Wendell Crenshaw Technologies

presents

Tumbleweed

All Your Baseband Are Belong To Us

over-the-air exploitation of memory corruptions in GSM software stacks

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Outline

- GSM / Smartphone basics
- Baseband software (in)security
- Practicality of exploitation
- Demo
- Scenarios for the “baseband apocalypse”
- Disclosure, outlook & conclusions

Part I: GSM and smartphone basics

Lay of the GSM/UMTS land

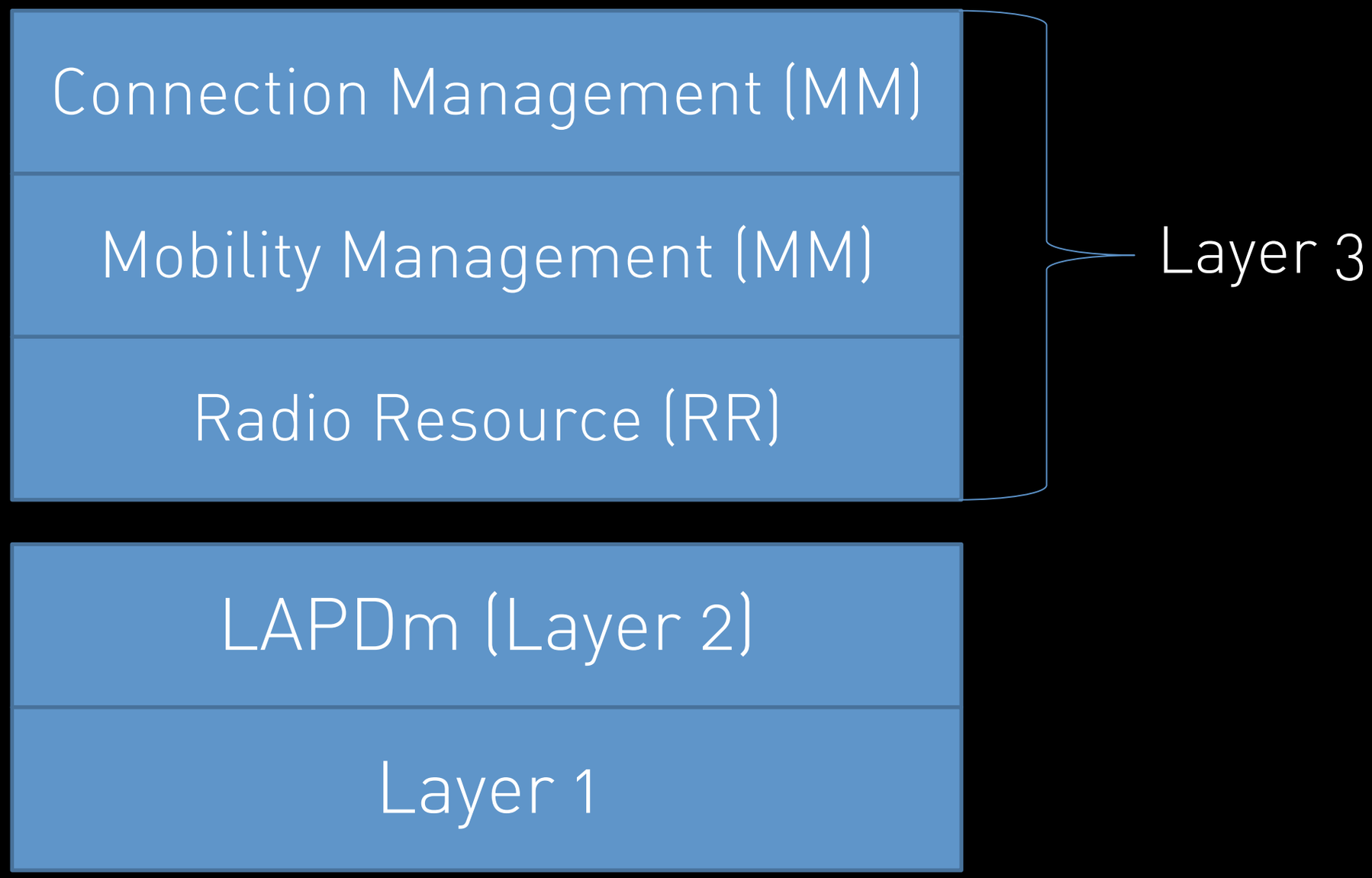
MS (Mobile Station)

links to outside world [BSCs, VLR, HLR/AUC, SS7]

Um (air) interface

BTS (base transceiver station) [Usually located at cell tower]

Layers of the GSM Um interface

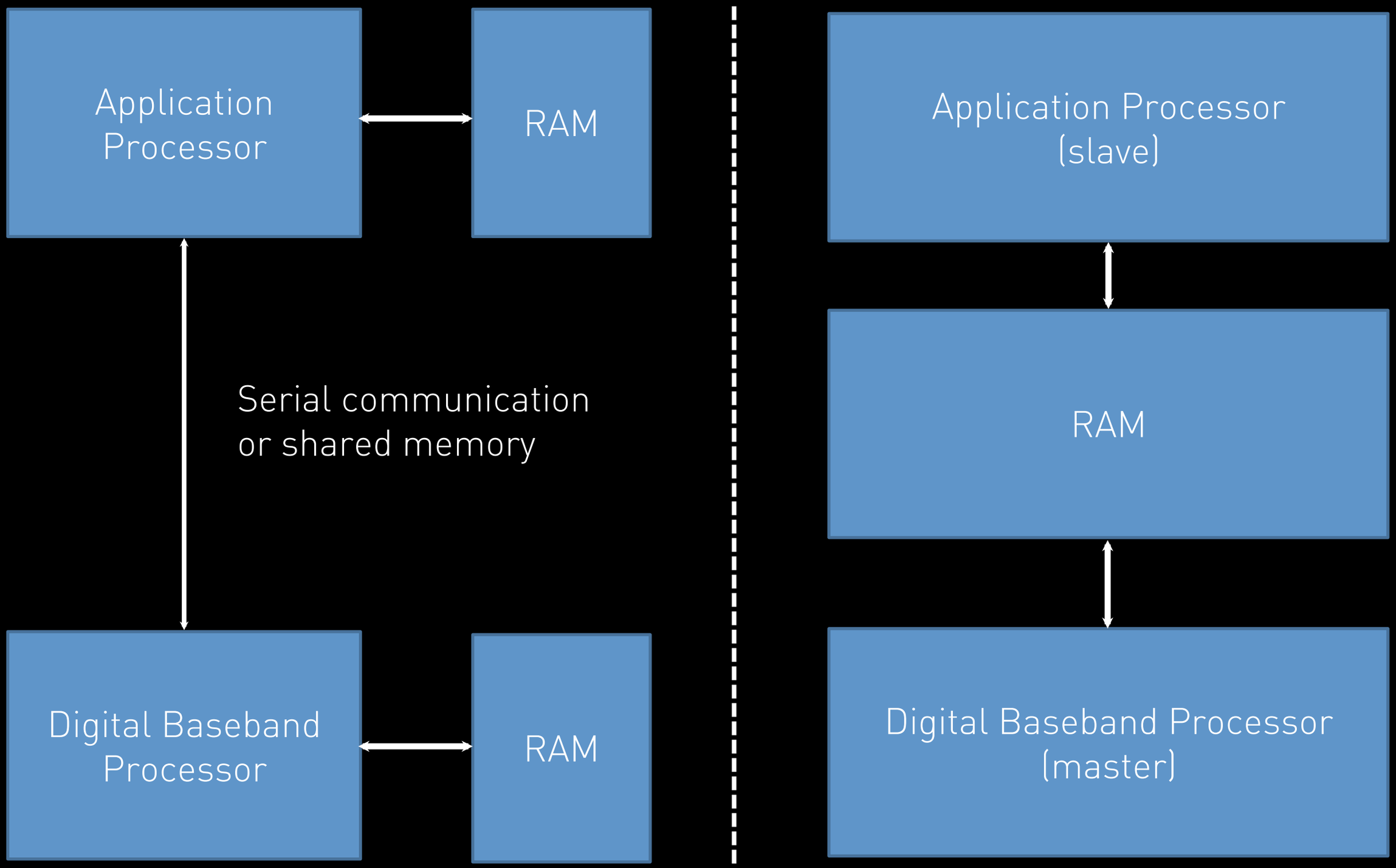


Smartphones

- Somewhen in the late 20th century, PDAs and cellular phones merged
- Result: smartphones
- Have driven PDAs into extinction
- Usually a multi-CPU architecture: application processor (APP) and baseband (BB) processor
- In 99% of all cases, ARM CPUs used for both
- Trend: single-chip APP/BB (for cost reasons)

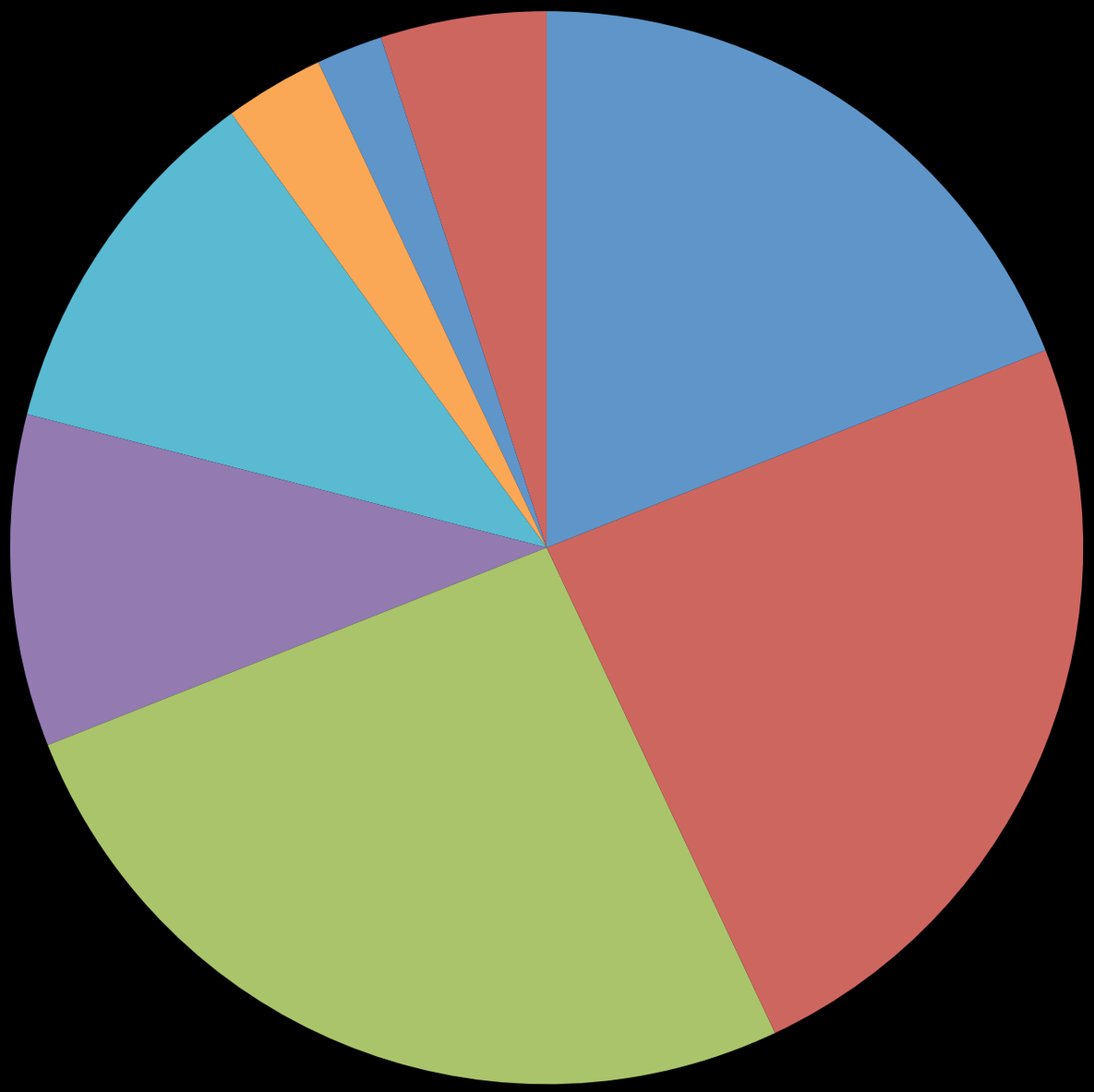
Dominant Smartphone archs

vs.



Let’s do some quick market research before we dive into the technical details...

Baseband market shares 3Q2009



- Qualcomm
- Mediatek
- Texas Instruments
- ST-Ericsson
- Infineon
- Broadcom
- Freescale
- Other

Source: Strategy Analytics

Cellular Baseband Suppliers & their 3Q' 09 shipment share)

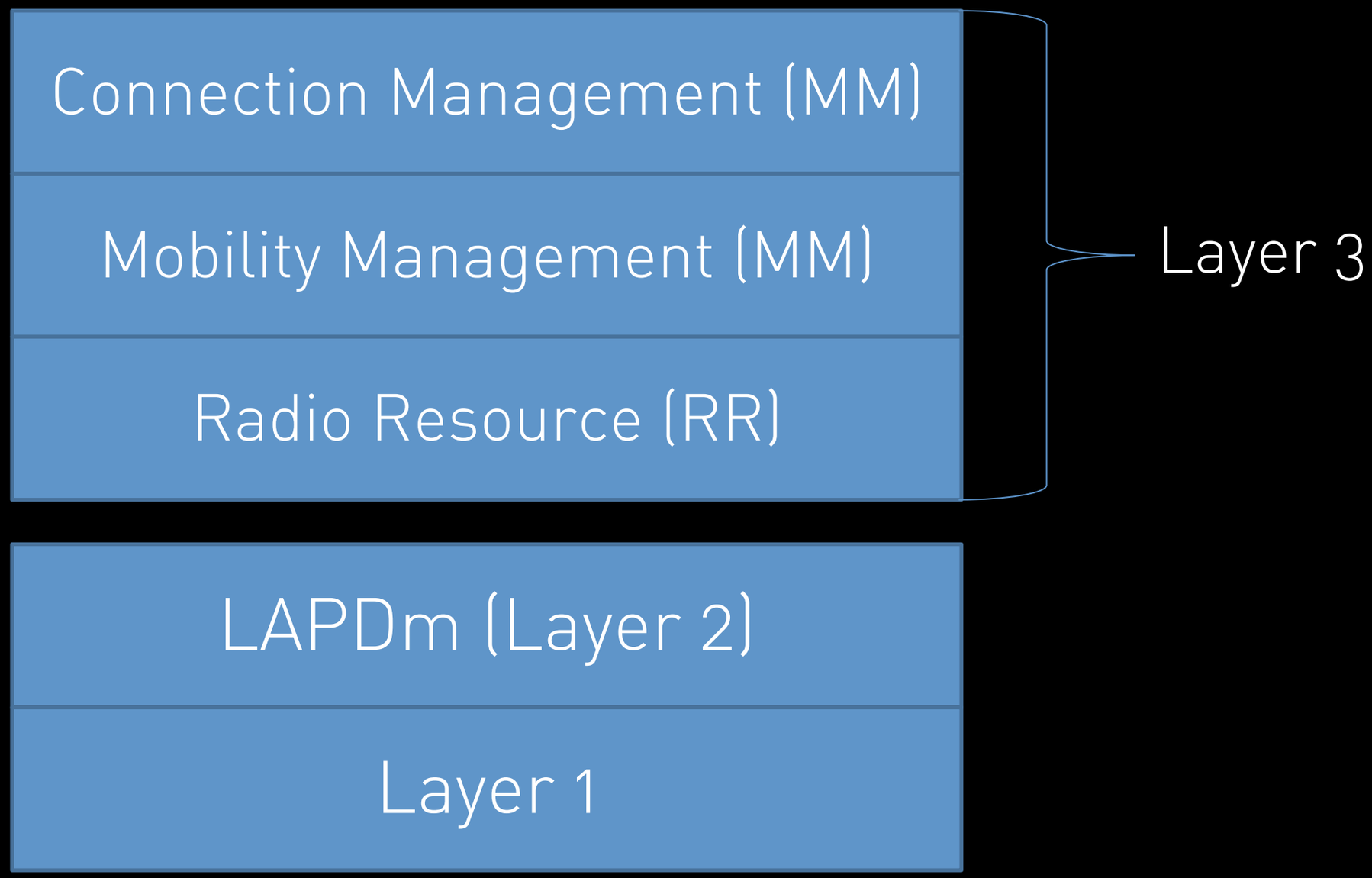
Part II: Baseband (in)security

Baseband (in)security

- Code base created in the 1990s...
- ... with a 1990s attitude towards security
- Network elements are considered trusted
- Both GSM and UMTS protocols have many, many length fields
- (Almost) no exploit mitigations
  [one counter-example: XMM6180 on iPhone4 has hardware DEP enabled]

I know you forgot what the GSM protocol stack looks like, so let's see it once more before we proceed.

Layers of the GSM Um interface



Where to look for bugs

- Layer 1 not fruitful
- Layer 2: messages to short
- Layer 3: specified in GSM 04.08
  - allows for variable length messages (TLV and LV)
  - Maximum length: 255 octets (length field: one octet)
- However: ASN.1 used as well (e.g. RRLP)
- GPRS layer very fruitful as well
  - GPRS not supported by OpenBTS
  - layer 1 different

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Initial Targets

Image credit: Yutaka Tsutano

Apple iPhones (Infineon baseband)

Image credit: Jose A. Gelado

HTC Dream [G1] (Qualcomm baseband)

Types of bugs found

- Many, many unchecked memory copies (can be found in binary once **`memcpy()`** et al. identified)
- Object/structure lifecycle issues (e.g. use after free, uninitialized variables, state engine confusion), can lead to infoleaks as well
- Protocol foo-bars: Code paths normally used for UMTS / CDMA can be triggered using GSM frames

An example (in QCOM codebase)

- GSM & UMTS use challenge-response auth
- Originally: fixed-length challenge in GSM
  - 16 bytes RAND
- 3GPP specification 24.008 added variable length challenge (AUTN)
- Functionality not needed in GSM!
- Allows to overwrite stack (limit 251 bytes)
- Result: remote code exec, pre-auth
- QCOM fixed after disclosure (pushed to OEMs)

How were the bugs found?

- Fuzzing was not successful
  - Lots of crashes, but no easy way to triage
- Static analysis
  - Located **`memcpy()`**-like functions
  - Identified functions handling GSM frames
    - Problem: apparently different tasks
    - Assertions/logging functions very helpful
  - After several were found, looked at standards and went back

Baseband Exploitation

- Baseband: what operating system?
- Unlock teams often have good info on this (iPhone dev team, XDA developers)
- Locate buffers used for GSM L3 messages
- Write custom code or use existing features (e.g. **`AT+S0=x`** handler in Infineon baseband)
- Debugging is hard, write own debugger first!

The AT+S0=n feature

- Hayes command to turn on auto-answer
- present in some software stacks (verified for Infineon & QCOM)
- Enable with *5005*AANS# on iPhones, disable with #5005*AANS#
- Excellent target to demonstrate memory corruptions
- Auto-answer can be made silent/invisible

Part III: Practicality

Why should we care

- New base stations: expensive (cheapest: 25k USD)
- Old gear however often is sold on eBay
- Threat model has entirely changed: hardware has become cheap, open-source SW appeared
- Open-source projects for running GSM base stations: OpenBSC & OpenBTS
- OpenBTS provided service at Burning Man 2008-2010
- HAR2009 had OpenBSC test network

- Siemens BS11
- used by OpenBSC
- **HEAVY**
- E1/Abis interface
- cheap: EUR 250
- hard to come by now.

Image credit:
Björn Heller

- ip.access nanoBTS
- supported by OpenBSC as well
- Abis over IPv4
- approx. USD 4500
- different versions for GSM900/1800, GSM850/1900
- supports GPRS

Image credit: Synthesis Studios

Our gear: Ettus USRPv1

- price: approx USD 1250 plus good clock
- software defined radio (SDR)
- versatile (different daughterboards)
- OpenBTS support, GSM850/900, GSM1800/1900
- no GPRS since layer 1 is different there
- clock: wrong freq (64Mhz) and imprecise

Part IV: Demo

Common failures (my experience)

- Lacking clock precision
- Misinterpreting stack traces
- Triggering the wrong bug ;)
- Overlooking code is placed is non-exec page

Some words about clocks

- Get a good one, seriously!
  - GSM spec requires 0.05ppm
  - equiv. to 50Hz in 900MHz band
- Time is too precious for fixing clock issues
- Using FA-SY on the road (EUR 40)
  - Si570 based design
  - not optimal: 20ppm uncalibrated
  - approx. 1ppm when calibrated
- ClockTamer apparently much better

Part V: The Baseband Apocalypse

The “Baseband Apocalypse”

- Place fake BTS in crowded/sensitive areas: airport lounges, financial districts, near embassies
- Stealth room monitor: record audio, compress, store in RAM, piggy-back onto next data connection (mic/camera usually hang off BB CPU)
- Shared mem CPUs: compromise APP CPU as well, place backdoor/rootkit

The “Baseband Apocalypse”

- Ping-pong games: compromise cellphone, then BTS/BSC, infect more phones from there
- Brick phones permanently (e.g. erase SecZone on iPhone)
- No easy forensics possible in BB land (JTAG disabled to prevent easy unlocks). Need exploits to perform forensics

The scary bit

- How do we defend ourselves?
  Turn off our cell phones? Hardly.
- Use a sound-proof enclosure for phone and encrypting Bluetooth Headset?
  [approach allegedly used by a German company that produces “secure” end-to-end solutions for governments]

Is there still hope for the paranoid?

OsmocomBB

- Free Software GSM baseband stack
- implements layer 1-3
- target platform: Calypso chipsets
- present in OpenMoko phones and Motorola C11x/C12x (e.g. C123)
- current functionality: about GSM Phase 1
  - supports sending/receiving SMS
  - supports voice calls

Part VI: Disclosure, outlook, conclusions

Disclosure & Reactions

- QCOM was fantastic
- Working with Apple to get 1st issue in Infineon stack fixed, update for TMSI bug out soon.
- Vendor outreach by Microsoft
- ST-Ericsson:
  "We have been using Coverity on our RTOS (incl. the entire L2/3 source code) for a few years – which may detect some of the vulnerabilities. And the canaries have always been there to enable the scheduler to detect stack overflows [...]"

Outlook

- Will see same problems for 3GPP/UMTS
- 3GPP uses mutual auth...
- Need Radio Resource Control (RRC) pre-auth
- RRC is about 1800 pages of specification!
- ASN.1 PER !!
- Only single vendor for the ASN.1 parser !!!
- Femto cells as cheap attack platforms
- LTE spec pre-auth simpler than 3GPP

Conclusions

- Memory corruptions over the Um interface: practical even with cheap hardware
- Vulnerabilities in GSM baseband codebases plentiful
- Small number of baseband vendors
- Malicious code execution on baseband CPU: compromises security
  - Shared memory between BB & APP: total compromise