

John C. Eidson

AIC

Advances in
Industrial Control

Measurement, Control and Communication Using IEEE 1588



Springer

Contents

Part I Background

- 1 Introduction to Time-based Measurement, Control, and Communication** 3
 - 1.1 Temporal Specifications in Systems Based on Modern Computer Technology 4
 - 1.2 The State of the Art in Implementing Real-time Systems 4
 - 1.3 IEEE 1588 7

- 2 The Evolution of Clocks and Clock Synchronization** 9
 - 2.1 The Influence of Time and Its Measurement on Our Lives 9
 - 2.2 The Measurement of Time and Time Intervals 10
 - 2.2.1 Clocks Through the Ages 10
 - 2.2.2 Characterization of Oscillators 12
 - 2.2.3 Properties of Modern Oscillators 19
 - 2.3 Time Scales and Calendars 25
 - 2.4 Synchronization Protocols 29
 - 2.4.1 Early Synchronization and Distribution Protocols 30
 - 2.4.2 IRIG-B 30
 - 2.4.3 Loran-C 31
 - 2.4.4 NTP 31
 - 2.4.5 GPS 32
 - 2.4.6 IEEE 1588 32

- 3 An Overview of Clock Synchronization Using IEEE 1588** .. 35
 - 3.1 The History of the Development and the Objectives of IEEE 1588 36
 - 3.2 Overview of the Standard 38
 - 3.3 Fundamental Operation of the Protocol 39
 - 3.3.1 System Boundaries and Communications 40
 - 3.3.2 Master-slave Synchronization Hierarchy 42

3.3.3	Startup and Reconfiguration	47
3.3.4	Synchronization Overview	50
3.3.5	System Management Overview	58

Part II IEEE 1588

4	A Detailed Analysis of IEEE 1588	61
4.1	System Boundaries and Communications	62
4.2	Master-slave Synchronization Hierarchy	64
4.2.1	States in the Master-slave Hierarchy	64
4.2.2	The PTP State Machine	66
4.2.3	The State Decision Algorithm and Data Set Updates . .	73
4.2.4	Data Set Comparison Algorithm	84
4.2.5	Clock Characterization	103
4.3	Startup and Reconfiguration	110
4.3.1	Powerup and Initialization	111
4.3.2	Changes in Clock Characteristics or Default Data Sets .	112
4.3.3	Changes in the Underlying Network Topology	113
4.3.4	Fault Management	113
4.4	Synchronization	114
4.4.1	The One and Two Message Synchronization Models . .	115
4.4.2	Message Timestamp Point and Internal Latency	120
4.4.3	Slave Clock Synchronization	121
4.4.4	Burst Mode Operation	123
4.4.5	External Timing Signals	124
4.5	System Management	124
4.5.1	Clock and Topology Discovery	125
4.5.2	Clock Initialization	125
4.5.3	Data Set Configuration and Visibility	126
4.5.4	Management Message Communications	126
4.6	Application Support	128
4.6.1	Performance Monitoring Features	128
4.6.2	Time Scale Support Features	128
4.7	Likely Extensions to IEEE 1588	129
5	Practical Issues in Implementing IEEE 1588	133
5.1	Clock and Boundary Clock Design	133
5.1.1	The Hardware Clock, Oscillator, and Clock Adjustment Blocks	134
5.1.2	The Packet Recognition, Identification, and Timestamp Capture Blocks	139
5.1.3	Boundary Clock Design	143
5.1.4	IEEE 1588 Code	145
5.2	Clock Servo Design	146

5.2.1	Model of the Slave Servo	146
5.2.2	Determining the Stability of the Slave Servo	150
5.2.3	Summary of Servo Design Issues	164
5.3	Oscillator Selection and Environmental Issues	164
5.4	IEEE 1588 in Non-UDP/IP Ethernet Systems	168
5.4.1	DeviceNet	168
5.4.2	Wireless Networks	168
5.4.3	Non-UDP/IP Ethernet	169
5.5	Synchronizing to UTC Sources	170

Part III Applying IEEE 1588

6	System Architecture Based on Synchronized Clocks	177
6.1	Partitioning in IEEE 1588 Systems	177
6.1.1	Application Partitioning	178
6.1.2	Execution Partitioning	180
6.1.3	The Boundary Between Soft and Hard Real-time Execution	184
6.2	Module Design Supporting Time-based Partitioning	188
6.3	Network Design for IEEE 1588 Systems	191
7	Case Studies in Industrial Automation and Power	193
7.1	The Monitoring and Control of Large Turbines	194
7.2	Power System Monitoring and Control	200
7.3	Boundary Clocks for Industrial Applications	204
7.4	Robotics	206
7.5	Motion Control and General Plant Automation	213
8	Case Studies in Instrumentation Systems	217
8.1	The LXI Specification	220
8.1.1	LXI Device Synchronization and LAN-based Triggering	220
8.1.2	Module-to-module Data Communication	222
8.2	LXI Module Design and System Programming Practices	222
8.3	LXI System Debugging	233
8.4	Data Acquisition Applications Using LXI	234
8.5	General Applications Using LXI	237
8.5.1	Characteristics of Future LXI-based Test Systems	237
8.5.2	Integration of LXI-based Test Equipment with VXI and PXI Equipment	238
8.5.3	Examples of Future LXI-based Test Systems	239

9	Case Studies in Communications	243
9.1	Background on the Application of IEEE 1588 in Telecommunications Systems.....	243
9.2	Proposed Telecommunications Applications Using IEEE 1588 ..	245
9.2.1	Wireless Networks	246
9.2.2	Linking SONET Rings via Ethernet	248
9.2.3	Timing in Cable TV Infrastructure	249
9.2.4	Timing Distribution in Central Offices	250
9.2.5	Circuit Emulation	251
9.2.6	Internal Timing in Telecommunications Equipment	252
9.3	Proposed Techniques to Enable IEEE 1588 in Telecommunications	252
9.3.1	Asymmetry	252
9.3.2	Latency Fluctuations	253
9.3.3	IEEE 1588 Timing Redundancy	254
9.4	Early Measurements of IEEE 1588 Operating on Metropolitan Networks	255
10	The Future of IEEE 1588 and Time-based Applications ...	261
10.1	Specific Concerns and Likely Outcomes	261
10.2	What Will the Future Bring?	263
10.3	Final Thoughts.....	263
<hr/>		
Part IV Appendices		
<hr/>		
A	Field Definitions for IEEE 1588 Messages	267
A.1	Message Fields Common to All PTP Messages	267
A.2	Sync and Delay_Req Message Fields	268
A.3	Follow_Up Message Fields	268
A.4	Delay_Resp Message Fields	269
A.5	Management Message Fields	269
B	IEEE 1588 Data Sets	271
B.1	Default Data Set	271
B.2	Current Data Set	271
B.3	Parent Data Set	271
B.4	Global Time Properties Data Set	272
B.5	Port Configuration Properties Data Set	272
B.6	Foreign Master Data Set	274
References		275
Index		281