

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	x
	LIST OF FIGURES	xi
	LIST OF SYMBOLS	xiv
	LIST OF ABBREVIATIONS	xv
	LIST OF APPENDICES	xvii
1	INTRODUCTION	
	1.1 Background	1
	1.2 Problem Statement	2
	1.3 The Objectives	4
	1.4 Scope of the Work	4
	1.5 Significance of the Study	5
	1.6 Contributions of the Thesis	5
	1.7 Research Outline	6

2	LITERATURE REVIEW	
	2.1 Introduction	7
	2.2 Types of Routing Protocol in WSN	8
	2.3 IEEE 802.15.4 Specification	10
	2.3.1 Physical Layer	12
	2.3.2 Medium Access Control (MAC) Layer	14
	2.4 Overview of WUSN	17
	2.4.1 Tunnel Environment	18
	2.4.2 Challenges in TWSN	19
	2.4.3 Application in TWSN	20
	2.5 Related Research Work	20
	2.5.1 The Nonuniform Clustering Routing Protocol	21
	2.5.2 Frequency Diversity (FD) Technique	21
	2.5.3 Bounce Routing in Tunnels (BRIT)	22
	2.5.4 Reviews on Real Time Load Distribution (RTLTD) Protocol	23
	2.5.5 Comparison The Related Works with The Proposed Work	24
	2.6 Biological Inspired Techniques	25
	2.7 Ant Colony Optimization (ACO)	26
	2.6.1 Method of Finding Food in Ant Colony	27
	2.6.2 Rules and Conditions	32
	2.8 Summary	33
3	RESEARCH METHODOLOGY	
	3.1 Introduction	34
	3.2 Structure of TunyOS 1.x	37
	3.2.1 The Value of RSSI and LQI	38
	3.3 System Design of Biological Tunnel Routing Protocol (BIOTROP)	40
	3.4 Cross Layer Design in BIOTROP	42
	3.5 Structures of BIOTROP	43

3.5.1	Routing Management Module	44
3.5.1.1	Optimal Forwarding Calculation	47
3.5.1.2	Unicast Forwarding Mechanism	53
3.5.1.3	Routing Problem Handler	54
3.5.1.4	ACO Routing Process	56
3.5.2	Neighbourhood Management Module	60
3.6	Experiment Test Bed	62
3.6.1	Hardware Component	62
3.6.2	Software Component	66
3.7	Summary	71
4	RESULT AND ANALYSIS	
4.1	Introduction	72
4.2	Programming Codes Size	74
4.3	The Result's Interface	75
4.4	Discussion on Experiment 1 at TWSN testbed	77
4.5	Discussion on Experiment 2 at TWSN testbed	80
4.6	Comparison between Experiment 1 and 2 Setup at TWSN testbed	84
4.7	Free-space Condition	86
4.8	Comparison between Tunnel Environment and Free-space Condition	88
4.9	Summary	97
5	CONCLUSIONS AND RECOMMENDATIONS	
5.1	Conclusions	99
5.2	Recommended Future Works	101
	REFERENCES	102
	Appendices A – C	106-120

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	The Comparison of ZigBee with Two Others IEEE 802 Standards	11
2.2	Physical layer description in IEEE 802.15.4	13
2.3	Comparison between the previous works and BIOTROP	25
2.4	Simple Rule of Ant Approach	32
3.1	Overall design of experimentation	35
4.1	Comparison of code size	74
4.2	The value of PDR (%) at -25 dBm power transmission	77
4.3	The value of PDropR (%) at -25 dBm power transmission	78
4.4	The value of PRR at -25 dBm power transmission	79
4.5	The value of PDR (%) at -15 dBm power transmission	81
4.6	The value of PDropR (%) at -15 dBm power transmission	82
4.7	The value of PRR at -15 dBm power transmission	83
4.8	The value of PRR at -25 dBm power transmission in free-space	87
4.9	The value of PRR at -15 dBm power transmission in free-space	88
4.10	The value of PRR for node 1	89
4.11	The value of PRR for node 2	91
4.12	The value of PRR for node 3	92
4.13	The value of PRR for node 4	94
4.14	The value of PRR for node 5	95
4.15	The value of PRR for node 6	97

LIST OF FIGURES

FIGURES NO.	TITLE	PAGE
2.1	Routing protocols in WSNs	8
2.2	Routing topologies of (a) flat, (b) hierarchical and (c) location-based	9
2.3	Wireless Network Groups	10
2.4	IEEE 802.15.4 star and peer-to-peer	12
2.5	Operating frequency bands in IEEE 802.15.4	13
2.6	IEEE 802.15.4 operational modes	14
2.7	The super-frame structure without GTSs	16
2.8	The super-frame structure with GTSs	16
2.9	Overview of WUSN architectures	17
2.10	Topology of TWSN with nonuniform clustering	21
2.11	Top view of the measurement geometry of FD technique	22
2.12	RTLTD routing protocol architecture	24
2.13	Detail Category of ACO in Routing Protocol	27
2.14	Four ants wander to get the food	28
2.15	Ant A reach the nest and laying down more pheromone	29
2.16	Two trail created by ant A and ant B	29
2.17	Each ant act with different role at this stage	30
2.18	All ants select the shortest path	30
3.1	The overall research process	36
3.2	Packet format of the LQI and RSSI	39
3.3	Proposed BIOTROP design approach	41
3.4	Cross-layer concepts in BIOTROP	42

3.5	Functional Components of BIOTROP	43
3.6	State Machine Diagram of BIOTROP	44
3.7	Routing management functional module	45
3.8	State Machine Diagram of Routing Management Module	45
3.9	The programming codes of PRR	50
3.10	Method to get <i>strength</i> value in PRR calculation	51
3.11	Method to get <i>lqi</i> value in LQI calculation	52
3.12	The programming codes of LQI calculation	52
3.13	The programming codes of battery voltage calculation	53
3.14	Node 6 meets its route to destination by Forward Ant agent	54
3.15	Base station fail to reply Backward Ant with same route to Node 6	55
3.16	Node 6 broadcast again RTR message when not receives Backward Ant	55
3.17	Visualization of Ant Agent structure	56
3.18	Forward Ant agent process	58
3.19	Backward Ant reads the table inversely	59
3.20	Data Ant sends data with same route recorded in the table	59
3.21	Neighbour table format	60
3.22	State Machine Diagram of Neighbourhood Management Module	61
3.23	TelosB block diagram	63
3.24	Front view of culvert	64
3.25	The side view of experiment setup	64
3.26	The base component for each node	65
3.27	The location of node 1, node 3 and node 5 at right edge of the tunnel	65
3.28	The location of node 2, node 4 and node 6 at left edge of the tunnel	66
3.29	Components of the <i>SurgeTelos</i> application	67
3.30	Components of the <i>SurgeTelosRTL</i> D application	67

3.31	Components of the proposed application	68
3.32	<i>Surge</i> application interface	70
4.1	The experiment setup in TWSN and free-space testbed	73
4.2	The <i>Surge</i> application interface for 2 meter in experiment 1 at (a) $t=0$ s and (b) $t=300$ s	76
4.3	Packet Delivery Ratio (PDR) at -25 dBm power transmission	77
4.4	Packets Dropped Ratio (PDR) at -25 dBm power transmission	78
4.5	Packets Received Rate (PRR) at -25 dBm power transmission	79
4.6	Packet Delivery Ratio (PDR) at -15 dBm power transmission	81
4.7	Packet Dropped Ratio (PDR) at -15 dBm power transmission	82
4.8	Packets Received Rate (PRR) at -15 dBm power transmission	83
4.9	The PRR in free-space condition at -25 dBm power transmission	86
4.10	The PRR in free-space condition at -15 dBm power transmission	87
4.11	The PRR of node 1 at two different areas with (a) -25 dBm and (b) -15 dBm power transmission	89
4.12	The PRR of node 2 at two different areas with (a) -25 dBm and (b) -15 dBm power transmission	90
4.13	The PRR of node 3 at two different areas with (a) -25 dBm and (b) -15 dBm power transmission	92
4.14	The PRR of node 4 at two different areas with (a) -25 dBm and (b) -15 dBm power transmission	93
4.15	The PRR of node 5 at two different areas with (a) -25 dBm and (b) -15 dBm power transmission	95
4.16	The PRR of node 6 at two different areas with (a) -25 dBm and (b) -15 dBm power transmission	96

LIST OF SYMBOLS

V_{mbatt}	-	Maximum battery volt
V_{m}	-	Maximum velocity
V_{batt}	-	Battery voltage
V_{ref}	-	Internal voltage reference

LIST OF ABBREVIATIONS

WSN	-	Wireless Sensor Network
WUSN	-	Wireless Underground Sensor Network
TWSN	-	Tunnel Wireless Sensor Network
EM	-	Electromagnetic
ACO	-	Ant Colony Optimization
RTLD	-	Real-time Routing Protocol with Load Distribution
FFD	-	Full Function Device
RFD	-	Reduce Function Device
BIOTROP	-	Biological of Tunnel Routing Protocol
QoS	-	Quality of Service
BS	-	Base Station
CH	-	Cluster Head
WPAN	-	Wireless Personal Area Network
PAN	-	Personal Area Network
LMSC	-	Local and Metropolitan Area Network Standards Committee
LoWPAN	-	Low-rate Wireless Personal Area Network
PHY	-	Physical
MAC	-	Medium Access Control
ISM	-	Industrial Scientific Medical
DSSS	-	Direct Sequence Spread Spectrum
CSMA/CA	-	Carrier Sense Multiple Access / Contention Avoidance
RTS	-	Request-to-send
CTS	-	Clear-to-send
CAP	-	Contention Access Period

CFP	-	Contention Free Period
GTSs	-	Guaranteed Time Slot
MI	-	Magnetic Induction
FD	-	Frequency Diversity
AODV	-	Ad hoc On-Demand Distance Vector
BRIT	-	Bounce Routing in Tunnel
RREQ	-	Route Request
RREP	-	Route Reply
PRR	-	Packet Reception Rate
RSSI	-	Received Signal Strength Indicator
LQI	-	Link Quality Indicator
SFD	-	Starts of Frame Delimiter
RTR	-	Request To Reply
FA	-	Forward Ant
BA	-	Backward Ant
DA	-	Data Ant
OF	-	Optimal Forwarding
SNR	-	Signal to Noise Ratio
ITI	-	Industrial Training Institute
PDR	-	Packet Delivery Ratio
PDropR	-	Packets Dropped Ratio
O-QPSK	-	Offset – Quadrature Phase Shift Keying
DSR	-	The Dynamic Source Routing Protocol for Mobile Ad Hoc Networks

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Datasheet of TelosB Mote Platform and CC2420 Transceiver	106
B	Source Code of BIOTROP	108
C	Screen Shot of TinyOS 1.x Result at TWSN Testbed	114