SMB 3.1.1

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Agenda

1. Dialect Changes
2. Extensible Negotiation
3. Preauthentication Integrity
4. Cluster Dialect Fencing
5. Cluster Client Failover (CCF) v2
6. Encryption Improvements
7. Future Directions
8. Questions
1 - Dialect Changes

- Dialects now written “Major.Minor.Rev”

  0x0202 = Major.Minor.Revision = 2.0.2

- Simplify to “Major.Minor” if revision is 0
- Examples: 2.0.2, 2.1, 3.0, 3.0.2, 3.1.1, …, 255.15.15
  (Windows Server 3015 - Quantum Computing Edition)
- Already updated in protocol document and UI
1 - Dialect Changes...

- The Windows 10 SMB dialect is 3.1.1 (0x0311)
  - At SDC 2014 (Windows 10 Preview) it was 3.1 (0x0310)
  - Very minor changes compared to SMB 3.1
  - Differences from 3.1 dialect are called out in italic red text
  - SMB 3.1 is now unsupported and will be rejected
  - We expect, but cannot promise, that the Windows Server 2016 SMB dialect will also be 3.1.1.
2 - Extensible Negotiation

- How to negotiate arbitrarily complex connection capabilities?
  - Few unused bits left in the negotiate request / response

- SMB 3.1.1 Extensible Negotiation
  - Exchange additional negotiate information via negotiate contexts (same idea as the existing create contexts).
  - Repurpose unused fields in negotiate request / response as `NegotiateContextOffset` and `NegotiateContextCount` fields.
  - Add list of negotiate contexts to end of existing negotiate request / response messages.
2 - Negotiate Contexts

SMB2 Header | SMB2 Negotiate Request / Response | Negotiate Context 0 | Negotiate Context 1 | …

<table>
<thead>
<tr>
<th>Byte 0</th>
<th>Byte 1</th>
<th>Byte 2</th>
<th>Byte 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID</td>
<td></td>
<td>DataLength</td>
<td></td>
</tr>
<tr>
<td>Reserved</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data (DataLength) …</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NegotiateContextCount

NegotiateContextOffset

Padding (if necessary) to 8-byte-align negotiate contexts

Data payload is determined by ID.
2 - Key Points

- Client sends negotiate contexts only if it supports the 3.1.1 dialect.
- Server sends negotiate contexts only if it selects 3.1.1 as the connection’s dialect.
- Receiver must ignore unknown negotiate contexts.
  - Allows new contexts to be added without requiring a new dialect.
- SMB 2/3 server implementations must be willing to accept negotiate requests that are larger than the SMB2_HEADER + SMB2_REQ_NEGOTIATE + Dialects array.
  - A client does not know apriori whether a server supports SMB 3.1.1, so must assume that it does and send negotiate contexts.
  - Windows accepts negotiate requests as large as 128 KiB
3 – Preauthentication Integrity

- How to protect negotiate / session setup messages from tampering?
  - No protection prior to SMB 3.0
  - SMB 3.0.x Negotiate Validation doesn’t protect negotiate contexts or session setup messages.

- SMB 3.1.1 Preauthentication Integrity
  - Provides end-to-end, dialect agnostic protection.
  - Session’s secret keys derived from hash of the preauthentication messages.
  - Server signs final session setup response.
  - *Client signs or encrypts tree connect requests.*
  - Signature validation/decryption of authenticated messages will fail in case of preauthentication message tampering.
3 - Selecting the Hash Function

- SMB 3.1.1 client and server exchange mandatory negotiate contexts for each connection.
- Client’s negotiate context specifies a set of supported hash functions.
- Server’s negotiate context specifies the selected hash function.
- SHA-512 is currently the only supported hash function.
- Preimage attack resistance is provided by a salt value that the client and server generate via a secure PRNG per request/response.

SMB2_PREAUTH_INTEGRITY_CAPABILITIES
(Negotiate Context ID: 0x0001)

<table>
<thead>
<tr>
<th>Byte 0</th>
<th>Byte 1</th>
<th>Byte 2</th>
<th>Byte 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>HashAlgorithmCount</td>
<td>SaltLength</td>
<td>HashAlgorithms</td>
<td>...</td>
</tr>
<tr>
<td>Salt</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>
3 - Computing the Integrity Hash Value

Client

N = 00…0
N = H(H(N || Request) || Response)
S = N
S = H(S || Request)
S = H(S || Response)
... 
S = H(S || Request)

Server

N = 00…0
N = H(N || Request)
N = H(N || Response)
N = H(N || Request)
S = N
S = H(S || Request)
S = H(S || Response)
... 
S = H(S || Request)

Derive secret keys using S (next slide) and verify signature.

H(x): hash value of bit string x using the negotiated hash function
A || B: concatenation of bit strings A and B
3 - Deriving Secret Keys in SMB 3.1.1

DerivedKey = KDF^1(SessionKey, Label^2, Context)

<table>
<thead>
<tr>
<th>Derived Key</th>
<th>Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application Key</td>
<td>“SMBAppKey”</td>
</tr>
<tr>
<td>Signing Key</td>
<td>“SMBSigningKey”</td>
</tr>
<tr>
<td>Client to server cipher key</td>
<td>“SMBC2SCipherKey”</td>
</tr>
<tr>
<td>Server to client cipher key</td>
<td>“SMBS2CCipherKey”</td>
</tr>
</tbody>
</table>

1. KDF is SP108-800-CTR-HMAC-SHA256 (same as SMB 3.0.x)
2. Note that KDF labels have changed since SMB 3.0.x
3. Key derivation for pre-3.1.1 dialects unchanged
3 - Key Points

- Preauthentication Integrity is mandatory for SMB 3.1.1.
- Preauthentication Integrity supersedes SMB 3.0.x Negotiate Validation for SMB 3.1.1 connections.
- Session setup hashes are only calculated for master and binding session setup exchanges, not reauthentication.
  - Reauthentication does not result in new keys
4 – Cluster Dialect Fencing

- **How to support Cluster Rolling Upgrades?**
  - Cluster nodes with upgraded OS may support a higher SMB dialect than nodes that have not yet been upgraded (3.1.1 vs. 3.0.2).
  - Transparent failover requires all cluster nodes to support the same set of dialects so that handles opened on one node can fail over to any other node in the cluster.

- **SMB 3.1.1 Cluster Dialect Fencing**
  - Define a maximum SMB cluster dialect that all nodes support.
  - Fence access to cluster shares based on the maximum SMB cluster dialect.
  - Fenced clients instructed to reconnect at a cluster-supported dialect.
4 - Fencing Clustered Tree Connects

An SMB 3.1.1 client accesses a clustered file share on an SMB 3.1.1 server that is a member of a cluster whose maximum SMB cluster dialect is 3.0.2.

1. Client negotiates 3.1.1, authenticates then issues tree connect.
2. Server fails tree connect request with an extended error (status = 0xC05D0001) whose data payload indicates the maximum cluster-supported dialect (3.0.2).
3. Client disconnects, reconnects with new Client GUID, negotiates 3.0.2, authenticates, then reissues tree connect.
4 – Tree Connect Request Changes

Once a client has successfully connected to a clustered share it must set the CLUSTER_RECONNECT (0x0001) flag on all subsequent clustered tree connect requests to the same server.

- Addresses a race condition when the maximum SMB cluster dialect has been raised but some nodes have not yet begun allowing the new, higher dialect.

<table>
<thead>
<tr>
<th>Byte 0</th>
<th>Byte 1</th>
<th>Byte 2</th>
<th>Byte 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure Size</td>
<td>Reserved</td>
<td>Flags</td>
<td></td>
</tr>
<tr>
<td>PathOffset</td>
<td>PathLength</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buffer</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Reserved field renamed to Flags:

<table>
<thead>
<tr>
<th>Value</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x0001</td>
<td>Client has already successfully connected to a clustered file share on this server at the current SMB dialect.</td>
</tr>
</tbody>
</table>
4 - Key Points

- Dialect fencing only affects clustered share access.
  - Clients can still access non-clustered shares using dialect X even if the maximum SMB cluster dialect is < X.
  - Can’t mix clustered and non-clustered access on same connection.

- Client implementation should protect against infinite loop of tree connect failure, disconnect, reconnect, tree connect failure, …
5 - Cluster Client Failover (CCF) v2

- CCF v1 Overview
  - Introduced with SMB 3.0 for clustered applications using SMB 3.0 storage
  - Permits clustered application to tag an open with `ApplicationInstance` identifier
  - An open issued by a different client with the same `ApplicationInstance` indicates workload has transitioned to a new node, so old opens are closed allowing new node to reopen handles.
5- Cluster Client Failover (CCF) v2…

- How to handle an application cluster partition?
  - Cluster loses network access to a node running an application but that node can still access storage.
  - Cluster restarts application on a new node.
  - Application now running on two nodes, fighting over access to handles.

- SMB 3.1.1 CCF v2
  - The cluster knows which node should be hosting an application. Along with the ApplicationInstance, it provides an ApplicationInstanceVersion to convey this knowledge to the application node.
  - The ApplicationInstanceVersion is increased every time the application is moved to a new node.
5 - Cluster Client Failover (CCF) v2…

- SMB 3.1.1 Client must
  - Pass ApplicationInstanceVersion alongside ApplicationInstance on create
  - It should attempt to keep the handle alive until it receives a non-ambiguous status code from the server indicating it has been superseded by another node (or the handle has timed out)

- SMB 3.1.1 Server must
  - Compare the ApplicationInstanceVersion on an invalidating open.
    - If the version is higher, the existing open should be orphaned as normal.
    - If the version is lower, the incoming open is failed with a non-ambiguous status code indicating it has been superseded.
5 - Cluster Client Failover (CCF) v2…

- To interact with older (pre-SMB 3.1.1) clients
  - Opens without a version are assumed to be version 0
  - A version 0 open will successfully invalidate other version 0 opens
  - Otherwise, the same rules apply
6 - Encryption Improvements

- SMB 3.0.x mandates the AES-128-CCM cipher
  - What if a different cipher is required for performance, regulatory requirements, etc?
  - What if a cipher is compromised and needs to be retired?

- SMB 3.1.1 Encryption Improvements
  - Ciphers are negotiated per-connection
  - Added support for AES-128-GCM
  - Clients can mandate that sessions be encrypted even if the server does not require encryption.
    - No protocol changes necessary. Client just requires signing during negotiation / session setup then issues only encrypted requests.
6 – Negotiating a Cipher

- SMB 3.1.1 client and server exchange negotiate contexts for each connection if they support encryption.
- Client’s negotiate context specifies a set of supported ciphers in order from most to least preferred.
- Server’s negotiate context specifies the selected cipher.
  - Selection policy is server’s choice: client-preferred, server-preferred, etc.
  - Reserved cipher ID 0x0000 indicates that the client and server have no common cipher.
  - No SMB2_ENCRYPTION_CAPABILITIES context in server response indicates that the server does not support encryption.
- Encryption capabilities flag is never set in an SMB 3.1.1 Negotiate Response.

SMB2_ENCRYPTION_CAPABILITIES
(Negotiate Context ID: 0x0002)

<table>
<thead>
<tr>
<th>Byte 0</th>
<th>Byte 1</th>
<th>Byte 2</th>
<th>Byte 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>CipherCount</td>
<td>Ciphers</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## 6 - Transform Header Changes

<table>
<thead>
<tr>
<th>Byte 0</th>
<th>Byte 1</th>
<th>Byte 2</th>
<th>Byte 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>ProtocolId</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signature</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>...</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Nonce</td>
<td></td>
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<td></td>
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<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
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<td>...</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OriginalMessageSize</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reserved</td>
<td>Flags</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SessionId</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### EncryptionAlgorithm field renamed to Flags:

<table>
<thead>
<tr>
<th>Value</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x0001</td>
<td>Payload is encrypted using cipher negotiated for the connection</td>
</tr>
</tbody>
</table>

### Nonce size determined by cipher:

<table>
<thead>
<tr>
<th>Cipher</th>
<th>Nonce Size (bytes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AES-128-CCM</td>
<td>11</td>
</tr>
<tr>
<td>AES-128-GCM</td>
<td>12</td>
</tr>
</tbody>
</table>
6 - Performance

- Examine large file copy performance
- SMB can copy at 10 Gbps line rate when not using signing or encryption.

<table>
<thead>
<tr>
<th>Test configuration (client and server)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU</td>
</tr>
<tr>
<td>OS Power Profile</td>
</tr>
<tr>
<td>Network Adapter</td>
</tr>
<tr>
<td>Storage Device</td>
</tr>
<tr>
<td>Storage Workload</td>
</tr>
</tbody>
</table>
6 – Performance...

- **SMB 3.1 (Windows 10 Preview @ SDC 2014)**
  - MB/sec (larger is better)
  - 10 Gbps line rate
  - AES-CMAC (Signing) blue, AES-128-CCM (Encryption) orange, AES-128-GCM (Encryption) green
  - 296, 236, 491

- **SMB 3.1.1 (latest internal Windows 10 build)**
  - MB/sec (larger is better)
  - 10 Gbps line rate
  - AES-CMAC (Signing) blue, AES-128-CCM (Encryption) orange, AES-128-GCM (Encryption) green
  - 318, 973, 1169

- **SMB 3.1.1 (latest internal Windows 10 build)**
  - CPU cycles/byte (smaller is better)
  - AES-CMAC (Signing) blue, AES-128-CCM (Encryption) orange, AES-128-GCM (Encryption) green
  - 7.1, 7.2, 4.8

- **Improvements:**
  - 4.12x faster than SMB 3.1
  - 2.38x faster than SMB 3.1
  - No protocol changes required!
  - 33% fewer cycles/byte than AES-128-CCM

These improvements will ship in the next Windows Server 2016 preview and the next Windows 10 client release.
6 - Key Points

- AES-CCM required for SMB 3.0.x compatibility.
- AES-GCM provides **significant** performance / efficiency improvements and should be supported.
- Session binding (multichannel) requires all of a session’s channels to negotiate the same cipher as the session’s original connection.
7 – Future Directions

Some of the following slides discuss experimental, protocol changes. Microsoft makes no promise that these changes will ship.
7 – Improving SMB Signing Performance

- SMB Encryption using AES-GCM is much faster / more efficient than SMB Signing.
  - But what if we only need integrity?
  - Why spend CPU cycles encrypting data if we don’t need privacy?
- Can SMB Signing be made faster / more efficient than SMB Encryption?
7 – AES-GMAC Signing

- AES-GMC
  - Authenticated encryption (integrity + privacy)
  - Fast / efficient
  - Used in SMB 3.1.1 for SMB Encryption

- AES-GMAC
  - Integrity-only mode of AES-GCM encryption
  - Should be faster / more efficient than AES-GCM since it does less work.

- Meet Aaron Friedlander
  - Microsoft 2015 summer intern from Carnegie Mellon
  - Prototyped AES-GMAC signing support for SMB 3.1.1
  - Did a really great job on a complex code base with no prior kernel development experience.
7 – Supporting AES-GMAC in SMB 3.1.1

- Define a new signing capabilities negotiate context that an SMB 3.1.1 client and server use to negotiate a signing algorithm on a per-connection basis.
  - Prototype SMB 3.1.1 clients and servers interoperate with standard SMB 3.1.1 clients and servers.
  - Proof that negotiate contexts allow features to be added without requiring a new dialect.
- Refactor the encryption code paths to handle both authenticated encryption (AES-CCM/GCM) as well as AES-GCM in signing-only mode (AES-GMAC)
- Add a new transform header flag value to indicate that the payload is signed, not encrypted.
7 – AES-GMAC file copy performance

- AES-GMAC results in significant performance improvements!
  - 46% reduction in Cycles/Byte compared to AES-CMAC
  - 21% reduction in Cycles/Byte compared to AES-GCM

- Prototype focused on functional correctness not performance
  - We identified several fairly easy improvements that could be made to further decrease CPU cycles/byte.
7 – Faster

100 x 2
7 - Dual 100GbE Multi-Vendor Test Configuration

- Windows Server 2016 TP3
  - SMB 3.1.1 + SMB Direct
- Arista DCS-7060CX-32S 32port 100Gb Switch
- Dell R730xd hosts
  - 2x E5-2660v3 (2.6Ghz 10c20t)
  - 256GiB DDR4 2133MT/s (16x 16GB)
  - 2x HGST UltraStar SN150 NVME (1.6TB PCIe 3.0 x4)
  - 2x Mellanox ConnectX-4 1 Port Connected (PCIe 3.0 x16)
  - Mellanox Copper 100Gb Cable

100Gb Logical Port

Case 1: To Memory

Case 2: To Storage
7 - Case 1: SMB3 to Remote Memory Cache

**Extreme Network Bandwidth**

<table>
<thead>
<tr>
<th>RDMA Activity</th>
<th>Mellanox ConnectX-4 VFI Adapter</th>
<th>Mellanox ConnectX-4 VFI Adapter #3</th>
</tr>
</thead>
<tbody>
<tr>
<td>RDMA Accepted Connections</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>RDMA Active Connections</td>
<td>2.000</td>
<td>2.000</td>
</tr>
<tr>
<td>RDMA Completion Queue Errors</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>RDMA Connection Errors</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>RDMA Failed Connection Attempts</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>RDMA Inbound Bytes/sec</td>
<td>11,010,314,665</td>
<td>10,883,119,850</td>
</tr>
<tr>
<td>RDMA Outbound Bytes/sec</td>
<td>34,000</td>
<td>34,000</td>
</tr>
<tr>
<td>RDMA Inbound Frames/sec</td>
<td>902,128,513</td>
<td>894,007,535</td>
</tr>
<tr>
<td>RDMA Outbound Frames/sec</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**SMB Client Shares**

| Avg. Bytes/Read       | 524,268,000  |
| Avg. Bytes/Write      | 0.000        |
| Avg. Data Bytes/Request| 524,268,000  |
| Avg. Data Queue Length| 6.462        |
| Avg. Read Queue Length | 6.462       |
| Avg. Write Queue Length| 0.000       |
| Avg. Write Queue Length| 0.000       |
| Avg. Data Queue Length | 0.000        |

| Data Bytes/sec         | 22,382,317,301,636 |
| Data Requests/sec      | 42,690,882        |

**Theoretical** ~11.5GB/s/link, ~23GB/s total

**22.3GB/s!**
7 - Case 2: SMB3 to HGST NVME Storage

Minimal Wire Latency to Remote Storage

- Load to dual HGST NVME on Remote System
- Latency measured End-to-End over SMB3 to DISKSPD
- Near-saturation NVME devices @ 5.7GB/s
- Only 28us latency introduced on the wire for the median IO
7 - 16 Years of Ethernet In The Rack
Questions?