NTLM Relay

01 Apr 2020 · 47 min

Author : **Pixis**

Active Directory Windows

In this post

NTLM relay is a technique of standing between a client and a server to perform actions on the server while impersonating the client. It can be very powerful and can be used to take control of an Active Directory domain from a black box context (no credentials). The purpose of this article is to explain NTLM relay, and to present its limits.

Preliminary

This article is not meant to be a tutorial to be followed in order to carry out a successful attack, but it will allow the reader to understand in detail the **technical details** of this attack, its limitations, and can be a basis to start developing his own tools, or understand how current tools work.

In addition, and to avoid confusion, here are some reminders:

- **NT Hash** and **LM Hash** are hashed versions of user passwords. LM hashes are totally obsolete, and will not be mentioned in this article. NT hash is commonly called, wrongly in my opinion, “NTLM hash”. This designation is confusing with the protocol name, NTLM. Thus, when we talk about the user’s password hash, we will refer to it as **NT hash**.
- **NTLM** is therefore the name of the **authentication protocol**. It also exists in version 2. In this article, if the version affects the explanation, then NTLMv1 and NTLMv2 will be the terms used. Otherwise, the term

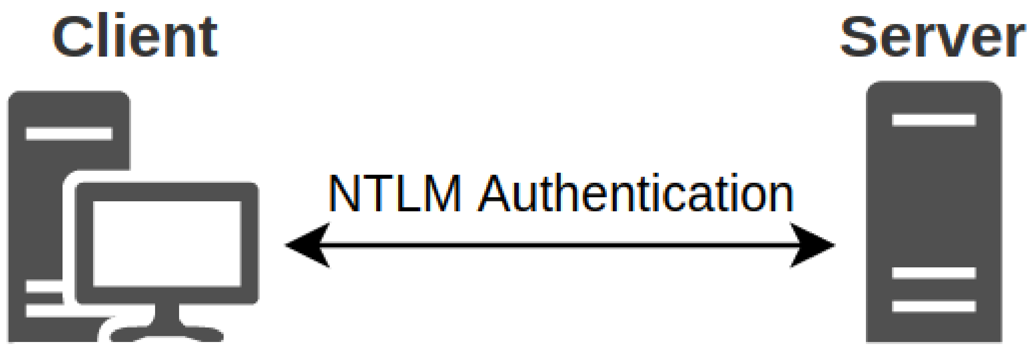
NTLM will be used to group all versions of the protocol.

- **NTLMv1 Hash** and **NTLMv2 Hash** will be the terminology used to refer to the challenge response sent by the client, for versions 1 and 2 of the NTLM protocol.
- **Net-NTLMv1** and **Net-NTLMv2** are pseudo-neo-terminologies used when the NT hash is called NTLM hash in order to distinguish the NTLM hash from the protocol. Since we do not use the NTLM hash terminology, these two terminologies will not be used.
- **Net-NTLMv1 Hash** and **Net-NTLMv2 Hash** are also terminologies to avoid confusion, but will also not be used in this article.

Introduction

NTLM relay relies, as its name implies, on NTLM authentication. The basics of NTLM have been presented in pass-the-hash article. I invite you to read at least the part about NTLM protocol and local and remote authentication.

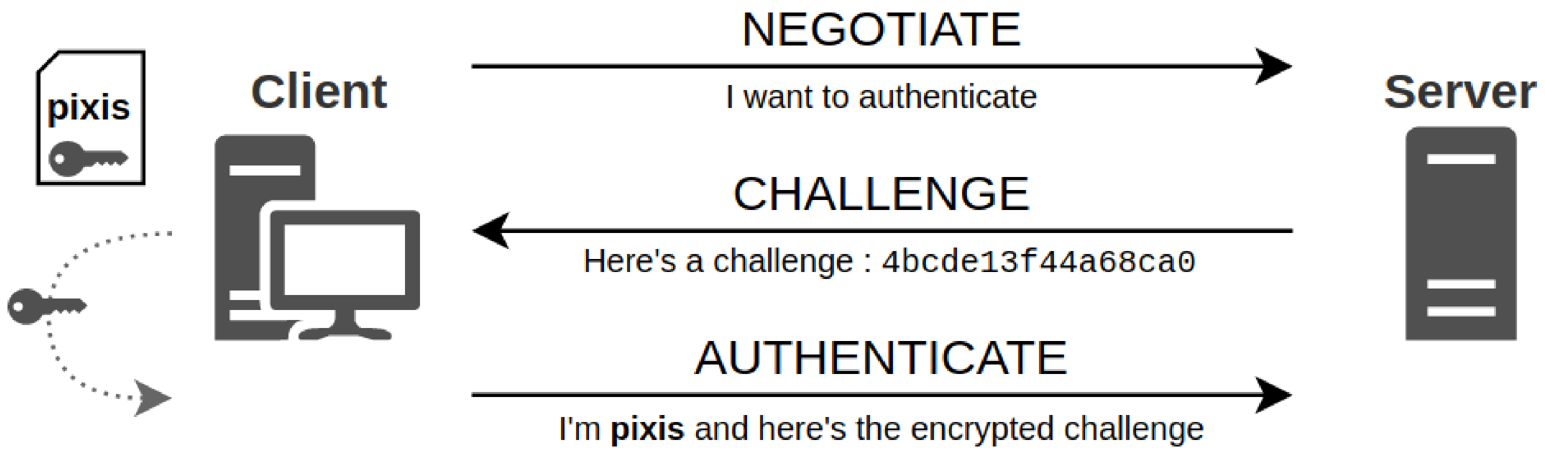
As a reminder, NTLM protocol is used to authenticate a client to a server. What we call client and server are the two parts of the exchange. The client is the one that wishes to authenticate itself, and the server is the one that validates this authentication.



This authentication takes place in 3 steps:

1. First the client tells the server that it wants to authenticate.
2. The server then responds with a challenge which is nothing more than a random sequence of characters.
3. The client encrypts this challenge with its secret, and sends the result back to the server. This is its response.

This process is called **challenge/response**.


pixis
Client
NEGOTIATE
I want to authenticate
Server
CHALLENGE
Here's a challenge : 4bcde13f44a68ca0
AUTHENTICATE
I'm pixis and here's the encrypted challenge

The advantage of this exchange is that the user's secret never passes through the network. This is known as Zero-knowledge proof.

NTLM Relay

With this information, we can easily imagine the following scenario: An attacker manages to be in a man-in-the-middle position between a client and a server, and simply relays information from one to the other.

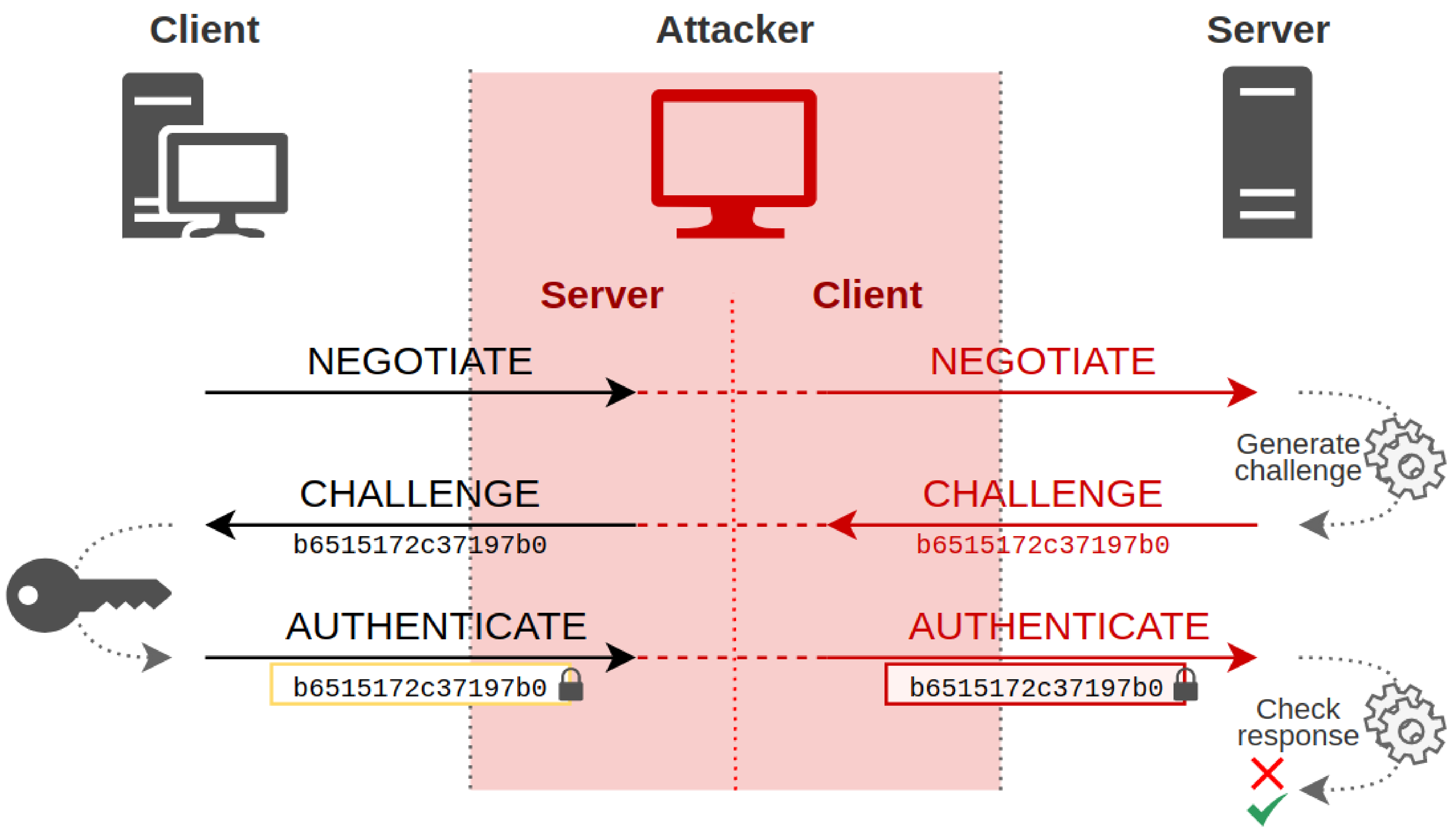
The man-in-the-middle position means that from the client's point of view, the attacker's machine is the server to which he wants to authenticate, and from the server's point of view, the attacker is a client like any other who wants to authenticate.

Except that the attacker does not "just" want to authenticate to the server. He wishes to do so by pretending to be the client. However, he does not know the secret of the client, and even if he listens to the conversations, as this secret is never transmitted over the network (zero-knowledge proof), the attacker is not able to extract any secret. So, how does it work?

Message Relaying

During NTLM authentication, a client can prove to a server its identify by encrypting with its password some piece of information provided by the server. So the only thing the attacker has to do is to let the client do his work, and passing the messages from the client to the server, and the replies from the server to the client.

All that the client has to send to the server, the attacker will receive it, and he will send the messages back to the real server, and all the messages that the server sends to the client, the attacker will also receive them, and he will forward them to the client, as is.

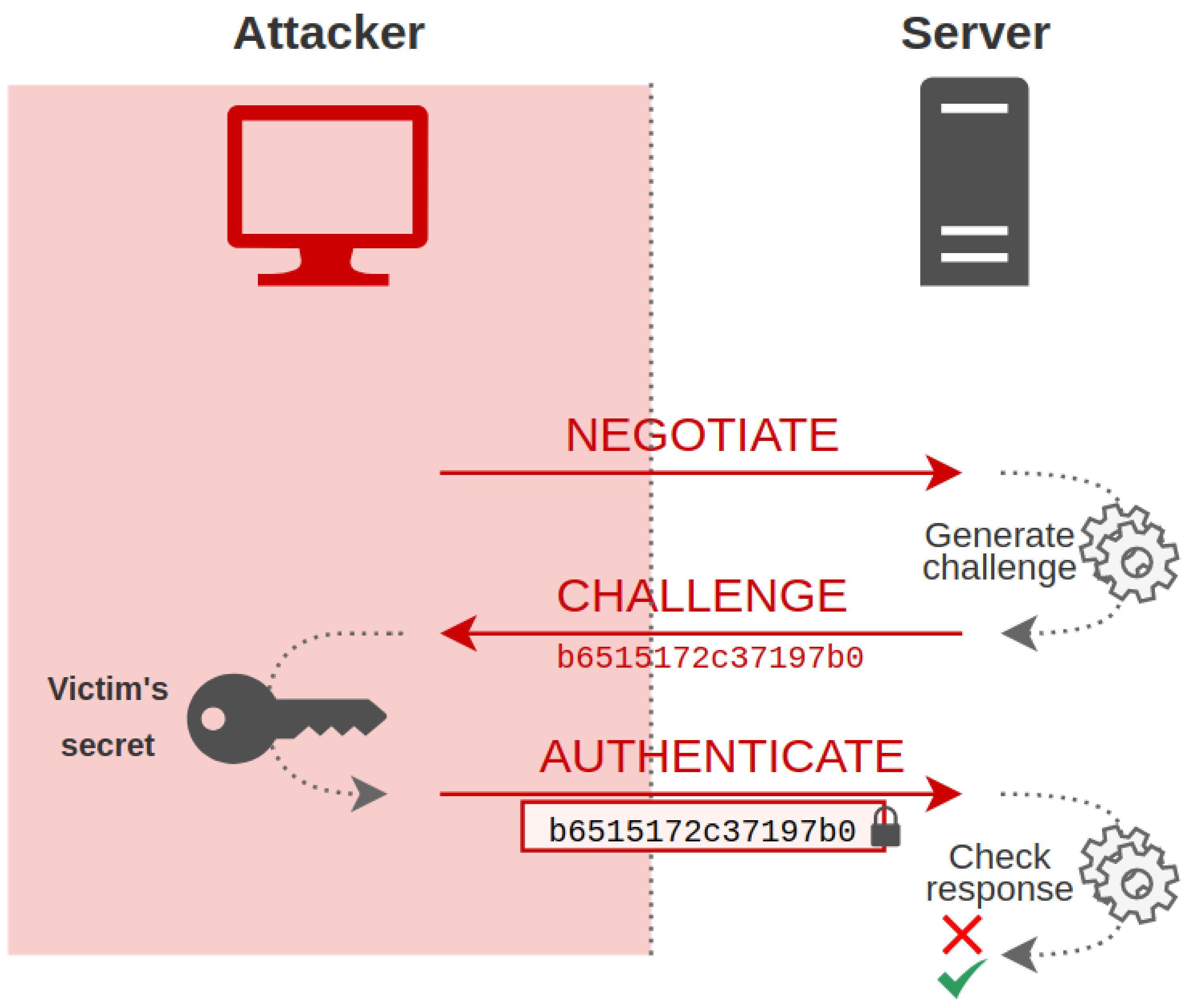


And it's all working out! Indeed, from the client's point of view, on the left part on the diagram, an NTLM authentication takes place between the attacker and him, with all the necessary bricks. The client sends a negotiate request in its first message, to which the attacker replies with a challenge. Upon receiving this challenge, the client builds its response using its secret, and finally sends the last authentication message containing the encrypted challenge.

Ok, that’s great but the attacker cannot do anything with this exchange. Fortunately, there is the right side of the diagram. Indeed, from the server’s point of view, the attacker is a client like any other. He sent a first message to ask for authentication, and the server responded with a challenge. As **the attacker sent this same challenge to the real client**, the real client **encrypted this challenge** with **its secret**, and responded **with a valid response**. The attacker can therefore send this **valid response** to the server.

This is where the interest of this attack lies. From the server’s point of view, the attacker has authenticated himself using the victim’s secret, but in a transparent way for the server. It has no idea that the attacker was replaying his messages to the client in order to get the client to give him the right answers.

So, from the server’s point of view, this is what happened:



At the end of these exchanges, the attacker is authenticated on the server with the client’s credentials.

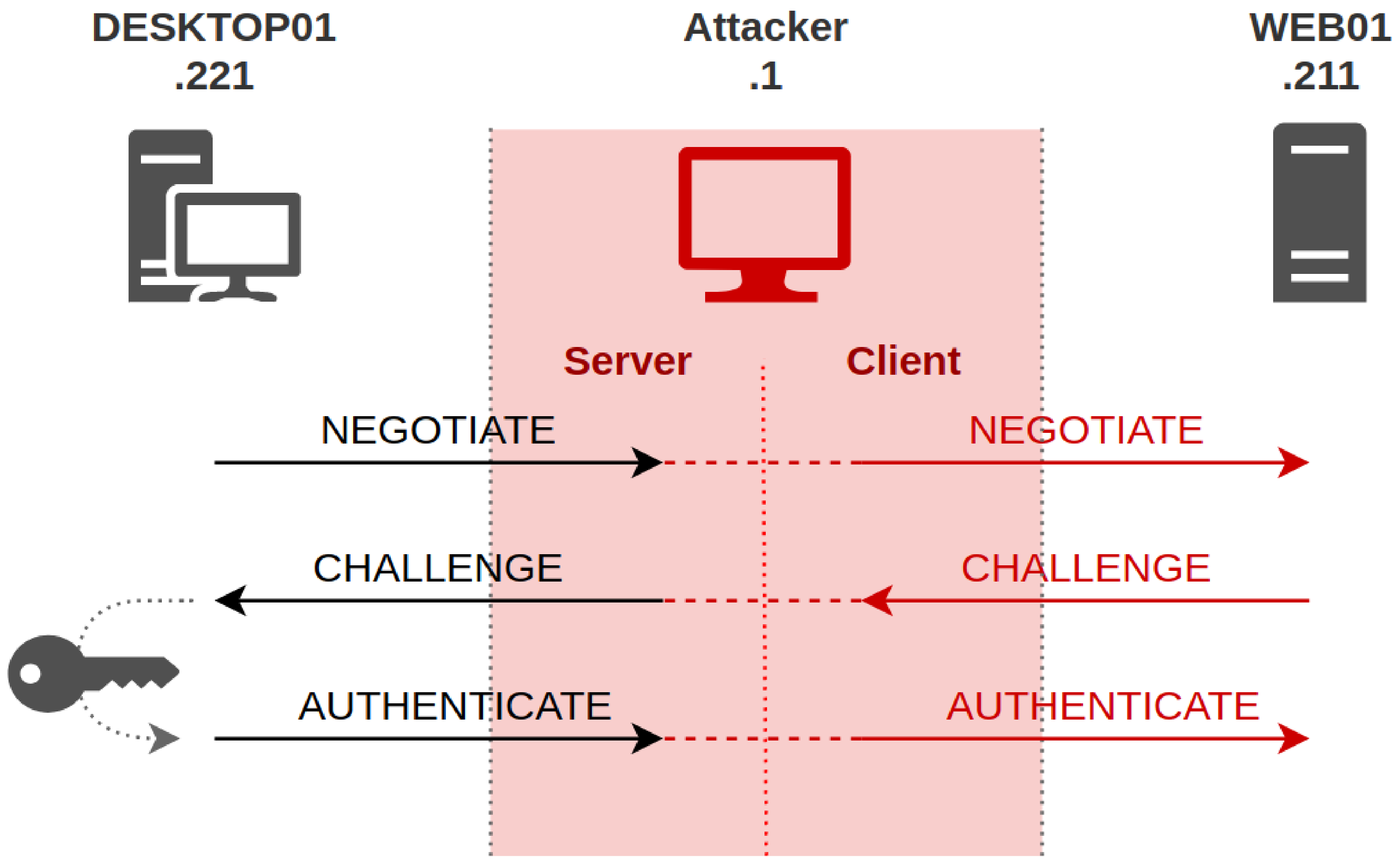
Net-NTLMv1 and Net-NTLMv2

For information, it is this **valid response** relayed by the attacker in message 3, the encrypted challenge, that is commonly called Net-NTLMv1 hash or Net-NTLMv2 hash. But in this article, it will be called **NTLMv1 hash** or **NTLMv2 hash**, as indicated in the preliminary paragraph.

To be exact, this is not exactly an encrypted version of the challenge, but a hash that uses the client's secret. It is HMAC_MD5 function which is used for NTLMv2 for example. This type of hash can only be broken by brute force. The cryptography associated with computation of the NTLMv1 hash is obsolete, and the NT hash that was used to create the hash can be retrieved very quickly. For NTLMv2, on the other hand, it takes much longer. It is therefore preferable and advisable **not to allow NTLMv1 authentication on a production network**.

In practice

As an example, I set up a small lab with several machines. There is **DESKTOP01** client with IP address **192.168.56.221** and **WEB01** server with IP address **192.168.56.211**. My host is the attacker, with IP address **192.168.56.1**. So we are in the following situation:



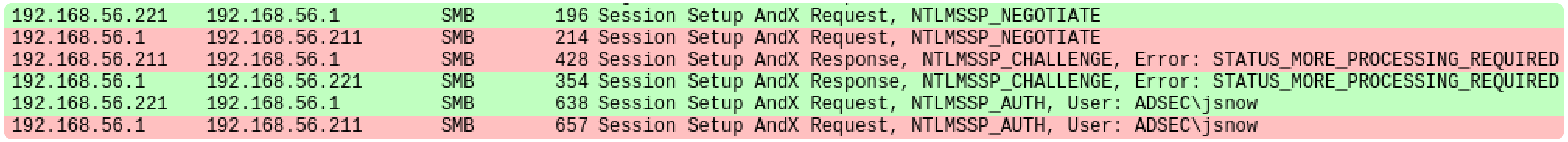
The attacker has therefore managed to put himself man-in-the-middle position. There are different techniques to achieve this, whether through abuse of default IPv6 configurations in a Windows environment, or through LLMNR and NBT-NS protocols. Either way, the attacker makes the client think that he is the server. Thus, when the client tries to authenticate itself, it is with the attacker that it will perform this operation.

The tool I used to perform this attack is ntlmrelayx from **impacket**. This tool is presented in details in this article by Agsolino, impacket (*almighty*) developer.

```
ntlmrelayx.py -t 192.168.56.221
```

The tool creates different servers, including an SMB server for this example. If it receives a connection on this server, it will relay it to the provided target, which is **192.168.56.221** in this example.

From a network point of view, here is a capture of the exchange, with the attacker relaying the information to the target.

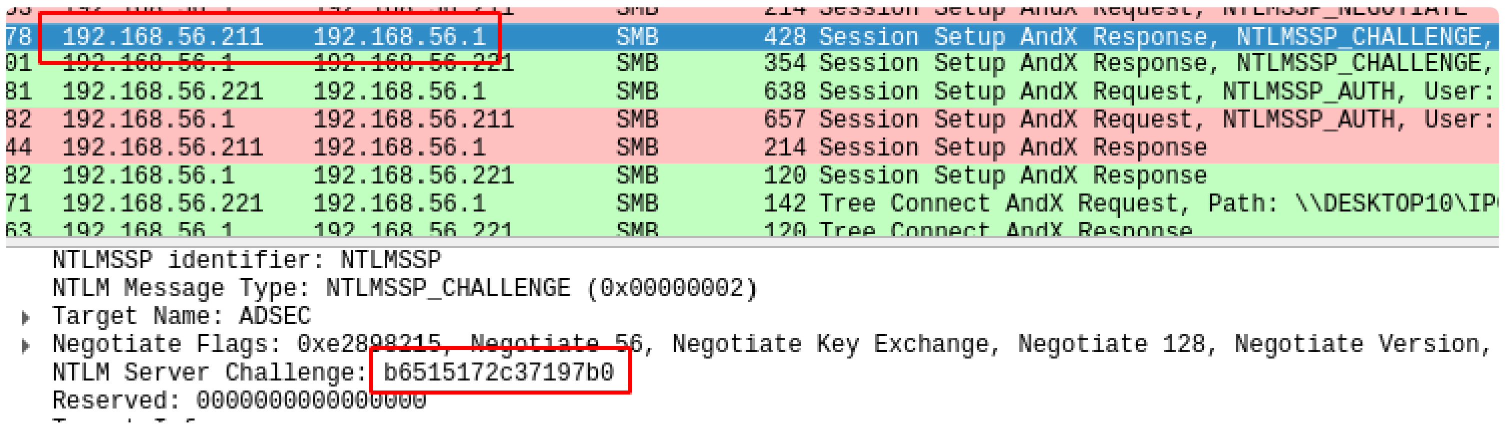


```
192.168.56.221   192.168.56.1     SMB    196 Session Setup AndX Request, NTLMSSP_NEGOTIATE
192.168.56.1     192.168.56.211   SMB    214 Session Setup AndX Request, NTLMSSP_NEGOTIATE
192.168.56.211   192.168.56.1     SMB    428 Session Setup AndX Response, NTLMSSP_CHALLENGE, Error: STATUS_MORE_PROCESSING_REQUIRED
192.168.56.1     192.168.56.221   SMB    354 Session Setup AndX Response, NTLMSSP_CHALLENGE, Error: STATUS_MORE_PROCESSING_REQUIRED
192.168.56.221   192.168.56.1     SMB    638 Session Setup AndX Request, NTLMSSP_AUTH, User: ADSEC\jsnow
192.168.56.1     192.168.56.211   SMB    657 Session Setup AndX Request, NTLMSSP_AUTH, User: ADSEC\jsnow
```

In green are the exchanges between **DESKTOP01** client and the attacker, and in red are the exchanges between the attacker and **WEB01** server. We can clearly see the 3 NTLM messages between **DESKTOP01** and the attacker, and between the attacker and **WEB01** server.

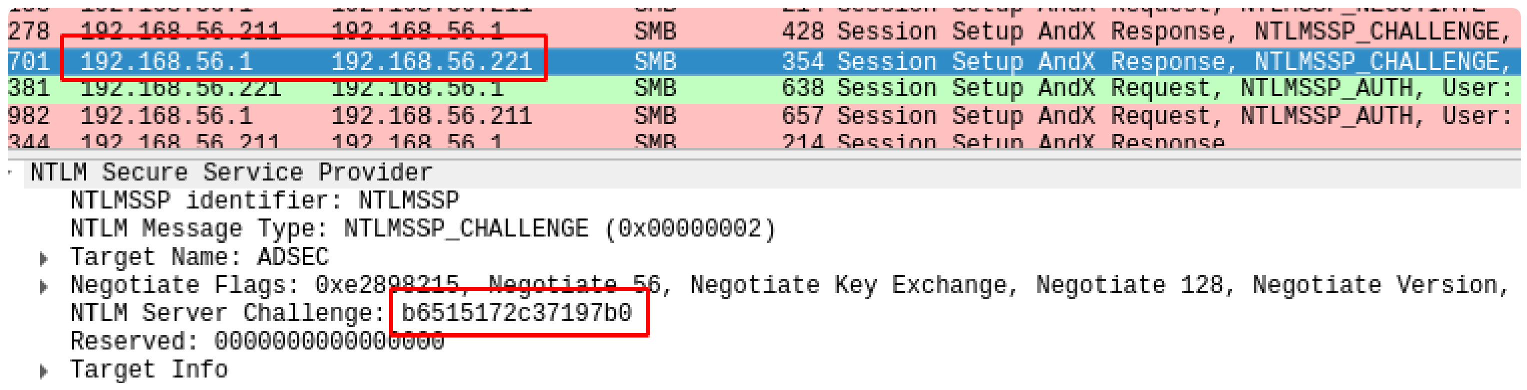
And to understand the notion of **relay**, we can verify that when **WEB01** sends a challenge to the attacker, the attacker sends back exactly the same thing to **DESKTOP01**.

Here is the challenge sent by **WEB01** to the attacker :



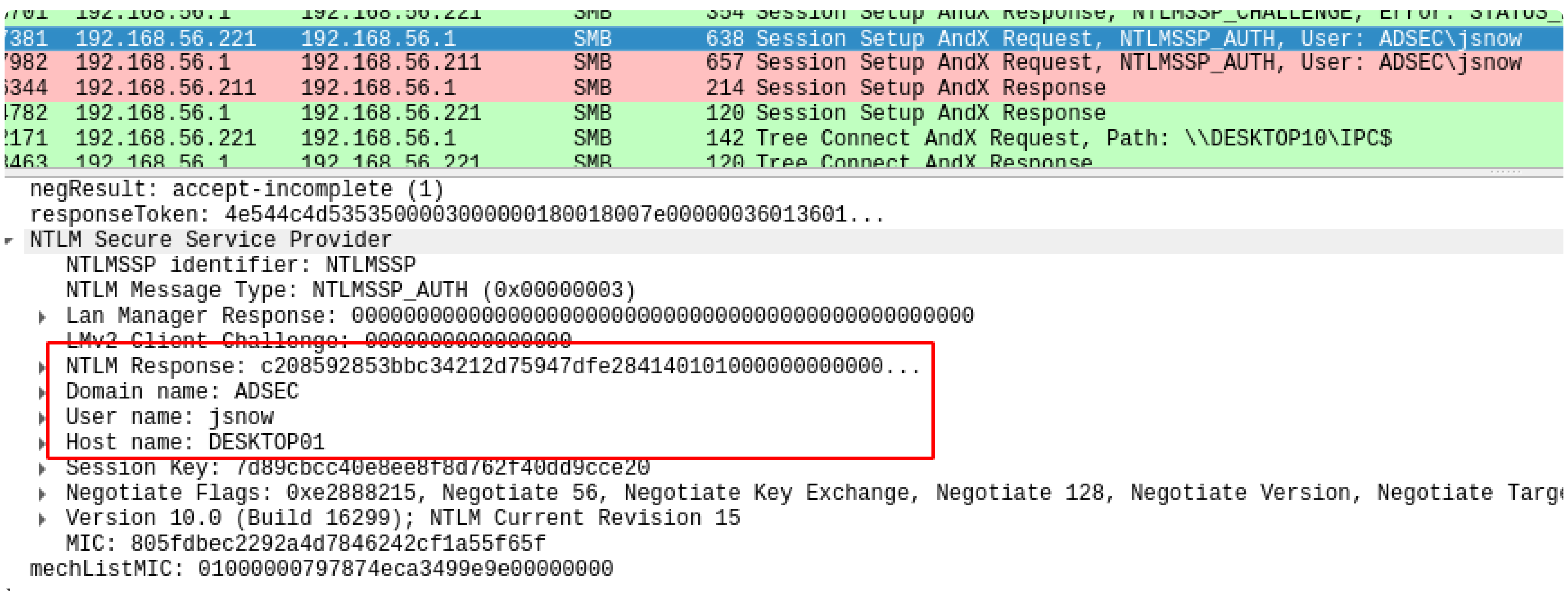
```
78  192.168.56.211    192.168.56.1      SMB     428 Session Setup AndX Response, NTLMSSP_CHALLENGE,
01  192.168.56.1      192.168.56.221    SMB     354 Session Setup AndX Response, NTLMSSP_CHALLENGE,
81  192.168.56.221    192.168.56.1      SMB     638 Session Setup AndX Request, NTLMSSP_AUTH, User:
82  192.168.56.1      192.168.56.211    SMB     657 Session Setup AndX Request, NTLMSSP_AUTH, User:
44  192.168.56.211    192.168.56.1      SMB     214 Session Setup AndX Response
82  192.168.56.1      192.168.56.221    SMB     120 Session Setup AndX Response
71  192.168.56.221    192.168.56.1      SMB     142 Tree Connect AndX Request, Path: \\DESKTOP10\IP
63  192.168.56.1      192.168.56.221    SMB     120 Tree Connect AndX Response

    NTLMSSP identifier: NTLMSSP
    NTLM Message Type: NTLMSSP_CHALLENGE (0x00000002)
  ▸ Target Name: ADSEC
  ▸ Negotiate Flags: 0xe2898215, Negotiate 56, Negotiate Key Exchange, Negotiate 128, Negotiate Version,
    NTLM Server Challenge: b6515172c37197b0
    Reserved: 0000000000000000
```

When the attacker receives this challenge, he sends it to **DESKTOP01** without any modification. In this example, the challenge is `b6515172c37197b0`.



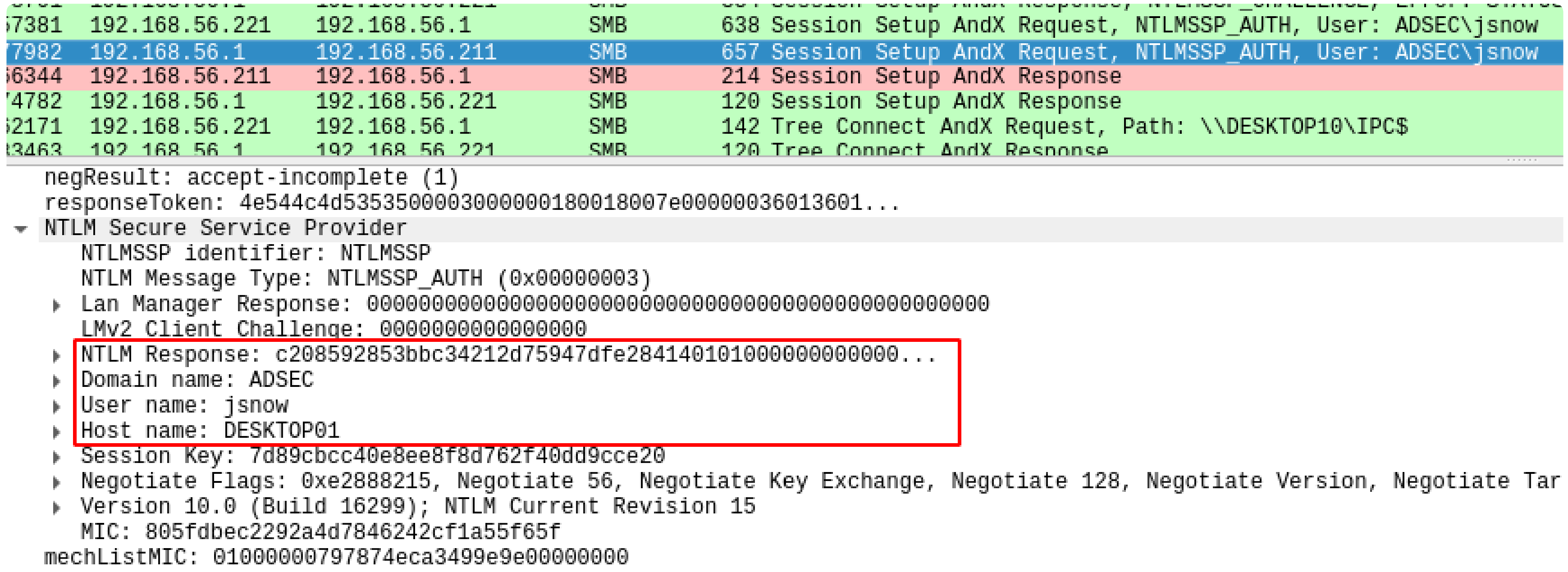
```
278  192.168.56.211    192.168.56.1      SMB     428 Session Setup AndX Response, NTLMSSP_CHALLENGE,
701  192.168.56.1      192.168.56.221    SMB     354 Session Setup AndX Response, NTLMSSP_CHALLENGE,
381  192.168.56.221    192.168.56.1      SMB     638 Session Setup AndX Request, NTLMSSP_AUTH, User:
982  192.168.56.1      192.168.56.211    SMB     657 Session Setup AndX Request, NTLMSSP_AUTH, User:
344  192.168.56.211    192.168.56.1      SMB     214 Session Setup AndX Response

  NTLM Secure Service Provider
    NTLMSSP identifier: NTLMSSP
    NTLM Message Type: NTLMSSP_CHALLENGE (0x00000002)
  ▸ Target Name: ADSEC
  ▸ Negotiate Flags: 0xe2898215, Negotiate 56, Negotiate Key Exchange, Negotiate 128, Negotiate Version,
    NTLM Server Challenge: b6515172c37197b0
    Reserved: 0000000000000000
  ▸ Target Info
```

The client will then compute the response using his secret, as we have seen in the previous paragraphs, and he will send his response alongside with his username (**jsnow**), his hostname (**DESKTOP01**), and in this example he indicates that he is a domain user, so he provides the domain name (**ADSEC**).



```
7381  192.168.56.221   192.168.56.1     SMB     638 Session Setup AndX Request, NTLMSSP_AUTH, User: ADSEC\jsnow
7982  192.168.56.1     192.168.56.211   SMB     657 Session Setup AndX Request, NTLMSSP_AUTH, User: ADSEC\jsnow
5344  192.168.56.211   192.168.56.1     SMB     214 Session Setup AndX Response
4782  192.168.56.1     192.168.56.221   SMB     120 Session Setup AndX Response
2171  192.168.56.221   192.168.56.1     SMB     142 Tree Connect AndX Request, Path: \\DESKTOP10\IPC$
3463  192.168.56.1     192.168.56.221   SMB     120 Tree Connect AndX Response
  negResult: accept-incomplete (1)
  responseToken: 4e544c4d535350000300000018001807e00000036013601...
▾ NTLM Secure Service Provider
     NTLMSSP identifier: NTLMSSP
     NTLM Message Type: NTLMSSP_AUTH (0x00000003)
   ▸ Lan Manager Response: 000000000000000000000000000000000000000000000000
     LMv2 Client Challenge: 0000000000000000
   ▸ NTLM Response: c208592853bbc34212d75947dfe28414010100000000000...
   ▸ Domain name: ADSEC
   ▸ User name: jsnow
   ▸ Host name: DESKTOP01
   ▸ Session Key: 7d89cbcc40e8ee8f8d762f40dd9cce20
   ▸ Negotiate Flags: 0xe2888215, Negotiate 56, Negotiate Key Exchange, Negotiate 128, Negotiate Version, Negotiate Targ
   ▸ Version 10.0 (Build 16299); NTLM Current Revision 15
     MIC: 805fdbec2292a4d7846242cf1a55f65f
  mechListMIC: 01000000797874eca3499e9e00000000
```

The attacker who gets all that doesn't ask questions. He sends the exact same information to the server. So he pretends to be **jsnow** on **DESKTOP01** and part of **ADSEC** domain, and he also sends the response that has been computed by the client, called **NTLM Response** in these screenshots. We call this response **NTLMv2 hash**.



```
57381  192.168.56.221   192.168.56.1     SMB    638 Session Setup AndX Request, NTLMSSP_AUTH, User: ADSEC\jsnow
77982  192.168.56.1     192.168.56.211   SMB    657 Session Setup AndX Request, NTLMSSP_AUTH, User: ADSEC\jsnow
56344  192.168.56.211   192.168.56.1     SMB    214 Session Setup AndX Response
74782  192.168.56.1     192.168.56.221   SMB    120 Session Setup AndX Response
52171  192.168.56.221   192.168.56.1     SMB    142 Tree Connect AndX Request, Path: \\DESKTOP10\IPC$
33463  192.168.56.1     192.168.56.221   SMB    120 Tree Connect AndX Response
```

```
negResult: accept-incomplete (1)
responseToken: 4e544c4d53535000030000001800180007e00000036013601...
NTLM Secure Service Provider
   NTLMSSP identifier: NTLMSSP
   NTLM Message Type: NTLMSSP_AUTH (0x00000003)
   Lan Manager Response: 000000000000000000000000000000000000000000000000
   LMv2 Client Challenge: 0000000000000000
   NTLM Response: c208592853bbc34212d75947dfe28414010100000000000...
   Domain name: ADSEC
   User name: jsnow
   Host name: DESKTOP01
   Session Key: 7d89cbcc40e8ee8f8d762f40dd9cce20
   Negotiate Flags: 0xe2888215, Negotiate 56, Negotiate Key Exchange, Negotiate 128, Negotiate Version, Negotiate Tar
   Version 10.0 (Build 16299); NTLM Current Revision 15
   MIC: 805fdbec2292a4d7846242cf1a55f65f
mechListMIC: 01000000797874eca3499e9e00000000
```

We can see that the attacker was only relaying stuff. He just relayed the information from the client to the server and vice versa, except that in the end, the server thinks that the attacker is successfully authenticated, and the attacker can then perform actions on the server on behalf of **ADSEC\jsnow**.

Authentication vs Session

Now that we have understood the basic principle of NTLM relay, the question that arises is how, concretely, can we perform actions on a server after relaying NTLM authentication? By the way, what do we mean by "actions"? What is it possible to do?

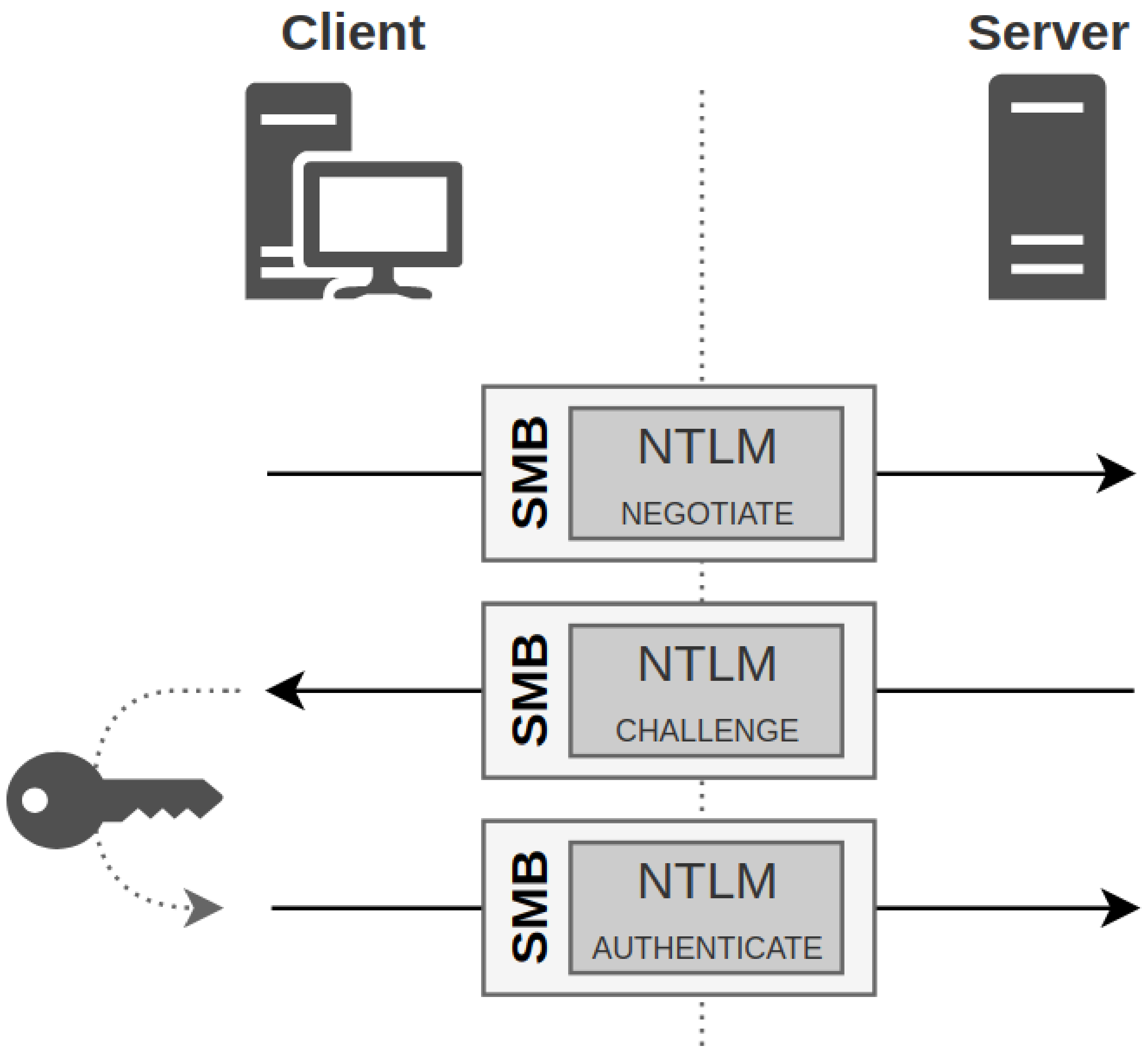
To answer this question, we must first clarify one fundamental thing. When a client authenticates to a server to do *something*, we must distinguish two things:

1. **Authentication**, allowing the server to verify that the client is who it claims to be.

2. **The session**, during which the client will be able to perform *actions*.

Thus, if the client has authenticated correctly, it will then be able to access the resources offered by the server, such as network shares, access to an LDAP directory, an HTTP server or a SQL database. This list is obviously not exhaustive.

To manage these two steps, the protocol that is used must be able to encapsulate the authentication, thus the exchange of NTLM messages.


Client
Server
SMB
NTLM
NEGOTIATE
SMB
NTLM
CHALLENGE
SMB
NTLM
AUTHENTICATE

Of course, if all the protocols were to integrate NTLM technical details, it would quickly become a holy mess. That's why Microsoft provides an interface that can be relied on to handle authentication, and packages have been specially developed to handle different types of authentication.

SSPI & NTLMSSP

The SSPI interface, or **Security Support Provider Interface**, is an interface proposed by Microsoft to standardize authentication, regardless of the type of authentication used. Different packages can connect to this interface to handle different types of authentication.

In our case, it is the NTLMSSP package (**NTLM Security Support Provider**) that interests us, but there is also a package for Kerberos authentication, for example.

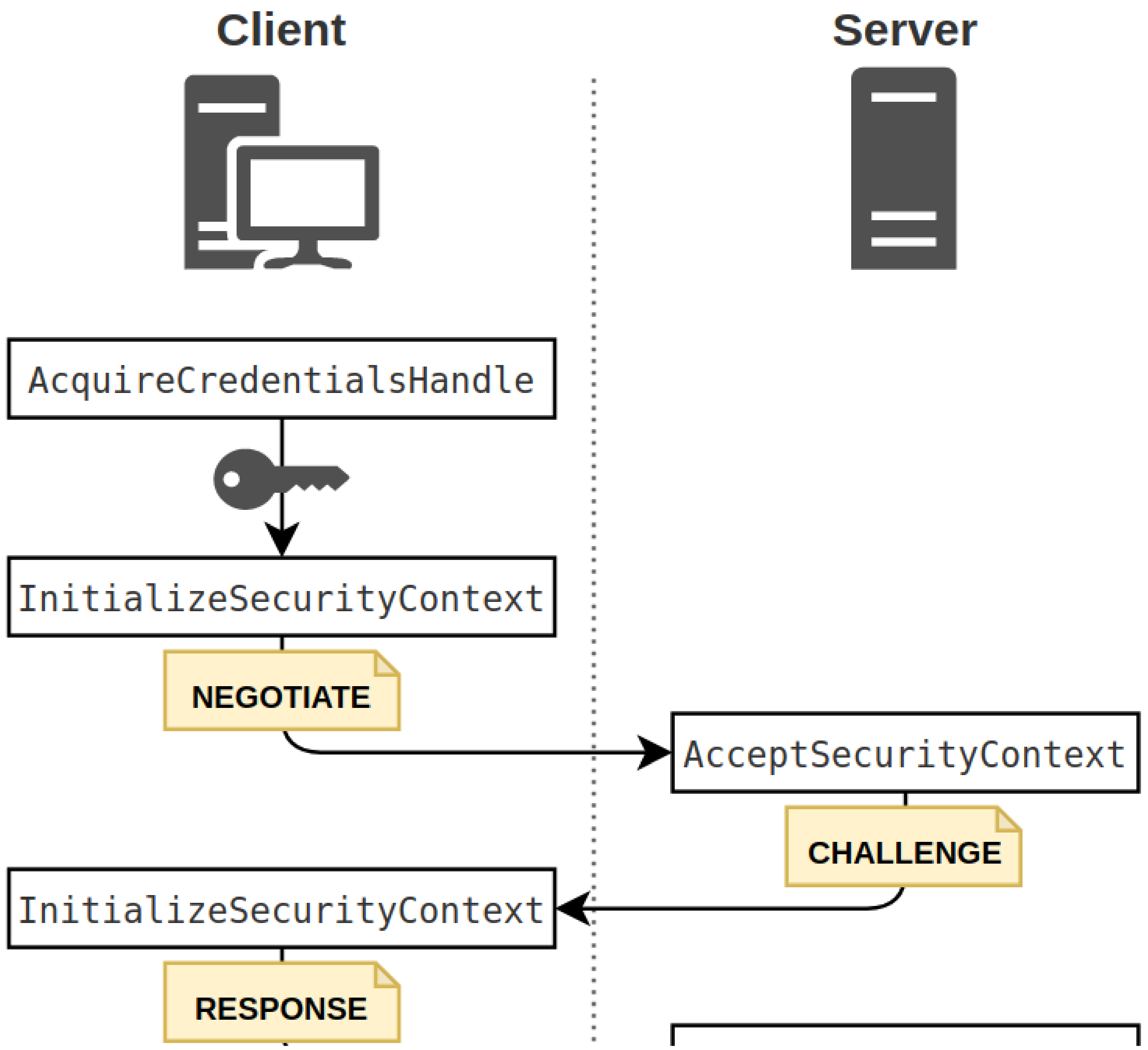
Without going into details, the SSPI interface provides several functions, including `AcquireCredentialsHandle`, `InitializeSecurityContext` and `AcceptSecurityContext`.

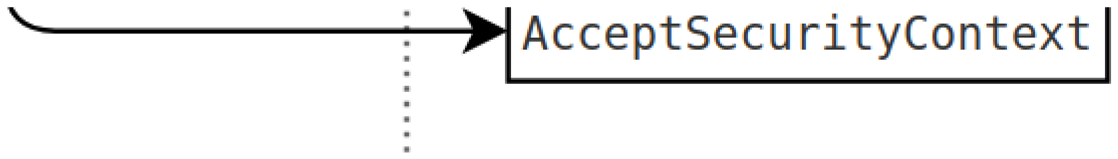
During NTLM authentication, both the client and the server will use these functions. The steps are only briefly described here.

1. The client calls `AcquireCredentialsHandle` in order to gain indirect access to the user credentials.
2. The client then calls `InitializeSecurityContext`, a function which, when called for the first time, will create a message of type 1, thus of type **NEGOTIATE**. We know this because we're interested in NTLM, but for a programmer, it doesn't matter what this message is. All that matters is to send it to the server.
3. The server, when receiving the message, calls the `AcceptSecurityContext` function. This function will then create the type 2 message, the **CHALLENGE**.
4. When receiving this message, the client will call `InitializeSecurityContext` again, but this time passing the **CHALLENGE** as an argument. The NTLMSSP package takes care of everything to compute the

response by encrypting the challenge, and will produce the last **AUTHENTICATE** message.

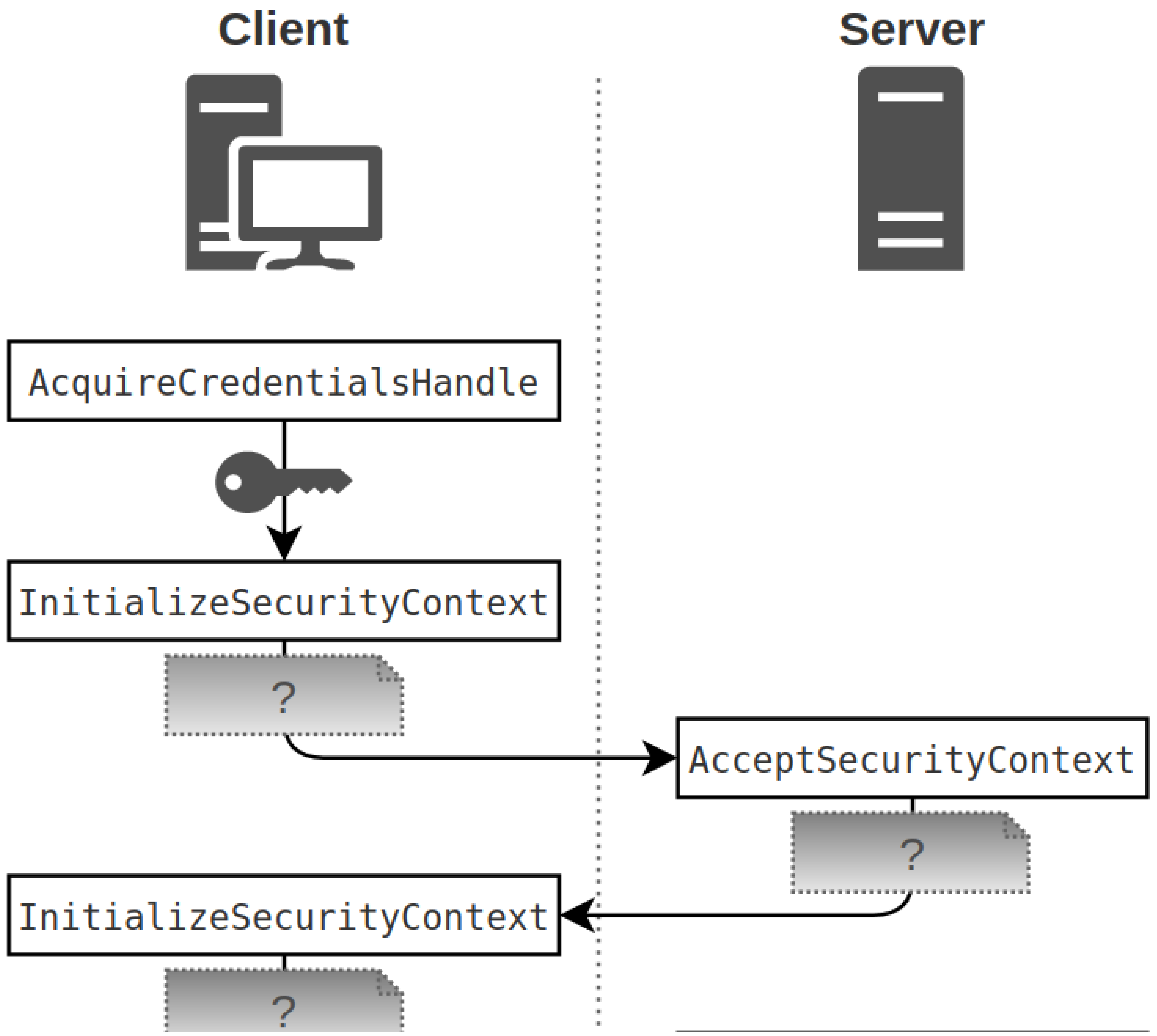
5. Upon receiving this last message, the server also calls `AcceptSecurityContext` again, and the authentication verification will be performed automatically.

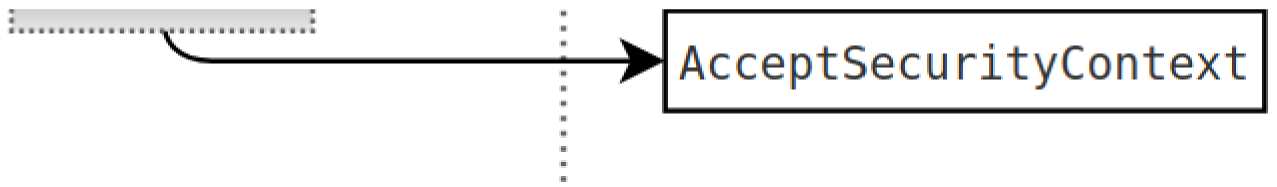

Client
Server
AcquireCredentialsHandle
InitializeSecurityContext
NEGOTIATE
AcceptSecurityContext
CHALLENGE
InitializeSecurityContext
RESPONSE



The reason these steps are explained is to show that in reality, from the client or server point of view, **the structure of the 3 messages that are exchanged does not matter**. We, with our knowledge of the NTLM protocol, know what these messages correspond to, but both the client and the server don't care. These messages are described in the Microsoft documentation as **opaque tokens**.

This means that these 5 steps are completely independent of client's type or server's type. They work regardless of the protocol used as long as the protocol has something in place to allow this opaque structure to be exchanged in one way or another from the client to the server.


Client
Server
AcquireCredentialsHandle
InitializeSecurityContext
?
AcceptSecurityContext
?
InitializeSecurityContext
?



So the protocols have adapted to find a way to put an NTLMSSP, Kerberos, or other authentication structure into a specific field, and if the client or server sees that there is data in that field, it just passes it to `InitializeSecurityContext` or `AcceptSecurityContext`.

This point is quite important, since it clearly shows that the application layer (HTTP, SMB, SQL, …) is completely independent from the authentication layer (NTLM, Kerberos, …). Therefore, security measures are both needed for the **authentication** layer **and** for the **application** layer.

For a better understanding, we will see the two examples of application protocols **SMB** and **HTTP**. It's quite easy to find documentation for other protocols. It's always the same principle.

Integration with HTTP

This is what a basic HTTP request looks like.

```
GET /index.html HTTP/1.1
Host: beta.hackndo.com
User-Agent: Mozilla/5.0
Accept: text/html
Accept-Language: fr
```

The mandatory elements in this example are the HTTP verb (**GET**), the path to the requested page (**/index.html**), the protocol version (**HTTP/1.1**), or the Host header (**Host: beta.hackndo.com**).

But it is quite possible to add other arbitrary headers. At best, the remote server is aware that these headers will be present, and it will know how to handle them, and at worst it will ignore them. This allows you to have the same request with some additional information.

```
GET /index.html HTTP/1.1
Host: beta.hackndo.com
User-Agent: Mozilla/5.0
Accept: text/html
Accept-Language: en
X-Name: pixis
Favorite-Food: Beer 'coz yes, beer is food
```

It is this feature that is used to be able to transfer NTLM messages from the client to the server. It has been decided that the client sends its messages in a header called `Authorization` and the server in a header called `WWW-Authenticate`. If a client attempts to access a web site requiring authentication, the server will respond by adding the `WWW-Authenticate` header, and highlighting the different authentication mechanisms it supports. For NTLM, it will simply say `NTLM`.

The client, knowing that NTLM authentication is required, will send the first message in the `Authorization` header, encoded in base 64 because the message does not only contain printable characters. The server will respond with a challenge in the `WWW-Authenticate` header, the client will compute the response and will send it in `Authorization`. If authentication is successful, the server will usually return a **200** return code indicating that everything went well.

```
> GET /index.html HTTP/1.1
> Host: beta.hackndo.com
> User-Agent: Mozilla/5.0
> Accept: text/html
> Accept-Language: en
```

```
  < HTTP/1.1 401 Unauthorized
  < WWW-Authenticate: NTLM
  < Content type: text/html
  < Content-Length: 0

> GET /index.html HTTP/1.1
> Host: beta.hackndo.com
> User-Agent: Mozilla/5.0
> Accept: text/html
> Accept-Language: en
=> Authorization: NTLM <NEGOTIATE in base 64>

  < HTTP/1.1 401 Unauthorized
  => WWW-Authenticate: NTLM <CHALLENGE in base 64>
  < Content type: text/html
  < Content-Length: 0

> GET /index.html HTTP/1.1
> Host: beta.hackndo.com
> User-Agent: Mozilla/5.0
> Accept: text/html
> Accept-Language: en
=> Authorization: NTLM <RESPONSE in base 64>

  < HTTP/1,200 OKAY.
  < WWW-Authenticate: NTLM
  < Content type: text/html
  < Content-Length: 0
  < Connection: close
```

As long as the TCP session is open, authentication will be effective. As soon as the session closes, however, the server will no longer have the client's security context, and a new authentication will have to take place. This can often happen, and thanks to Microsoft's SSO (**Single Sign On**) mechanisms, it is often transparent to the user.

Integration with SMB

Let’s take another example frequently encountered in a company network. It is SMB protocol, used to access network shares, but not only.

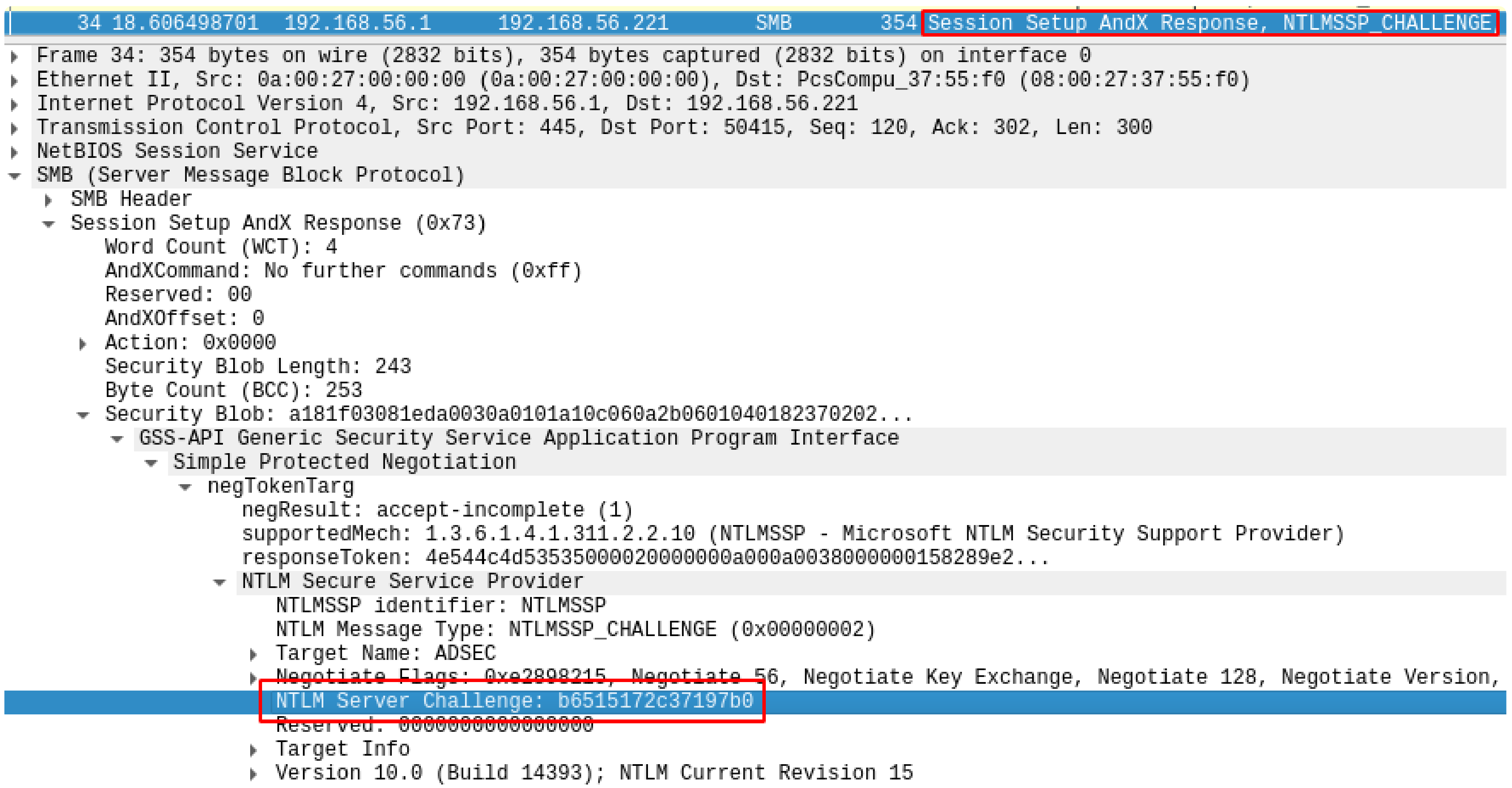
SMB protocol works by using commands. They are documented by Microsoft, and there are many of them. For example, there are `SMB_COM_OPEN`, `SMB_COM_CLOSE` or `SMB_COM_READ`, commands to open, close or read a file.

SMB also has a command dedicated to configuring an SMB session, and this command is `SMB_COM_SESSION_SETUP_ANDX`. Two fields are dedicated to the contents of the NTLM messages in this command.

- LM/LMv2 Authentication: OEMPassword
- NTLM/NTLMv2 authentication: UnicodePassword

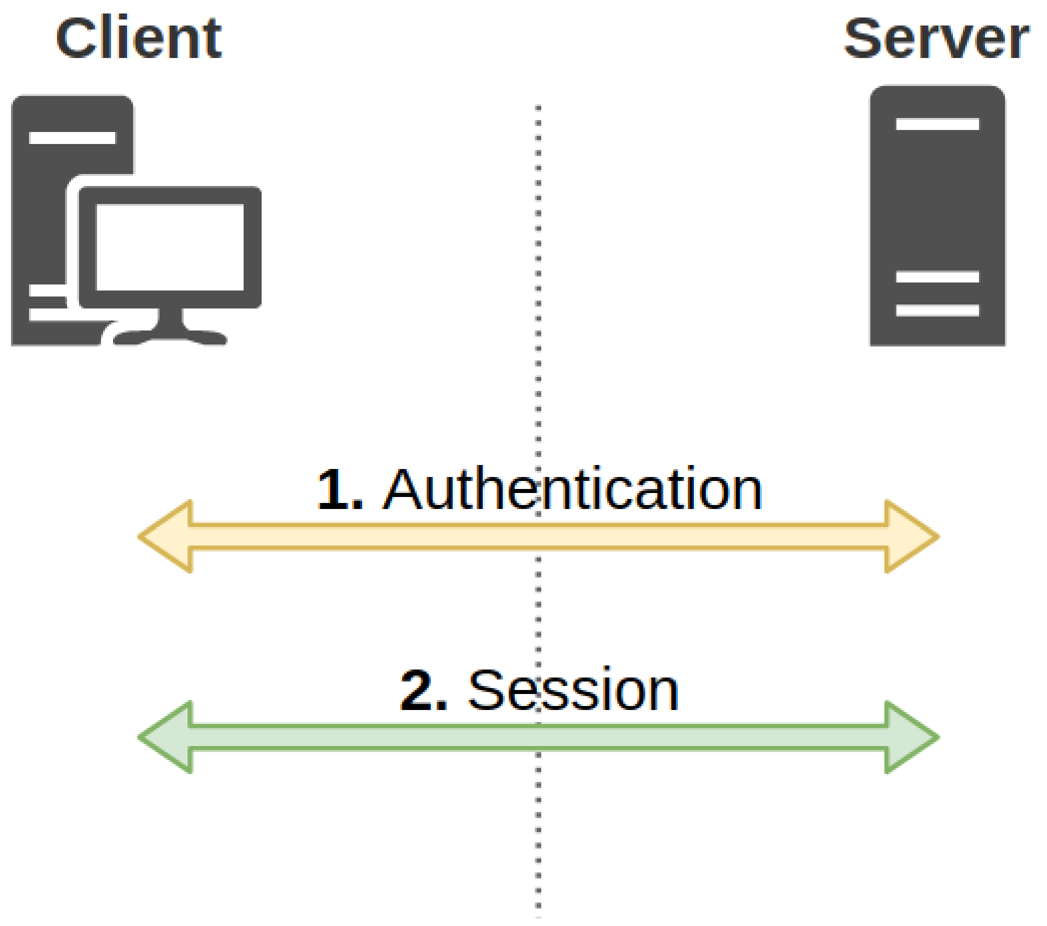
What is important to remember is that there is a specific SMB command with an allocated field for NTLM messages.

Here is an example of an SMB packet containing the response of a server to an authentication.

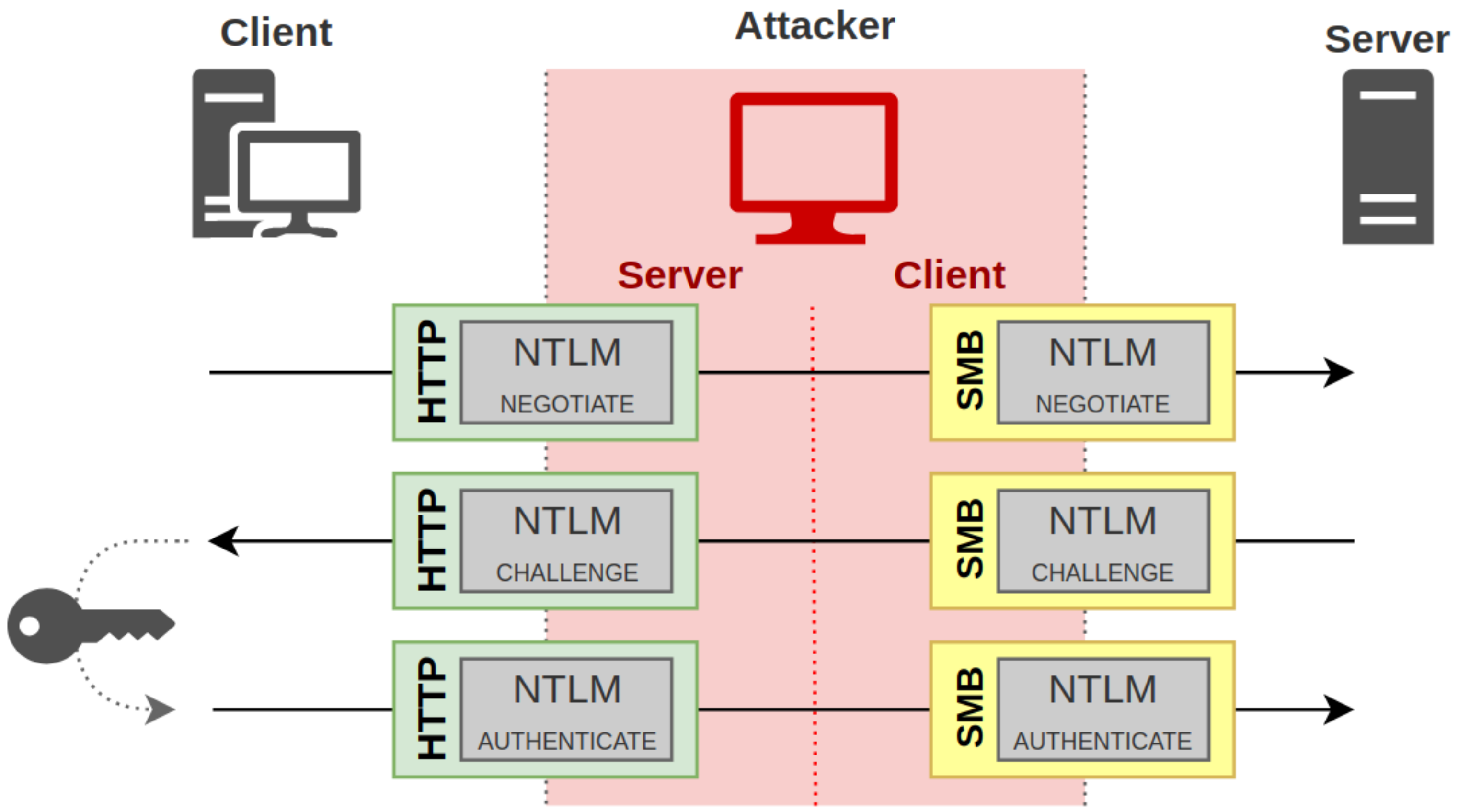

```
   34 18.606498701  192.168.56.1       192.168.56.221        SMB        354 Session Setup AndX Response, NTLMSSP_CHALLENGE
 Frame 34: 354 bytes on wire (2832 bits), 354 bytes captured (2832 bits) on interface 0
 Ethernet II, Src: 0a:00:27:00:00:00 (0a:00:27:00:00:00), Dst: PcsCompu_37:55:f0 (08:00:27:37:55:f0)
 Internet Protocol Version 4, Src: 192.168.56.1, Dst: 192.168.56.221
 Transmission Control Protocol, Src Port: 445, Dst Port: 50415, Seq: 120, Ack: 302, Len: 300
 NetBIOS Session Service
 SMB (Server Message Block Protocol)
    SMB Header
    Session Setup AndX Response (0x73)
       Word Count (WCT): 4
       AndXCommand: No further commands (0xff)
       Reserved: 00
       AndXOffset: 0
       Action: 0x0000
       Security Blob Length: 243
       Byte Count (BCC): 253
       Security Blob: a181f03081eda0030a0101a10c060a2b0601040182370202...
          GSS-API Generic Security Service Application Program Interface
             Simple Protected Negotiation
                negTokenTarg
                   negResult: accept-incomplete (1)
                   supportedMech: 1.3.6.1.4.1.311.2.2.10 (NTLMSSP - Microsoft NTLM Security Support Provider)
                   responseToken: 4e544c4d53535000020000000a000a0038000000158289e2...
                   NTLM Secure Service Provider
                      NTLMSSP identifier: NTLMSSP
                      NTLM Message Type: NTLMSSP_CHALLENGE (0x00000002)
                      Target Name: ADSEC
                      Negotiate Flags: 0xe2898215, Negotiate 56, Negotiate Key Exchange, Negotiate 128, Negotiate Version,
                      NTLM Server Challenge: b6515172c37197b0
                      Reserved: 0000000000000000
                      Target Info
                      Version 10.0 (Build 14393); NTLM Current Revision 15
```

These two examples show that the content of NTLM messages is protocol-independent. It can be included in any protocol that supports it.

It is then very important to clearly distinguish the authentication part, i.e. the NTLM exchanges, from the application part, or the session part, which is the continuation of the exchanges via the protocol used once the client is authenticated, like browsing a website via HTTP or accessing files on a network share if we use SMB.



As this information is independent, it means that a man-in-the-middle may very well receive authentication via HTTP, for example, and relay it to a server but using SMB. This is called **cross-protocol relay**.



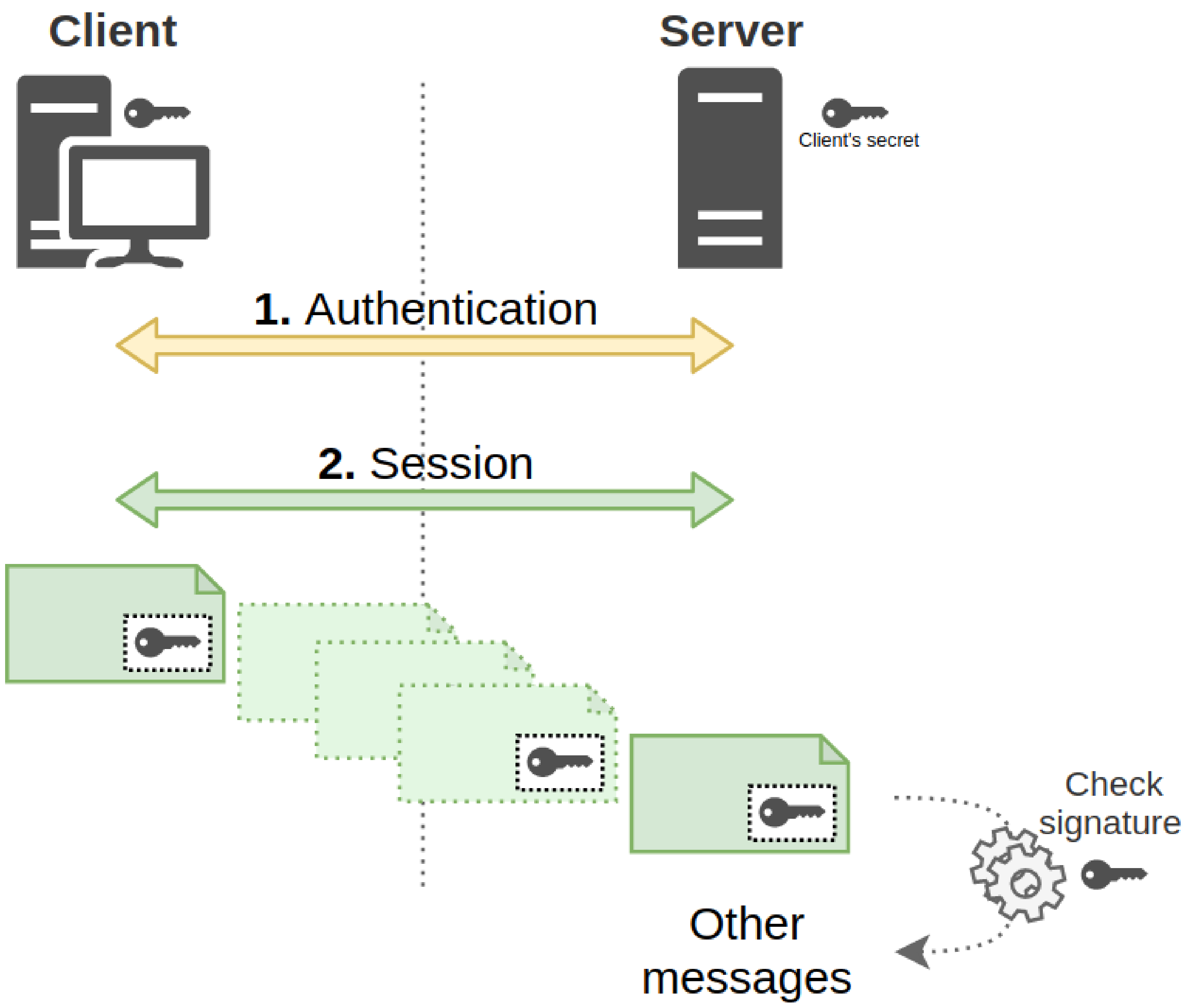
With all these aspects in mind, the following chapters will highlight the various weaknesses that exist or have existed, and the security mechanisms that come into play to address them.

Session signing

Principle

A signature is an authenticity verification method, and it ensures that the item has not been tampered with between sending and receiving. For example, if the user `jdoe` sends the text `I love hackndo`, and digitally signs this document, then anyone who receives this document and his signature can verify that it was `jdoe` who edited it, and can be assured that he wrote this sentence, and not another, since the signature guarantees that the document has not been modified.

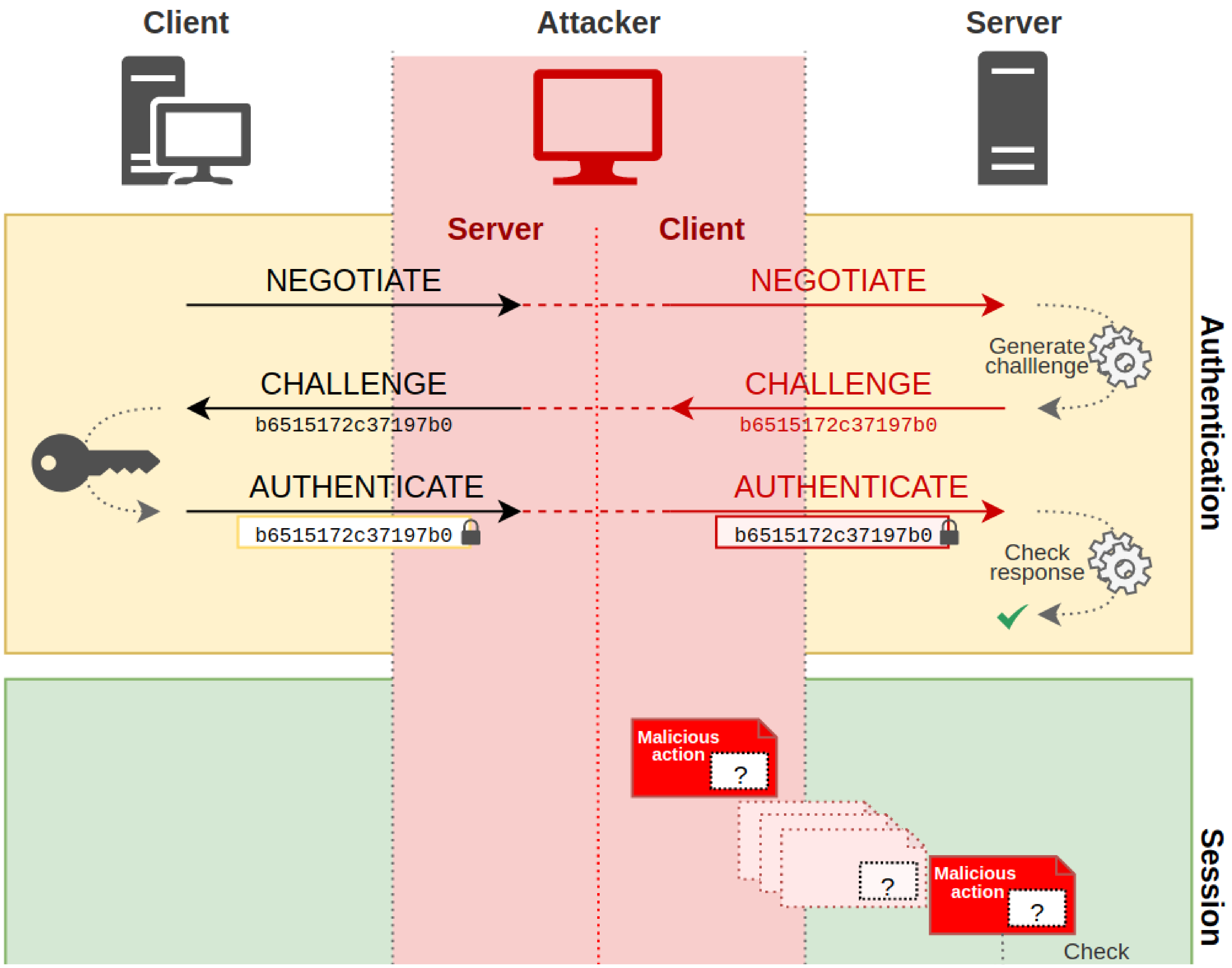
The signature principle can be applied to any exchange, as long as the protocol supports it. This is for example the case of SMB, LDAP and even HTTP. In practice, the signing of HTTP messages is rarely implemented.

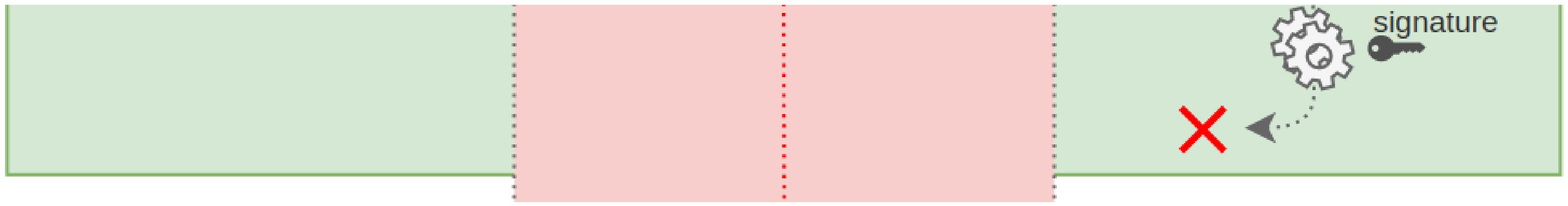

Client
Server
Client's secret
1. Authentication
2. Session
Check signature
Other messages

But then, what’s the point of signing packages? Well, as discussed earlier, session and authentication are two separate steps when a client wants to use a service. Since an attacker can be in a man-in-the-middle position and relay authentication messages, he can impersonate the client when talking with the server.

This is where signing comes into play. Even if the attacker has managed to authenticate to the server as the client, he will not be able to sign packets, regardless of authentication. Indeed, in order to be able to sign a packet, one must **know the secret** of the client.

In NTLM relay, the attacker **wants to pretend to be a client**, but he has **no knowledge of his secret**. He is therefore unable to sign anything on behalf of the client. Since he can’t sign any packet, the server receiving packets will either see that the signature is not present, or that it doesn’t exist, and will reject the attacker’s request.


Client
Attacker
Server
Server
Client
NEGOTIATE
NEGOTIATE
Generate challlenge
CHALLENGE
b6515172c37197b0
CHALLENGE
b6515172c37197b0
AUTHENTICATE
b6515172c37197b0
AUTHENTICATE
b6515172c37197b0
Check response
Authentication
Malicious action
?
?
Malicious action
?
Check
Session



So you understand that if packets must necessarily be signed after authentication, then the attacker can no longer operate, since he has no knowledge of the client's secret. So the attack will fail. **This is a very effective measure to protect against NTLM relay**.

That's all very well, but how do the client and the server agree on whether or not to sign packets? Well that's a very good question. Yes, I know, I'm the one asking it, but that doesn't make it irrelevant.

There are two things that come into play here.

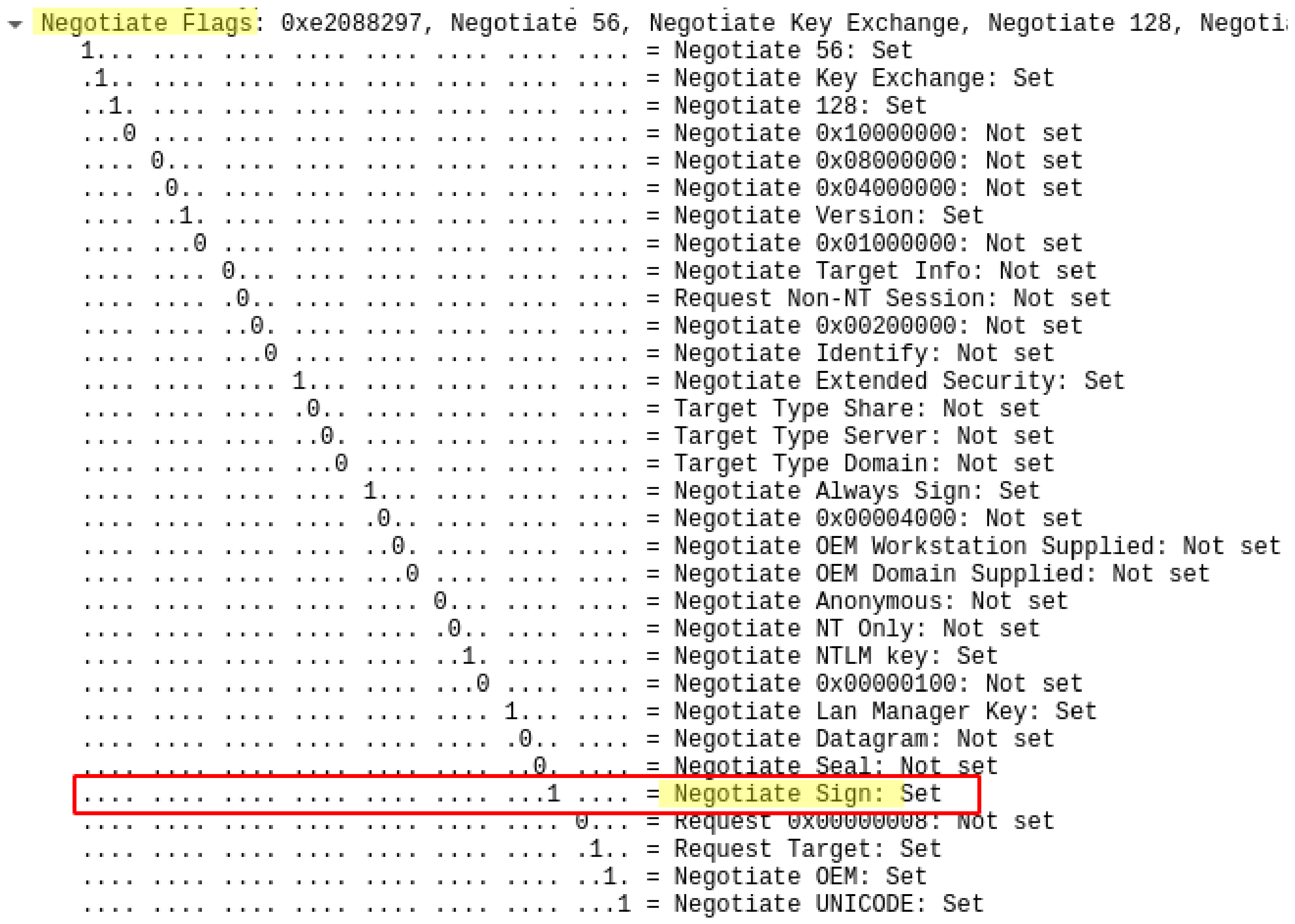
1. The first one is to indicate if signing is **supported**. This is done during NTLM negotiation.
2. The second one allows to indicate if signing will be **required**, **optional** or **disabled**. This is a setting that is done at the client and server level.

NTLM Negotiation

This negotiation allows to know if the client and/or the server support signing (among other things), and is done during the NTLM exchange. So I lied to you a bit earlier, authentication and session are not *completely* independent. (By the way, I said that since it was independent, you could change protocol when relaying, but there are limits, we will see them in the chapter on MIC in NTLM authentication).

In fact, in NTLM messages, there is other information other than a challenge and the response that are exchanged. There are also negotiation flags, or **Negotiate Flags**. These flags indicate what the sending entity supports.

There are several flags, but the one of interest here is **NEGOTIATE_SIGN**.



```
Negotiate Flags: 0xe2088297, Negotiate 56, Negotiate Key Exchange, Negotiate 128, Negoti
    1... .... .... .... .... .... .... .... = Negotiate 56: Set
    .1.. .... .... .... .... .... .... .... = Negotiate Key Exchange: Set
    ..1. .... .... .... .... .... .... .... = Negotiate 128: Set
    ...0 .... .... .... .... .... .... .... = Negotiate 0x10000000: Not set
    .... 0... .... .... .... .... .... .... = Negotiate 0x08000000: Not set
    .... .0.. .... .... .... .... .... .... = Negotiate 0x04000000: Not set
    .... ..1. .... .... .... .... .... .... = Negotiate Version: Set
    .... ...0 .... .... .... .... .... .... = Negotiate 0x01000000: Not set
    .... .... 0... .... .... .... .... .... = Negotiate Target Info: Not set
    .... .... .0.. .... .... .... .... .... = Request Non-NT Session: Not set
    .... .... ..0. .... .... .... .... .... = Negotiate 0x00200000: Not set
    .... .... ...0 .... .... .... .... .... = Negotiate Identify: Not set
    .... .... .... 1... .... .... .... .... = Negotiate Extended Security: Set
    .... .... .... .0.. .... .... .... .... = Target Type Share: Not set
    .... .... .... ..0. .... .... .... .... = Target Type Server: Not set
    .... .... .... ...0 .... .... .... .... = Target Type Domain: Not set
    .... .... .... .... 1... .... .... .... = Negotiate Always Sign: Set
    .... .... .... .... .0.. .... .... .... = Negotiate 0x00004000: Not set
    .... .... .... .... ..0. .... .... .... = Negotiate OEM Workstation Supplied: Not set
    .... .... .... .... ...0 .... .... .... = Negotiate OEM Domain Supplied: Not set
    .... .... .... .... .... 0... .... .... = Negotiate Anonymous: Not set
    .... .... .... .... .... .0.. .... .... = Negotiate NT Only: Not set
    .... .... .... .... .... ..1. .... .... = Negotiate NTLM key: Set
    .... .... .... .... .... ...0 .... .... = Negotiate 0x00000100: Not set
    .... .... .... .... .... .... 1... .... = Negotiate Lan Manager Key: Set
    .... .... .... .... .... .... .0.. .... = Negotiate Datagram: Not set
    .... .... .... .... .... .... ..0. .... = Negotiate Seal: Not set
    .... .... .... .... .... .... ...1 .... = Negotiate Sign: Set
    .... .... .... .... .... .... .... 0... = Request 0x00000008: Not set
    .... .... .... .... .... .... .... .1.. = Request Target: Set
    .... .... .... .... .... .... .... ..1. = Negotiate OEM: Set
    .... .... .... .... .... .... .... ...1 = Negotiate UNICODE: Set
```

When this flag is set to **1** by the client, it means that the client **supports** signing. Be careful, it does not mean that he **will necessarily sign** his packets. Just that he’s capable of it.

Similarly when the server replies, if it supports signing then the flag will also be set to **1**.

This negotiation thus allows each of the two parties, client and server, to indicate to the other if it is able sign packets. For some protocols, even if the client and the server support signing, this does not necessarily mean that the packets will be signed.

Implementation

Now that we’ve seen how both parties indicate to the other their **ability** to sign packets, they have to agree on it. This time, this decision is made according to the protocol. So it will be decided differently for SMBv1, for SMBv2, or for LDAP. But the idea remains the same.

Depending on the protocol, there are usually 2 or even 3 options that can be set to decide wether signing will be enforced, or not. The 3 options are :

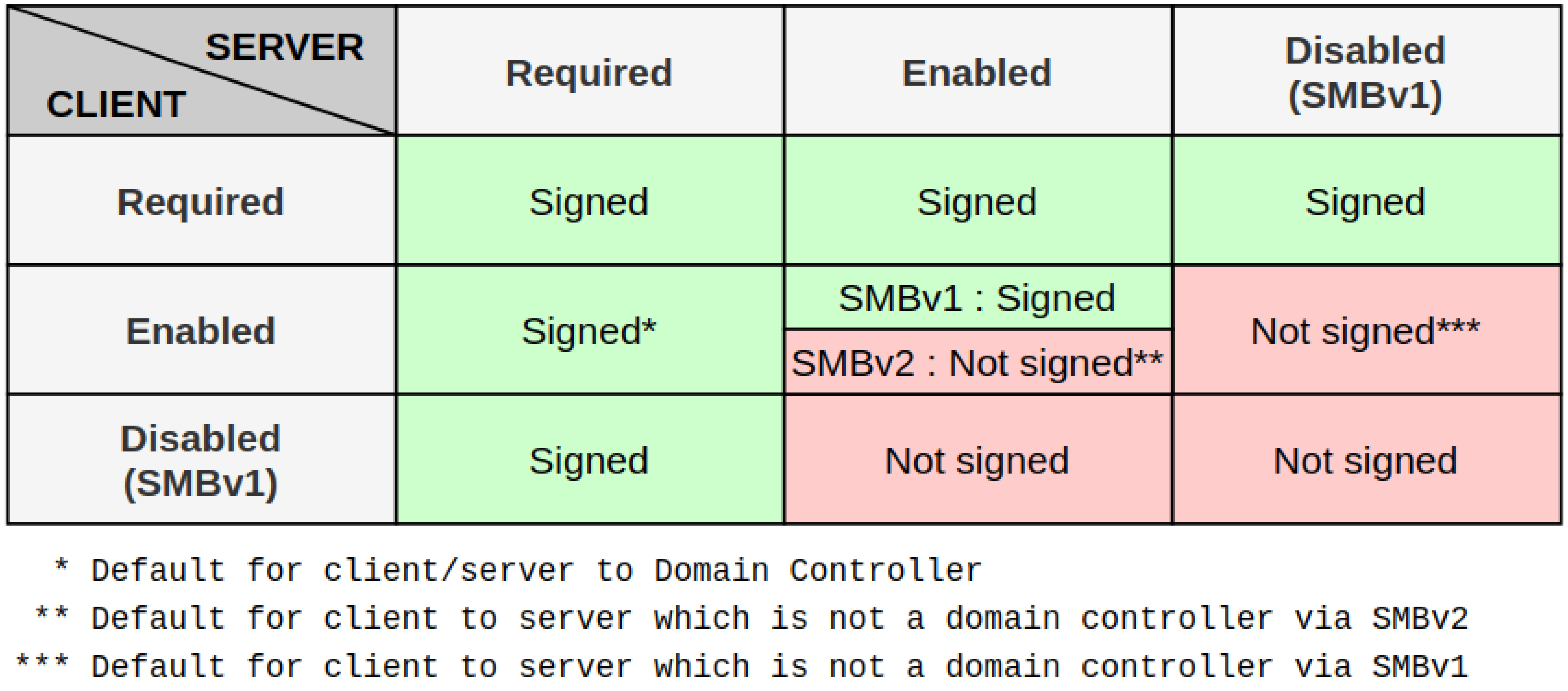
- Disabled : This means that signing is not managed.
- Enabled: This option indicates that the machine can handle signing if need be, but it does not require signing.
- Mandatory: This finally indicates that signing is not only supported, but that packets **must** be signed in order for the session to continue.

We will see here the example of two protocols, SMB and LDAP.

SMB

Signature matrix

A matrix is provided in Microsoft documentation to determine whether or not SMB packets are signed based on client-side and server-side settings. I’ve reported it in this table. Note however that for SMBv2 and higher, signing is necessarily handled, the **Disabled** parameter no longer exists.



SERVER / CLIENT	Required	Enabled	Disabled (SMBv1)
Required	Signed	Signed	Signed
Enabled	Signed*	SMBv1 : Signed SMBv2 : Not signed**	Not signed***
Disabled (SMBv1)	Signed	Not signed	Not signed

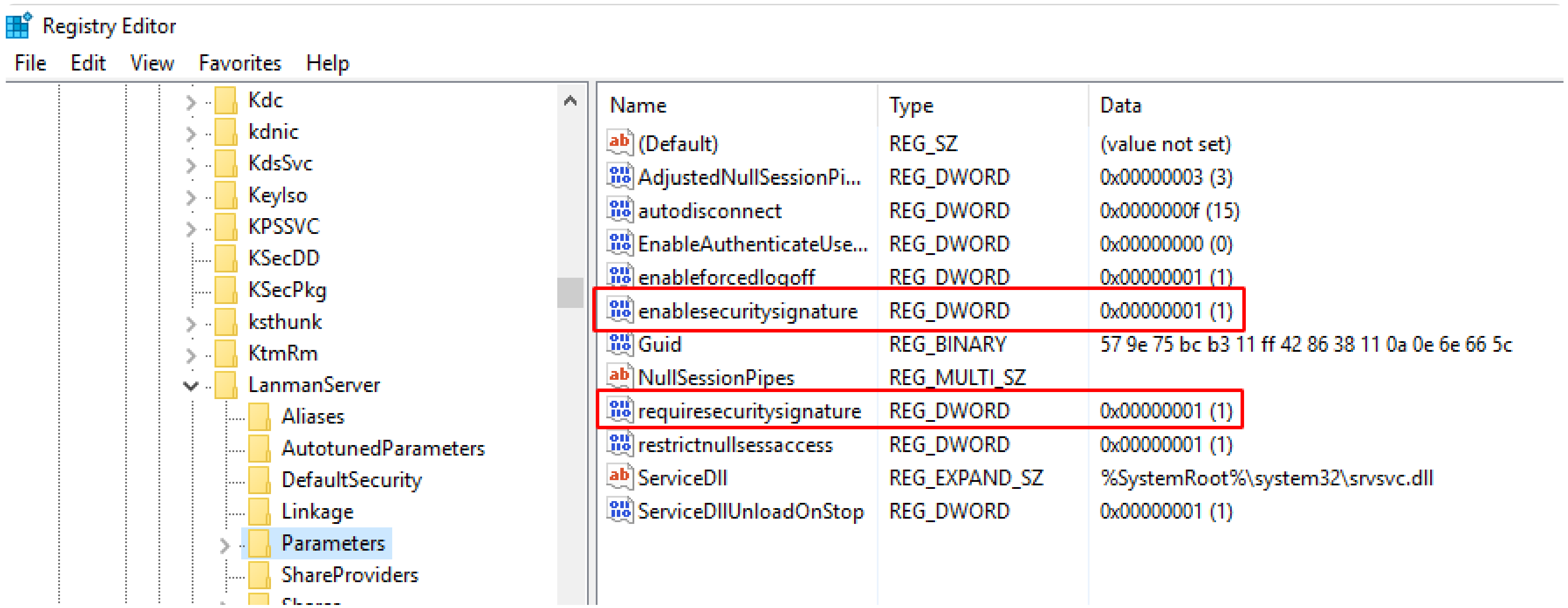
```
  * Default for client/server to Domain Controller
 ** Default for client to server which is not a domain controller via SMBv2
*** Default for client to server which is not a domain controller via SMBv1
```

There is a difference when client and server have the **Enabled** setting. In SMBv1, the default setting for servers was **Disabled**. Thus, all SMB traffic between clients and servers was not signed by default. This avoided overloading the servers by preventing them from computing signatures each time an SMB packet was sent. As the **Disabled** status no longer exists for SMBv2, and servers are now **Enabled** by default, in order to keep this load saving, the behavior between two **Enable** entites has been modified, and signing is no longer required in this case. The client and/or the server must necessarily **require** the signature for SMB packets to be signed.

Settings

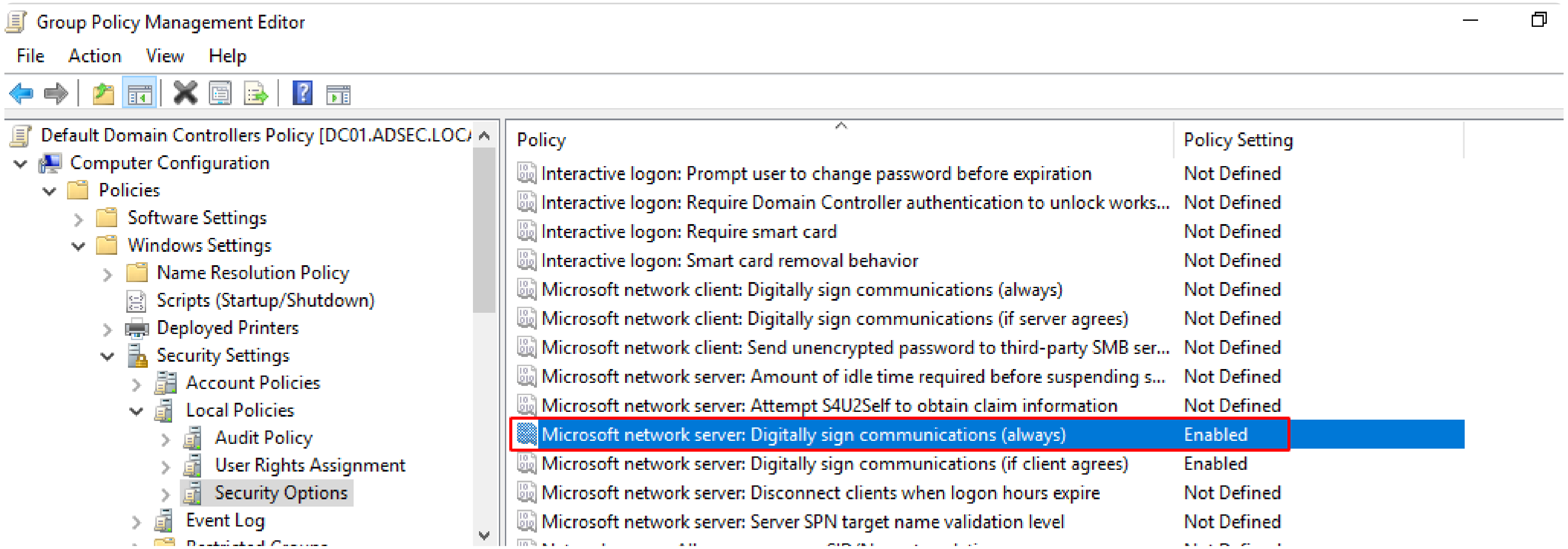
In order to change the default signing settings on a server, the `EnableSecuritySignature` and `RequireSecuritySignature` keys must be changed in registry hive

`HKEY_LOCAL_MACHINE\System\CurrentControlSet\Services\LanmanServer\Parameters` .



Name	Type	Data
(Default)	REG_SZ	(value not set)
AdjustedNullSessionPi...	REG_DWORD	0x00000003 (3)
autodisconnect	REG_DWORD	0x0000000f (15)
EnableAuthenticateUse...	REG_DWORD	0x00000000 (0)
enableforcedlogoff	REG_DWORD	0x00000001 (1)
enablesecuritysignature	REG_DWORD	0x00000001 (1)
Guid	REG_BINARY	57 9e 75 bc b3 11 ff 42 86 38 11 0a 0e 6e 66 5c
NullSessionPipes	REG_MULTI_SZ	
requiresecuritysignature	REG_DWORD	0x00000001 (1)
restrictnullsessaccess	REG_DWORD	0x00000001 (1)
ServiceDll	REG_EXPAND_SZ	%SystemRoot%\system32\srvsvc.dll
ServiceDllUnloadOnStop	REG_DWORD	0x00000001 (1)

This screenshot was taken on a domain controller. By default, domain controllers require SMB signing when a client authenticates to them. Indeed, the GPO applied to domain controllers contains this entry:



Group Policy Management Editor

File Action View Help

Default Domain Controllers Policy [DC01.ADSEC.LOCA
- Computer Configuration
  - Policies
    - Software Settings
    - Windows Settings
      - Name Resolution Policy
      - Scripts (Startup/Shutdown)
      - Deployed Printers
      - Security Settings
        - Account Policies
        - Local Policies
          - Audit Policy
          - User Rights Assignment
          - Security Options
        - Event Log

Policy	Policy Setting
Interactive logon: Prompt user to change password before expiration	Not Defined
Interactive logon: Require Domain Controller authentication to unlock works...	Not Defined
Interactive logon: Require smart card	Not Defined
Interactive logon: Smart card removal behavior	Not Defined
Microsoft network client: Digitally sign communications (always)	Not Defined
Microsoft network client: Digitally sign communications (if server agrees)	Not Defined
Microsoft network client: Send unencrypted password to third-party SMB ser...	Not Defined
Microsoft network server: Amount of idle time required before suspending s...	Not Defined
Microsoft network server: Attempt S4U2Self to obtain claim information	Not Defined
Microsoft network server: Digitally sign communications (always)	Enabled
Microsoft network server: Digitally sign communications (if client agrees)	Enabled
Microsoft network server: Disconnect clients when logon hours expire	Not Defined
Microsoft network server: Server SPN target name validation level	Not Defined

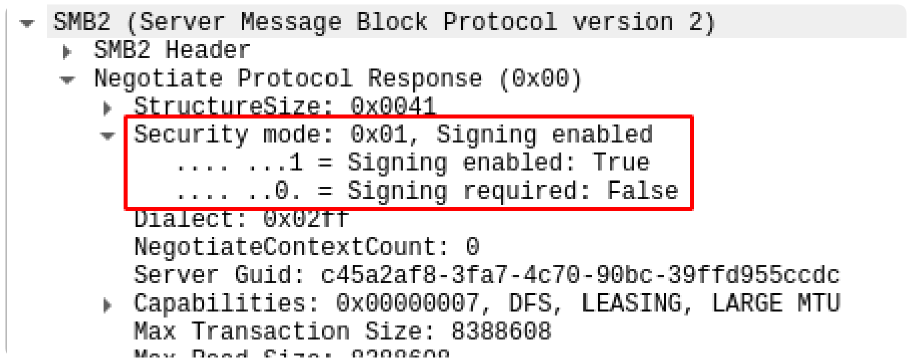
On the other hand, we can see on this capture that above this setting, the same parameter applied to **Microsoft network client** is not applied. So when the domain controller acts as an SMB server, SMB signing is required, but if a connection comes **from** the domain controller **to** a server, SMB signing is **not** required.

Setup

Now that we know where SMB signing is configured, we can see this parameter applied during an communication. It is done just before authentication. In fact, when a client connects to the SMB server, the steps are as follows:

1. Negotiation of the SMB version and signing requirements
2. Authentication
3. SMB session with negotiated parameters

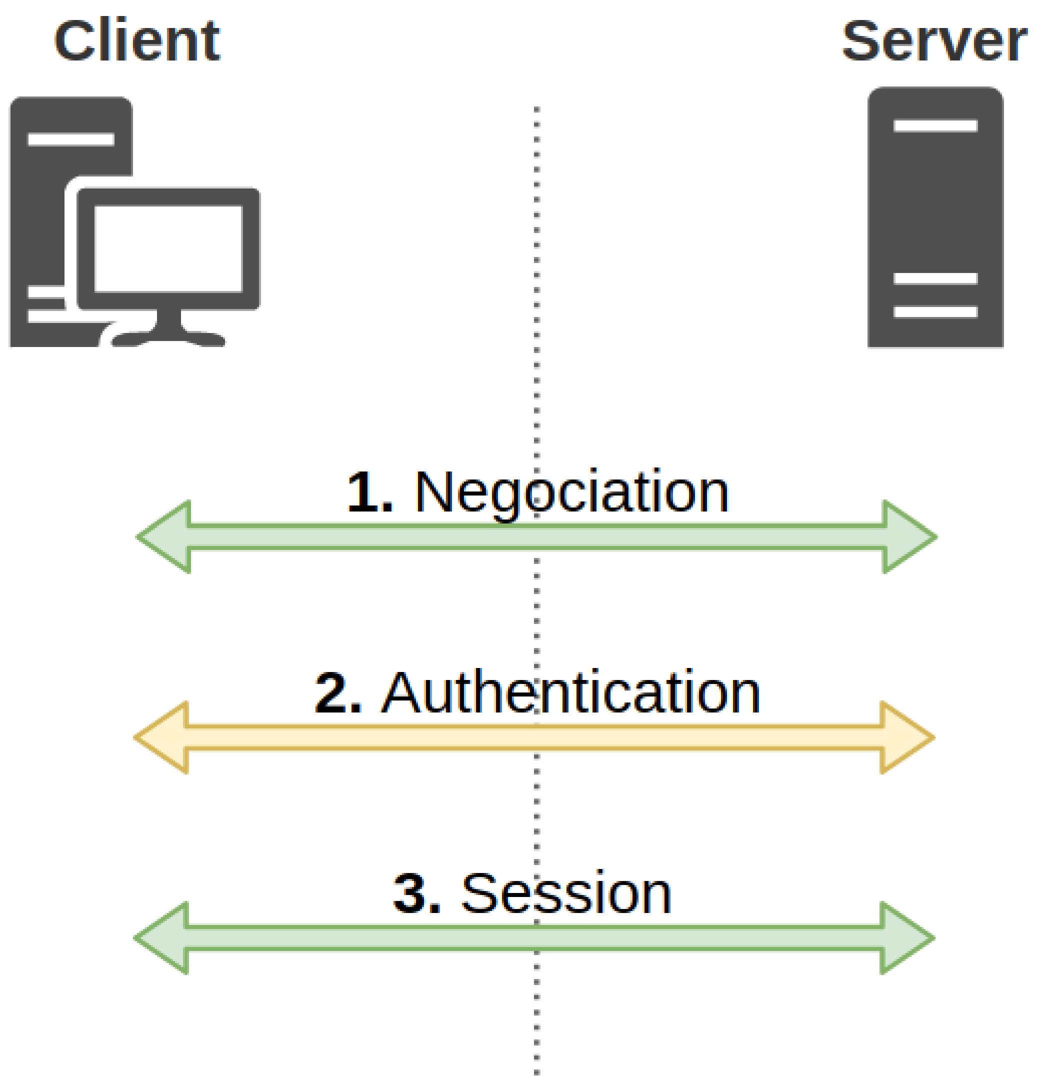
Here is an example of SMB signing negotiation:



```
▾ SMB2 (Server Message Block Protocol version 2)
  ▸ SMB2 Header
  ▾ Negotiate Protocol Response (0x00)
    ▸ StructureSize: 0x0041
    ▾ Security mode: 0x01, Signing enabled
        .... ...1 = Signing enabled: True
        .... ..0. = Signing required: False
      Dialect: 0x02ff
      NegotiateContextCount: 0
      Server Guid: c45a2af8-3fa7-4c70-90bc-39ffd955ccdc
    ▸ Capabilities: 0x00000007, DFS, LEASING, LARGE MTU
      Max Transaction Size: 8388608
```

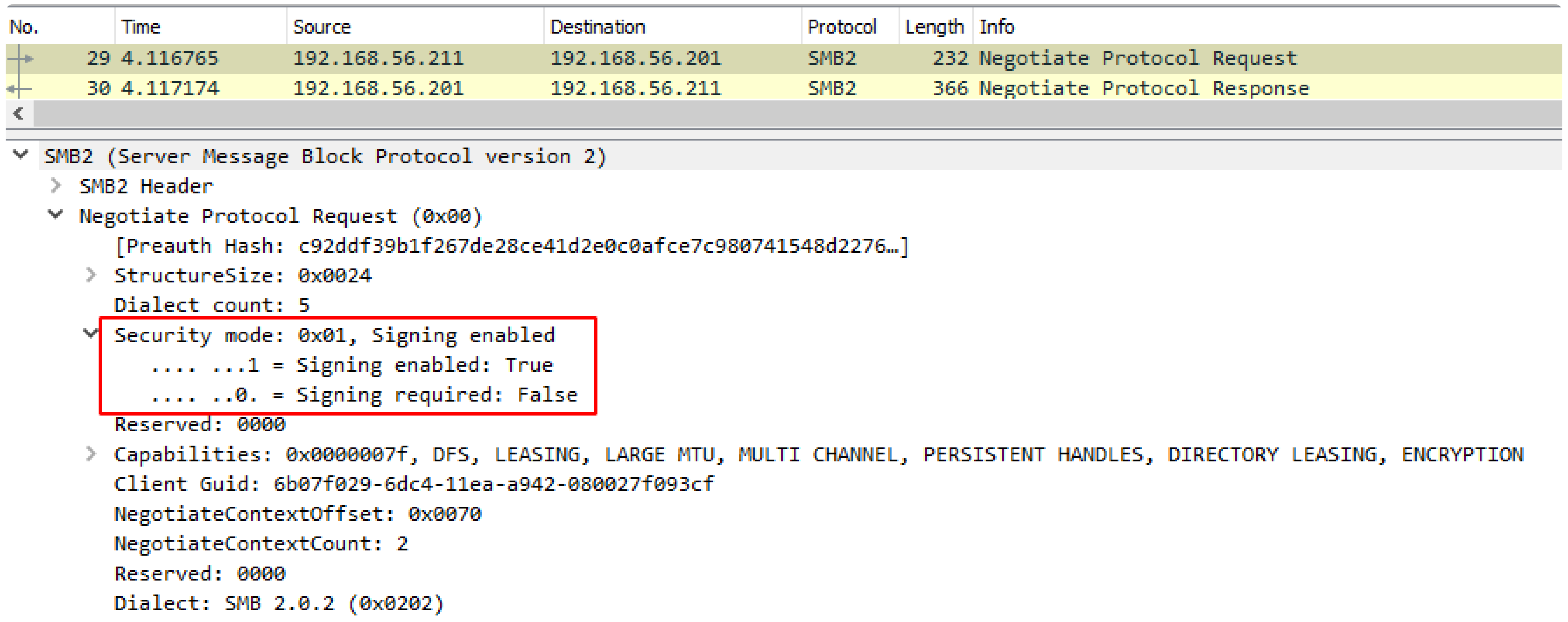
We see a response from a server indicating that it has the **Enable** parameter, but that it does not **require** signing.

To summarize, here is how a negotiation / authentication / session takes place :



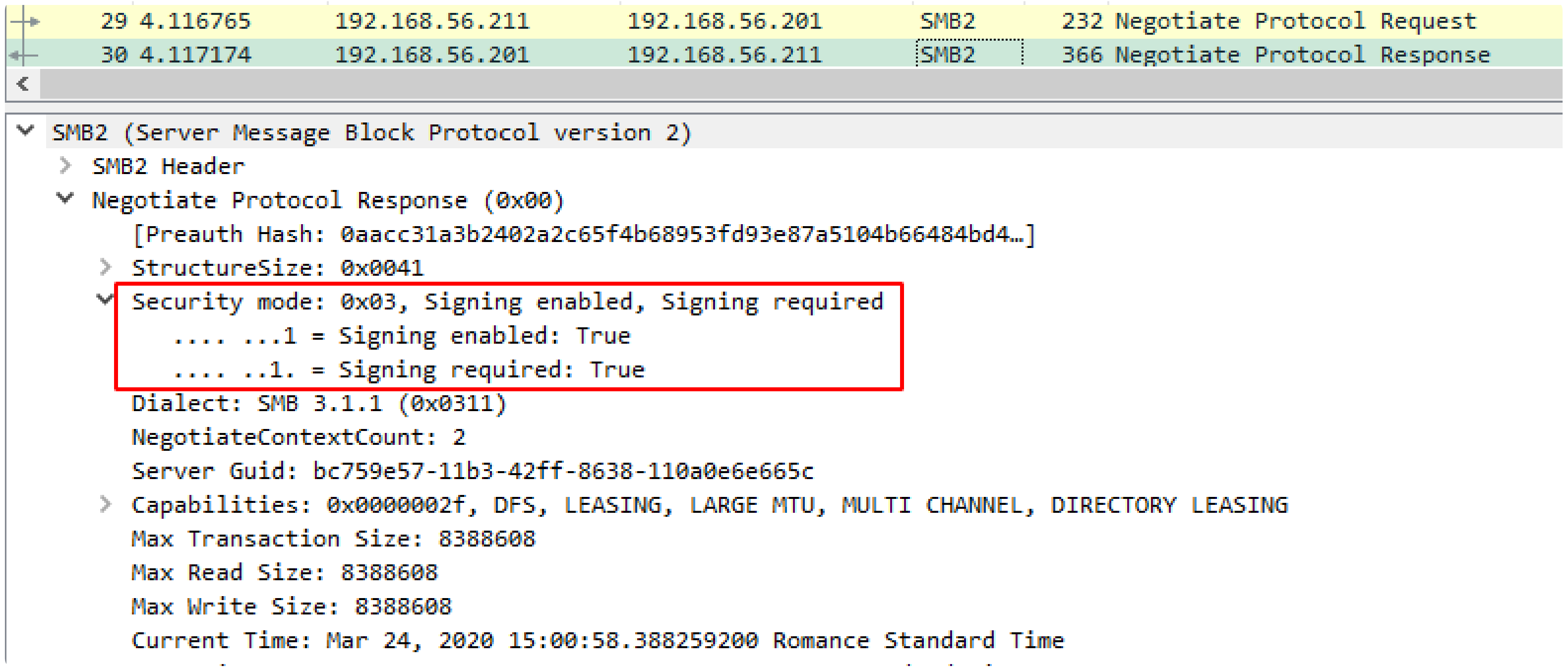
1. In the negotiation phase, both parties indicate their requirements: Is signing required for one of them?
2. In the authentication phase, both parties indicate what they support. Are they **capable** of signing?
3. In the session phase, if the **capabilities** and the **requirements** are compatible, the session is carried out applying what has been negotiated.

For example, if **DESKTOP01** client wants to communicate with **DC01** domain controller, **DESKTOP01** indicates that it does not require signing, but that that he can handle it, if needed.



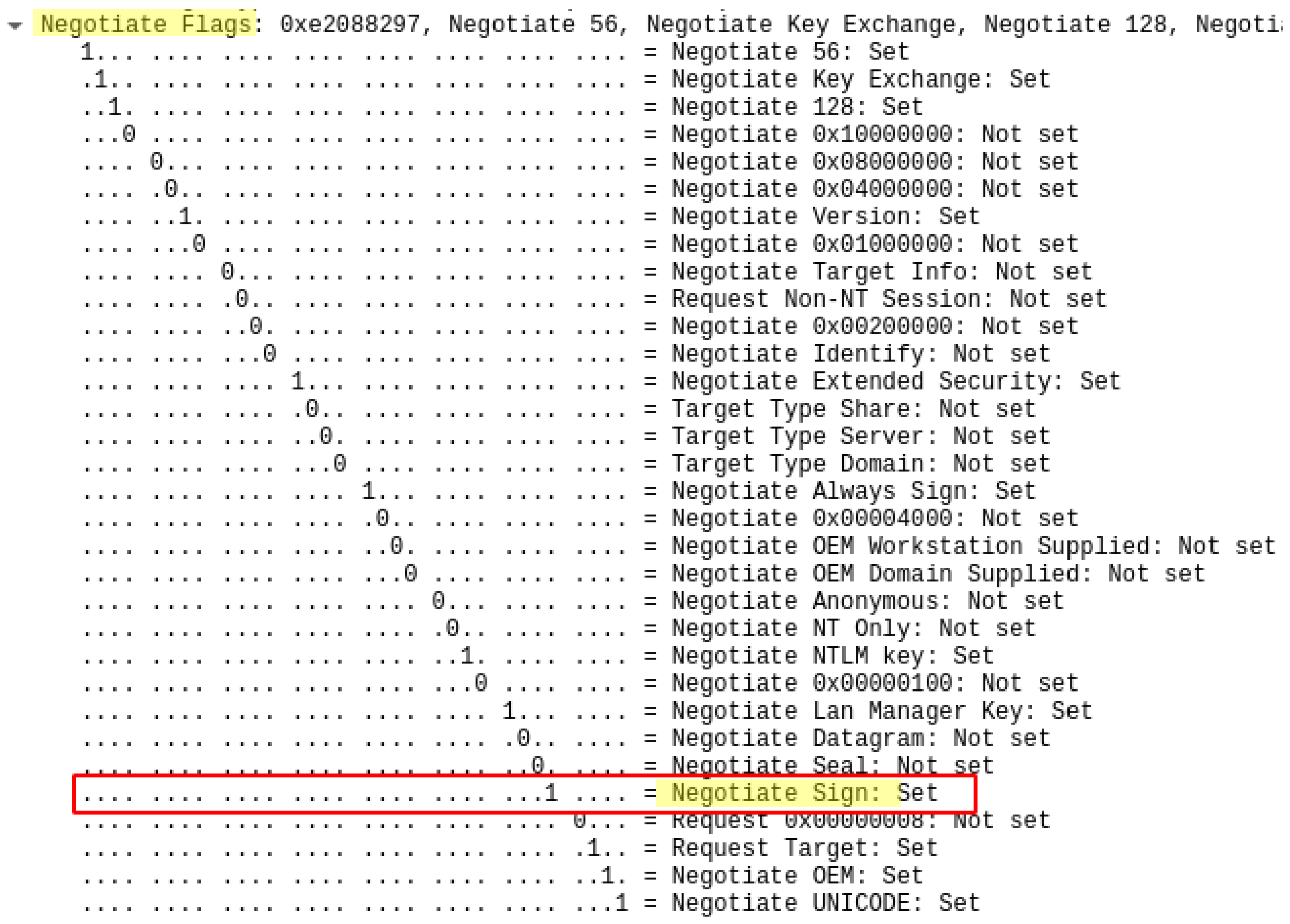
```
No.    Time       Source            Destination       Protocol  Length  Info
    29 4.116765   192.168.56.211    192.168.56.201    SMB2         232  Negotiate Protocol Request
    30 4.117174   192.168.56.201    192.168.56.211    SMB2         366  Negotiate Protocol Response

SMB2 (Server Message Block Protocol version 2)
  SMB2 Header
  Negotiate Protocol Request (0x00)
    [Preauth Hash: c92ddf39b1f267de28ce41d2e0c0afce7c980741548d2276…]
    StructureSize: 0x0024
    Dialect count: 5
    Security mode: 0x01, Signing enabled
      .... ...1 = Signing enabled: True
      .... ..0. = Signing required: False
    Reserved: 0000
    Capabilities: 0x0000007f, DFS, LEASING, LARGE MTU, MULTI CHANNEL, PERSISTENT HANDLES, DIRECTORY LEASING, ENCRYPTION
    Client Guid: 6b07f029-6dc4-11ea-a942-080027f093cf
    NegotiateContextOffset: 0x0070
    NegotiateContextCount: 2
    Reserved: 0000
    Dialect: SMB 2.0.2 (0x0202)
```

DC01 indicates that not only he supports signing, but that he requires it.



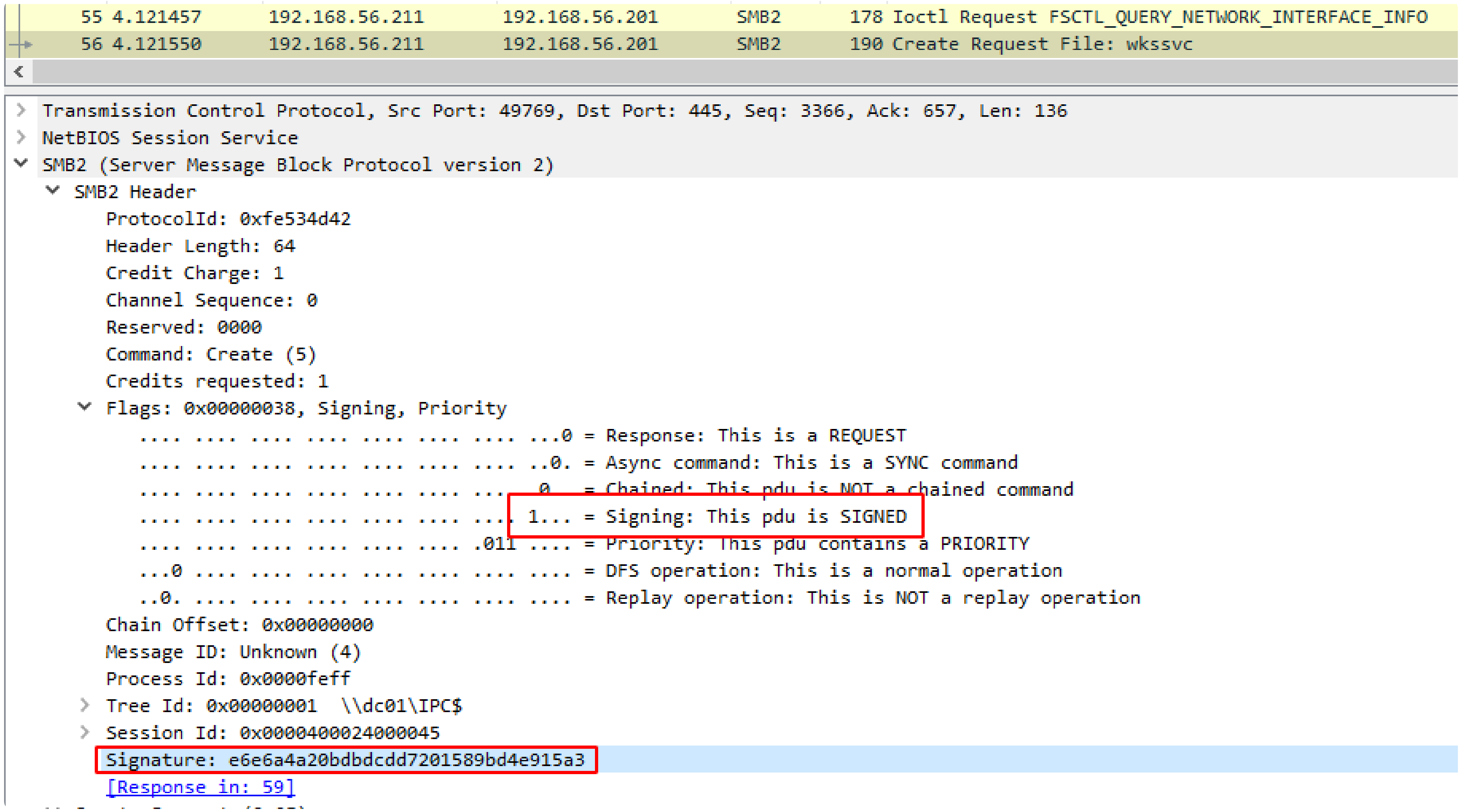
```
29 4.116765    192.168.56.211    192.168.56.201    SMB2    232 Negotiate Protocol Request
30 4.117174    192.168.56.201    192.168.56.211    SMB2    366 Negotiate Protocol Response

SMB2 (Server Message Block Protocol version 2)
  SMB2 Header
  Negotiate Protocol Response (0x00)
    [Preauth Hash: 0aacc31a3b2402a2c65f4b68953fd93e87a5104b66484bd4…]
    StructureSize: 0x0041
    Security mode: 0x03, Signing enabled, Signing required
      .... ...1 = Signing enabled: True
      .... ..1. = Signing required: True
    Dialect: SMB 3.1.1 (0x0311)
    NegotiateContextCount: 2
    Server Guid: bc759e57-11b3-42ff-8638-110a0e6e665c
    Capabilities: 0x0000002f, DFS, LEASING, LARGE MTU, MULTI CHANNEL, DIRECTORY LEASING
    Max Transaction Size: 8388608
    Max Read Size: 8388608
    Max Write Size: 8388608
    Current Time: Mar 24, 2020 15:00:58.388259200 Romance Standard Time
```

During negotiation phase, the client and server set the `NEGOTIATE_SIGN` flag to **1** since they both support signing.



```
▾ Negotiate Flags: 0xe2088297, Negotiate 56, Negotiate Key Exchange, Negotiate 128, Negoti
    1... .... .... .... .... .... .... .... = Negotiate 56: Set
    .1.. .... .... .... .... .... .... .... = Negotiate Key Exchange: Set
    ..1. .... .... .... .... .... .... .... = Negotiate 128: Set
    ...0 .... .... .... .... .... .... .... = Negotiate 0x10000000: Not set
    .... 0... .... .... .... .... .... .... = Negotiate 0x08000000: Not set
    .... .0.. .... .... .... .... .... .... = Negotiate 0x04000000: Not set
    .... ..1. .... .... .... .... .... .... = Negotiate Version: Set
    .... ...0 .... .... .... .... .... .... = Negotiate 0x01000000: Not set
    .... .... 0... .... .... .... .... .... = Negotiate Target Info: Not set
    .... .... .0.. .... .... .... .... .... = Request Non-NT Session: Not set
    .... .... ..0. .... .... .... .... .... = Negotiate 0x00200000: Not set
    .... .... ...0 .... .... .... .... .... = Negotiate Identify: Not set
    .... .... .... 1... .... .... .... .... = Negotiate Extended Security: Set
    .... .... .... .0.. .... .... .... .... = Target Type Share: Not set
    .... .... .... ..0. .... .... .... .... = Target Type Server: Not set
    .... .... .... ...0 .... .... .... .... = Target Type Domain: Not set
    .... .... .... .... 1... .... .... .... = Negotiate Always Sign: Set
    .... .... .... .... .0.. .... .... .... = Negotiate 0x00004000: Not set
    .... .... .... .... ..0. .... .... .... = Negotiate OEM Workstation Supplied: Not set
    .... .... .... .... ...0 .... .... .... = Negotiate OEM Domain Supplied: Not set
    .... .... .... .... .... 0... .... .... = Negotiate Anonymous: Not set
    .... .... .... .... .... .0.. .... .... = Negotiate NT Only: Not set
    .... .... .... .... .... ..1. .... .... = Negotiate NTLM key: Set
    .... .... .... .... .... ...0 .... .... = Negotiate 0x00000100: Not set
    .... .... .... .... .... .... 1... .... = Negotiate Lan Manager Key: Set
    .... .... .... .... .... .... .0.. .... = Negotiate Datagram: Not set
    .... .... .... .... .... .... ..0. .... = Negotiate Seal: Not set
    .... .... .... .... .... .... ...1 .... = Negotiate Sign: Set
    .... .... .... .... .... .... .... 0... = Request 0x00000008: Not set
    .... .... .... .... .... .... .... .1.. = Request Target: Set
    .... .... .... .... .... .... .... ..1. = Negotiate OEM: Set
    .... .... .... .... .... .... .... ...1 = Negotiate UNICODE: Set
```

Once this authentication is completed, the session continues, and the SMB exchanges are effectively signed.



```
55 4.121457    192.168.56.211    192.168.56.201    SMB2    178 Ioctl Request FSCTL_QUERY_NETWORK_INTERFACE_INFO
56 4.121550    192.168.56.211    192.168.56.201    SMB2    190 Create Request File: wkssvc

> Transmission Control Protocol, Src Port: 49769, Dst Port: 445, Seq: 3366, Ack: 657, Len: 136
> NetBIOS Session Service
v SMB2 (Server Message Block Protocol version 2)
  v SMB2 Header
      ProtocolId: 0xfe534d42
      Header Length: 64
      Credit Charge: 1
      Channel Sequence: 0
      Reserved: 0000
      Command: Create (5)
      Credits requested: 1
    v Flags: 0x00000038, Signing, Priority
        .... .... .... .... .... .... .... ...0 = Response: This is a REQUEST
        .... .... .... .... .... .... .... ..0. = Async command: This is a SYNC command
        .... .... .... .... .... .... .... .0.. = Chained: This pdu is NOT a chained command
        .... .... .... .... .... .... .... 1... = Signing: This pdu is SIGNED
        .... .... .... .... .... .... .011 .... = Priority: This pdu contains a PRIORITY
        ...0 .... .... .... .... .... .... .... = DFS operation: This is a normal operation
        ..0. .... .... .... .... .... .... .... = Replay operation: This is NOT a replay operation
      Chain Offset: 0x00000000
      Message ID: Unknown (4)
      Process Id: 0x0000feff
    > Tree Id: 0x00000001  \\dc01\IPC$
    > Session Id: 0x0000400024000045
      Signature: e6e6a4a20bdbdcdd7201589bd4e915a3
      [Response in: 59]
```

LDAP

Signing matrix

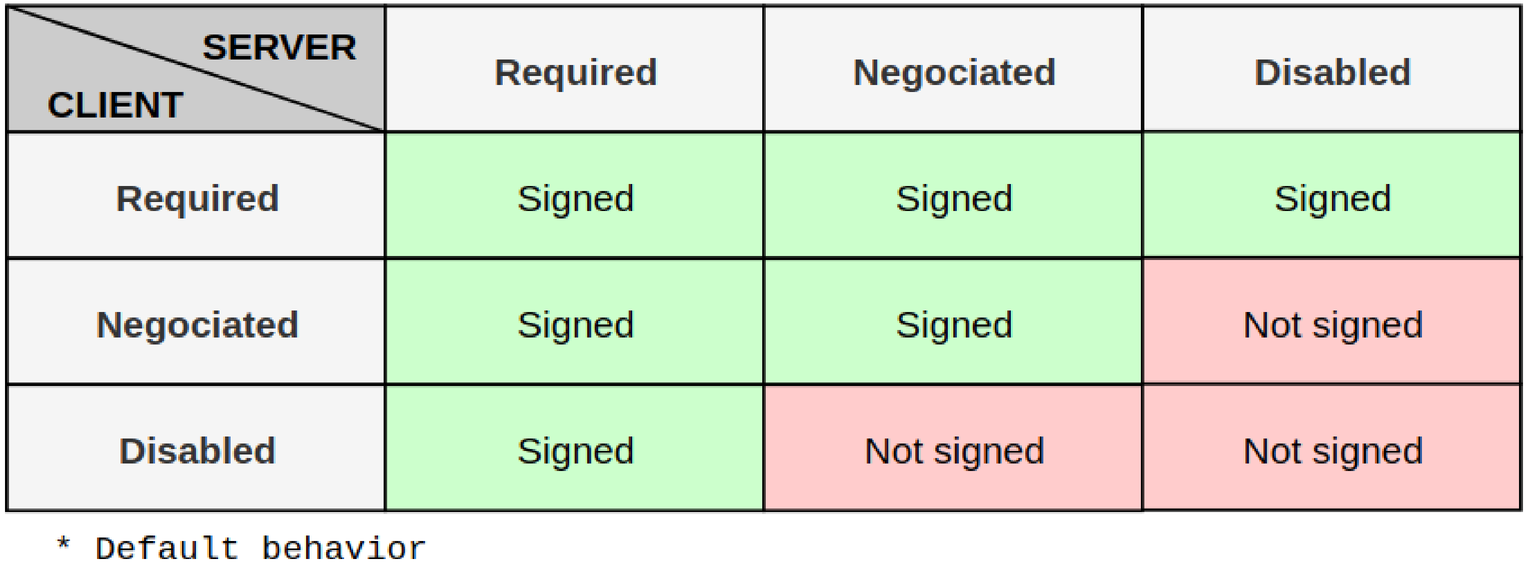
For LDAP, there are also three levels:

- Disabled: This means that packet signing is not supported.

- Negotiated Signing: This option indicates that the machine can handle signing, and if the machine it is communicating with also handles it, then they will be signed.
- Required: This finally indicates that signing is not only supported, but that packets **must** be signed in order for the session to continue.

As you can read, the intermediate level, **Negotiated Signing** differs from the SMBv2 case, because this time, if the client and the server are **able to** sign packets, then **they will**. Whereas for SMBv2, packets were **only** signed if it was a requirement for at least one entity.

So for LDAP we have a matrix similar to SMBv1, except for the default behaviors.



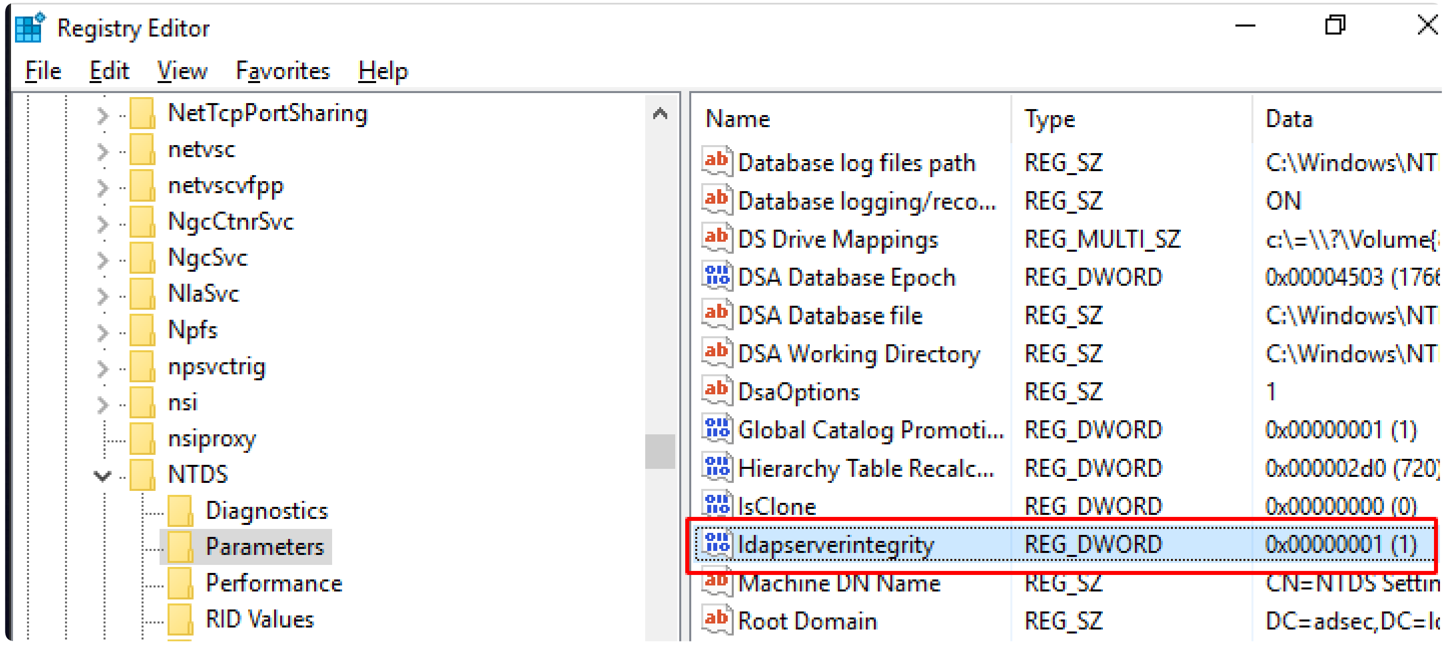
SERVER CLIENT	Required	Negociated	Disabled
Required	Signed	Signed	Signed
Negociated	Signed	Signed	Not signed
Disabled	Signed	Not signed	Not signed

* Default behavior

The difference with SMB is that in Active Directory domain, **all** hosts have **Negotiated Signing** setting. The domain controller doesn't **require** signing.

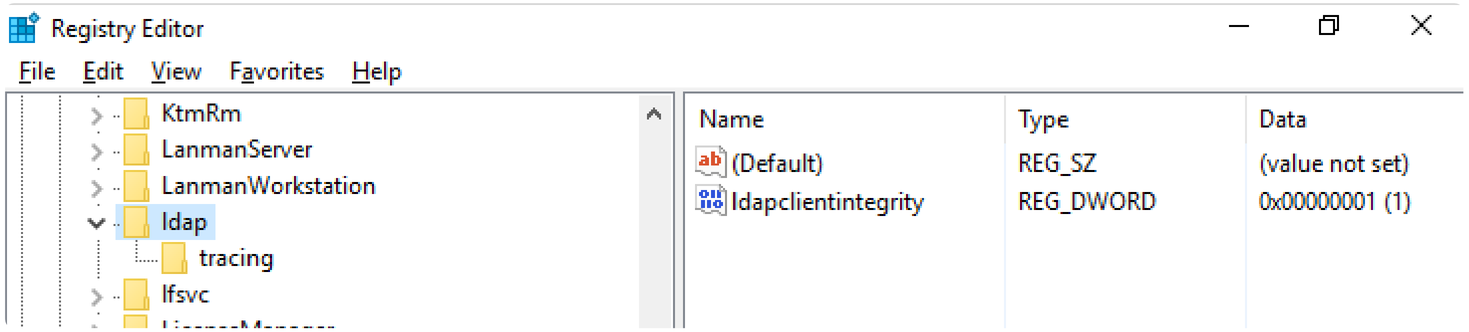
Settings

For the **domain controller**, the `ldapserverintegrity` registry key is in `HKEY_LOCAL_MACHINE\System\CurrentControlSet\Services\NTDS\Parameters` hive and can be 0, 1 or 2 depending on the level. It is set to **1** on the domain controller by default.



```
Name                          Type           Data
Database log files path       REG_SZ         C:\Windows\NT
Database logging/reco...      REG_SZ         ON
DS Drive Mappings             REG_MULTI_SZ   c:\=\\?\Volume{
DSA Database Epoch            REG_DWORD      0x00004503 (176
DSA Database file             REG_SZ         C:\Windows\NT
DSA Working Directory         REG_SZ         C:\Windows\NT
DsaOptions                    REG_SZ         1
Global Catalog Promoti...     REG_DWORD      0x00000001 (1)
Hierarchy Table Recalc...     REG_DWORD      0x000002d0 (720)
IsClone                       REG_DWORD      0x00000000 (0)
ldapserverintegrity           REG_DWORD      0x00000001 (1)
Machine DN Name               REG_SZ         CN=NTDS Settin
Root Domain                   REG_SZ         DC=adsec,DC=l
```

For the **clients**, this registry key is located in `HKEY_LOCAL_MACHINE\System\CurrentControlSet\Services\ldap`



Name	Type	Data
(Default)	REG_SZ	(value not set)
ldapclientintegrity	REG_DWORD	0x00000001 (1)

It is also set to **1** for clients. Since all clients and domain controllers have **Negotiated Signing**, **all LDAP packets are signed by default**.

Setup

Unlike SMB, there is no flag in LDAP that indicates whether packets will be signed or not. Instead, LDAP uses flags set in NTLM negotiation. There is no need for more information. In the case where both client and server support LDAP signing, then the `NEGOTIATE_SIGN` flag will be set and the packets will be signed.

If one party **requires** signing, and the other party does not **support** it, then the session simply won't start. The party requiring signing will ignore the unsigned packets.

So now we then understand that, contrary to SMB, if we are between a client and a server and we want to relay an authentication to the server using LDAP, we need two things :

1. The **server** must not require packet signing, which is the case for all machines by default
2. The **client** must not set the `NEGOTIATE_SIGN` flag to **1**. If he does, then the signature will be expected by the server, and since we don't know the client's secret, we won't be able to sign our crafted LDAP packets.

Regarding requirement **2**, sometimes clients don't set this flag, but unfortunately, the Windows SMB client sets it! By default, it is not possible to relay SMB authentication to LDAP.

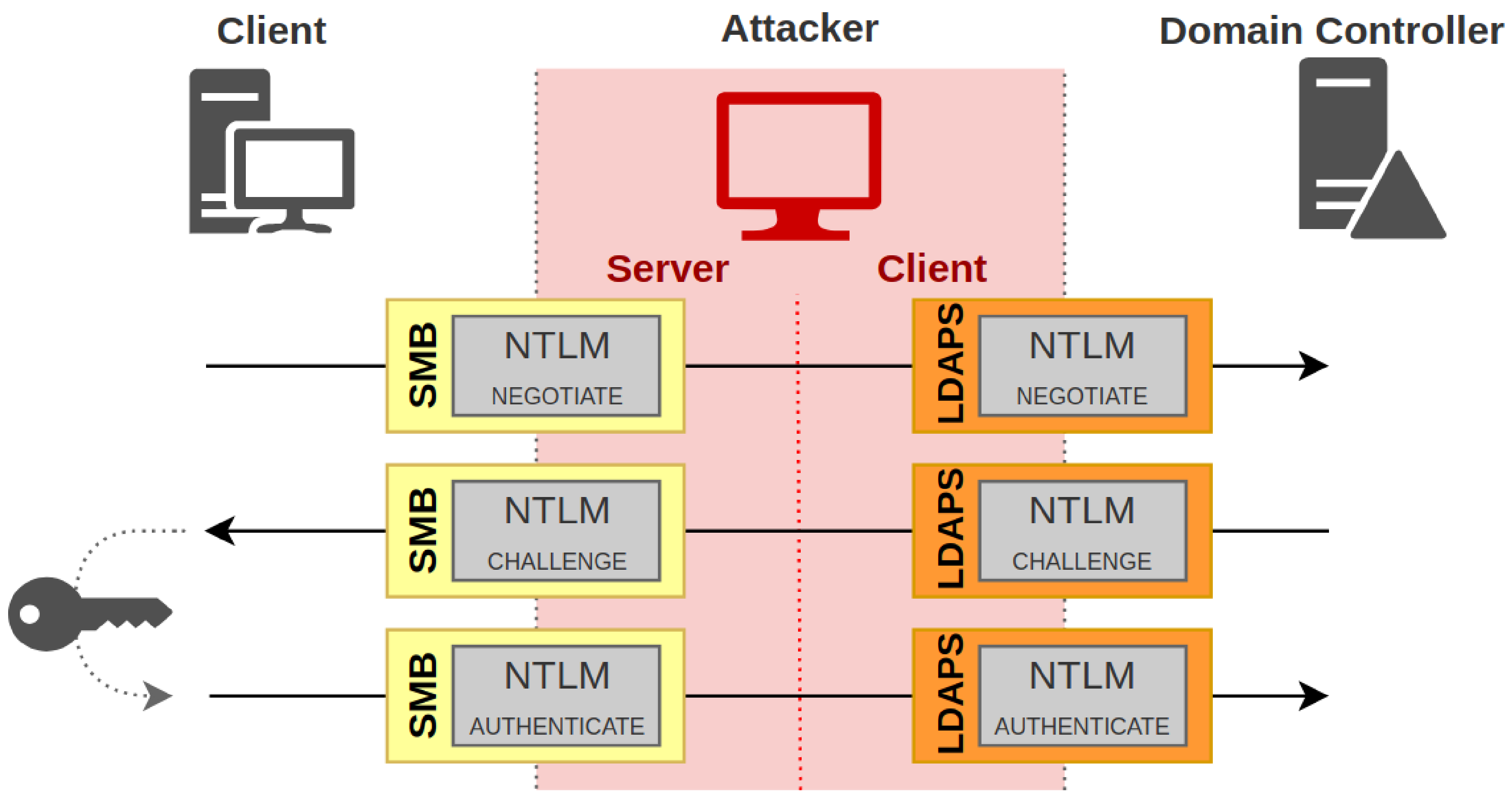
So why not just change the `NEGOTIATE_FLAG` flag and set it to **0**? Well… NTLM messages are also signed. This is what we will see in the next paragraph.

Authentication signing (MIC)

We saw how a session could be protected against a middle man attacker. Now, to understand the interest of this chapter, let’s look at a specific case.

Edge case

Let’s imagine that an attacker manages to put himself in man-in-the-middle position between a client and a domain controller, and that he receives an authentication request via SMB. Knowing that a domain controller requires SMB signing, it is not possible for the attacker to relay this authentication via SMB. On the other hand, it is possible to change protocol, as we have seen above, and the attacker decides to relay to the **LDAPS** protocol, as authentication and session should be independant.



Well, they are **almost** independent.

Almost, because we saw that in the authentication data, there was the `NEGOTIATE_SIGN` flag which was only present to indicate whether the client and server supported signing. But in some cases, this flag is taken into account, as we saw with LDAP.

Well for LDAPS, this flag is also taken into account by the server. If a server receives an authentication request with the `NEGOTIATE_SIGN` flag set to **1**, it will reject the authentication. This is because LDAPS is LDAP over

TLS, and it is TLS layer that handles packet signing (and encryption). Thus, an LDAPS client has no reason to indicate that it can sign its packets, and if it claims to be able to do so, the server laughs at it and slams the door.

Now in our attack, the client we're relaying wanted to authenticate via SMB, so yes, it supports packet signing, and yes, it sets the `NEGOTIATE_SIGN` flag to **1**. But if we relay its authentication, without changing anything, via LDAPS, then the LDAPS server will see this flag, and will terminate the authentication phase, no question asked.

We could simply modify the NTLM message and remove the flag, couldn't we? If we could, we would, it would work well. Except that there is also a **signature at NTLM level**.

That signature, it's called the **MIC**, or **Message Integrity Code**.

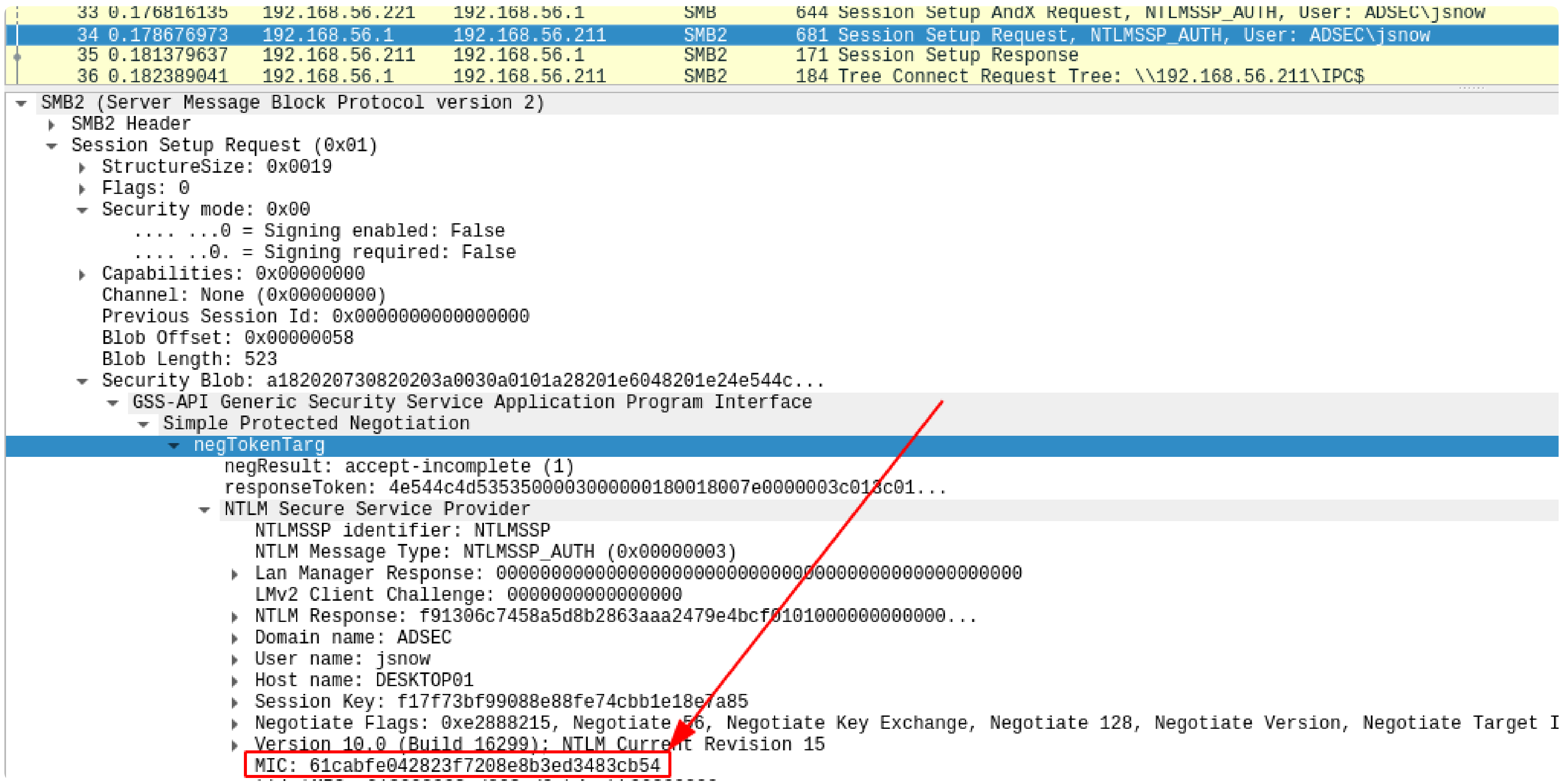
MIC - Message Integrity Code

The MIC is a signature that is sent only in the last message of an NTLM authentication, the **AUTHENTICATE** message. It takes into account the 3 messages. The MIC is computed with **HMAC_MD5** function, using as a key that depends on the client's secret, called the **session key**.

```
HMAC_MD5(Session key, NEGOTIATE_MESSAGE + CHALLENGE_MESSAGE + AUTHENTICATE_MESSAGE)
```

What is important is that the session key **depends on the client's secret**, so an attacker can't re-calculate the MIC.

Here's an example of MIC:

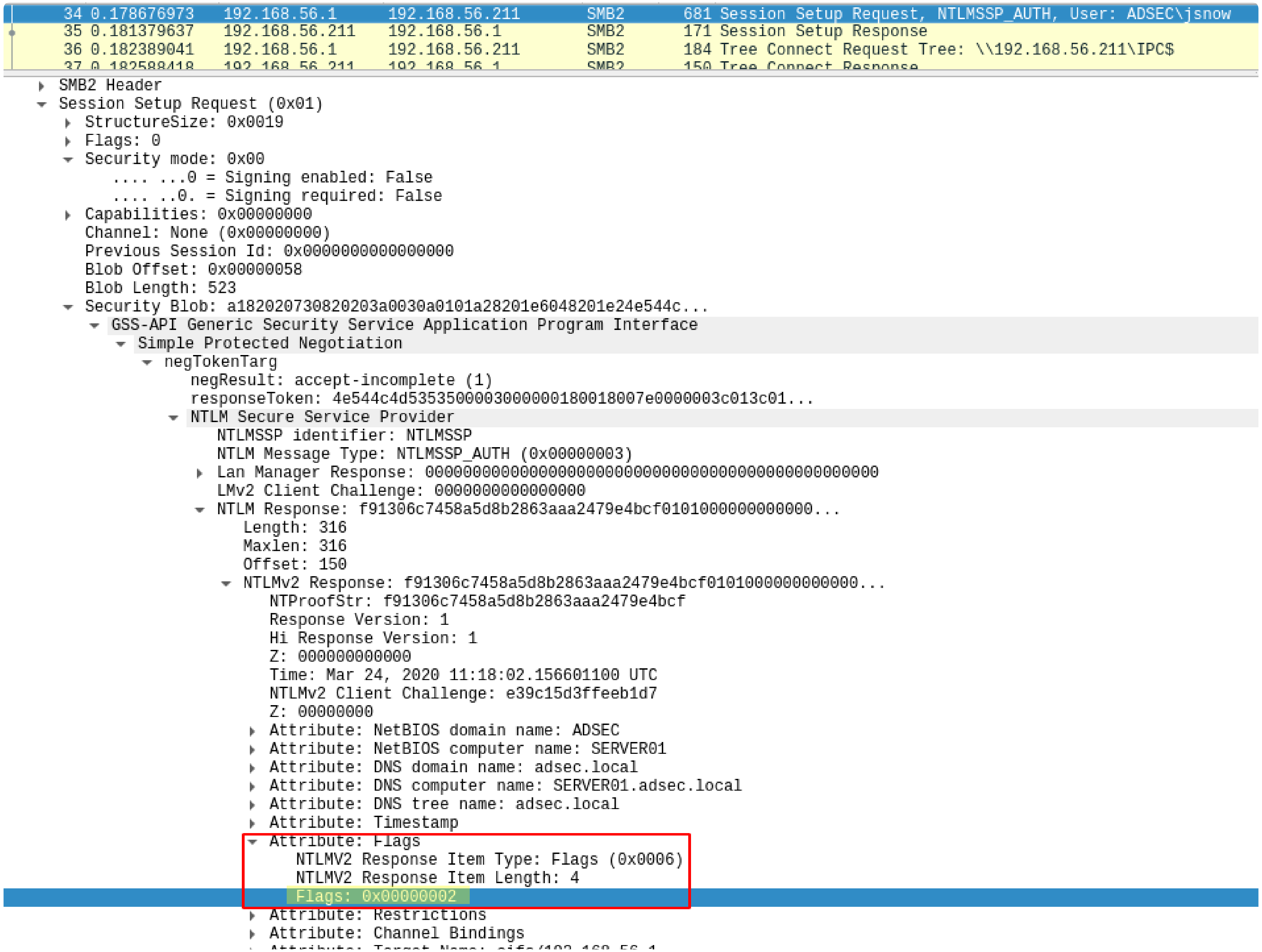


```
   33 0.176816135   192.168.56.221   192.168.56.1      SMB      644 Session Setup AndX Request, NTLMSSP_AUTH, User: ADSEC\jsnow
   34 0.178676973   192.168.56.1     192.168.56.211    SMB2     681 Session Setup Request, NTLMSSP_AUTH, User: ADSEC\jsnow
   35 0.181379637   192.168.56.211   192.168.56.1      SMB2     171 Session Setup Response
   36 0.182389041   192.168.56.1     192.168.56.211    SMB2     184 Tree Connect Request Tree: \\192.168.56.211\IPC$
SMB2 (Server Message Block Protocol version 2)
   SMB2 Header
   Session Setup Request (0x01)
      StructureSize: 0x0019
      Flags: 0
      Security mode: 0x00
         .... ...0 = Signing enabled: False
         .... ..0. = Signing required: False
      Capabilities: 0x00000000
      Channel: None (0x00000000)
      Previous Session Id: 0x0000000000000000
      Blob Offset: 0x00000058
      Blob Length: 523
      Security Blob: a182020730820203a0030a0101a28201e6048201e24e544c...
         GSS-API Generic Security Service Application Program Interface
            Simple Protected Negotiation
               negTokenTarg
                  negResult: accept-incomplete (1)
                  responseToken: 4e544c4d535350000300000018001800 7e0000003c013c01...
                  NTLM Secure Service Provider
                     NTLMSSP identifier: NTLMSSP
                     NTLM Message Type: NTLMSSP_AUTH (0x00000003)
                     Lan Manager Response: 000000000000000000000000000000000000000000000000
                     LMv2 Client Challenge: 0000000000000000
                     NTLM Response: f91306c7458a5d8b2863aaa2479e4bcf0101000000000000...
                     Domain name: ADSEC
                     User name: jsnow
                     Host name: DESKTOP01
                     Session Key: f17f73bf99088e88fe74cbb1e18e7a85
                     Negotiate Flags: 0xe2888215, Negotiate 56, Negotiate Key Exchange, Negotiate 128, Negotiate Version, Negotiate Target I
                     Version 10.0 (Build 16299); NTLM Current Revision 15
                     MIC: 61cabfe042823f7208e8b3ed3483cb54
```

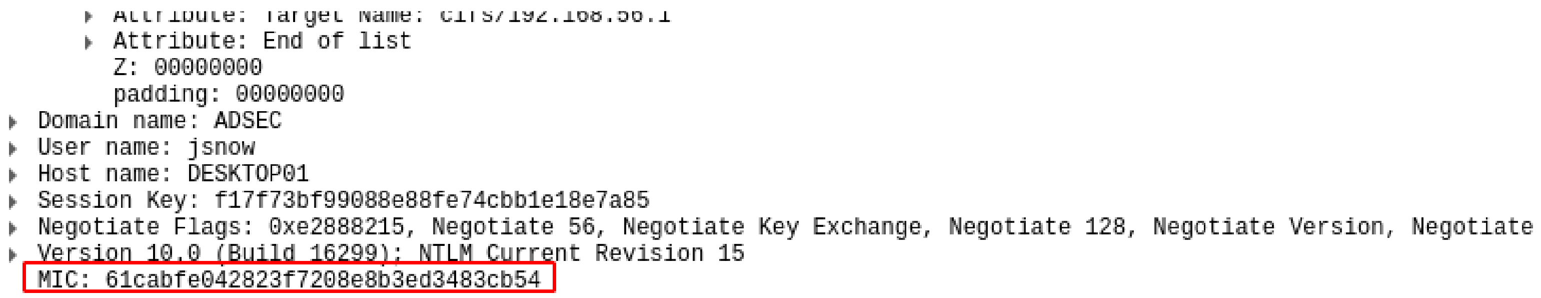
Therefore, if only one of the 3 messages has been modified, the MIC will no longer be valid, since the concatenation of the 3 messages will not be the same. So you can't change the `NEGOTIATE_SIGN` flag, as suggested in our example.

What if we just remove the MIC? Because yes, the MIC is optional.

Well it won't work, because there is another flag that indicates that a MIC will be present, **msAvFlags**. It is also present in NTLM response and if it is **0x00000002**, it tells the server that a MIC **must** be present. So if the server doesn’t see the MIC, it will know that there is something going on, and it will terminate the authentication. If the flag says there must be a MIC, then there **must** be a MIC.



```
    34 0.178676973   192.168.56.1     192.168.56.211     SMB2      681 Session Setup Request, NTLMSSP_AUTH, User: ADSEC\jsnow
    35 0.181379637   192.168.56.211   192.168.56.1       SMB2      171 Session Setup Response
    36 0.182389041   192.168.56.1     192.168.56.211     SMB2      184 Tree Connect Request Tree: \\192.168.56.211\IPC$
    37 0.182588418   192.168.56.211   192.168.56.1       SMB2      150 Tree Connect Response

  ▸ SMB2 Header
  ▾ Session Setup Request (0x01)
    ▸ StructureSize: 0x0019
    ▸ Flags: 0
    ▾ Security mode: 0x00
        .... ...0 = Signing enabled: False
        .... ..0. = Signing required: False
    ▸ Capabilities: 0x00000000
      Channel: None (0x00000000)
      Previous Session Id: 0x0000000000000000
      Blob Offset: 0x00000058
      Blob Length: 523
    ▾ Security Blob: a182020730820203a0030a0101a28201e6048201e24e544c...
      ▾ GSS-API Generic Security Service Application Program Interface
        ▾ Simple Protected Negotiation
          ▾ negTokenTarg
              negResult: accept-incomplete (1)
              responseToken: 4e544c4d53535000030000001800180007e0000003c013c01...
            ▾ NTLM Secure Service Provider
                NTLMSSP identifier: NTLMSSP
                NTLM Message Type: NTLMSSP_AUTH (0x00000003)
              ▸ Lan Manager Response: 000000000000000000000000000000000000000000000000
                LMv2 Client Challenge: 0000000000000000
              ▾ NTLM Response: f91306c7458a5d8b2863aaa2479e4bcf0101000000000000...
                  Length: 316
                  Maxlen: 316
                  Offset: 150
                ▾ NTLMv2 Response: f91306c7458a5d8b2863aaa2479e4bcf0101000000000000...
                    NTProofStr: f91306c7458a5d8b2863aaa2479e4bcf
                    Response Version: 1
                    Hi Response Version: 1
                    Z: 000000000000
                    Time: Mar 24, 2020 11:18:02.156601100 UTC
                    NTLMv2 Client Challenge: e39c15d3ffeeb1d7
                    Z: 00000000
                  ▸ Attribute: NetBIOS domain name: ADSEC
                  ▸ Attribute: NetBIOS computer name: SERVER01
                  ▸ Attribute: DNS domain name: adsec.local
                  ▸ Attribute: DNS computer name: SERVER01.adsec.local
                  ▸ Attribute: DNS tree name: adsec.local
                  ▸ Attribute: Timestamp
                  ▾ Attribute: Flags
                      NTLMV2 Response Item Type: Flags (0x0006)
                      NTLMV2 Response Item Length: 4
                      Flags: 0x00000002
                  ▸ Attribute: Restrictions
                  ▸ Attribute: Channel Bindings
                  ▸ Attribute: Target Name: cifs/192.168.56.1
```



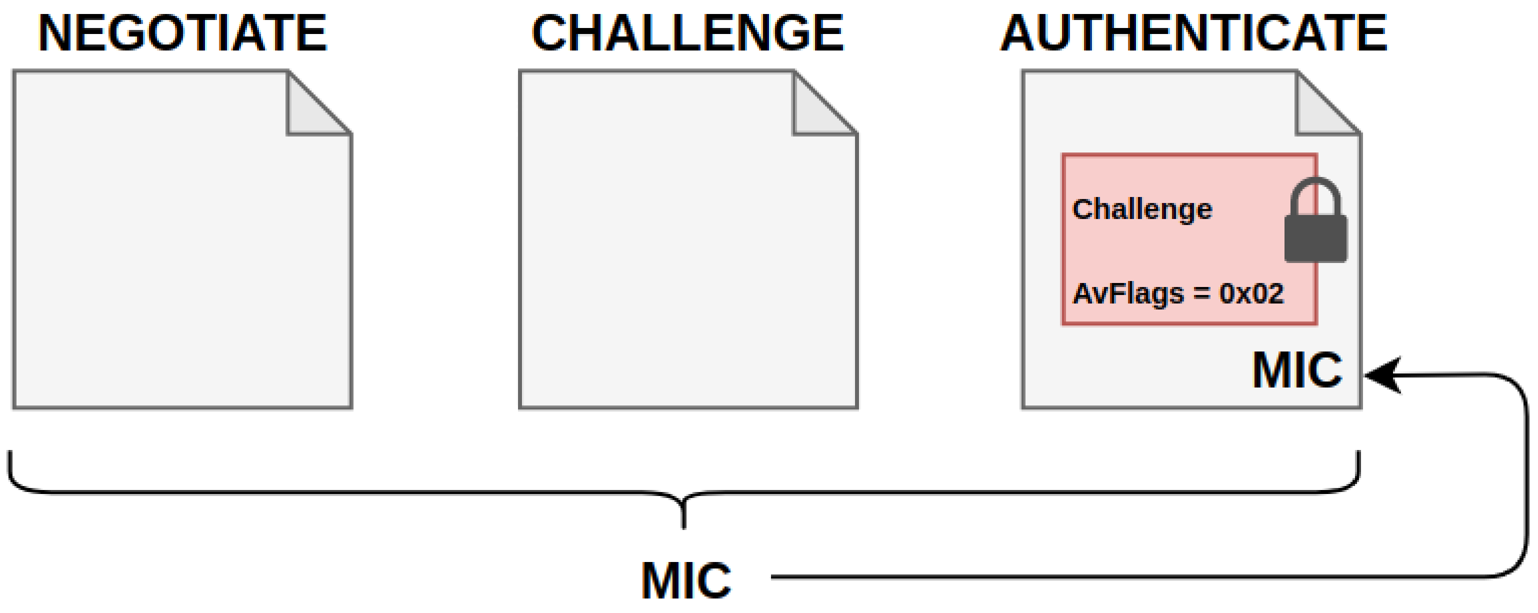
```
    Attribute: Target Name: cifs/192.168.56.1
    Attribute: End of list
    Z: 00000000
    padding: 00000000
Domain name: ADSEC
User name: jsnow
Host name: DESKTOP01
Session Key: f17f73bf99088e88fe74cbb1e18e7a85
Negotiate Flags: 0xe2888215, Negotiate 56, Negotiate Key Exchange, Negotiate 128, Negotiate Version, Negotiate
Version 10.0 (Build 16299); NTLM Current Revision 15
MIC: 61cabfe042823f7208e8b3ed3483cb54
```

All right, and if we set that `msAcFlags` to **0**, and we remove the MIC, what happens? Since there's no more MICs, we can't verify that the message has been changed, can we?

…

Well, we can. It turns out that the **NTLMv2 Hash**, which is the response to the challenge sent by the server, is a hash that takes into account not only the challenge (obviously), but also all the flags of the response. As you may have guessed, the flag indicating the MIC presence is part of this response.

Changing or removing this flag would make the **NTLMv2 hash** invalid, since the data will have been modified. Here what it looks like.



The MIC protects the integrity of the 3 messages, the msAvFlags protects the presence of the MIC, and the NTLMv2 hash protects the presence of the flag. The attacker, not being aware of the user's secret, cannot recalculate this hash.

So you will have understood that, we can do nothing in this case, and that's thanks to the MIC.

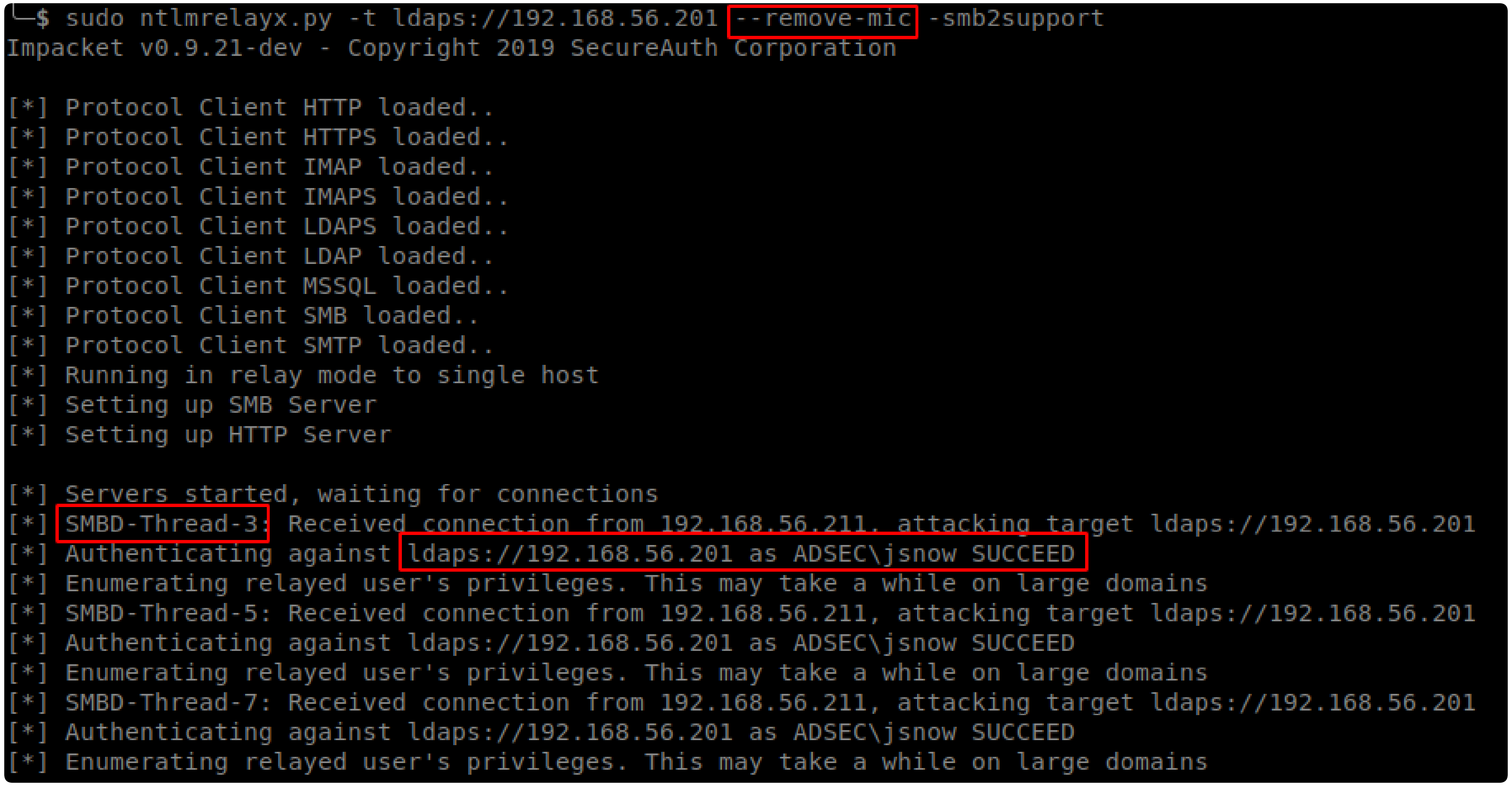
Drop the MIC

A little review of a recent vulnerability found by Preempt that you will easily understand now.

It's CVE-2019-1040 nicely named **Drop the MIC**. This vulnerability showed that if the MIC was just removed, even if the flag indicated its presence, the server accepted the authentication without flinching. This was obviously a bug that has since been fixed.

It has been integrated in ntlmrelayx tool via the use of the `--remove-mic` parameter.

Let's take our example from earlier, but this time with a domain controller that is still vulnerable. This is what it looks like in practice.



```
└─$ sudo ntlmrelayx.py -t ldaps://192.168.56.201 --remove-mic -smb2support
Impacket v0.9.21-dev - Copyright 2019 SecureAuth Corporation

[*] Protocol Client HTTP loaded..
[*] Protocol Client HTTPS loaded..
[*] Protocol Client IMAP loaded..
[*] Protocol Client IMAPS loaded..
[*] Protocol Client LDAPS loaded..
[*] Protocol Client LDAP loaded..
[*] Protocol Client MSSQL loaded..
[*] Protocol Client SMB loaded..
[*] Protocol Client SMTP loaded..
[*] Running in relay mode to single host
[*] Setting up SMB Server
[*] Setting up HTTP Server

[*] Servers started, waiting for connections
[*] SMBD-Thread-3: Received connection from 192.168.56.211, attacking target ldaps://192.168.56.201
[*] Authenticating against ldaps://192.168.56.201 as ADSEC\jsnow SUCCEED
[*] Enumerating relayed user's privileges. This may take a while on large domains
[*] SMBD-Thread-5: Received connection from 192.168.56.211, attacking target ldaps://192.168.56.201
[*] Authenticating against ldaps://192.168.56.201 as ADSEC\jsnow SUCCEED
[*] Enumerating relayed user's privileges. This may take a while on large domains
[*] SMBD-Thread-7: Received connection from 192.168.56.211, attacking target ldaps://192.168.56.201
[*] Authenticating against ldaps://192.168.56.201 as ADSEC\jsnow SUCCEED
[*] Enumerating relayed user's privileges. This may take a while on large domains
```

Our attack is working. Amazing.

For information, another vulnerability was discovered by the very same team, and they called it Drop The MIC 2.

Session key

Earlier we were talking about session and authentication signing, saying that to sign something you have to know the user's secret. We said in the chapter about MIC that in reality it's not exactly the user's secret that is used, but a key called **session key**, which depends on the user's secret.

To give you an idea, here's how the session key is computed for NTLMv1 and NTLMv2.

```
# For NTLMv1
Key = MD4(Hash NT)

# For NTLMv2
Key = HMAC_MD5(NTLMv2 Hash, HMAC_MD5(NTLMv2 Hash, NTLMv2 Response + Challenge))
```

Going into the explanations would not be very useful, but there is clearly a complexity difference from one version to the other. I repeat, **do not use NTLMv1 in a production network**.

With this information, we understand that the client can compute this key on his side, since he has all the information in hand to do so.

The server, on the other hand, can't always do it alone, like a big boy. For local authentication, there is no problem since the server knows the user's NT hash.

On the other hand, for authentication with a domain account, the server will have to ask the domain controller to compute the session key for him, and send it back. We saw in pass-the-hash article that the server sends a request to the domain controller in a NETLOGON_NETWORK_INFO structure and the domain controller responds with a NETLOGON_VALIDATION_SAM_INFO4 structure. It is in this response from the domain controller that the session key is sent, if authentication is successful.

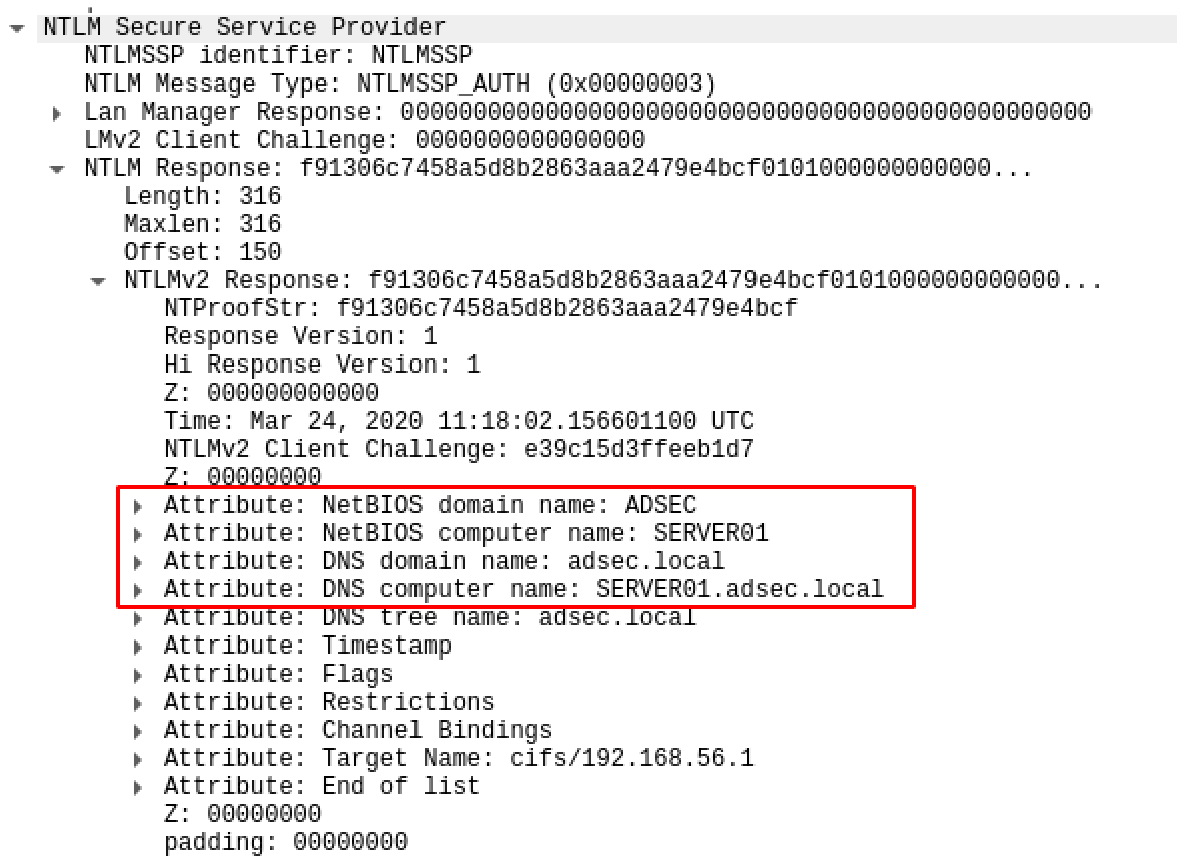
```
typedef struct _NETLOGON_VALIDATION_SAM_INFO4 {
  OLD_LARGE_INTEGER LogonTime;
  OLD_LARGE_INTEGER LogoffTime;
  OLD_LARGE_INTEGER KickOffTime;
  OLD_LARGE_INTEGER PasswordLastSet;
  OLD_LARGE_INTEGER PasswordCanChange;
  OLD_LARGE_INTEGER PasswordMustChange;
  RPC_UNICODE_STRING EffectiveName;
  RPC_UNICODE_STRING FullName;
  RPC_UNICODE_STRING LogonScript;
  RPC_UNICODE_STRING ProfilePath;
  RPC_UNICODE_STRING HomeDirectory;
  RPC_UNICODE_STRING HomeDirectoryDrive;
  unsigned short LogonCount;
  unsigned short BadPasswordCount;
  unsigned long UserId;
  unsigned long PrimaryGroupId;
  unsigned long GroupCount;
  [size_is(GroupCount)] PGROUP_MEMBERSHIP GroupIds;
  unsigned long UserFlags;
  USER_SESSION_KEY UserSessionKey;
  RPC_UNICODE_STRING LogonServer;
  RPC_UNICODE_STRING LogonDomainName;
  PRPC_SID LogonDomainId;
  unsigned char LMKey[8];
  ULONG UserAccountControl;
  ULONG SubAuthStatus;
  OLD_LARGE_INTEGER LastSuccessfulILogon;
  OLD_LARGE_INTEGER LastFailedILogon;
  ULONG FailedILogonCount;
  ULONG Reserved4[1];
  unsigned long SidCount;
```

The question then arises as to what prevents an attacker from making the same request to the domain controller as the target server. Well before CVE-2015-005, nothing!

> What we found while implementing the NETLOGON protocol [12] is the domain controller not verifying whether the authentication information being sent, was actually meant to the domain-joined machine that is requesting this operation (e.g. NetrLogonSamLogonWithFlags()). What this means is that **any domain-joined machine can verify any pass-through authentication against the domain controller**, and to get the base key for cryptographic operations for any session within the domain.

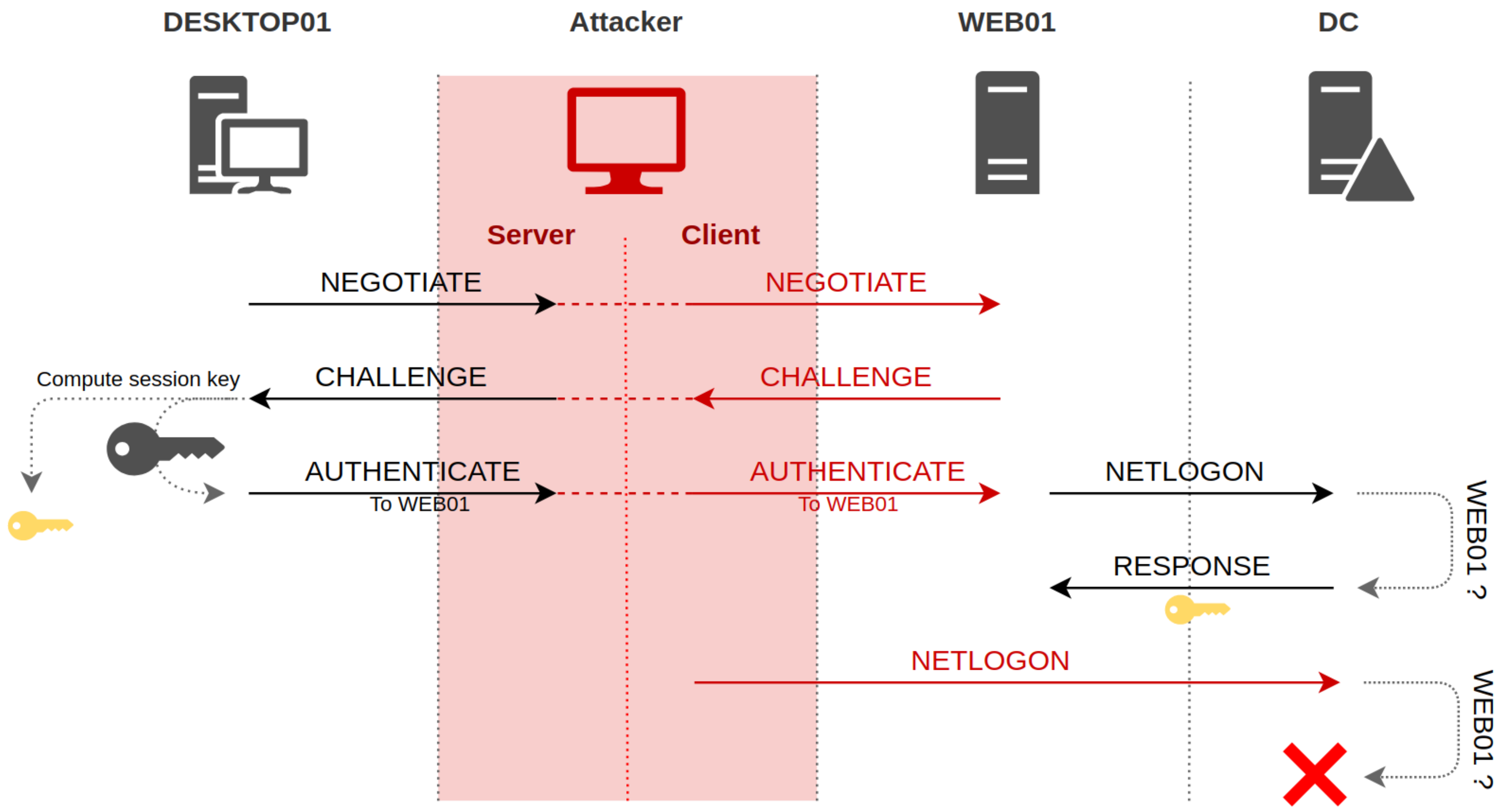
So obviously, Microsoft has fixed this bug. To verify that only the server the user is authenticating to has the right to ask for the session key, the domain controller will verify that the target machine in the `AUTHENTICATE` response is the same as the host making the NetLogon request.

In the `AUTHENTICATE` response, we detailed the presence of `msAvFlags` indicating whether or not the MIC is present, but there is also other information, such as the Netbios name of the target machine.



```
NTLM Secure Service Provider
    NTLMSSP identifier: NTLMSSP
    NTLM Message Type: NTLMSSP_AUTH (0x00000003)
  Lan Manager Response: 000000000000000000000000000000000000000000000000
    LMv2 Client Challenge: 0000000000000000
  NTLM Response: f91306c7458a5d8b2863aaa2479e4bcf0101000000000000...
        Length: 316
        Maxlen: 316
        Offset: 150
      NTLMv2 Response: f91306c7458a5d8b2863aaa2479e4bcf0101000000000000...
            NTProofStr: f91306c7458a5d8b2863aaa2479e4bcf
            Response Version: 1
            Hi Response Version: 1
            Z: 000000000000
            Time: Mar 24, 2020 11:18:02.156601100 UTC
            NTLMv2 Client Challenge: e39c15d3ffeeb1d7
            Z: 00000000
          Attribute: NetBIOS domain name: ADSEC
          Attribute: NetBIOS computer name: SERVER01
          Attribute: DNS domain name: adsec.local
          Attribute: DNS computer name: SERVER01.adsec.local
          Attribute: DNS tree name: adsec.local
          Attribute: Timestamp
          Attribute: Flags
          Attribute: Restrictions
          Attribute: Channel Bindings
          Attribute: Target Name: cifs/192.168.56.1
          Attribute: End of list
            Z: 00000000
            padding: 00000000
```

This is the name that is compared with the host making the NetLogon request. Thus, if the attacker tries to make a NetLogon request for the session key, since the attacker's name does not match the targeted host name in NTLM response, the domain controller will reject the request.



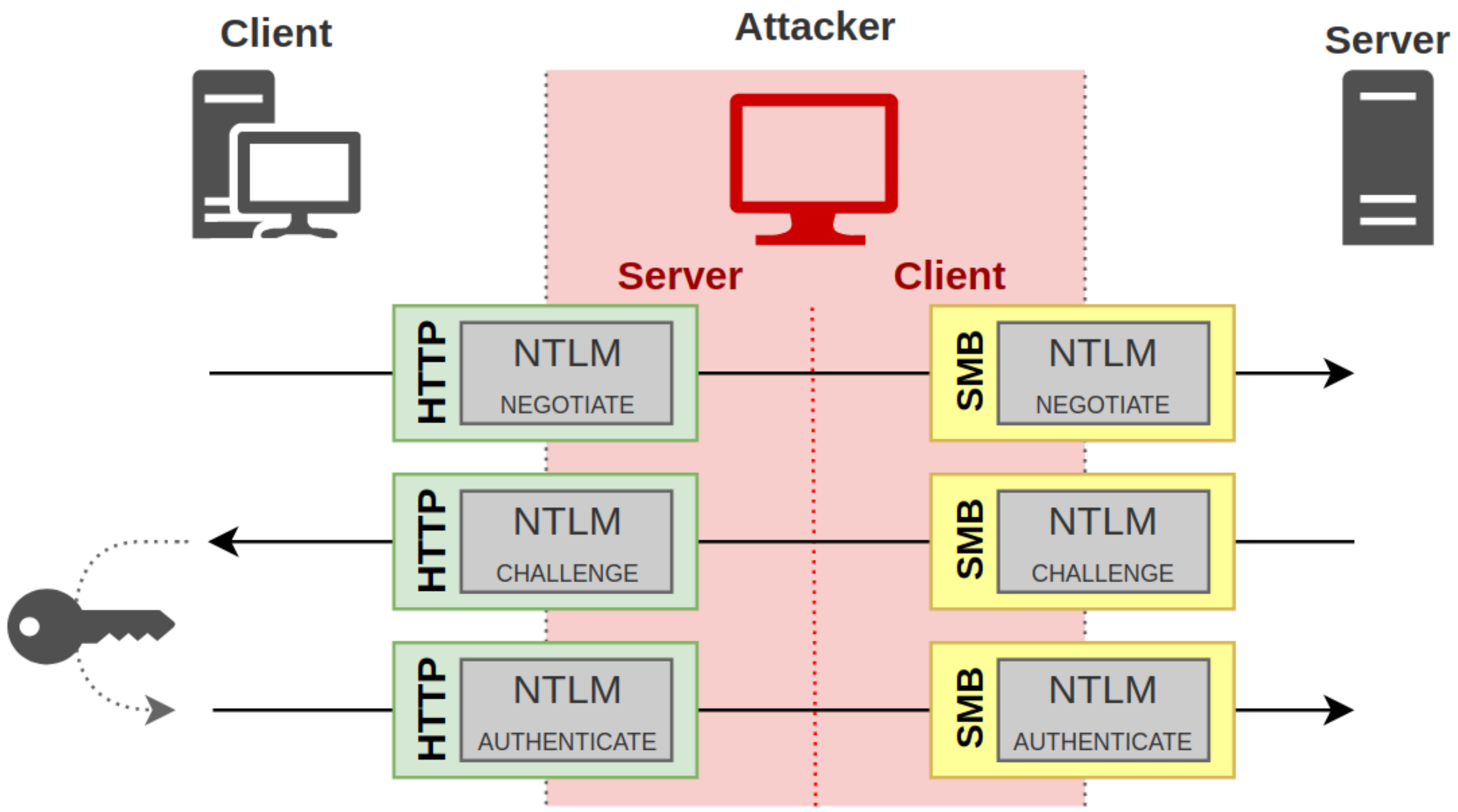
Finally, in the same way as `msAvFlags`, we cannot change the machine name on the fly in the NTLM response, because it is taken into account in the calculation of the NTLMv2 response.

A vulnerability similar to **Drop the MIC 2** has been discovered recently by Preempt security team. Here is the link to their post if you're curious.

Channel Binding

We’re going to talk about one last notion. Several times we have repeated that the authentication layer, thus NTLM messages, was almost independent of the application layer, the protocol in use (SMB, LDAP, …). I say “almost” because we have seen that some protocols use some NTLM messages flags to know if the session must be signed or not.

In any case, as it stands, it is quite possible for an attacker to retrieve an NTLM message from protocol A, and send it back using protocol B. This is called **cross-protocol relay** as we already mentioned.



Well, a new protection exists to counter this attack. It's called **channel binding**, or **EPA** (Enhanced Protection for Authentication). The principle of this protection is to bind the authentication layer with the protocol in use, even with the TLS layer when it exists (LDAPS or HTTPS for example). The general idea being that in the last NTLM `AUTHENTICATE` message, a piece of information is put there and cannot be modified by an attacker. This information indicates the desired service, and potentially another information that contains the target server's certificate's hash.

We'll look at these two principles in a little more detail, but don't you worry, it's relatively simple to understand.

Service binding

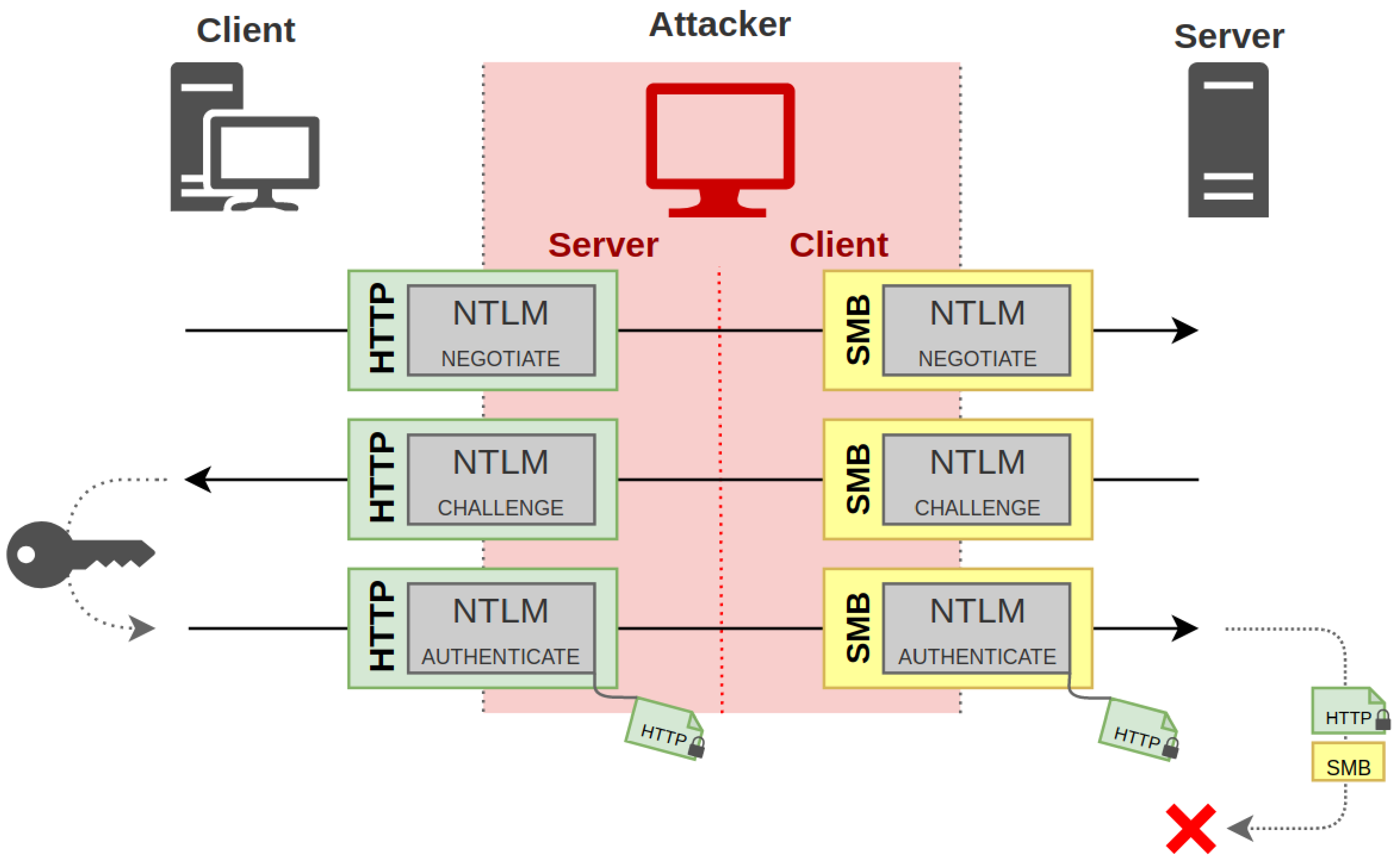
This first protection is quite simple to understand. If a client wishes to authenticate to a server to use a specific service, the information identifying the service will be added in the NTLM response.

This way, when the legitimate server receives this authentication, it can see the service that was requested by the client, and if it differs from what is actually requested, it will not agree to provide the service.

Since the service name is in the NTLM response, it is protected by the **NtProofStr** response, which is an HMAC_MD5 of this information, the challenge, and other information such as **msAvFlags**. It is computed with the client's secret.

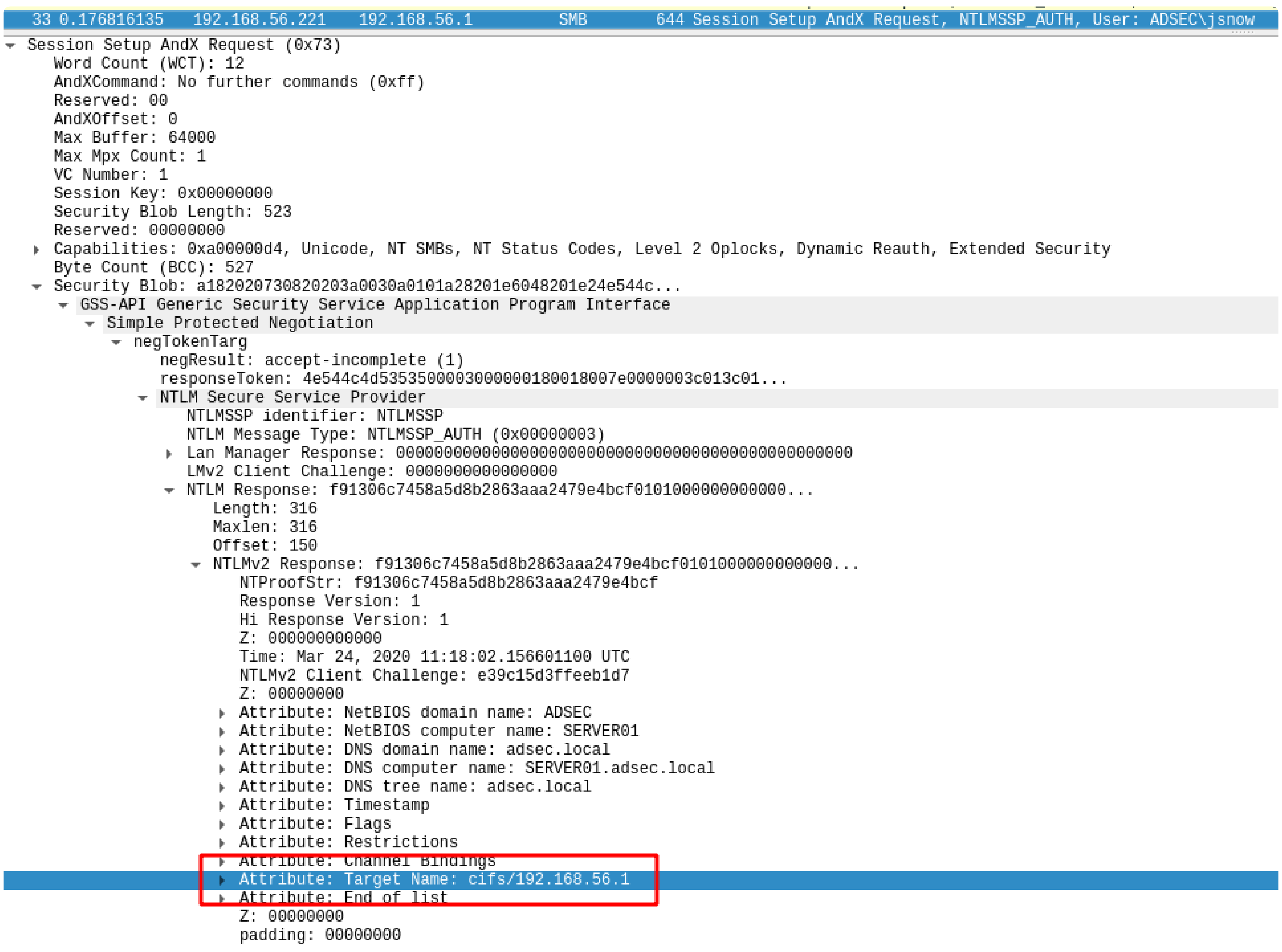
In the example shown in the last diagram, we see a client trying to authenticate itself via HTTP to the server. Except that the server is an attacker, and the attacker replays this authentication to a legitimate server, to access a network share (SMB).

Except that the client has indicated the service he wants to use in his NTLM response, and since the attacker cannot modify it, he has to relay it as is. The server then receives the last message, compares the service requested by the attacker (SMB) with the service specified in the NTLM message (HTTP), and refuses the connection, finding that the two services do not match.



Concretely, what is called **service** is in fact the **SPN** or **Service Principal Name**. I dedicated a whole article to the explanation of this notion.

Here is a screenshot of a client sending SPN in its NTLM response.



```
33 0.176816135   192.168.56.221   192.168.56.1       SMB      644 Session Setup AndX Request, NTLMSSP_AUTH, User: ADSEC\jsnow
▾ Session Setup AndX Request (0x73)
    Word Count (WCT): 12
    AndXCommand: No further commands (0xff)
    Reserved: 00
    AndXOffset: 0
    Max Buffer: 64000
    Max Mpx Count: 1
    VC Number: 1
    Session Key: 0x00000000
    Security Blob Length: 523
    Reserved: 00000000
  ▸ Capabilities: 0xa00000d4, Unicode, NT SMBs, NT Status Codes, Level 2 Oplocks, Dynamic Reauth, Extended Security
    Byte Count (BCC): 527
  ▾ Security Blob: a182020730820203a0030a0101a28201e6048201e24e544c...
    ▾ GSS-API Generic Security Service Application Program Interface
      ▾ Simple Protected Negotiation
        ▾ negTokenTarg
            negResult: accept-incomplete (1)
            responseToken: 4e544c4d535350000300000018001800 7e0000003c013c01...
          ▾ NTLM Secure Service Provider
              NTLMSSP identifier: NTLMSSP
              NTLM Message Type: NTLMSSP_AUTH (0x00000003)
            ▸ Lan Manager Response: 000000000000000000000000000000000000000000000000
              LMv2 Client Challenge: 0000000000000000
            ▾ NTLM Response: f91306c7458a5d8b2863aaa2479e4bcf0101000000000000...
                Length: 316
                Maxlen: 316
                Offset: 150
              ▾ NTLMv2 Response: f91306c7458a5d8b2863aaa2479e4bcf0101000000000000...
                  NTProofStr: f91306c7458a5d8b2863aaa2479e4bcf
                  Response Version: 1
                  Hi Response Version: 1
                  Z: 000000000000
                  Time: Mar 24, 2020 11:18:02.156601100 UTC
                  NTLMv2 Client Challenge: e39c15d3ffeeb1d7
                  Z: 00000000
                ▸ Attribute: NetBIOS domain name: ADSEC
                ▸ Attribute: NetBIOS computer name: SERVER01
                ▸ Attribute: DNS domain name: adsec.local
                ▸ Attribute: DNS computer name: SERVER01.adsec.local
                ▸ Attribute: DNS tree name: adsec.local
                ▸ Attribute: Timestamp
                ▸ Attribute: Flags
                ▸ Attribute: Restrictions
                ▸ Attribute: Channel Bindings
                ▸ Attribute: Target Name: cifs/192.168.56.1
                ▸ Attribute: End of list
                  Z: 00000000
                  padding: 00000000
```

We can see that it indicates to use the **CIFS** service (equivalent to SMB, just a different terminology). Relaying this to an LDAP server that takes this information into account will result in a nice **Access denied** from the server.

But as you can see, not only there is the service name (CIFS) but there is also the target name, or IP address. It means that if an attacker relays this message to a server, the server will also check the target part, and will refuse the connexion because the IP address found in the SPN does not match his IP address.

So if this protection is supported by all clients and all servers, and is required by every server, it mitigaes all relay attempts.

TLS Binding

This time, the purpose of this protection is to link the authentication layer, i.e. NTLM messages, to the TLS layer that can potentially be used.

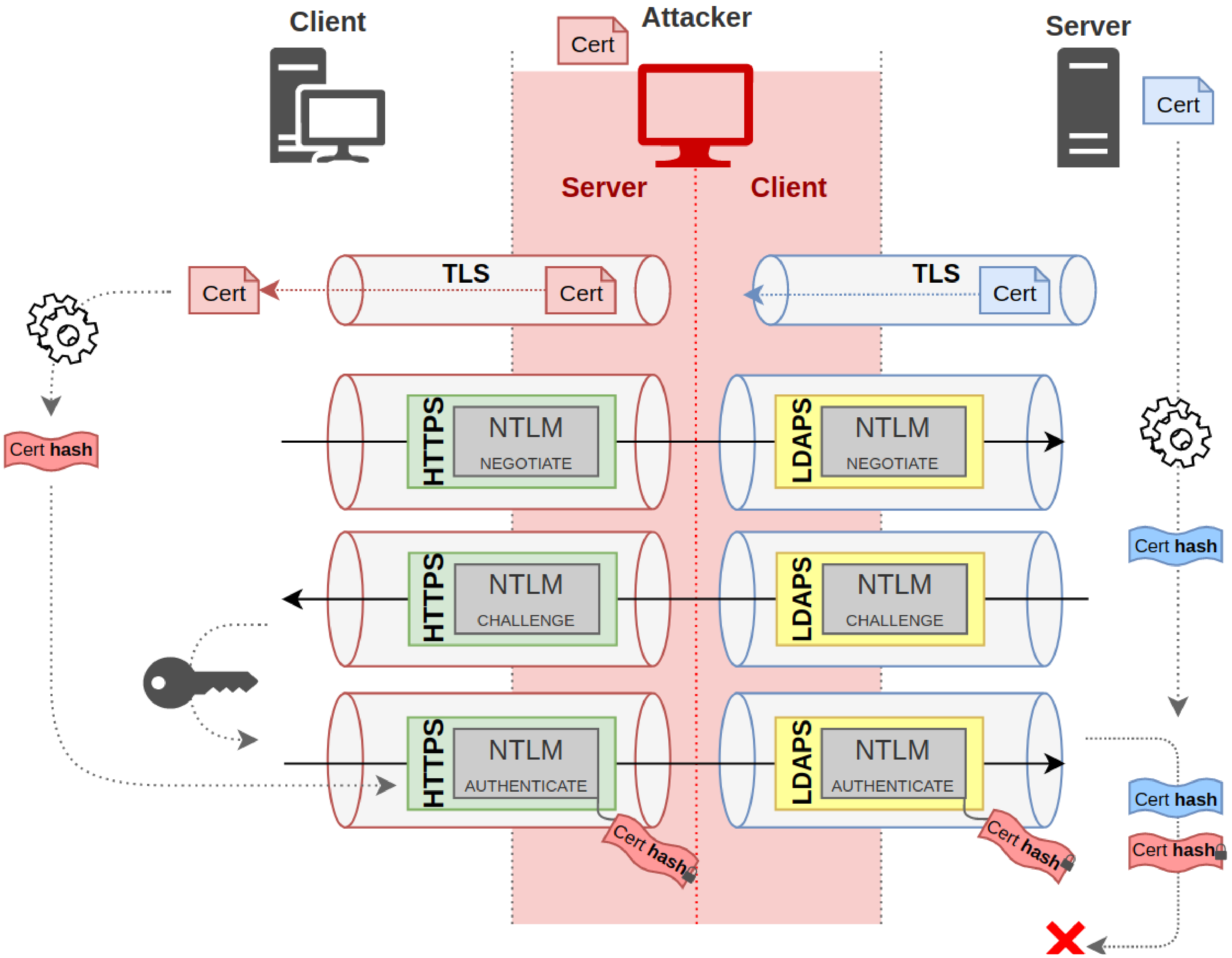
If the client wants to use a protocol encapsulated in TLS (HTTPS, LDAPS for example), it will establish a TLS session with the server, and it will compute the server certificate hash. This hash is called the **Channel Binding Token**, or CBT. Once computed, the client will put this hash in its NTLM response. The legitimate server will then receive the NTLM message at the end of the authentication, read the provided hash, and compare it with the real hash of its certificate. If it is different, it means he wasn’t the original recipient of the NTLM exchange.

Again, since this hash is in the NTLM response, it is protected by the **NtProofStr** response, like the **SPN** for **Service Binding**.

Thanks to this protection, the following two attacks are no longer possible :

1. If an attacker wishes to relay information from a client using a protocol **without** a TLS layer to a protocol **with** a TLS layer (HTTP to LDAPS, for example), the attacker will not be able to add the certificate hash from the target server into the NTLM response, since it cannot update the NtProofStr.
2. If an attacker wishes to relay a protocol with TLS to another protocol with TLS (HTTPS to LDAPS), when establishing the TLS session between the client and the attacker, the attacker will not be able to provide the server certificate, since it does not match the attacker's identity. It will therefore have to provide a "homemade" certificate, identifying the attacker. The client will then hash this certificate, and when the attacker relays the NTLM response to the legitimate server, the hash in the response will not be the same as the hash of the real certificate, so the server will reject the authentication.

Here is a diagram to illustrate the 2nd case. Seems complicated, but it's not.


Client
Attacker
Cert
Server
Cert
Server
Client
TLS
Cert
Cert
TLS
Cert
Cert hash
HTTPS
NTLM
NEGOTIATE
LDAPS
NTLM
NEGOTIATE
Cert hash
HTTPS
NTLM
CHALLENGE
LDAPS
NTLM
CHALLENGE
HTTPS
NTLM
AUTHENTICATE
LDAPS
NTLM
AUTHENTICATE
Cert hash
Cert hash
Cert hash
Cert hash

It shows the establishment of two TLS sessions. One between the client and the attacker (in red) and one between the attacker and the server (in blue). The client will retrieve the attacker's certificate, and calculate a hash, **cert hash**, in red.

At the end of the NTLM exchanges, this hash will be added in the NTLM response, and will be protected since it is part of the encrypted data of the NTLM response. When the server receives this hash, it will hash his own certificate, and seeing that it is not the same result, it will refuse the connection.

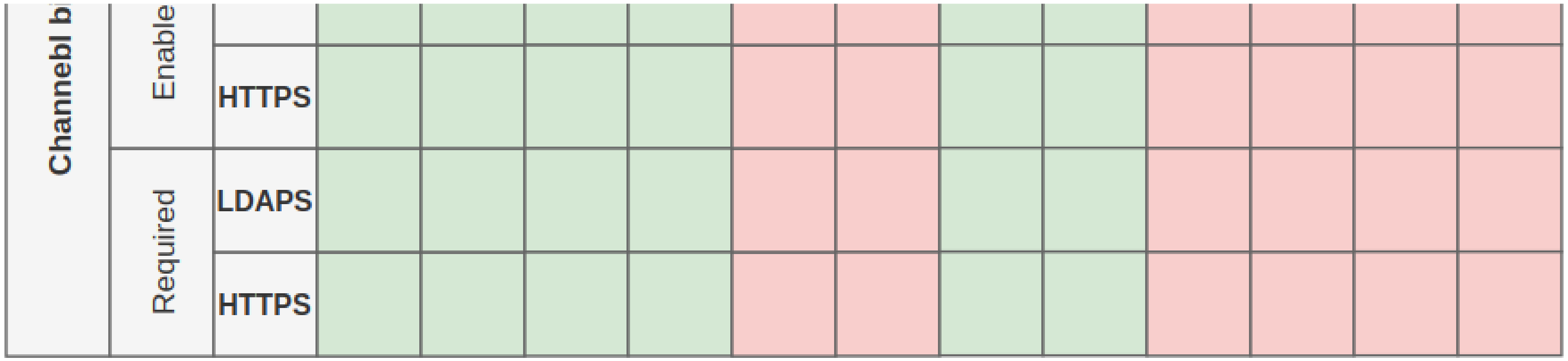
Again, Preempt recently found a vulnerability which has been fixed since then.

What can be relayed?

With all this information, you should be able to know which protocols can be relayed to which protocols. We have seen that it is impossible to relay from SMB to LDAP or LDAPS, for example. On the other hand, any client that does not set the `NEGOTIATE_SIGN` flag can be relayed to LDAP if the signature is not required, or LDAPS is channel binding is not required.

As there are many cases, here is a table summarizing some of them.

SERVER / CLIENT			Signing						Channel binding					
			Disabled		Enabled		Required		Disabled		Enabled		Required	
			SMB v1	HTTP	SMB v2	LDAP	SMB	LDAP	LDAPS	HTTPS	LDAPS	HTTPS	LDAPS	HTTPS
Signing	Disabled	SMB v1	🟩	🟩	🟩	🟩	🟥	🟥	🟩	🟩	🟩	🟩	🟥	🟥
		HTTP	🟩	🟩	🟩	🟩	🟥	🟥	🟩	🟩	🟩	🟩	🟥	🟥
	Enabled	SMBv2	🟩	🟩	🟩	🟥	🟥	🟥	🟥	▨	🟥	▨	🟥	🟥
		LDAP	🟩	🟩	🟩	🟥	🟥	🟥	🟥	▨	🟥	▨	🟥	🟥
	Required	SMB	🟩	🟩	🟩	🟥	🟥	🟥	🟥	▨	🟥	▨	🟥	🟥
		LDAP	🟩	🟩	🟩	🟥	🟥	🟥	🟥	▨	🟥	▨	🟥	🟥
inding	Disabled	LDAPS	🟩	🟩	🟩	🟩	🟥	🟥	🟩	🟩	🟩	🟩	🟥	🟥
		HTTPS	🟩	🟩	🟩	🟩	🟥	🟥	🟩	🟩	🟩	🟩	🟥	🟥
	d	LDAPS	🟩	🟩	🟩	🟩	🟥	🟥	🟩	🟩	🟥	🟥	🟥	🟥



Channebl b	Enable		🟩	🟩	🟩	🟩	🟥	🟥	🟩	🟩	🟥	🟥	🟥	🟥
		HTTPS	🟩	🟩	🟩	🟩	🟥	🟥	🟩	🟩	🟥	🟥	🟥	🟥
	Required	LDAPS	🟩	🟩	🟩	🟩	🟥	🟥	🟩	🟩	🟥	🟥	🟥	🟥
		HTTPS	🟩	🟩	🟩	🟩	🟥	🟥	🟩	🟩	🟥	🟥	🟥	🟥

I think we can't relay LDAPS or HTTPS since the attacker doesn't have a valid certificate but let's say the client is permissive and allowed untrusted certificates. Other protocols could be added, such as SQL or SMTP, but I must admit I didn't read the documentation for all the protocols that exist. Shame on me.

For gray boxes, I don't know how an HTTPS server handles an authentication with the `NEGOTIATE_SIGN` flag set to **1**.

Stop. Using. NTLMv1.

Here is a little "fun fact" that Marina Simakov suggested me to add. As we discussed, NTLMv2 hash takes into account the server's challenge, but also the `msAvFlags` flag which indicates the presence of a MIC field, the field indicating the NetBios name of the target host during authentication, the SPN in case of service binding, and the certificate hash in case of TLS binding.

Well NTLMv1 protocol **doesn't do that**. It only takes into account the server's challenge. In fact, there is no longer any additional information such as the target name, the `msAvFlags`, the SPN or the CBT.

So, if an NTLMv1 authentication is allowed by a server, an attacker can simply remove the MIC and thus relay authentications to LDAP or LDAPS, for example.

But more importantly, he can make NetLogon requests to retrieve the session key. Indeed, the domain controller has no way to check if he has the right to do so. And since it won't block a production network that isn't completely up to date, it will kindly give it to the attacker, for "retro-compatibility reasons".

Once he has the session key, he can sign any packet that he wants. It means that even if the target requests signing, he will be able to do so.

This is by design and it can not be fixed. So I repeat, **do not allow NTLMv1 in a production network**.

Conclusion

Well, that's a lot of information.

We have seen here the **details of NTLM relay**, being aware that authentication and session that follows are two distinct notions allowing to do **cross-protocol relay** in many cases. Although the protocol somehow includes authentication data, it is opaque to the protocol and managed by SSPI.

We have also shown how **packet signing** can protect the server from man-in-the-middle attacks. To do this, the target must wait for signed packet coming from the client, otherwise the attacker will be able to pretend to be someone else without having to sign the messages he sends.

We saw that MIC was very important to protect NTLM exchanges, especially the flag indicating whether packets will be signed for certain protocols, or information about channel binding.

We ended by showing how channel binding can link the authentication layer and the session layer, either via the service name or via a link with the server certificate.

I hope this long article has given you a better understanding of what happens during an NTLM relay attack and the protections that exist.

Since this article is quite substantial, it is quite likely that some mistakes have slipped in. Feel free to contact me on twitter or on my Discord Server to discuss this.

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