## **Contents**

Co	ontent	S		IX
Li	st of T	lables		ХШ
Li	st of I	igures		XV
Li	st of A	Abbrevi	ations	XXI
Li	st of S	Symbols	5	XXV
1	Intr	oductio	n	. 1
	1.1	Logist	ics	. 1
	1.2	Wirele	ess Sensor Networks in Logistics	. 1
	1.3	Logist	ical Requirements of Wireless Sensor Networks	. 3
	1.4	Servic	es in Wireless Sensor Networks	. 4
	1.5	Object	tive	. 5
	1.6	Applic	cation Scenarios	. 8
	1.7		butions of this Thesis	
	1.8	Overv	iew	. 10
2	Stat	e of the	Art	13
	2.1	Wirele	ess Sensor Networks	. 13
		2.1.1	Organisations and Standardisation Bodies	. 14
		2.1.2	Marketing Alliances	. 24
		2.1.3	Research Community	. 24
		2.1.4	Commercial Companies	. 25
	2.2	Servic	e Discovery	
		2.2.1	Service discovery protocols in Internet Protocol network	
		2.2.2	Service frameworks in WSN	
	2.3	Trickle	e Algorithm	
		2.3.1	Trickle Variables	
		2.3.2	Trickle Constants	. 34
		2.3.3	Trickle Rules	. 34

		2.3.4	Trickle Applicability	35			
3	Serv	Service Distribution Algorithms					
	3.1	Requir	rements of a Service Distribution Algorithm	37			
	3.2	_	ng	37			
	3.3		Interval Pushing	38			
	3.4		Inteval Pushing with Vanish Support	38			
	3.5		B	39			
	3.6		e with Vanish Support	39			
	3.7		thm Comparison	40			
4	Wir	Wireless Sensor Services Network Framework 4					
	4.1	Servic	e Layer Software Components	45			
	4.2	Servic	e Frame Format	47			
	4.3	Servic	e Forwarding in the Wireless Sensor Network	49			
	4.4	Interne	et Host Service Application	50			
5	Eva	luation	Metrics and Scenarios	51			
	5.1	Evalua	ation Metrics	51			
		5.1.1	Number of Packets Sent	51			
		5.1.2	Energy Spent	52			
		5.1.3	Time to Consistency	52			
		5.1.4	Scalability with the Number of Nodes	52			
		5.1.5	Scalability with the Number of Services	52			
	5.2	Scenar	rios	52			
		5.2.1	Line Scenario	53			
			5.2.1.1 Only Direct Neighbours	53			
			5.2.1.2 Neighbours According to Propagation Model	53			
		5.2.2	Grid Scenario	53			
		5.2.3	Random Scenario	53			
		5.2.4	Container Scenario	54			
6	Sim	Simulation of Service Discovery					
	6.1	1 Simulation Environment					
	6.2	Simulation Evaluation					
	6.3						
		6.3.1	Statistical Significance	60			
		6.3.2	Uniform Spatial Distribution of Sent Packets	63			
		6.3.3	Results for Grid and Random Scenarios	64			

Contents XI

		6.3.4	Trickle Parameter Analysis	64
		6.3.5	95 Percentiles and Application Requirement Optimisation	66
		6.3.6	Trickle and Push Comparison	67
		6.3.7	Service Vanish Comparison	69
		6.3.8	Routing Protocol Simulation Results	70
7	Anal	ytical N	Modelling of Service Discovery	75
	7.1	Model	s for the Service Distribution	75
		7.1.1	Analytical Model for the Time to Consistency	75
			7.1.1.1 Base Distributions $f_{h,c,a}(t)$	77
			7.1.1.2 Relative Frequency $p_{h,c,a}(t)$	86
		7.1.2	Analytical Model for the Number of Packets Sent	87
8	Mea	sureme	nts of Service Discovery in Wireless Sensor Networks	93
	8.1	Measu	rement Setup	93
		8.1.1	Link Assessment Measurements	94
	8.2	Measu	rement Results	100
9	Eval	uation		101
	9.1	Compa	•	101
		9.1.1		102
		9.1.2	Mean Number of Sent Packets	118
			9.1.2.1 Mean Number of Packets: Varying K, N=4, Line	118
			9.1.2.2 Mean Number of Packets: Varying K, N=64, Line	122
			9.1.2.3 Mean Number of Packets: Varying N, K=1, Line	124
			9.1.2.4 Mean Number of Packets: Varying N, K=3, Line	126
			9.1.2.5 Mean Number of Packets: Line/Grid, N=4, K=3	128
			9.1.2.6 Mean Number of Packets: Line/Grid, N=64, K=3	131
			9.1.2.7 Mean Number of Packets: Line/Grid, N=225, K=3	133
		9.1.3	Runtime behaviour	135
	9.2	Compa	arison of Measurement Results with Simulations and Ana-	
		lytical	Model	135
		9.2.1	Delay	136
		9.2.2	Mean Number of Sent Packets	140
10				141
	10.1	Conclu	usions	141
	10.2	Outloo	ok	143
A	Othe	er cont	ributions to communication networks research	145

XΠ	Contents

В	The Minimum of Several Random Variables	147
C	The Kaplan-Meier Estimator	149
D	Simulated PRR Topologies (Line-CPM)	151
E	Simulated PRR Topologies (Grid-CPM)	155
F	Radio Models	159
	F.1 Signal Attenuation Model	159
	F.2 Packet Reception Ratio Model	
G	Approximating Step-Wise Linear Model	161
	G.1 Approximating Linear Model for Line Scenarios	161
	G.2 Approximating Linear Model for Grid Scenarios	161
Bi	diography	163