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Technical Report 90-6-1 June 1990

## **Network Time Protocol (Version 3) Specification, Implementation and Analysis**

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### **Abstract**

This document describes the Network Time Protocol (NTP), specifies its formal structure and summarizes information useful for its implementation. NTP provides the mechanisms to synchronize time and coordinate time distribution in a large, diverse internet operating at rates from mundane to lightwave. It uses a returnable-time design in which a distributed subnet of time servers operating in a self-organizing, hierarchical-master-slave configuration synchronizes local clocks within the subnet and to national time standards via wire or radio. The servers can also redistribute reference time via local routing algorithms and time daemons.

This is an Internet Standard Recommended Protocol. Distribution of this memo is unlimited.

Keywords: network clock synchronization, standard time distribution, fault-tolerant architecture, maximum-likelihood estimation, disciplined oscillator, internet protocol, high-speed networks, formal specification.

Sponsored by: Defense Advanced Research Projects Agency contract number N00140-87-C-8901, NASA Ames Research Center contract number NAG 2-638 and National Science Foundation grant number NCR-89-13623.

## Preface

This document describes Version 3 of the Network Time Protocol (NTP). It supersedes Version 2 of the protocol described in RFC-1119 dated September 1989. However, it neither changes the protocol in any significant way nor obsoletes previous versions or existing implementations. The main motivation for the new version is to refine the analysis and implementation models for new applications at much higher network speeds to the gigabit-per-second regime and to provide for the enhanced stability, accuracy and precision required at such speeds. In particular, the sources of time and frequency errors have been rigorously examined and error bounds established in order to improve performance, provide a model for correctness assertions and indicate timekeeping quality to the user. The revision also incorporates two new optional features, (1) an algorithm to combine the offsets of a number of peer time servers in order to enhance accuracy and (2) improved local-clock algorithms which allow the poll intervals on all synchronization paths to be substantially increased in order to reduce network overhead. An overview of the changes, which are described in detail in Appendix D, follows:

1. In Version 3 The local-clock algorithm has been overhauled to improve stability and accuracy. Appendix G presents a detailed mathematical model and design example which has been refined with the aid of feedback-control analysis and extensive simulation using data collected over ordinary Internet paths. Section 5 of RFC-1119 on the NTP local clock has been completely rewritten to describe the new algorithm. Since the new algorithm can result in message rates far below the old ones, it is highly recommended that they be used in new implementations. Note that this algorithm is not integral to the NTP protocol specification itself and its use does not affect interoperability with previous versions or existing implementations; however, in order to insure overall NTP subnet stability in the Internet, it is essential that the local-clock characteristics of all NTP time servers conform to the analytical models presented previously and in this document.
2. In Version 3 a new algorithm to combine the offsets of a number of peer time servers is presented in Appendix F. This algorithm is modelled on those used by national standards laboratories to combine the weighted offsets from a number of standard clocks to construct a synthetic laboratory timescale more accurate than that of any clock separately. It can be used in an NTP implementation to improve accuracy and stability and reduce errors due to asymmetric paths in the Internet. The new algorithm has been simulated using data collected over ordinary Internet paths and, along with the new local-clock algorithm, implemented and tested in the Fuzzball time servers now running in the Internet. Note that this algorithm is not integral to the NTP protocol specification itself and its use does not affect interoperability with previous versions or existing implementations.
3. Several inconsistencies and minor errors in previous versions have been corrected in Version 3. The description of the procedures has been rewritten in pseudo-code augmented by English commentary for clarity and to avoid ambiguity. Appendix I has been added to illustrate C-language implementations of the various filtering and selection algorithms suggested for NTP. Additional information is included in Section 5 and in Appendix E, which includes the tutorial material formerly included in Section 2 of RFC-1119, as well as much new material clarifying the interpretation of timescales and leap seconds.

4. Minor changes have been made in the Version-3 local-clock algorithms to avoid problems observed when leap seconds are introduced in the UTC timescale and also to support an auxiliary precision oscillator, such as a cesium clock or timing receiver, as a precision timebase. In addition, changes were made to some procedures described in Section 3 and in the clock-filter and clock-selection procedures described in Section 4. While these changes were made to correct minor bugs found as the result of experience and are recommended for new implementations, they do not affect interoperability with previous versions or existing implementations in other than minor ways (at least until the next leap second).
5. In Version 3 changes were made to the way delay, offset and dispersion are defined, calculated and processed in order to reliably bound the errors inherent in the time-transfer procedures. In particular, the error accumulations were moved from the delay computation to the dispersion computation and both included in the clock filter and selection procedures. The clock-selection procedure was modified to remove the first of the two sorting/discarding steps and replace with an algorithm first proposed by Marzullo and later incorporated in the Digital Time Service. These changes do not significantly affect the ordinary operation of or compatibility with various versions of NTP, but they do provide the basis for formal statements of correctness as described in Appendix H.

## Table of Contents

1.	Introduction . . . . .	1
1.1.	Related Technology . . . . .	2
2.	System Architecture . . . . .	4
2.1.	Implementation Model . . . . .	5
2.2.	Network Configurations . . . . .	6
3.	Network Time Protocol . . . . .	8
3.1.	Data Formats . . . . .	8
3.2.	State Variables and Parameters . . . . .	8
3.2.1.	Common Variables . . . . .	9
3.2.2.	System Variables . . . . .	11
3.2.3.	Peer Variables . . . . .	11
3.2.4.	Packet Variables . . . . .	13
3.2.5.	Clock-Filter Variables . . . . .	13
3.2.6.	Authentication Variables . . . . .	14
3.2.7.	Parameters . . . . .	15
3.3.	Modes of Operation . . . . .	16
3.4.	Event Processing . . . . .	18
3.4.1.	Notation Conventions . . . . .	18
3.4.2.	Transmit Procedure . . . . .	19
3.4.3.	Receive Procedure . . . . .	21
3.4.4.	Packet Procedure . . . . .	23
3.4.5.	Clock-Update Procedure . . . . .	25
3.4.6.	Primary-Clock Procedure . . . . .	26
3.4.7.	Initialization Procedures . . . . .	27
3.4.7.1.	Initialization Procedure . . . . .	27
3.4.7.2.	Initialization-Instantiation Procedure . . . . .	27
3.4.7.3.	Receive-Instantiation Procedure . . . . .	28
3.4.7.4.	Primary Clock-Instantiation Procedure . . . . .	29
3.4.8.	Clear Procedure . . . . .	29
3.4.9.	Poll-Update Procedure . . . . .	30
3.5.	Synchronization Distance Procedure . . . . .	30
3.6.	Access Control Issues . . . . .	31
4.	Filtering and Selection Algorithms . . . . .	31
4.1.	Clock-Filter Procedure . . . . .	32
4.2.	Clock-Selection Procedure . . . . .	33
5.	Local Clocks . . . . .	36
5.1.	Fuzzball Implementation . . . . .	37
5.2.	Gradual Phase Adjustments . . . . .	38
5.3.	Step Phase Adjustments . . . . .	40
5.4.	Implementation Issues . . . . .	41
6.	Acknowledgments . . . . .	42
7.	References . . . . .	42
A.	Appendix A. NTP Data Format - Version 3 . . . . .	46
B.	Appendix B. NTP Control Messages . . . . .	49

B.1.	NTP Control Message Format . . . . .	50
B.2.	Status Words . . . . .	51
B.2.1.	System Status Word . . . . .	52
B.2.2.	Peer Status Word . . . . .	53
B.2.3.	Clock Status Word . . . . .	53
B.2.4.	Error Status Word . . . . .	54
B.3.	Commands . . . . .	54
C.	Appendix C. Authentication Issues . . . . .	57
C.1.	NTP Authentication Mechanism . . . . .	58
C.2.	NTP Authentication Procedures . . . . .	59
C.2.1.	Encrypt Procedure . . . . .	59
C.2.2.	Decrypt Procedure . . . . .	60
C.2.3.	Control-Message Procedures . . . . .	60
D.	Appendix D. Differences from Previous Versions. . . . .	61
E.	Appendix E. The NTP Timescale and its Chronometry . . . . .	64
E.1.	Introduction . . . . .	64
E.2.	Primary Frequency and Time Standards . . . . .	65
E.3.	Time and Frequency Dissemination . . . . .	66
E.4.	Determination of Frequency . . . . .	68
E.5.	Calendar Systems . . . . .	68
E.6.	The Modified Julian Day System . . . . .	70
E.7.	Determination of Time and Leap Seconds . . . . .	70
E.8.	The NTP Timescale and Reckoning with UTC . . . . .	71
F.	Appendix F. The NTP Clock-Combining Algorithm . . . . .	73
F.1.	Introduction . . . . .	73
F.2.	Determining Time and Frequency . . . . .	73
F.3.	Clock Modelling . . . . .	73
F.4.	Development of a Composite Timescale . . . . .	74
F.5.	Application to NTP . . . . .	76
F.6.	Clock-Combining Procedure . . . . .	77
G.	Appendix G. NTP Phase-Lock Loop Analysis . . . . .	78
G.1.	Mathematical Model . . . . .	78
G.2.	Implementation . . . . .	80
H.	Appendix H. Analysis of Errors and Correctness Principles . . . . .	83
H.1.	Introduction . . . . .	83
H.2.	Timestamp Errors . . . . .	83
H.3.	Measurement Errors . . . . .	85
H.4.	Network Errors . . . . .	86
H.5.	Inherited Errors . . . . .	87
H.6.	Correctness Principles . . . . .	89
I.	Appendix I. Selected C-Language Program Listings . . . . .	91
I.1.	Common Definitions and Variables . . . . .	91
I.2.	Clock-Filter Algorithm . . . . .	92
I.3.	Interval Intersection Algorithm . . . . .	93
I.4.	Clock-Selection Algorithm . . . . .	94
I.5.	Clock-Combining Procedure . . . . .	95

I.6.	Subroutine to Compute Synchronization Distance . . . . .	96
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**List of Figures**

Figure 1.	Implementation Model . . . . .	5
Figure 2.	Calculating Delay and Offset . . . . .	23
Figure 3.	Clock Registers . . . . .	37
Figure 4.	NTP Message Header . . . . .	46
Figure 5.	NTP Control Message Header . . . . .	50
Figure 6.	Status Word Formats . . . . .	51
Figure 7.	Authenticator Format . . . . .	59
Figure 8.	Comparison of UTC and NTP Timescales at Leap . . . . .	72
Figure 9.	Network Time Protocol . . . . .	73
Figure 10.	NTP Phase-Lock Loop (PLL) Model . . . . .	78
Figure 11.	Timing Intervals . . . . .	81
Figure 12.	Measuring Delay and Offset . . . . .	84
Figure 13.	Error Accumulations . . . . .	87
Figure 14.	Confidence Intervals and Intersections . . . . .	89

**List of Tables**

Table 1.	System Variables . . . . .	11
Table 2.	Peer Variables . . . . .	12
Table 3.	Packet Variables . . . . .	13
Table 4.	Parameters . . . . .	14
Table 5.	Modes and Actions . . . . .	21
Table 6.	Clock Parameters . . . . .	38
Table 7.	Characteristics of Standard Oscillators . . . . .	64
Table 8.	Table of Leap-Second Insertions . . . . .	70
Table 9.	Notation Used in PLL Analysis . . . . .	78
Table 10.	PLL Parameters . . . . .	80
Table 11.	Notation Used in Error Analysis . . . . .	83