Who Controls the Controllers?

Hacking Crestron IoT Automation Systems

Who am I?

- Offensive Security Research on ASR team at Trend Micro
  - Focused mainly on IoT research
  - Break things in interesting ways and build cool exploit demos
  - Report vulns to ZDI and work with vendors to fix issues
  - 40+ disclosed vulnerabilities
- Conference speaker
  - Defcon, Recon, Ruxcon, Toorcon, etc

What is Crestron?

IoT Device Controllers

- Audio/video distribution
- Lighting/shades
- Home automation
- Building management systems (BACNET)
- Access control/security
- Etc…

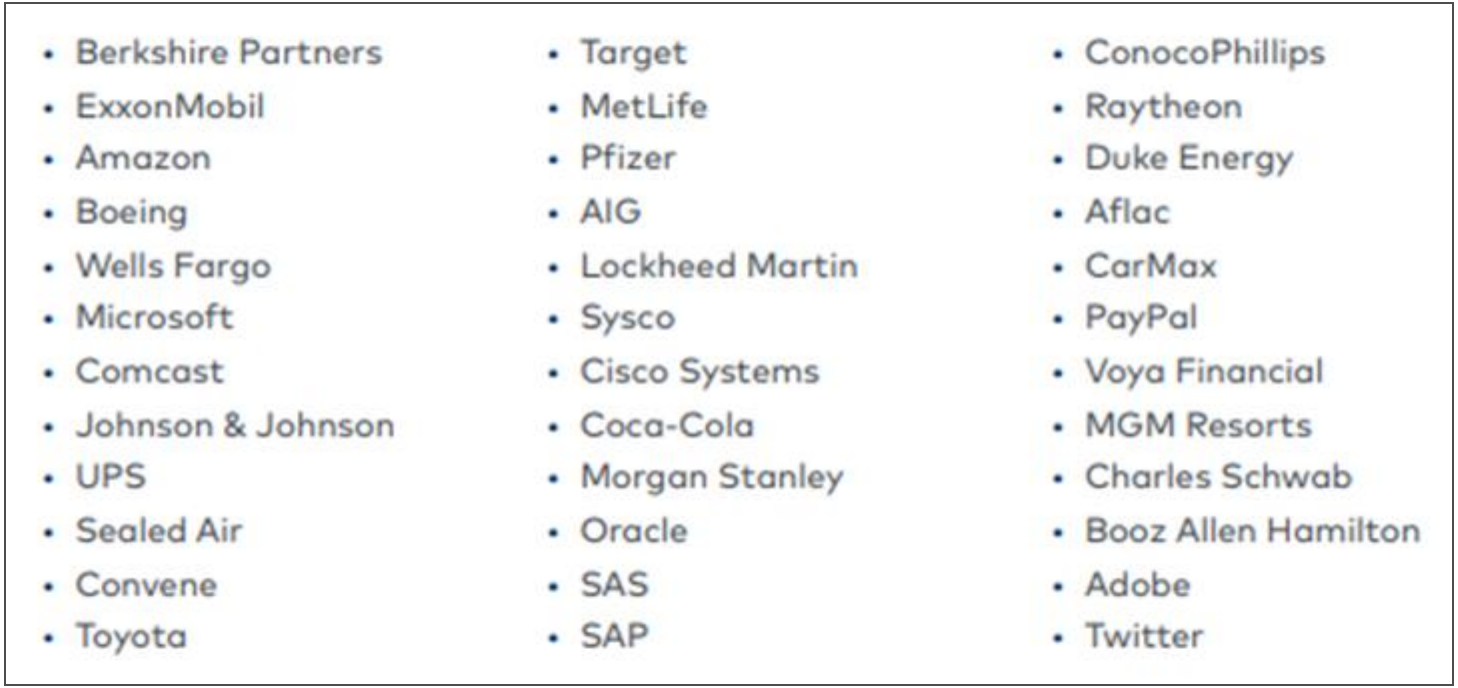
Fully Programmable/Customizable

- SIMPL
  - Symbol Intensive Master Programming Language
  - Write programs for UI and device actions
- Device control methods
  - IR
  - Serial
  - TCP/IP
  - Relay
  - MIDI
  - Cresnet
- Interact with and program controllers via Crestron Terminal Protocol (CTP)
- Crestron devices intercommunicate via Crestron Internet Protocol (CIP)
- Programming can be complex, usually handled by professionals

Deployment

- Universities
- Office environments
- Sports arenas
- Airports
- Hotels
- Rich people's houses

Deployment



- Berkshire Partners
- ExxonMobil
- Amazon
- Boeing
- Wells Fargo
- Microsoft
- Comcast
- Johnson & Johnson
- UPS
- Sealed Air
- Convene
- Toyota
- Target
- MetLife
- Pfizer
- AIG
- Lockheed Martin
- Sysco
- Cisco Systems
- Coca-Cola
- Morgan Stanley
- Oracle
- SAS
- SAP
- ConocoPhillips
- Raytheon
- Duke Energy
- Aflac
- CarMax
- PayPal
- Voya Financial
- MGM Resorts
- Charles Schwab
- Booz Allen Hamilton
- Adobe
- Twitter

https://www.crestron.com/getmedia/06b92c9d-c262-4190-bf52-4180d8f77fca/mg_2017_Brochure_Workplace-Tech-Design-Guide

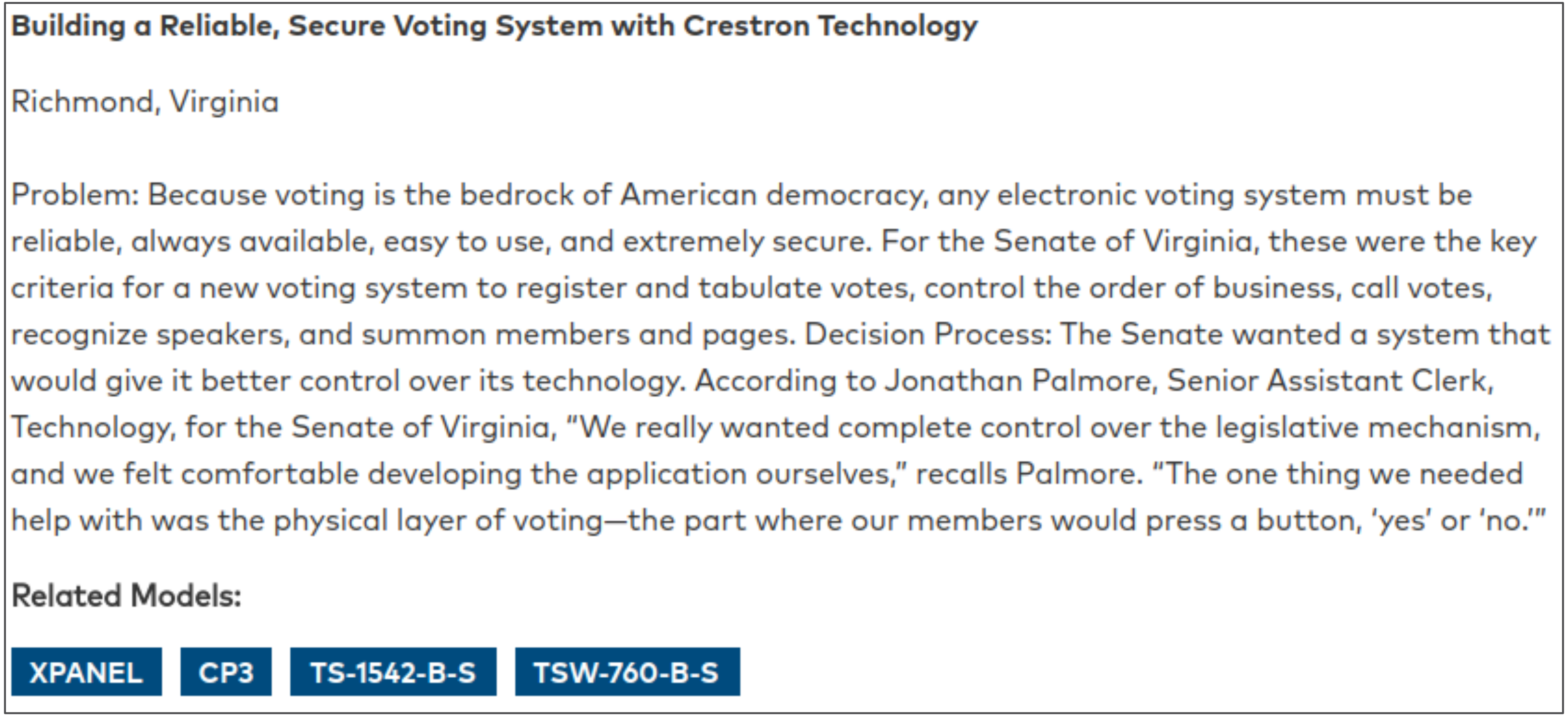
Deployment

- “Microsoft chose Crestron as its exclusive partner to manage all AV and meeting room resources worldwide.”
  - https://support.crestron.com/app/answers/answer_view/a_id/4818/~/what-kind-of-security-and-encryption-crestron-deploys
- “Crestron and Microsoft are technology leaders now working together to develop future digital media innovations.”
  - http://www.crestron.com/getmedia/3321a1e7-f0d6-47b8-9021-a473981f8983/cs_Microsoft_World_Headquarters

Deployment

- Massachusetts Bay Transit Authority
  - https://www.crestron.com/en-US/News/Case-Studies/Massachusetts-Bay-Transit-Authority
- Chicago Police Department
  - https://www.crestron.com/en-US/News/Case-Studies/Chicago-Police-Department
- American Water Corporate Headquarters
  - https://www.crestron.com/en-US/News/Case-Studies/American-Water-Corporate-Headquarters

Deployment



Building a Reliable, Secure Voting System with Crestron Technology

Richmond, Virginia

Problem: Because voting is the bedrock of American democracy, any electronic voting system must be reliable, always available, easy to use, and extremely secure. For the Senate of Virginia, these were the key criteria for a new voting system to register and tabulate votes, control the order of business, call votes, recognize speakers, and summon members and pages. Decision Process: The Senate wanted a system that would give it better control over its technology. According to Jonathan Palmore, Senior Assistant Clerk, Technology, for the Senate of Virginia, "We really wanted complete control over the legislative mechanism, and we felt comfortable developing the application ourselves," recalls Palmore. "The one thing we needed help with was the physical layer of voting—the part where our members would press a button, 'yes' or 'no.'"

Related Models:

https://www.crestron.com/en-US/News/Case-Studies/Senate-of-Virginia

Deployment

MGM Properties

MGM Grand - Las Vegas

MGM Grand - Detroit

MGM Grand – Macau

MGM Grand at Foxwoods

Bellagio

Vdara

ARIA

Mandalay Bay

Luxor

Monte Carlo

New York – New York

Circus Circus

Excalibur

Railroad Pass (Henderson, NV)

M Resort (Henderson, NV)

Silver Legacy Reno

Other Las Vegas Properties

Wynn Hotel & Casino

Mandarin Oriental

Encore

Venetian Hotel & Casino

Palazzo

Caesars Palace

Hard Rock Hotel

Palms

Stations Red Rock Casino

Golden Nugget

The Aladdin Hotel & Casino

Planet Hollywood

Paris

Rio

Palms

Palms Place

Green Valley Ranch

Harrahs

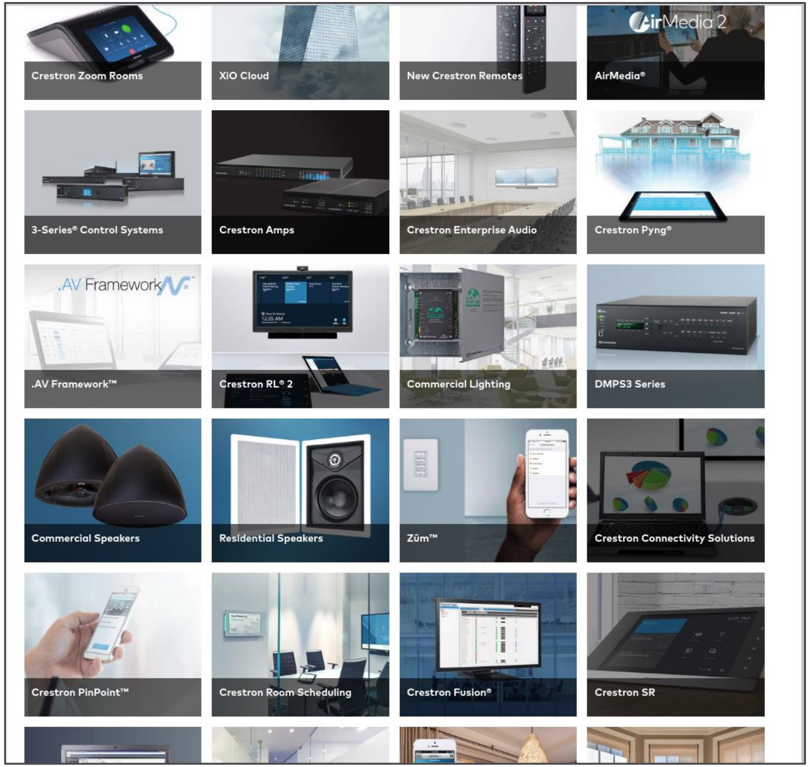
http://hughsaudiovideo.com/hospitality_showcase.pdf

Products

- 3-Series controllers
  - CP3, MC3, PRO3
  - DIN rail
- Touch screens
  - TSx
  - TPCS, TPMC
  - “One in every room” type deployments

Products

And more…



Platforms

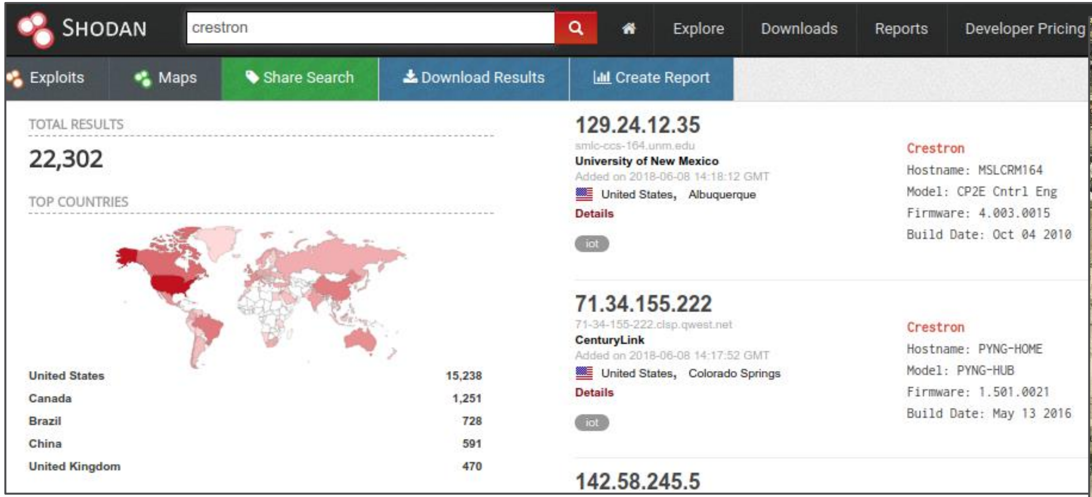
- Mainly Windows
  - Most products run WinCE 6
  - Some other embedded Win versions allegedly
- Some Android/Linux
  - Touch screens (TSx)
  - Video processors and digital media streamers (DGE-100, DMC-STR, etc)
  - More?
- If something is specific to either the Windows or Android platform, I'll do my best to call it out

Discovery

- Magic packet to UDP 41794 (broadcast or unicast)
  - "\x14\x00\x00\x00\x01\x04\x00\x03\x00\x00" + hostname + "\x00" * (256 - hostname.length)
- Response gives:
  - Hostname
  - Product
  - Firmware version
  - Build date

Discovery

- Shodan results between 20,000 and 23,000
- Most common product is split between CP3 and MC3



TOTAL RESULTS

22,302

TOP COUNTRIES

United States	15,238
Canada	1,251
Brazil	728
China	591
United Kingdom	470

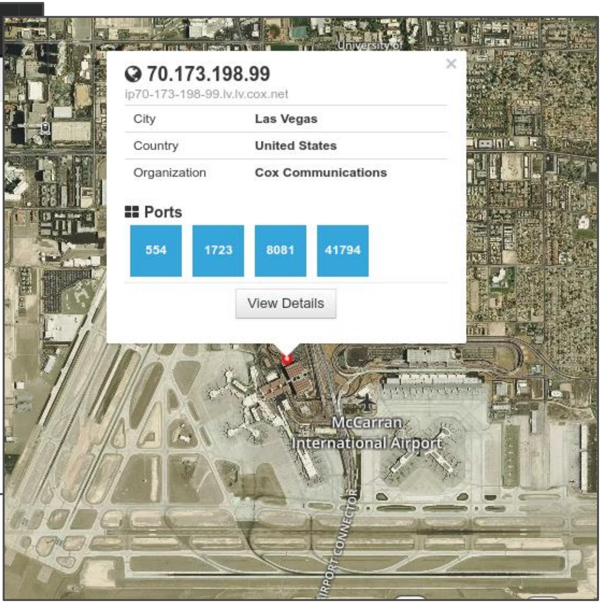
129.24.12.35
smlc-ccs-164.unm.edu
University of New Mexico
Added on 2018-06-08 14:18:12 GMT
United States, Albuquerque
Details
iot

```
Crestron
Hostname: MSLCRM164
Model: CP2E Cntrl Eng
Firmware: 4.003.0015
Build Date: Oct 04 2010
```

71.34.155.222
71-34-155-222.clsp.qwest.net
CenturyLink
Added on 2018-06-08 14:17:52 GMT
United States, Colorado Springs
Details
iot

```
Crestron
Hostname: PYNG-HOME
Model: PYNG-HUB
Firmware: 1.501.0021
Build Date: May 13 2016
```

142.58.245.5



70.173.198.99
ip70-173-198-99.lv.lv.cox.net

City	Las Vegas
Country	United States
Organization	Cox Communications

Ports

results from 2018/06/11

So What is Crestron?

- A lot of different things
- Running different programs
- On different platforms
- In different environments

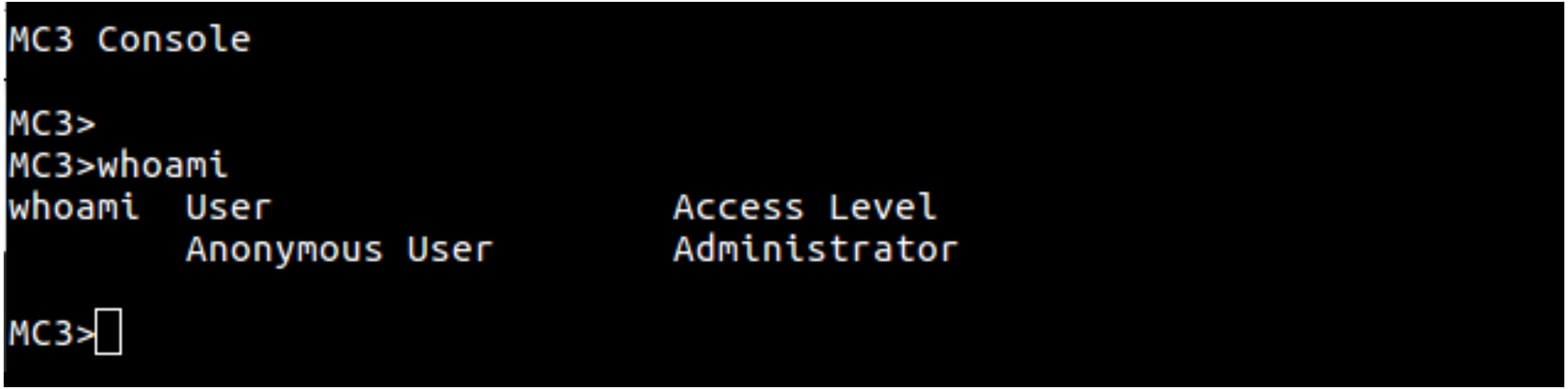
But there are a couple universal truths…

Anonymous Admin on CTP Console

CTP Console

- Main programming interface for devices
- Telnet-like console on TCP 41795
- Sandbox file system/commands
- Auth is available
  - Different user levels (Administrator, Operator, Programmer, User, etc)
  - Active Directory tie-ins
  - Encryption
- Auth is disabled by default
  - Reliant on programmer/installer to be security conscious
  - Adds more complexity to already complex system
  - Enabling is a multi-step process
  - Never gets turned on

CTP Console



```
MC3 Console

MC3>
MC3>whoami
whoami  User                   Access Level
        Anonymous User         Administrator

MC3>
```

Standard CTP Functionality

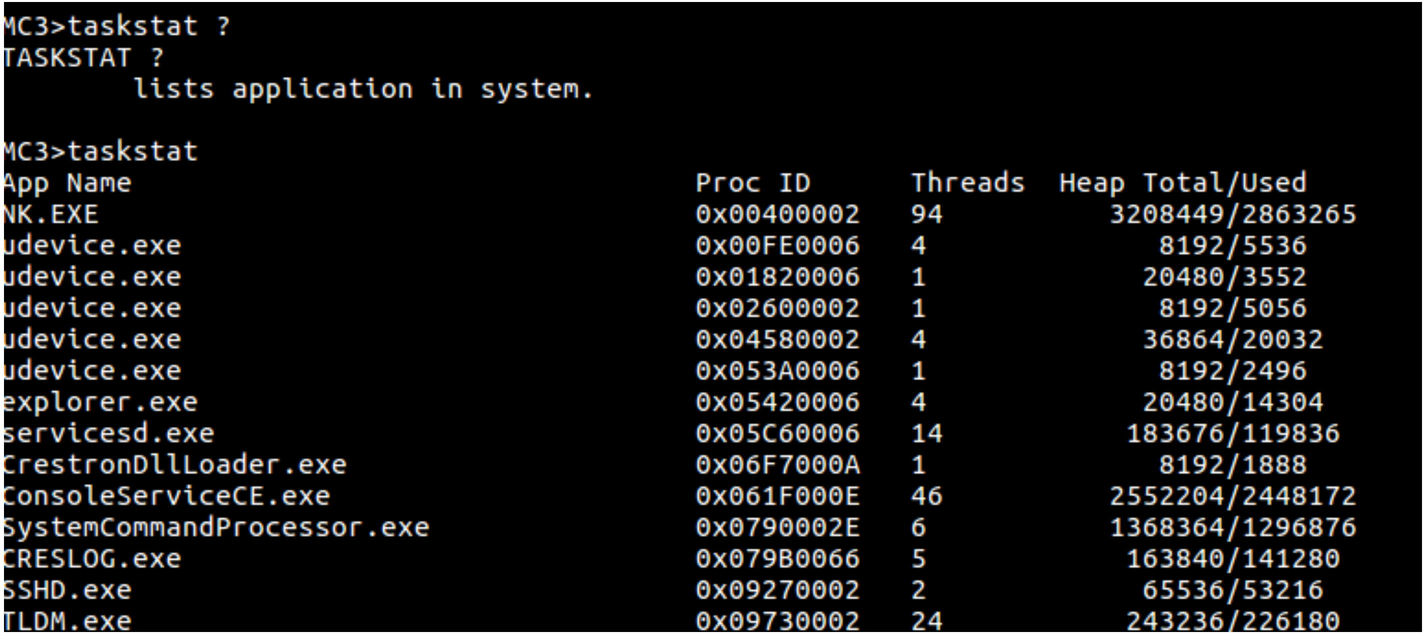
- Change system and service settings
  - Auth settings
  - Web portal settings
  - SSH/Telnet/FTP
  - Basic SIP settings (Android?)
- Networking info/config
- Arbitrary file upload
  - fgetfile/fputfile - HTTP/FTP file transfer
  - xgetfile/xputfile - XMODEM file transfer

Standard CTP Functionality

- Firmware updates
- Run and control user programs
- Control output to other devices
  - Display messages on OSD
  - Play audio/video files

Hidden CTP Functionality

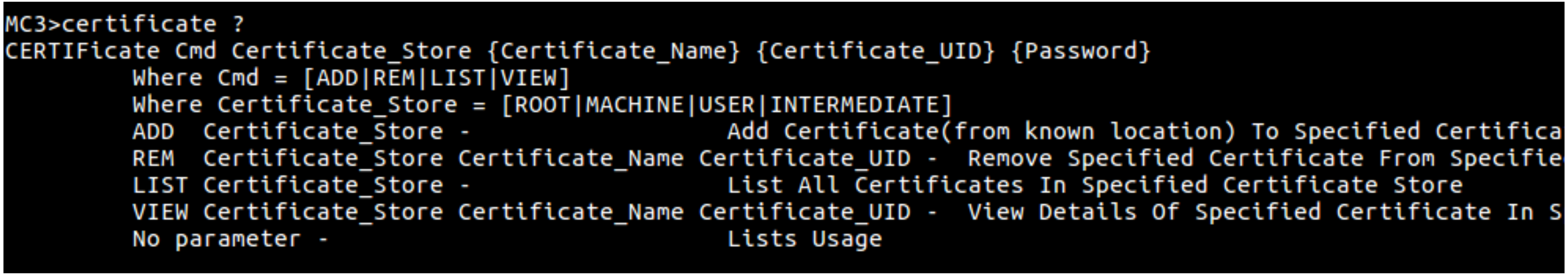
- Running processes: taskstat



```
MC3>taskstat ?
TASKSTAT ?
        lists application in system.

MC3>taskstat
App Name                                   Proc ID      Threads  Heap Total/Used
NK.EXE                                     0x00400002   94          3208449/2863265
udevice.exe                                0x00FE0006   4              8192/5536
udevice.exe                                0x01820006   1             20480/3552
udevice.exe                                0x02600002   1              8192/5056
udevice.exe                                0x04580002   4             36864/20032
udevice.exe                                0x053A0006   1              8192/2496
explorer.exe                               0x05420006   4             20480/14304
servicesd.exe                              0x05C60006   14           183676/119836
CrestronDllLoader.exe                      0x06F7000A   1              8192/1888
ConsoleServiceCE.exe                       0x061F000E   46          2552204/2448172
SystemCommandProcessor.exe                 0x0790002E   6           1368364/1296876
CRESLOG.exe                                0x079B0066   5            163840/141280
SSHD.exe                                   0x09270002   2             65536/53216
TLDM.exe                                   0x09730002   24           243236/226180
```

Hidden CTP Functionality

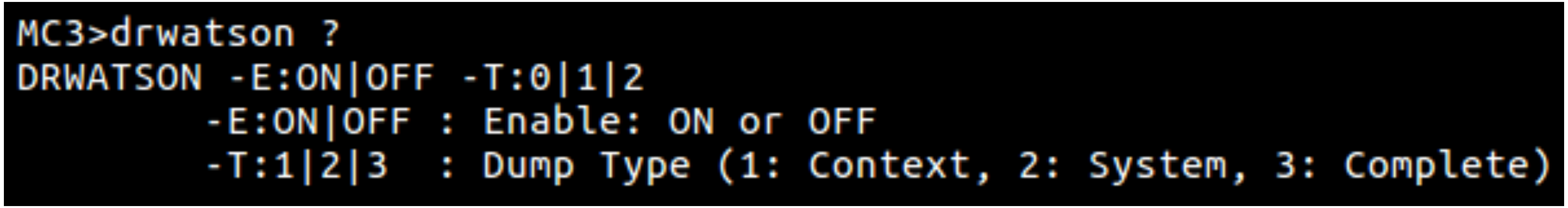
- View/modify stored certificates: certificate



```
MC3>certificate ?
CERTIFicate Cmd Certificate_Store {Certificate_Name} {Certificate_UID} {Password}
         Where Cmd = [ADD|REM|LIST|VIEW]
         Where Certificate_Store = [ROOT|MACHINE|USER|INTERMEDIATE]
         ADD  Certificate_Store -                        Add Certificate(from known location) To Specified Certifica
         REM  Certificate_Store Certificate_Name Certificate_UID -  Remove Specified Certificate From Specifie
         LIST Certificate_Store -                        List All Certificates In Specified Certificate Store
         VIEW Certificate_Store Certificate_Name Certificate_UID -  View Details Of Specified Certificate In S
         No parameter -                                  Lists Usage
```

Hidden CTP Functionality

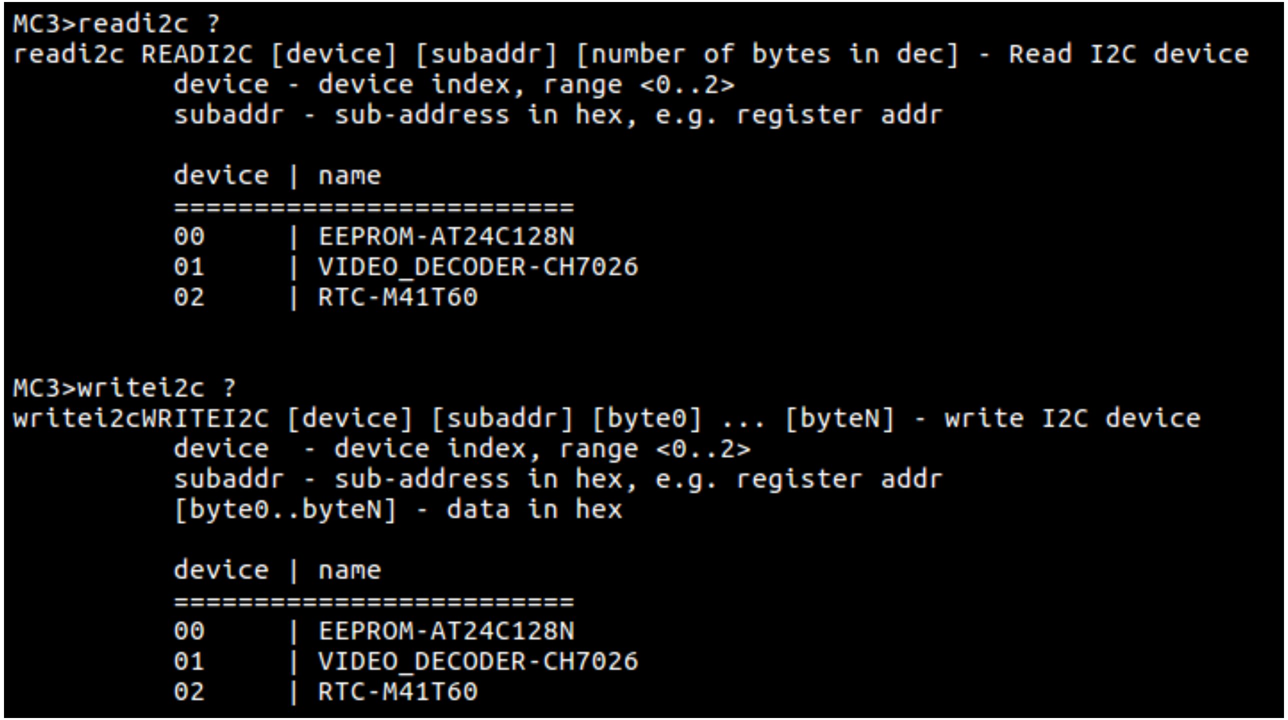
- Dr Watson dumps: drwatson (WinCE)



```
MC3>drwatson ?
DRWATSON -E:ON|OFF -T:0|1|2
        -E:ON|OFF : Enable: ON or OFF
        -T:1|2|3  : Dump Type (1: Context, 2: System, 3: Complete)
```

Hidden CTP Functionality

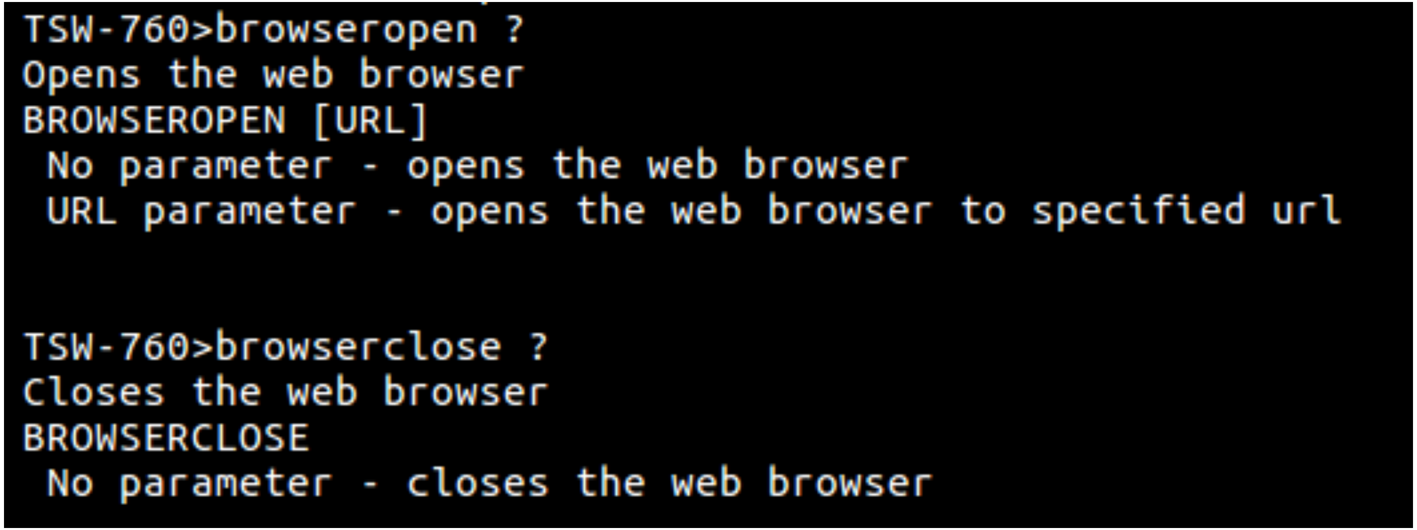
- Direct chip communication: readi2c/writei2c (WinCE?)



```
MC3>readi2c ?
readi2c READI2C [device] [subaddr] [number of bytes in dec] - Read I2C device
          device - device index, range <0..2>
          subaddr - sub-address in hex, e.g. register addr

          device | name
          =========================
          00     | EEPROM-AT24C128N
          01     | VIDEO_DECODER-CH7026
          02     | RTC-M41T60


MC3>writei2c ?
writei2cWRITEI2C [device] [subaddr] [byte0] ... [byteN] - write I2C device
          device  - device index, range <0..2>
          subaddr - sub-address in hex, e.g. register addr
          [byte0..byteN] - data in hex

          device | name
          =========================
          00     | EEPROM-AT24C128N
          01     | VIDEO_DECODER-CH7026
          02     | RTC-M41T60
```

Hidden CTP Functionality

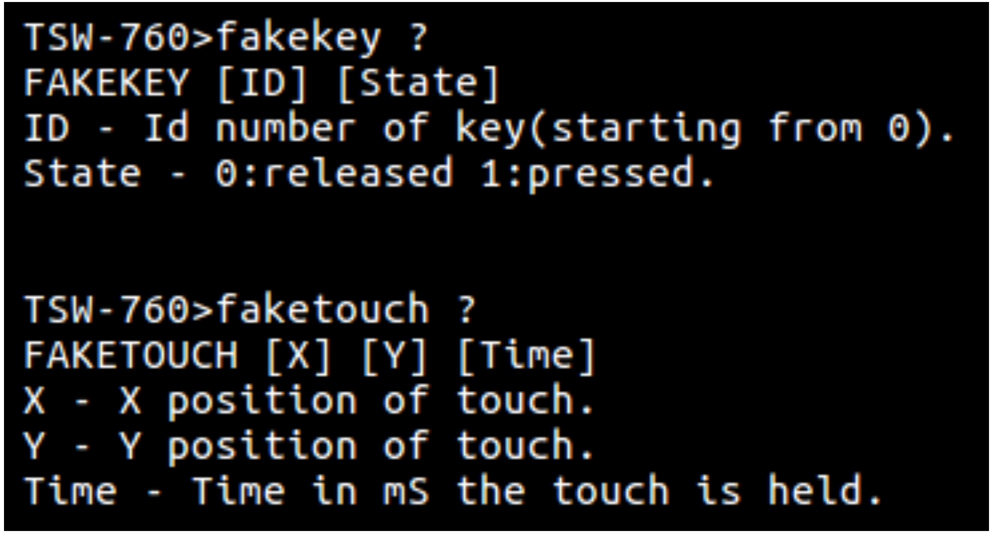
- Browser remote control: browseropen/browserclose (Android)



```
TSW-760>browseropen ?
Opens the web browser
BROWSEROPEN [URL]
 No parameter - opens the web browser
 URL parameter - opens the web browser to specified url


TSW-760>browserclose ?
Closes the web browser
BROWSERCLOSE
 No parameter - closes the web browser
```

Hidden CTP Functionality

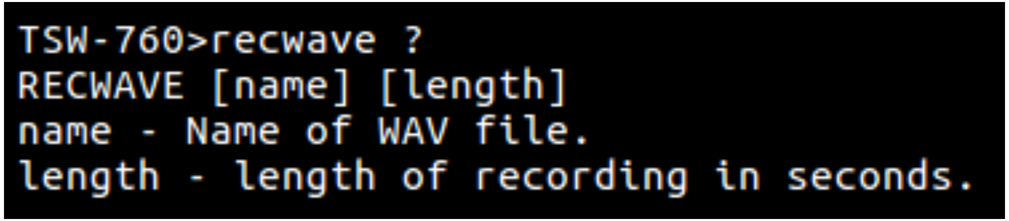
- UI interaction: fakekey/faketouch (Android)



```
TSW-760>fakekey ?
FAKEKEY [ID] [State]
ID - Id number of key(starting from 0).
State - 0:released 1:pressed.


TSW-760>faketouch ?
FAKETOUCH [X] [Y] [Time]
X - X position of touch.
Y - Y position of touch.
Time - Time in mS the touch is held.
```

Hidden CTP Functionality

- Record audio via microphone: recwave (Android)



```
TSW-760>recwave ?
RECWAVE [name] [length]
name - Name of WAV file.
length - length of recording in seconds.
```

DEMO

A Few RCE Vulns…

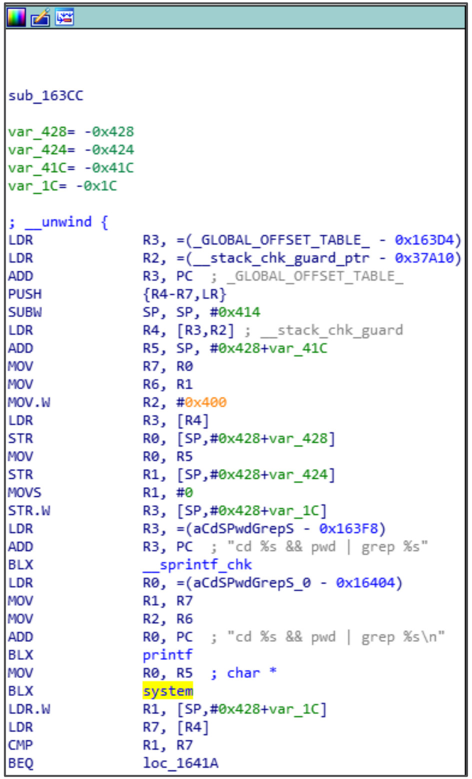
Cmd Inj Vulns on Android Platform

- 22 command injection vulns so far in CTP console
  - ping (CVE-2018-5553)
    - Simultaneously discovered by Cale Black and Jordan Larose of Rapid7
    - https://blog.rapid7.com/2018/06/12/r7-2018-15-cve-2018-5553-crestron-dge-100-console-command-injection-fixed/
  - But also adduser, cd, copyfile, delete, dir, fgetfile, fputfile, isdir, makedir, movefile, removedir, routeadd, routedelete, udir, updatepassword, wifipskpassword, wifissid, wifiwephexpassword, wifiweppassword, and more…

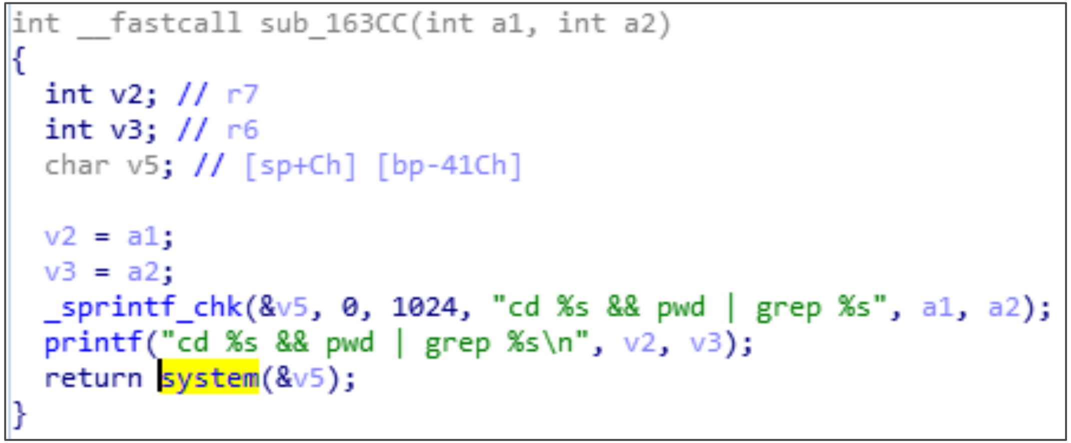
Cmd Inj Vulns on Android Platform

- Commands implemented programatically on WinCE platform
- Just punted to shell on Android
- Most were simple to exploit
  - EX: isdir `cmd`

Cmd Inj Vulns on Android Platform



```
sub_163CC

var_428= -0x428
var_424= -0x424
var_41C= -0x41C
var_1C= -0x1C

; __unwind {
LDR             R3, =(_GLOBAL_OFFSET_TABLE_ - 0x163D4)
LDR             R2, =(__stack_chk_guard_ptr - 0x37A10)
ADD             R3, PC  ; _GLOBAL_OFFSET_TABLE_
PUSH            {R4-R7,LR}
SUBW            SP, SP, #0x414
LDR             R4, [R3,R2] ; __stack_chk_guard
ADD             R5, SP, #0x428+var_41C
MOV             R7, R0
MOV             R6, R1
MOV.W           R2, #0x400
LDR             R3, [R4]
STR             R0, [SP,#0x428+var_428]
MOV             R0, R5
STR             R1, [SP,#0x428+var_424]
MOVS            R1, #0
STR.W           R3, [SP,#0x428+var_1C]
LDR             R3, =(aCdSPwdGrepS - 0x163F8)
ADD             R3, PC  ; "cd %s && pwd | grep %s"
BLX             __sprintf_chk
LDR             R0, =(aCdSPwdGrepS_0 - 0x16404)
MOV             R1, R7
MOV             R2, R6
ADD             R0, PC  ; "cd %s && pwd | grep %s\n"
BLX             printf
MOV             R0, R5  ; char *
BLX             system
LDR.W           R1, [SP,#0x428+var_1C]
LDR             R7, [R4]
CMP             R1, R7
BEQ             loc_1641A
```



```
int __fastcall sub_163CC(int a1, int a2)
{
  int v2; // r7
  int v3; // r6
  char v5; // [sp+Ch] [bp-41Ch]

  v2 = a1;
  v3 = a2;
  _sprintf_chk(&v5, 0, 1024, "cd %s && pwd | grep %s", a1, a2);
  printf("cd %s && pwd | grep %s\n", v2, v3);
  return system(&v5);
}
```

routeadd/routedelete Exploitation

- First problem
  - Arguments get up-cased before use
  - Linux commands are case-sensitive
- Solution
  - Create shell script containing desired commands
  - Name it “BLAH”
  - Upload it with fgetfile command

routeadd/routedelete Exploitation

- Second problem
  - Uploaded script doesn’t have exec perms
  - $SHELL/$BASH not set
- Solution
  - $0 returns name of calling program
  - When used in system() call, it returns name of shell instead
  - Final injected string: `$0$IFS./BLAH`
  - Could have also used . (as in the command) in place of $0

DEMO

Round 2?

- Kept finding more vulns while root causing others
- Had to cut myself off due to time constraints
- Pretty positive there is more to find

I Want More!

- Significant amount of control by default
- Can escape CTP sandbox on Android using vulns
- But what about WinCE?...What about a more "legit" escape on Android?

SUPER SECRET BONUS DEMO

Conclusions

- Potential for good security practice is there but disabled by default
  - Installers/programmers not security conscious or just concerned with getting everything working
  - Normal users unaware of problem
  - If security isn't enabled by default, it is probably not going to be enabled

Conclusions

- Wide deployment, including sensitive environments
  - High potential for abuse by insider threats
    - Boardroom spying/corporate espionage
    - Messing with building/access control systems
    - Hotel guests spying on other guests
  - Even “isolated networks” are not good enough

Conclusions

- Android platform seems much less secure than WinCE platform
  - Surprising at first, but makes sense
    - Crestron has long history with WinCE
    - Microsoft partnerships
    - Newer to the Linux/Android world
    - Too much product fragmentation?

Huge Amount of Auditing Left

- More CTP attack surface
  - More RCE vulns?
  - SIMPL and PUF
- Other services
  - CIP, HTTP, FTP, SIP, SNMP, SSH, Telnet, etc…
- Other products
  - Fusion, Xpanel, AirMedia, XIO Cloud, etc…
- IOAVA

Questions? Hit Me Up

- Twitter
  - https://twitter.com/HeadlessZeke
- Email
  - ricky[underscore]lawshae[at]trendmicro[dot]com
- Github
  - https://github.com/headlesszeke

Thank You