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Transport Layer Security (TLS) Protocol Compression Using Lempel-Ziv-Stac (LZS)

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Abstract

The Transport Layer Security (TLS) protocol (RFC 2246) includes features to negotiate selection of a lossless data compression method as part of the TLS Handshake Protocol and then to apply the algorithm associated with the selected method as part of the TLS Record Protocol. TLS defines one standard compression method, which specifies that data exchanged via the record protocol will not be compressed. This document describes an additional compression method associated with the Lempel-Ziv-Stac (LZS) lossless data compression algorithm for use with TLS. This document also defines the application of the LZS algorithm to the TLS Record Protocol.

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1. Introduction

1.1. General

The Transport Layer Security (TLS) protocol (RFC 2246, [2]) includes features to negotiate selection of a lossless data compression method as part of the TLS Handshake Protocol and then to apply the algorithm associated with the selected method as part of the TLS Record Protocol. TLS defines one standard compression method, CompressionMethod.null, which specifies that data exchanged via the record protocol will not be compressed. Although this single compression method helps ensure that TLS implementations are interoperable, the lack of additional standard compression methods has limited the ability to develop interoperative implementations that include data compression.

TLS is used extensively to secure client-server connections on the World Wide Web. Although these connections can often be characterized as short-lived and exchanging relatively small amounts of data, TLS is also being used in environments where connections can be long-lived and the amount of data exchanged can extend into thousands or millions of octets. For example, TLS is now increasingly being used as an alternative Virtual Private Network (VPN) connection. Compression services have long been associated with IPSec and PPTP VPN connections, so extending compression services to TLS VPN connections preserves the user experience for any VPN connection. Compression within TLS is one way to help reduce the bandwidth and latency requirements associated with exchanging large amounts of data while preserving the security services provided by TLS.

This document describes an additional compression method associated with a lossless data compression algorithm for use with TLS. This document specifies the application of Lempel-Ziv-Stac (LZS) compression, a lossless compression algorithm, to TLS record payloads. This specification also assumes a thorough understanding of the TLS protocol [2].

1.2. Specification of Requirements

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14, RFC 2119 [1].

2. Compression Methods

As described in section 6 of RFC 2246 [2], TLS is a stateful protocol. Compression methods used with TLS can be either stateful (the compressor maintains its state through all compressed records) or stateless (the compressor compresses each record independently), but there seems to be little known benefit in using a stateless compression method within TLS. The LZS compression method described in this document is stateful.

Compression algorithms can occasionally expand, rather than compress, input data. The worst-case expansion factor of the LZS compression method is only 12.5%. Thus, TLS records of 15K bytes can never exceed the expansion limits described in section 6.2.2 of RFC 2246 [2]. If TLS records of 16K bytes expand to an amount greater than 17K bytes, then the uncompressed version of the TLS record must be transmitted, as described below.

2.1. LZS CompressionMethod

The LZS CompressionMethod is a 16-bit index and is negotiated as described in RFC 2246 [2] and RFC 3749 [3]. The LZS CompressionMethod is stored in the TLS Record Layer connection state as described in RFC 2246 [2].

IANA has assigned 64 as compression method identifier for applying LZS compression to TLS record payloads.

2.2. Security Issues with Compression Histories

Sharing compression histories between or among more than one TLS session may potentially cause information leakage between the TLS sessions, as pathological compressed data can potentially reference data prior to the beginning of the current record. LZS implementations guard against this situation. However, to avoid this potential threat, implementations supporting TLS compression MUST use separate compression histories for each TLS session. This is not a limitation of LZS compression but is an artifact for any compression algorithm.

Furthermore, the LZS compression history (as well as any compression history) contains plaintext. Specifically, the LZS history contains the last 2K bytes of plaintext of the TLS session. Thus, when the TLS session terminates, the implementation SHOULD treat the history as it does any plaintext (e.g., free memory, overwrite contents).

3. LZS Compression

3.1. Background of LZS Compression

Starting with a sliding window compression history, similar to LZ1 [8], a new, enhanced compression algorithm identified as LZS was developed. The LZS algorithm is a general-purpose lossless compression algorithm for use with a wide variety of data types. Its encoding method is very efficient, providing compression for strings as short as two octets in length.

The LZS algorithm uses a sliding window of 2,048 bytes. During compression, redundant sequences of data are replaced with tokens that represent those sequences. During decompression, the original sequences are substituted for the tokens in such a way that the original data is exactly recovered. LZS differs from lossy compression algorithms, such as those often used for video compression, that do not exactly reproduce the original data. The details of LZS compression can be found in section 3.5 below.

3.2. LZS Compression History and Record Processing

This standard specifies "stateful" compression -- that is, maintaining the compression history between records within a particular TLS compression session. Within each separate compression history, the LZS CompressionMethod can maintain compression history information when compressing and decompressing record payloads. Stateful compression provides a higher compression ratio to be achieved on the data stream, as compared to stateless compression (resetting the compression history between every record), particularly for small records.

Stateful compression requires both a reliable link and sequenced record delivery to ensure that all records can be decompressed in the same order they were compressed. Since TLS and lower-layer protocols provide reliable, sequenced record delivery, compression history information MAY be maintained and exploited when the LZS CompressionMethod is used.

Furthermore, there MUST be a separate LZS compression history associated with each open TLS session. This not only provides enhanced security (no potential information leakage between sessions via a shared compression history), but also enables superior compression ratio (bit bandwidth on the connection) across all open TLS sessions with compression. A shared history would require resetting the compression (and decompression) history when switching between TLS sessions, and a single history implementation would require resetting the compression (and decompression) history between each record.

The sender MUST reset the compression history prior to compressing the first TLS record of a TLS session after TLS handshake completes. It is advantageous for the sender to maintain the compression history for all subsequent records processed during the TLS session. This results in the greatest compression ratio for a given data set. In either case, this compression history MUST NOT be used for any other open TLS session, to ensure privacy between TLS sessions.

The sender MUST "flush" the compressor each time it transmits a compressed record. Flushing means that all data going into the compressor is included in the output, i.e., no data is retained in the hope of achieving better compression. Flushing ensures that each compressed record payload can be decompressed completely. Flushing is necessary to prevent a record’s data from spilling over into a later record. This is important for synchronizing compressed data with the authenticated and encrypted data in a TLS record. Flushing is handled automatically in most LZS implementations.

When the TLS session terminates, the implementation SHOULD dispose of the memory resources associated with the related TLS compression history. That is, the compression history SHOULD be handled as the TLS key material is handled.

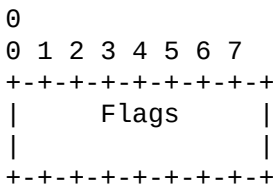
The LZS CompressionMethod also features "decompressing" uncompressed data in order to maintain the history if the "compressed" data actually expanded. The LZS CompressionMethod record format facilitates identifying whether records contain compressed or uncompressed data. The LZS decoding process accommodates decompressing either compressed or uncompressed data.

3.3. LZS Compressed Record Format

Prior to compression, the uncompressed data (TLSPlaintext.fragment) is composed of a plaintext TLS record. After compression, the compressed data (TLSCompressed.fragment) is composed of an 8-bit TLSComp header followed by the compressed (or uncompressed) data.

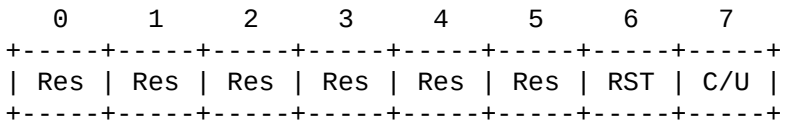
3.4. TLSComp Header Format

The one-octet header has the following structure:



3.4.1. Flags

The format of the 8-bit Flags TLSComp field is as follows:



Res-Reserved

Reserved for future use. MUST be set to zero. MUST be ignored by the receiving node.

RST-Reset Compression History

The RST bit is used to inform the decompressing peer that the compression history in this TLS session was reset prior to the data contained in this TLS record being compressed. When the RST bit is set to "1", a compression history reset is performed; when RST is set to "0", a compression history reset is not performed.

This bit MUST be set to a value of "1" for the first compressed TLS transmitted record of a TLS session. This bit may also be used by the transmitter for other exception cases when the compression history must be reset.

C/U-Compressed/Uncompressed Bit

The C/U indicates whether the data field contains compressed or uncompressed data. A value of 1 indicates compressed data (often referred to as a compressed record), and a value of 0 indicates uncompressed data (or an uncompressed record).

3.5. LZS Compression Encoding Format

The LZS compression method, encoding format, and application examples are described in RFC 1967 [6], RFC 1974 [5], and RFC 2395 [4].

Some implementations of LZS allow the sending compressor to select from among several options to provide varying compression ratios, processing speeds, and memory requirements. Other implementations of LZS provide optimal compression ratio at byte-per-clock speeds.

The receiving LZS decompressor automatically adjusts to the settings selected by the sender. Also, receiving LZS decompressors will update the decompression history with uncompressed data. This facilitates never obtaining less than a 1:1 compression ratio in the session and never transmitting with expanded data.

The input to the payload compression algorithm is TLSPlaintext data destined to an active TLS session with compression negotiated. The output of the algorithm is a new (and hopefully smaller) TLSCompressed record. The output payload contains the input payload's data in either compressed or uncompressed format. The input and output payloads are each an integral number of bytes in length.

The output payload is always prepended with the TLSComp header. If the uncompressed form is used, the output payload is identical to the input payload, and the TLSComp header reflects uncompressed data.

If the compressed form is used, encoded as defined in ANSI X3.241 [7], and the TLSComp header reflects compressed data. The LZS encoded format is repeated here for informational purposes ONLY.

```
<Compressed Stream> := [<Compressed String>*] <End Marker>
<Compressed String> := 0 <Raw Byte> | 1 <Compressed Bytes>

<Raw Byte> := <b><b><b><b><b><b><b><b>          (8-bit byte)
<Compressed Bytes> := <Offset> <Length>

<Offset> := 1 <b><b><b><b><b><b><b> |           (7-bit offset)
            0 <b><b><b><b><b><b><b><b><b><b><b> (11-bit offset)
<End Marker> := 110000000
<b> := 1 | 0

<Length> :=
00        = 2     1111 0110      = 14
01        = 3     1111 0111      = 15
10        = 4     1111 1000      = 16
1100      = 5     1111 1001      = 17
1101      = 6     1111 1010      = 18
1110      = 7     1111 1011      = 19
1111 0000 = 8     1111 1100      = 20
1111 0001 = 9     1111 1101      = 21
1111 0010 = 10    1111 1110      = 22
1111 0011 = 11    1111 1111 0000 = 23
1111 0100 = 12    1111 1111 0001 = 24
1111 0101 = 13     ...
```

3.6. Padding

A datagram payload compressed with LZS always ends with the last compressed data byte (also known as the <end marker>), which is used to disambiguate padding. This allows trailing bits, as well as bytes, to be considered padding.

The size of a compressed payload MUST be in whole octet units.

4. Sending Compressed Datagrams

All TLS records processed with a TLS session state that includes LZS compression are processed as follows. The reliable and efficient transport of LZS compressed records in the TLS session depends on the following processes.

4.1. Transmitter Process

The compression operation results in either compressed or uncompressed data. When a TLS record is received, it is assigned to a particular TLS context that includes the LZS compression history buffer. It is processed according to ANSI X3.241-1994 to form compressed data or used as is to form uncompressed data. For the first record of the session, or for exception conditions, the compression history MUST be cleared. In performing the compression operation, the compression history MUST be updated when either a compressed record or an uncompressed record is produced. Uncompressed TLS records MAY be sent at any time. Uncompressed TLS records MUST be sent if compression causes enough expansion to make the data compression TLS record size exceed the MTU defined in section 6.2.2 in RFC 2246. The output of the compression operation is placed in the fragment field of the TLSCompressed structure (TLSCompressed.fragment).

The TLSComp header byte is located just prior to the first byte of the compressed TLS record in TLSCompressed.fragment. The C/U bit in the TLSComp header is set according to whether the data field contains compressed or uncompressed data. The RST bit in the TLSComp header is set to "1" if the compression history was reset prior to compressing the TLSplaintext.fragment that is composed of a TLSCompressed.fragment. Uncompressed data MUST be transmitted (and the C/U bit set to 0) if the "compressed" (expanded) data exceeded 17K bytes.

4.2. Receiver Process

Prior to decompressing the first compressed TLS record in the TLS session, the receiver MUST reset the decompression history. Subsequent records are decompressed in the order received. The receiver decompresses the Payload Data field according to the encoding specified in section 3.5 above.

If the received datagram is not compressed, the receiver does not need to perform decompression processing, and the Payload Data field of the datagram is ready for processing by the next protocol layer.

After a TLS record is received from the peer and decrypted, the RST and C/U bits MUST be checked.

If the C/U bit is set to "1", the resulting compressed data block MUST be decompressed according to section 3.5 above.

If the C/U bit is set to "0", the specified decompression history MUST be updated with the received uncompressed data.

If the RST bit is set to "1", the receiving decompression history MAY be reset to an initial state prior to decompressing the TLS record. (However, due to the characteristics of the Hifn LZS algorithm, a decompression history reset is not required). After reset, any compressed or uncompressed data contained in the record is processed.

4.3. Anti-expansion Mechanism

During compression, there are two workable options for handling records that expand:

1) Send the expanded data (as long as TLSCompressed.length is 17K or less) and maintain the history, thus allowing loss of current bandwidth but preserving future bandwidth on the link.

2) Send the uncompressed data and do not clear the compression history; the decompressor will update its history, thus conserving the current bandwidth and future bandwidth on the link.

The second option is the preferred option and SHOULD be implemented.

There is a third option:

3) Send the uncompressed data and clear the history, thus conserving current bandwidth but allowing possible loss of future bandwidth on the link.

This option SHOULD NOT be implemented.

5. Internationalization Considerations

The compression method identifiers specified in this document are machine-readable numbers. As such, issues of human internationalization and localization are not introduced.

6. IANA Considerations

Section 2 of RFC 3749 [3] describes a registry of compression method identifiers to be maintained by the IANA and to be assigned within three zones.

IANA has assigned an identifier for the LZS compression method from the RFC 2434 Specification Required IANA pool, as described in sections 2 and 5 of RFC 3749 [3].

The IANA-assigned compression method identifier for LZS is 64 decimal (0x40).

7. Security Considerations

This document does not introduce any topics that alter the threat model addressed by TLS. The security considerations described throughout RFC 2246 [2] apply here as well.

However, combining compression with encryption can sometimes reveal information that would not have been revealed without compression. Data that is the same length before compression might be a different length after compression, so adversaries that observe the length of the compressed data might be able to derive information about the corresponding uncompressed data. Some symmetric encryption ciphersuites do not hide the length of symmetrically encrypted data at all. Others hide it to some extent but not fully. For example, ciphersuites that use stream cipher encryption without padding do not hide length at all; ciphersuites that use Cipher Block Chaining (CBC) encryption with padding provide some length hiding, depending on how the amount of padding is chosen. Use of TLS compression SHOULD take into account that the length of compressed data may leak more information than the length of the original uncompressed data.

Another security issue to be aware of is that the LZS compression history contains plaintext. In order to prevent any kind of information leakage outside the system, when a TLS session with compression terminates, the implementation SHOULD treat the compression history as it does plaintext -- that is, care should be taken not to reveal the compression history in any form or to use it again. This is described in sections 2.2 and 3.2 above.

This information leakage concept can be extended to the situation of sharing a single compression history across more than one TLS session, as addressed in section 2.2 above.

Other security issues are discussed in RFC 3749 [3].

8. Acknowledgements

The concepts described in this document were derived from RFC 1967 [6], RFC 1974 [5], RFC 2395 [4], and RFC 3749 [3]. The author acknowledges the contributions of Scott Hollenbeck, Douglas Whiting, and Russell Dietz, and help from Steve Bellovin, Russ Housley, and Eric Rescorla.

9. References

9.1. Normative References

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9.2. Informative References

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