
1980
1990
2000
2010
2020

5G - NR - Network Architecture

- Access and Mobility Management Function **(AMF)**
- Session Management Function **(SMF)**
  - PDU management, pcf interaction for data network profile
  - UPF selection, IP address allocation if IP based
- User Plane Function **(UPF)**
  - Also would have been in **MME**
  - Anchor for NG-RAN mobility and QoS flow, Policy enforcement
- Unified Data Management **(UDM)**
  - Access authorization, Data network profiles
  - Registration and Mobility Management
- Policy Control Function **(PCF)**
  - Dynamic policy decisions and conditions.

5G - NR



5G - NR


SERVICES
NDDP
PLATFORM
SPECTRUM
ANALYZER
Baseband 6502
Baseband 6303
Baseband C608
Baseband P614
Radio 2205
Radio 2242
Radio 4412
Radio 4407
Radio 8808
AIR 6468

Mitigations from 4G

- Initial NAS message confidentiality!
- Subscription Concealed Identifier (**SUCI**) and Subscription Permanent Identifier (**SUPI**) to protect IMSI
- Security and Mobility separated in the core network
- 256bit keys supported
  - ("prepared to" in 4G docs, now "must")
- Mutual auth between Network Exposure Function (**NEF**) and Application Function (**AF**)
- Inter-PLMN UP Security (IPUPS) in UPF at perimeter to protect user plane messages (GTP-U).
- **AUSF** and **UE** now have SoR counter to mitigate replay attacks.
- Security Anchor Function (**SEAF**) allows AKA to skip full reauth

5G Attack Vectors

- RA and CN don't require authentication. Location sniffing attack
  - Place sniffing tool near target UE
    - Monitor for plaintext AuthReq msg
    - The message contains RAND and AUTN
  - Build an AuthReq message using that RAND and AUTN.
  - Broadcast fake message.
    - MAC check fails if not target UE
    - Victim UE passes MAC, fails SEQ
    - If all messages fail MAC verification, the UE is not nearby. If one SEQ failure, it is nearby.

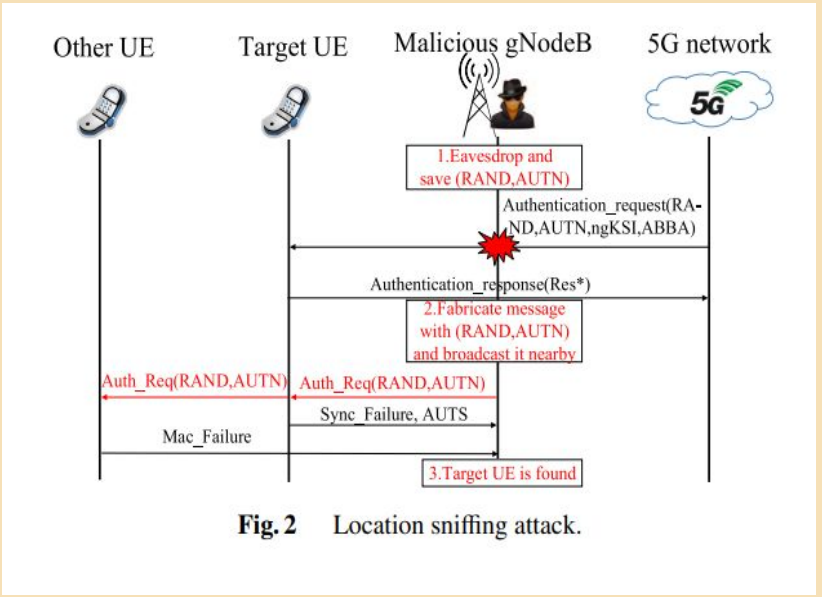


Fig. 2 Location sniffing attack.

https://www.jstage.jst.go.jp/article/transinf/E103.D/8/E103.D_2019FOL0001/_pdf

5G Attack Vectors

- Attach Req Injection
- Battery Draining
  - NB-IOT and LTE-M devices in particular can be drained like 5x faster than expected
- AKA Attack
- Sending malformed packets can trigger crashes in 5g cores. Yes, still.
- Network Slicing Vuln
  - Deloitte gave a talk at RSA about this.
  - Navigate up a network slice looking for other vulnerable devices.
- Multi-Access Edge Computing (MEC)
- HTTP/2 Attacks
  - Stream Reuse
  - Closed Stream
- End-to-end China Unicom

Review

- 2G: Digital Technology! Voice and Data. Circuit Switched. User, BSS, MSC, GMSC.
- GPRS: Both Circuit and Packet Switched! Added the SGSN and GGSN.
- 3G: UMTS NodeB, RNC, kept SGSN and GGSN.
- LTE: Evolved packet core! eNodeB, Mobility Management, Signal Gateway and PDN Gateway.
- 4G: VoLTE, IPv6, IMS. Kept devices same.
- 5G: Virtualization. Network slicing. gNodeB. Functionality generally split into "functions" instead of devices.

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Questions?

Thank you!!!

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