

---

## Contents

---

<b>PREFACE . . . . .</b>	<b>xi</b>
<b>LIST OF FIGURES . . . . .</b>	<b>xv</b>
<b>LIST OF TABLES . . . . .</b>	<b>xix</b>
<b>CHAPTER 1. SCHEDULING IN ENERGY</b>	
<b>AUTONOMOUS OBJECTS . . . . .</b>	<b>1</b>
Maryline CHETTO	
1.1. Introduction . . . . .	2
1.2. Modeling and terminology . . . . .	5
1.2.1. System model . . . . .	5
1.2.2. Types of starvation. . . . .	7
1.2.3. Terminology . . . . .	8
1.3. Weaknesses of classical schedulers . . . . .	9
1.3.1. Scheduling by EDF . . . . .	9
1.3.2. ASAP strategy . . . . .	11
1.3.3. ALAP strategy . . . . .	11
1.4. Fundamental properties . . . . .	13
1.5. Concepts related to energy . . . . .	15
1.5.1. Processor demand . . . . .	15
1.5.2. Energy demand . . . . .	16

1.6. ED-H scheduling . . . . .	18
1.6.1. Informal description . . . . .	18
1.6.2. Rules of ED-H . . . . .	19
1.6.3. Optimality analysis . . . . .	21
1.6.4. Clairvoyance analysis . . . . .	23
1.6.5. Schedulability test . . . . .	23
1.7. Conclusion . . . . .	24
1.8. Bibliography . . . . .	25
<b>CHAPTER 2. PROBABILISTIC SCHEDULING . . . . .</b>	<b>29</b>
Liliana CUCU-GROSJEAN, Adriana GOGONEL and Dorin MAXIM	
2.1. Introduction . . . . .	30
2.2. Notations and definitions . . . . .	33
2.3. Modeling a probabilistic real-time system . . . . .	34
2.4. Imposed properties . . . . .	36
2.5. Worst-case probabilistic models . . . . .	37
2.5.1. Real-time systems with probabilistic arrivals . . . . .	38
2.5.2. Comparison of the two models . . . . .	38
2.6. Probabilistic real-time scheduling . . . . .	40
2.7. Probabilistic schedulability analysis . . . . .	43
2.8. Classification of the main existing results . . . . .	45
2.9. Bibliography . . . . .	47
<b>CHAPTER 3. CONTROL AND SCHEDULING</b>	
<b>JOINT DESIGN . . . . .</b>	<b>53</b>
Daniel SIMON, Ye-Qiong SONG and Olivier SENAME	
3.1. Control objectives and models . . . . .	54
3.1.1. Closed loop control . . . . .	55
3.1.2. Control and temporal parameters . . . . .	57
3.2. Scheduling of control loops . . . . .	61
3.2.1. Robustness and relaxation of hard real-time constraints . . . . .	64

---

3.3. Continuous approach: regulated scheduling . . . . .	68
3.3.1. Architecture, sensors and actuators . . . . .	68
3.3.2. Sensors . . . . .	70
3.3.3. Actuators . . . . .	71
3.3.4. Control laws . . . . .	73
3.4. Discrete approach: scheduling under the (m,k)-firm constraint . . . . .	75
3.4.1. (m,k)-firm model . . . . .	76
3.4.2. Scheduling under the (m,k)-firm constraint . . . . .	78
3.4.3. Regulated (m,k)-firm scheduling . . . . .	80
3.5. Case study: regulated scheduling of a video decoder . . . . .	83
3.6. Conclusion . . . . .	90
3.7. Bibliography . . . . .	91

**CHAPTER 4. SYNCHRONOUS APPROACH AND  
SCHEDULING . . . . .** 97  
Yves SOREL and Dumitru POTOP-BUTUCARU

4.1. Introduction . . . . .	97
4.2. Classification . . . . .	103
4.2.1. Synchronous languages . . . . .	103
4.2.2. Related languages . . . . .	109
4.3. Synchronous languages . . . . .	110
4.3.1. SIGNAL . . . . .	110
4.3.2. LUSTRE . . . . .	121
4.3.3. ESTEREL . . . . .	125
4.4. Scheduling with synchronous languages . . . . .	127
4.5. Synchronous languages extended to perform scheduling . . . . .	132
4.5.1. LUSTRE . . . . .	132
4.5.2. PRELUDE . . . . .	133
4.5.3. SYNDEX . . . . .	136
4.5.4. TAXYS . . . . .	142

4.5.5. PSIC, Embedded Code and Network Code . . . . .	143
4.6. Conclusion . . . . .	145
4.7. Bibliography. . . . .	145

**CHAPTER 5. INDUCTIVE APPROACHES FOR PACKET SCHEDULING IN COMMUNICATION NETWORKS** 151  
Malika BOURENANE and Abdelhamid MELLOUK

5.1. Introduction . . . . .	151
5.2. Scheduling problem. . . . .	156
5.3. Approaches for real-time scheduling. . . . .	158
5.3.1. The strict priority . . . . .	158
5.3.2. The Generalized processor sharing paradigm . . . . .	159
5.3.3. The packet-by-packet generalized processor sharing (PGPS) scheduler . . . . .	160
5.3.4. Earliest deadline first. . . . .	160
5.3.5. Adaptive scheduling. . . . .	161
5.4. Basic concepts . . . . .	165
5.4.1. Monoagent learning . . . . .	165
5.4.2. Multi-agent reinforcement learning . . . . .	171
5.5. Proposed model. . . . .	175
5.6. Q-learning with approximation . . . . .	179
5.7. Conclusion . . . . .	188
5.8. Acknowledgment . . . . .	189
5.9. Bibliography. . . . .	189

**CHAPTER 6. SCHEDULING IN NETWORKS** . . . . . 195  
Ye-Qiong SONG

6.1. Introduction . . . . .	195
6.2. The CAN protocol . . . . .	199
6.3. Example of an automotive embedded application distributed around a CAN network . . . . .	204

---

6.4. Response time analysis of CAN messages . . . . .	206
6.4.1. Worst-case response time analysis method . . . . .	207
6.4.2. Method of computing the response time bounds . . . . .	210
6.4.3. Application to CAN messaging . . . . .	212
6.5. Conclusion and discussion . . . . .	213
6.6. Bibliography. . . . .	215
<b>CHAPTER 7. FOCUS ON AVIONICS NETWORKS . . . . .</b>	<b>217</b>
Jean-Luc SCHARBARG and Christian FRABOUL	
7.1. Introduction . . . . .	217
7.2. Avionics network architectures. . . . .	219
7.2.1. Historical evolution . . . . .	219
7.2.2. The AFDX network . . . . .	221
7.3. Temporal analysis of an AFDX network . . . . .	222
7.4. Properties of a worst-case scenario . . . . .	223
7.5. Calculating an upper bound of the delay . . . . .	230
7.5.1. An upper bound on the delay by network calculus . . . . .	230
7.5.2. An upper bound on the delay by the trajectory method . . . . .	235
7.6. Results on an embedded avionic configuration . . . . .	239
7.7. Conclusion . . . . .	242
7.8. Bibliography. . . . .	244
<b>LIST OF AUTHORS. . . . .</b>	<b>247</b>
<b>INDEX . . . . .</b>	<b>249</b>
<b>SUMMARY OF VOLUME 1 . . . . .</b>	<b>251</b>