the baseband bane

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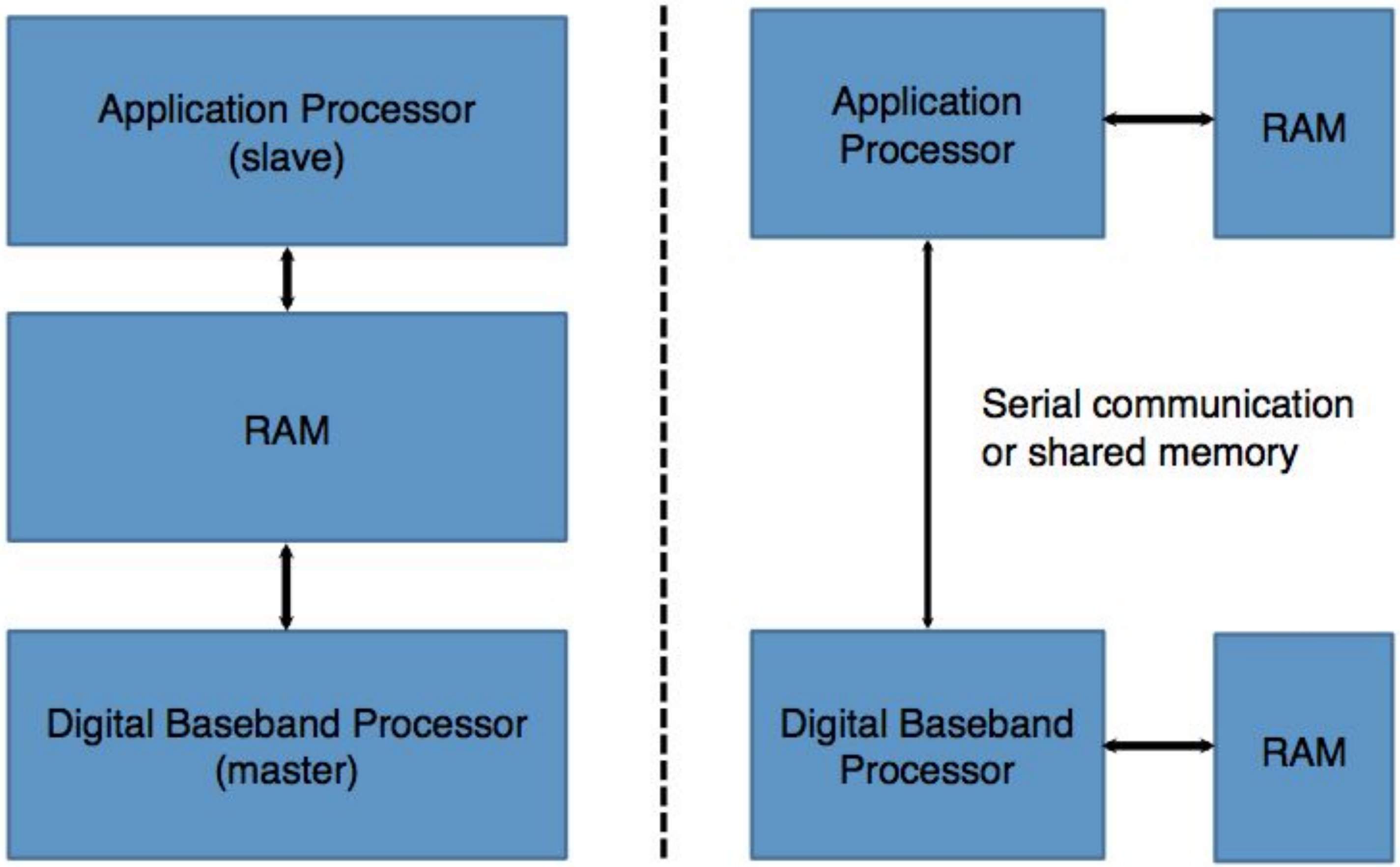
A Typical Smartphone

- How many processors?
  - The application processor (AP) – The one advertisements talk about
  - Qualcomm Snapdragon, Samsung Exynos, Apple A series
  - The communications processor (CP) – The Internet!
  - Low power ARM CPUs – Protocol Stack Processor
  - Qualcomm X12, Samsung Shannon S333
- How many Operating Systems?
  - AP – Android, iOS
  - CP – RTOS to handle time critical operations
    - Proprietary, closed source
    - Nulceus OS, ThreadX, Shannon OS



Application Processor (slave)

RAM

Digital Baseband Processor (master)

Application Processor

RAM

Serial communication or shared memory

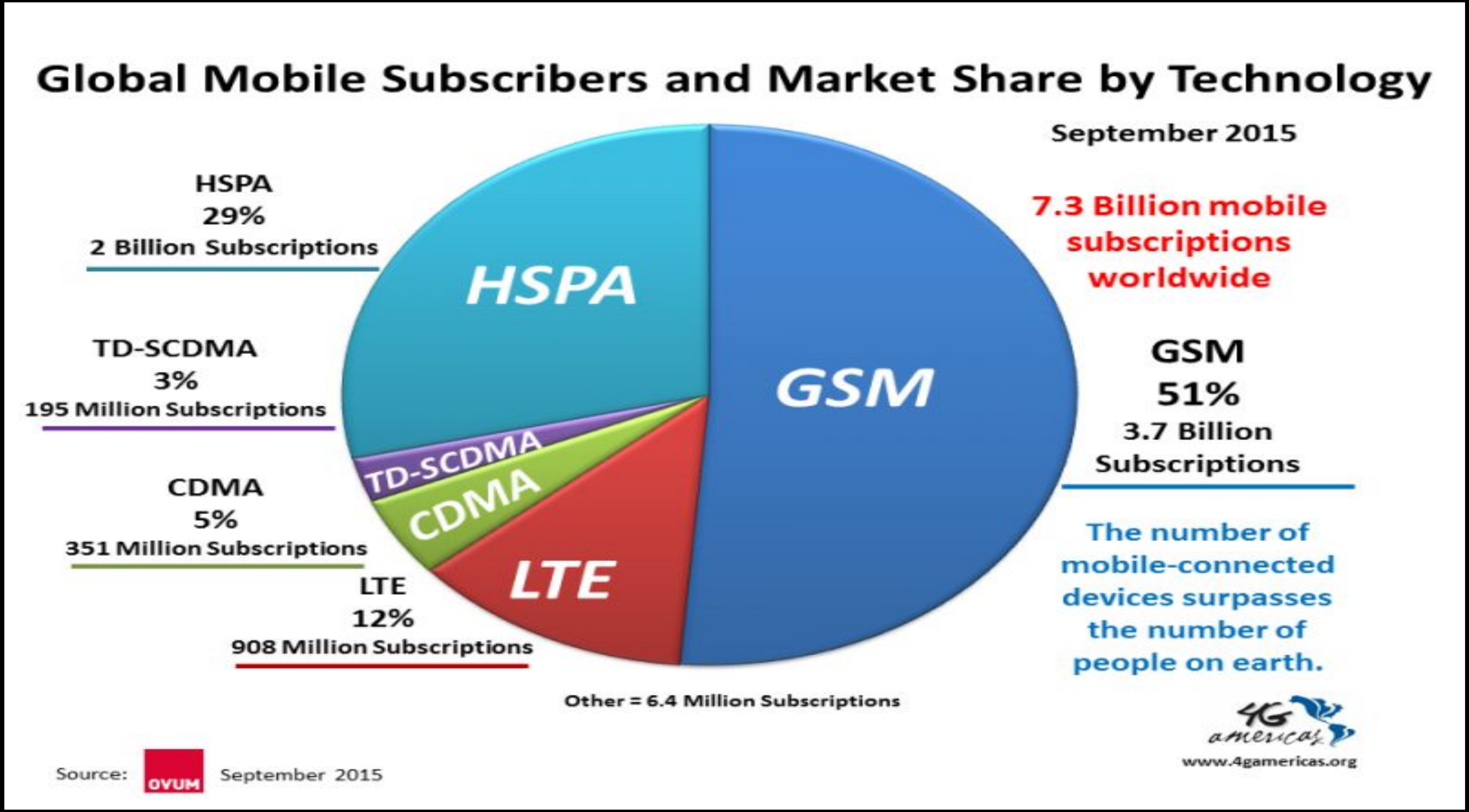
Digital Baseband Processor

RAM

Shared memory architecture

Baseband as modem

Radio access technology



Global Mobile Subscribers and Market Share by Technology

September 2015

7.3 Billion mobile subscriptions worldwide

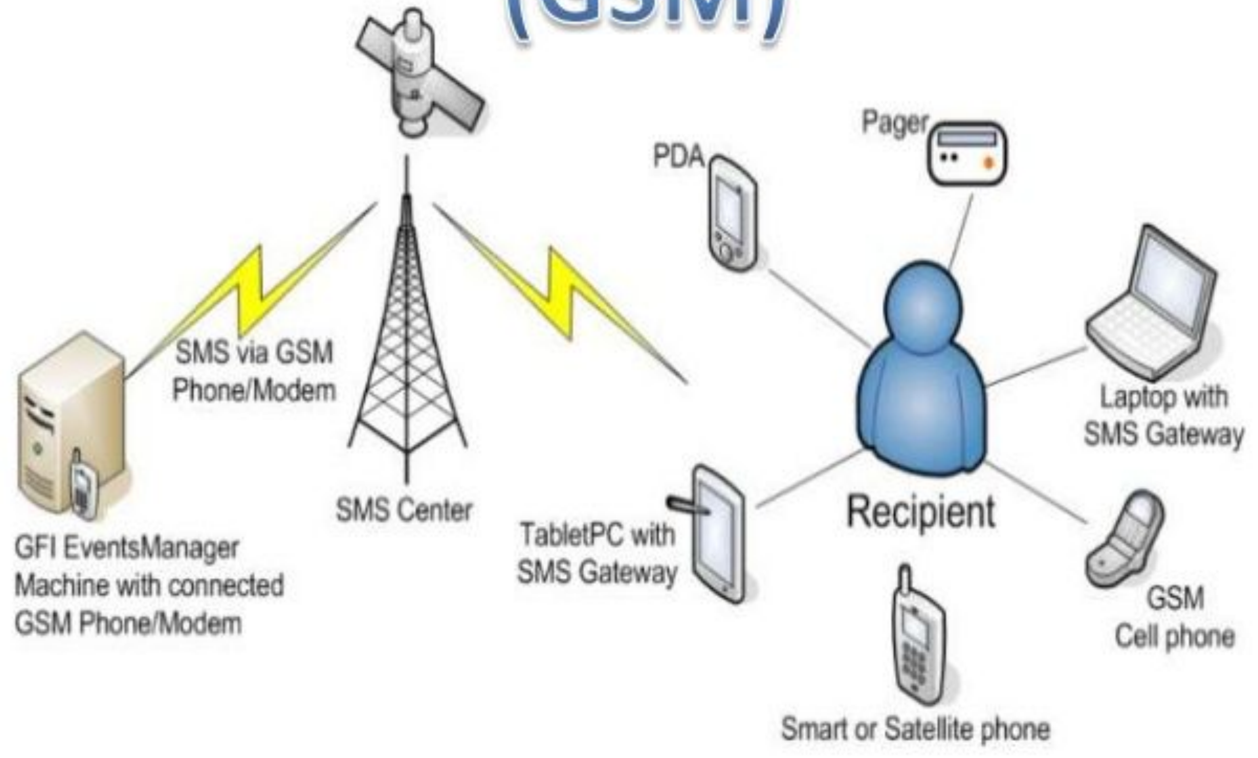
The number of mobile-connected devices surpasses the number of people on earth.

Other = 6.4 Million Subscriptions

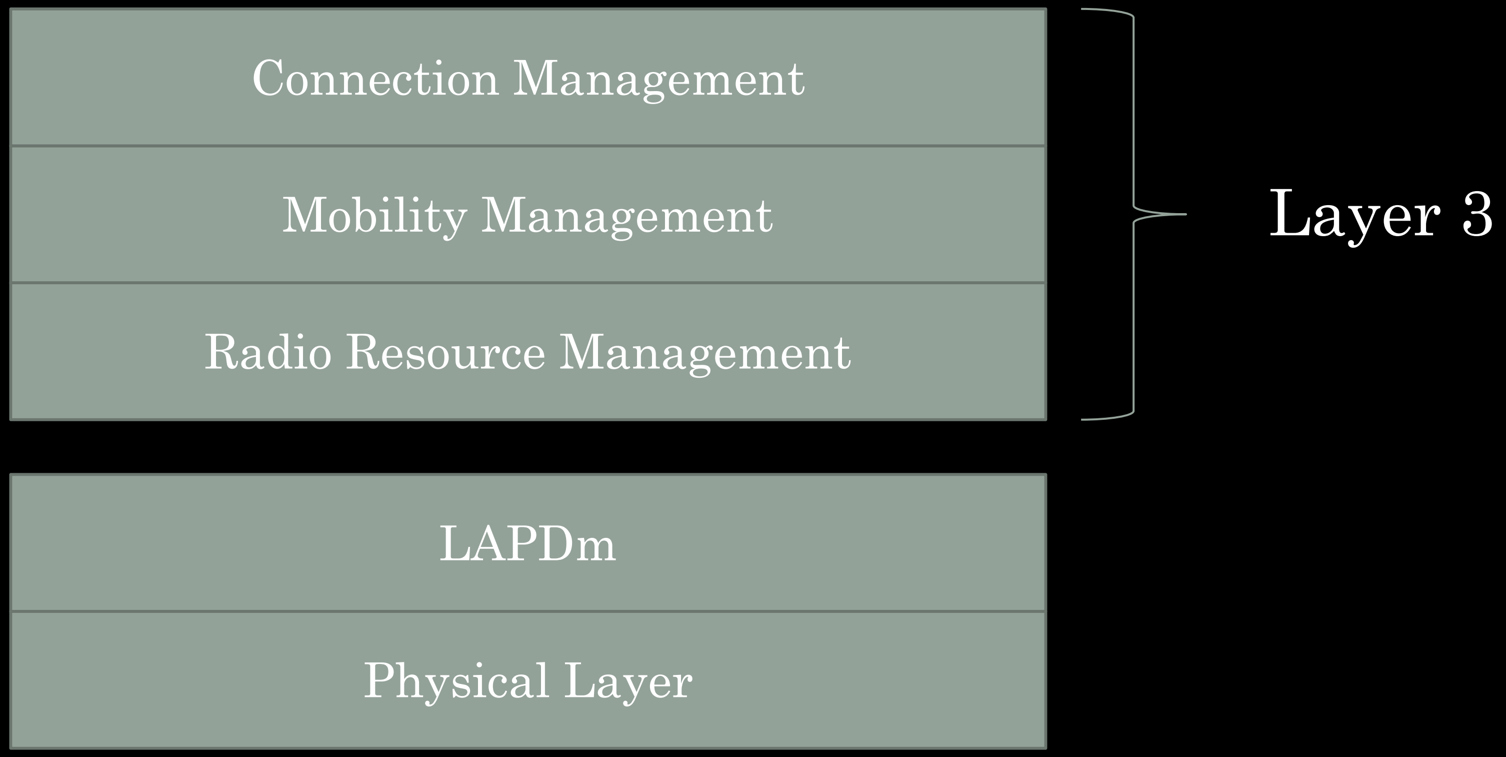
Source: OVUM September 2015

4G americas www.4gamericas.org

Global System for Mobile (GSM)



GSM PROTOCOL STACK



Connection Management

Mobility Management

Radio Resource Management

Layer 3

LAPDm

Physical Layer

Baseband Protocol stack

- Code base created in the 1990s… With a 1990s attitude towards security
- Network elements like Base Transceiver Station(BTS) are considered trusted
  - Very expensive back then
  - Now - Rogue BTS can be fashioned for as little as 1500 USD
- Layer 3 Protocol – Specified in GSM 04.08
  - Allows for variable length messages
  - Maximum Length: 255 Bytes (Length Field: One Byte)
- Some messages specified to be encoded as variable length messages
- …even though the message description implies that it is of fixed length
- Potential Exploit!

Finding Bugs

- Fuzzing – Providing invalid, unexpected and random data as protocol messages
  - Baseband crashes, but no way to glean any information from crash logs
- Static Analysis – Analyze code without executing it
  - No source code publicly available
  - Exception – Vitelcom TSM30 source code was leaked in 2004
  - Helped understand the general architecture of the GSM protocol stack code
- Conclusion – Reverse engineer binaries
- OTA firmware updates contain baseband firmware as well

Reverse engineering binaries

- Tools for identifying interesting code paths – IDA Pro Disassembler and Google BinDiff
- Disassembler translates machine language into assembly language – inverse of assembler
- BinDiff compares and identifies identical and similar functions in disassembled code
- BinDiff generates function “fingerprints”
- Run both tools on target binary and a known code base – VSM30 to the rescue!
- Helped identify functions like memcpy() and memmov()
- Then identify functions that used variable-length memory copies
- Check if they employed sufficient length checking for the copied or moved data

The bugs!

- Insufficient length checks, aka, unchecked memory copies
  - Found in binary once memcpy() et al. are identified
- Object/structure lifecycle issues
  - Generous use of state machines in GSM
  - Use-after-free bugs, uninitialized variables, unhandled states
  - Harder to exploit these bugs
- Code path pains
  - Code paths used for 3G (UMTS) can be triggered using GSM messages

Example (Infineon Code base)

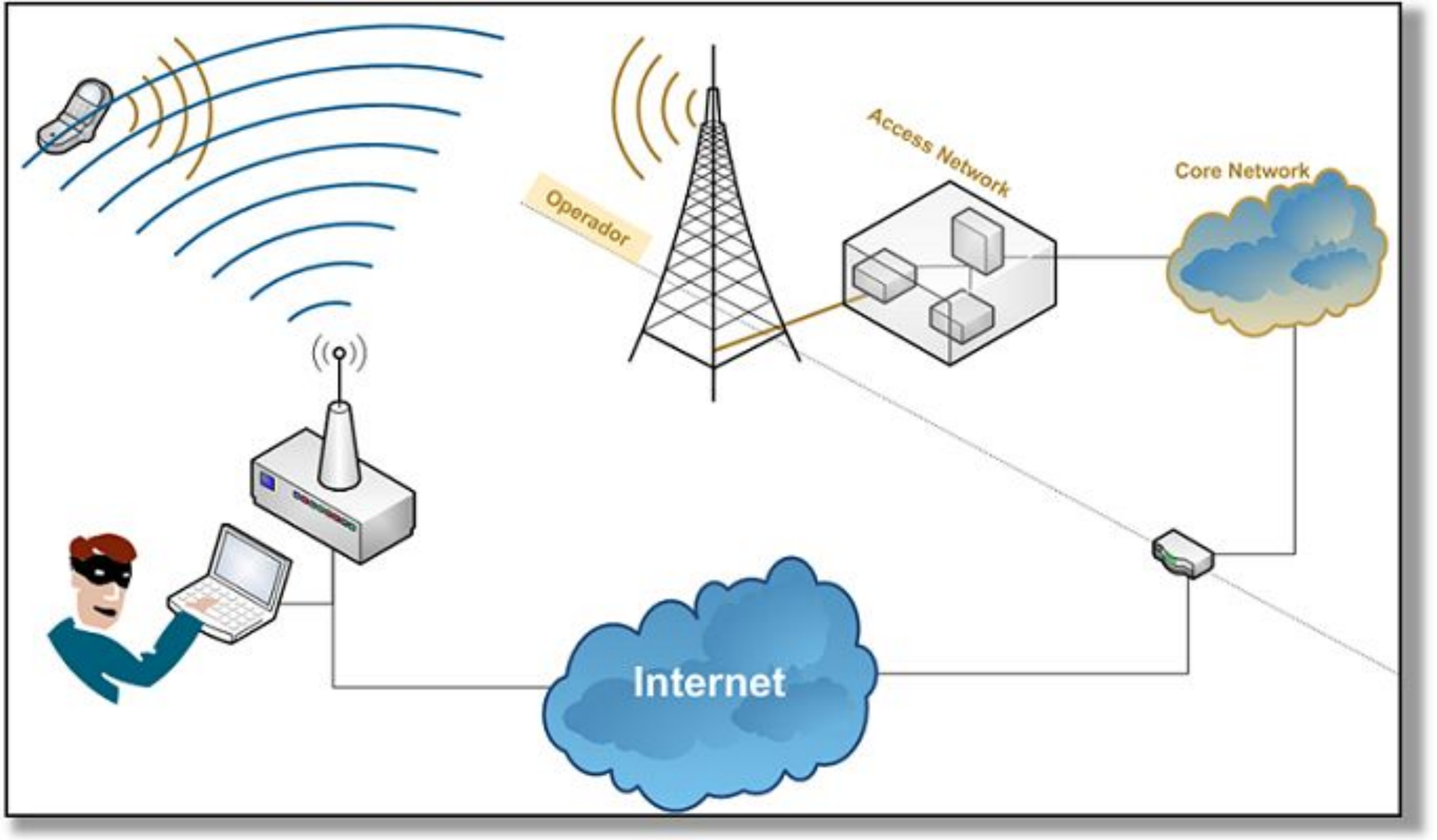
- TMSI – Temporary Mobile Subscriber Identity
  - Always a 32 bit value
  - For some reason, encoded with a length field
- Engineer A allocates only 32 bits for the TSMI value
- Engineer B trusts the length field and copies the value sent by rogue BTS into location above
- Results in a heap overflow
- Tricky to exploit in a stable way – leads to a modem crash
- Issue identified in iPhone 4 – Fixed in the subsequent point update to the OS

Example (Qualcomm code base)

- For authentication in GSM, BTS transmits a 16 byte challenge value called RAND
- 3G (UMTS) uses a variable length message called AUTN, but is specified to also be only 16 bytes long
- Qualcomm stack accepts the AUTN challenge even when operating in GSM mode
- Apparently a workaround used by Qualcomm for compatibility reasons
- Rogue BTS sends AUTN message of length > 16 bytes
- Stack overflow as only 16 bytes are provisioned for RAND challenges
- Result – Remote code execution (before successful authentication)
- Qualcomm fixed it after disclosure

‘AT + s0 = n’ feature exploited

- Hayes AT command set – a specific command language developed for modems in 1981
  - Short text strings combined to produce commands for operations like dialing, hanging up and changing connection parameters
- AT + S0 is a Hayes command to turn on auto-answer
- Code exists in Infineon and Qualcomm stacks to enable this feature
- For instance, *5005*AANS# enables auto answer on the iPhone 4
- First, locate the AT command handler function for setting S0 register
- Requires examining memory and register contents at runtime
- Enter, JTAG
  - **Joint Test Action Group – developed standards for on-chip instrumentation**
  - **Processors use JTAG-specified port to provide debugging information**
  - **Software Patch allows JTAG access in HTC dream (Qualcomm baseband)**


Operador
Access Network
Core Network
Internet

Target – HTC Dream (Qualcomm)

- Rogue BTS - Ettus Research USRPv1, provides RF processing capability
  - Supports two daughter RF boards, for transmit and receive
  - OpenBTS, running on a laptop, modified with patches to perform the exploit
- Phone tries to authenticate with the rogue BTS
- Use the AUTN exploit previously discussed, which causes a stack buffer overflow
- Overwrite the program counter and register r0 of the stack frame
- PC with the entry point of s0 register handler, r0 with value 1
- Overwrite the subsequent stack frame's PC as well to ensure smooth execution (no crash)
- With the rogue AUTN message, less than 100 bytes long, this exploit is possible
- Auto answer is enabled without the user being aware

Impact

- Place Rogue BTS in crowded/sensitive areas
- Audio routing on most chipsets is done on baseband CPU
- Which means it has access to the built-in mic
- Baseband processors have large quantities of RAM available
- Record audio, store in ram, piggy back onto the next data connection
- Shared memory architecture – AP can also be compromised
  - Higher layer security features are bypassed
- Brick phones permanently

Solutions?

- Open source baseband stack
  - Quicker at identifying bugs
  - But still hard to patch them as phones need to be carrier certified – long process
- Isolation
  - Cut off baseband access to the mic when not on a call
- Stringent quality control by CP manufacturers
  - Use tools like coverity to check for possible buffer overflows
- Problem is worse with 3G
  - Radio Resource Control protocol specifications almost 1800 pages long
  - Messy, complicated
  - LTE is cleaner

References

- Baseband Attacks: Remote Exploitation of Memory Corruptions in Cellular Protocol Stacks - Ralf-Philipp Weinmann, *University of Luxembourg*