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UDP Checksum Complement in the Network Time Protocol (NTP)

Abstract

The Network Time Protocol (NTP) allows clients to synchronize to a time server using timestamped protocol messages. To facilitate accurate timestamping, some implementations use hardware-based timestamping engines that integrate the accurate transmission time into every outgoing NTP packet during transmission. Since these packets are transported over UDP, the UDP Checksum field is then updated to reflect this modification. This document proposes an extension field that includes a 2-octet Checksum Complement, allowing timestamping engines to reflect the checksum modification in the last 2 octets of the packet rather than in the UDP Checksum field. The behavior defined in this document is interoperable with existing NTP implementations.

Status of This Memo

This document is not an Internet Standards Track specification; it is published for examination, experimental implementation, and evaluation.

This document defines an Experimental Protocol for the Internet community. This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Not all documents approved by the IESG are a candidate for any level of Internet Standard; see Section 2 of RFC 5741.

Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at http://www.rfc-editor.org/info/rfc7821.

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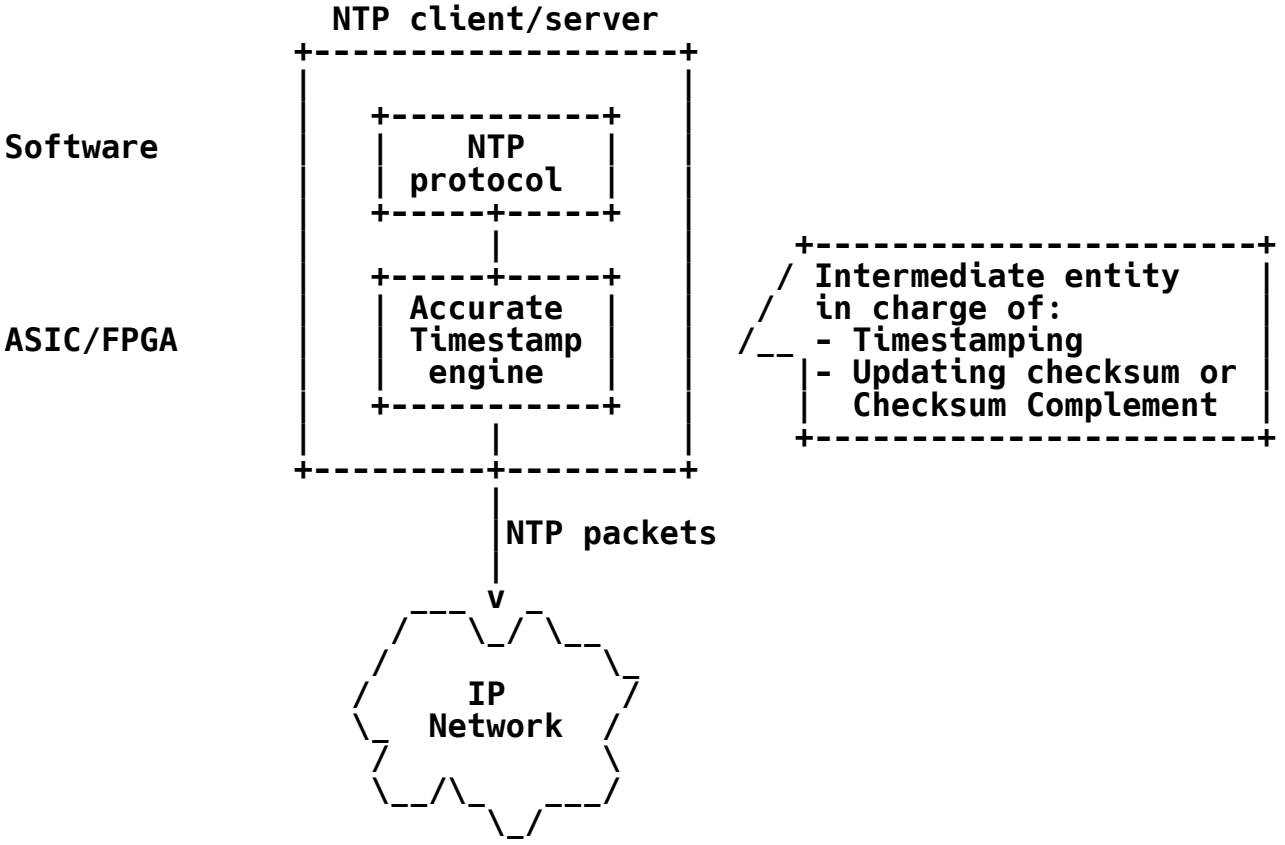
1. Introduction

The Network Time Protocol [NTPv4] allows clients to synchronize their clocks to a time server by exchanging NTP packets. The increasing demand for highly accurate clock synchronization motivates implementations that provide accurate timestamping.

1.1. Intermediate Entities

In this document, we use the term "intermediate entity" to refer to an entity that resides on the path between the sender and the receiver of an NTP packet and that modifies this NTP packet en route.

In order to facilitate accurate timestamping, an implementation can use a hardware-based timestamping engine, as shown in Figure 1. In such cases, NTP packets are sent and received by a software layer, whereas a timestamping engine modifies every outgoing NTP packet by incorporating its accurate transmission time into the <Transmit Timestamp> field in the packet.



ASIC: Application-Specific Integrated Circuit
FPGA: Field-Programmable Gate Array

Figure 1: Accurate Timestamping in NTP

The accuracy of clock synchronization over packet networks is highly sensitive to delay jitters in the underlying network; this dramatically affects clock accuracy. To address this challenge, the Precision Time Protocol (PTP) [IEEE1588] defines Transparent Clocks (TCs) -- switches and routers that improve end-to-end clock accuracy by updating a "Correction Field" in the PTP packet by adding the latency caused by the current TC. In NTP, no equivalent entity is currently defined, but future versions of NTP may define an intermediate node that modifies en-route NTP packets using a "Correction Field".

1.2. Updating the UDP Checksum

When the UDP payload is modified by an intermediate entity, the UDP Checksum field needs to be updated to maintain its correctness. When using UDP over IPv4 [UDP], an intermediate entity that cannot update

the value of the UDP Checksum has no choice except to assign a value of zero to the Checksum field, causing the receiver to ignore the Checksum field and potentially accept corrupted packets. UDP over IPv6, as defined in [IPv6], does not allow a zero checksum, except in specific cases [ZeroChecksum]. As discussed in [ZeroChecksum], the use of a zero checksum is generally not recommended and should be avoided to the extent possible.

Since an intermediate entity only modifies a specific field in the packet, i.e., the Timestamp field, the UDP Checksum update can be performed incrementally, using the concepts presented in [Checksum].

This document defines the Checksum Complement for [NTPv4]. The Checksum Complement is a 2-octet field that resides at the end of the UDP payload. It allows intermediate entities to update NTP packets and maintain the correctness of the UDP Checksum by modifying the last 2 octets of the packet, instead of updating the UDP Checksum field. This is performed by adding an NTP extension field at the end of the packet, in which the last 2 octets are used as a Checksum Complement.

The usage of the Checksum Complement can in some cases simplify the implementation, because if the packet data is processed in serial order, it is simpler to first update the Timestamp field and then update the Checksum Complement, rather than to update the timestamp and then update the UDP Checksum residing at the UDP header. Note that while it is not impossible to implement a hardware timestamper that updates the UDP Checksum, using the Checksum Complement instead can significantly simplify the implementation.

Note that the software layer and the intermediate entity (see Figure 1) are two modules in a single NTP clock. It is assumed that these two modules are in agreement regarding whether transmitted NTP packets include the Checksum Complement or not.

[RFC7820] defines the Checksum Complement mechanism for the One-Way Active Measurement Protocol (OWAMP) and the Two-Way Active Measurement Protocol (TWAMP). A similar mechanism is presented in Annex E of [IEEE1588].

2. Conventions Used in This Document

2.1. Terminology

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 [KEYWORDS].

2.2. Abbreviations

MAC	Message Authentication Code
NTP	Network Time Protocol
PTP	Precision Time Protocol
UDP	User Datagram Protocol

3. Using the UDP Checksum Complement in NTP

3.1. Overview

The UDP Checksum Complement is a 2-octet field that is appended at the end of the UDP payload, using an NTP extension field. Figure 2 illustrates the packet format of an NTP packet with a Checksum Complement extension.

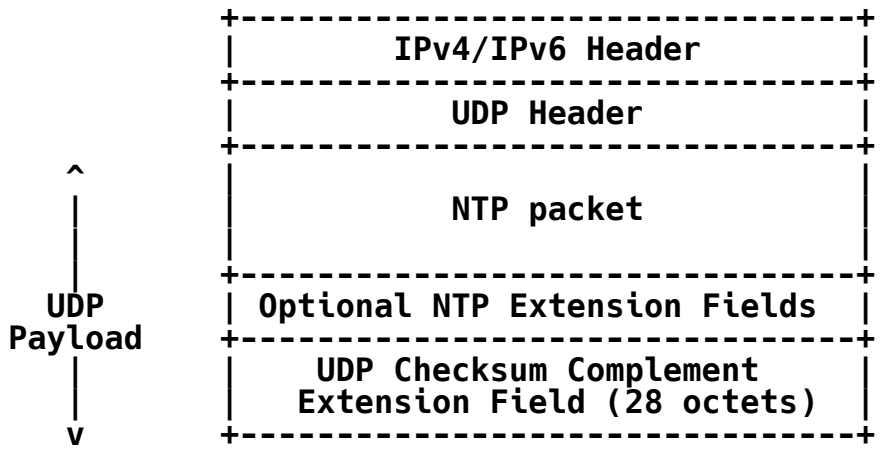


Figure 2: Checksum Complement in NTP Packets

The Checksum Complement is used to compensate for changes performed in the NTP packet by intermediate entities, as described in the Introduction (Section 1). An example of the usage of the Checksum Complement is provided in Appendix A.

3.2. Checksum Complement in NTP Packets

NTP is transported over UDP, either over IPv4 or over IPv6. This document applies to both NTP over IPv4 and NTP over IPv6.

NTP packets may include one or more extension fields, as defined in [NTPv4]. The Checksum Complement in NTP packets resides in a dedicated NTP extension field, as shown in Figure 3.

If the NTP packet includes more than one extension field, the Checksum Complement extension is always the last extension field. Thus, the Checksum Complement is the last 2 octets in the UDP payload and is located at (UDP Length - 2 octets) after the beginning of the UDP header. Note that the Checksum Complement is not used in authenticated NTP packets, as further discussed in Section 3.4.

3.2.1. Using the Checksum Complement

As described in Section 1, an intermediate entity that updates the timestamp in the NTP packet can use the Checksum Complement in order to maintain the correctness of the UDP Checksum field. Specifically, if the value of the timestamp is updated, this update yields a change in the UDP Checksum value; thus, the intermediate entity assigns a new value in the Checksum Complement that cancels this change, leaving the current value of the UDP Checksum correct. An example of the usage of the Checksum Complement is provided in Appendix A.

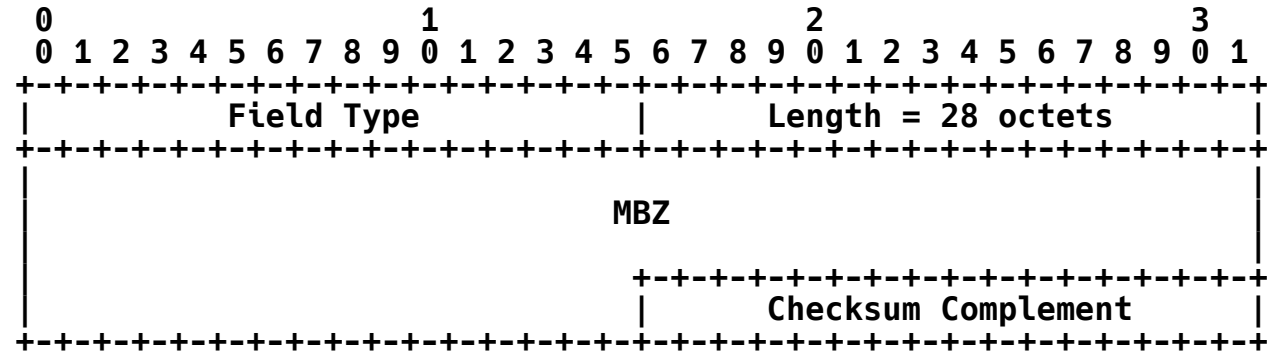


Figure 3: NTP Checksum Complement Extension Field

Field Type

A dedicated Field Type value is used to identify the Checksum Complement extension. See Section 5.

Length

The Checksum Complement extension field length is 28 octets.

This length guarantees that the host that receives the packet parses it correctly, whether the packet includes a MAC or not. [RFC7822] provides further details about the length of an extension field in the absence of a MAC.

MBZ

The extension field includes a 22-octet MBZ (MUST be zero) field. This field MUST be set to 0 and MUST be ignored by the recipient. The MBZ field is used for padding the extension field to 28 octets.

Checksum Complement

The Checksum Complement extension includes the Checksum Complement field, residing in the last 2 octets of the extension.

3.2.2. Transmission of NTP with Checksum Complement

The transmitter of an NTP packet MAY include a Checksum Complement extension field.

3.2.3. Updates of NTP with Checksum Complement

An intermediate entity that receives and alters an NTP packet containing a Checksum Complement extension MAY use the Checksum Complement to maintain a correct UDP Checksum value.

3.2.4. Reception of NTP with Checksum Complement

This document does not impose new requirements on the receiving end of an NTP packet.

The UDP layer at the receiving end verifies the UDP Checksum of received NTP packets, and the NTP layer SHOULD ignore the Checksum Complement extension field.

3.3. Interoperability with Existing Implementations

The behavior defined in this document does not impose new requirements on the reception of NTP packets beyond the requirements defined in [RFC7822]. Note that, as defined in [RFC7822], a host that receives an NTP message with an unknown extension field SHOULD ignore the extension field and MAY drop the packet if policy requires it. Thus, transmitters and intermediate entities that support the Checksum Complement can transparently interoperate with receivers that are not Checksum Complement compliant, as long as these receivers ignore unknown extension fields. It is noted that existing implementations that discard packets with unknown extension fields cannot interoperate with transmitters that use the Checksum Complement.

It should be noted that when hardware-based timestamping is used, it will likely be used at both ends, and thus both hosts that take part in the protocol will support the functionality described in this memo. If only one of the hosts uses hardware-based timestamping, then the Checksum Complement can only be used if it is known that the peer host can accept the Checksum Complement.

3.4. The Checksum Complement and Authentication

A Checksum Complement MUST NOT be used when authentication is enabled. The Checksum Complement is useful in unauthenticated mode, allowing the intermediate entity to perform serial processing of the packet without storing and forwarding it.

On the other hand, when message authentication is used, an intermediate entity that alters NTP packets must also recompute the Message Authentication Code (MAC) accordingly. In this case, it is not possible to update the Checksum Complement; updating the Checksum Complement would result in having to recalculate the MAC, and there would be a cyclic dependency between the MAC and the Checksum Complement. Hence, when updating the MAC, it is necessary to update the UDP Checksum field, making the Checksum Complement field unnecessary in the presence of authentication.

4. Security Considerations

This document describes how a Checksum Complement extension can be used for maintaining the correctness of the UDP Checksum. The security considerations of time protocols in general are discussed in [SecTime], and the security considerations of NTP are discussed in [NTPv4].

The purpose of this extension is to ease the implementation of accurate timestamping engines, as illustrated in Figure 1. The extension is intended to be used internally in an NTP client or server. This extension is not intended to be used by switches and routers that reside between the client and the server. As opposed to PTP [IEEE1588], NTP does not require intermediate switches or routers to modify the content of NTP messages, and thus any such modification should be considered as a malicious man-in-the-middle (MITM) attack.

It is important to emphasize that the scheme described in this document does not increase the protocol's vulnerability to MITM attacks; a MITM attacker who maliciously modifies a packet and its Checksum Complement is logically equivalent to a MITM attacker who modifies a packet and its UDP Checksum field.

The concept described in this document is intended to be used only in unauthenticated mode. As discussed in Section 3.4, if a cryptographic security mechanism is used, then the Checksum Complement does not simplify the implementation compared to using the conventional Checksum, and therefore the Checksum Complement is not used.

5. IANA Considerations

IANA has allocated a new value in the "NTP Extension Field Types" registry:

0x2005 Checksum Complement

6. References

6.1. Normative References

[Checksum] Rijsinghani, A., Ed., "Computation of the Internet Checksum via Incremental Update", RFC 1624, DOI 10.17487/RFC1624, May 1994, <http://www.rfc-editor.org/info/rfc1624>.

[IPv6] Deering, S. and R. Hinden, "Internet Protocol, Version 6 (IPv6) Specification", RFC 2460, DOI 10.17487/RFC2460, December 1998, <http://www.rfc-editor.org/info/rfc2460>.

[KEYWORDS] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <http://www.rfc-editor.org/info/rfc2119>.

[NTPv4] Mills, D., Martin, J., Ed., Burbank, J., and W. Kasch, "Network Time Protocol Version 4: Protocol and Algorithms Specification", RFC 5905, DOI 10.17487/RFC5905, June 2010, <http://www.rfc-editor.org/info/rfc5905>.

[RFC7822] Mizrahi, T. and D. Mayer, "Network Time Protocol Version 4 (NTPv4) Extension Fields", RFC 7822, DOI 10.17487/RFC7822, March 2016, <http://www.rfc-editor.org/info/rfc7822>.

[UDP] Postel, J., "User Datagram Protocol", STD 6, RFC 768, DOI 10.17487/RFC768, August 1980, <http://www.rfc-editor.org/info/rfc768>.

6.2. Informative References

[IEEE1588] IEEE, "IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems", IEEE Std 1588-2008, DOI 10.1109/IEEESTD.2008.4579760, July 2008.

[RFC7820] Mizrahi, T., "UDP Checksum Complement in the One-Way Active Measurement Protocol (OWAMP) and Two-Way Active Measurement Protocol (TWAMP)", RFC 7820, DOI 10.17487/RFC7820, March 2016, <http://www.rfc-editor.org/info/rfc7820>.

[SecTime] Mizrahi, T., "Security Requirements of Time Protocols in Packet Switched Networks", RFC 7384, DOI 10.17487/RFC7384, October 2014, <http://www.rfc-editor.org/info/rfc7384>.

[ZeroChecksum] Fairhurst, G. and M. Westerlund, "Applicability Statement for the Use of IPv6 UDP Datagrams with Zero Checksums", RFC 6936, DOI 10.17487/RFC6936, April 2013, <http://www.rfc-editor.org/info/rfc6936>.

Appendix A. Checksum Complement Usage Example

Consider an NTP packet sent by an NTP client to an NTP server.

The client's software layer (see Figure 1) generates an NTP packet with an Origin Timestamp T and a UDP Checksum value U. The value of U is the checksum of the UDP header, UDP payload, and pseudo-header. Thus, U is equal to:

$$U = Const + checksum(T) \quad (1)$$

Where "Const" is the checksum of all the fields that are covered by the checksum, except the Origin Timestamp T.

Recall that the client's software emits the NTP packet with a Checksum Complement extension field, which resides at the end of the PTP packet. It is assumed that the client initially assigns zero to the value of the Checksum Complement.

The client's timestamping engine updates the Origin Timestamp field to the accurate time, changing its value from T to T'. The engine also updates the Checksum Complement field from zero to a new value C, such that:

$$checksum(C) = checksum(T) - checksum(T') \quad (2)$$

When the NTP packet is transmitted by the client's timestamping engine, the value of the checksum remains U as before:

$$U = Const + checksum(T) = Const + checksum(T) + checksum(T') - checksum(T') = Const + checksum(T') + checksum(C) \quad (3)$$

Thus, after the timestamping engine has updated the timestamp, U remains the correct checksum of the packet.

When the NTP packet reaches the NTP server, the server performs a conventional UDP Checksum computation, and the computed value is U. Since the Checksum Complement is part of the extension field, its value (C) is transparently included in the computation, as per Equation (3), without requiring special treatment by the server.

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