

**IMPROVE ENERGY EFFICIENCY IN
COOPERATIVE MEDIUM ACCESS CONTROL
PROTOCOL FOR WIRELESS NETWORKS**

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CONTROL PROTOCOL FOR WIRELESS NETWORKS**

by

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TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENT	ii
TABLE OF CONTENTS	iv
LIST OF TABLES	ix
LIST OF FIGURES	x
LIST OF ABBREVIATIONS	xiv
LIST OF SYMBOLS	xviii
ABSTRAK	xxiv
ABSTRACT	xxvi
CHAPTER ONE: INTRODUCTION	
1.1 Problem Statement	4
1.2 Research Objectives	6
1.3 Scope of Work	7
1.4 Outline of the Thesis	8
CHAPTER TWO: LITERATURE REVIEW	
2.1 Wireless Ad-hoc Networks	10
2.1.1 Cooperative Communications	12
2.1.1(a) Amplify-and-Forward Relaying	13
2.1.1(b) Decode-and-Forward Relaying	13
2.1.1(c) Coded Cooperation	14
2.1.2 Energy Harvesting in Cooperative Networks	14
2.1.2(a) Time Switching Scheme	15
2.1.2(b) Power Splitting Scheme	18

2.1.3	Energy-Efficiency Techniques/Methods in Wireless Networks	21
2.1.3(a)	Outage Probability QoS Requirement Technique	21
2.1.3(b)	Outage Probability Optimization Technique	22
2.1.3(c)	Transmission Power Optimization Technique	23
2.1.3(d)	Network Lifetime Optimization Technique	24
2.1.3(e)	Energy Efficiency Optimization Technique	25
2.1.4	MAC Protocol for Cooperative Network	26
2.1.4(a)	Legacy 802.11 MAC Protocol	26
2.1.4(b)	Classification of C-MAC Protocols	27
2.2	Review of Related Works	31
2.2.1	Fundamental Design, Implementation and Challenges	31
2.2.1(a)	Resource Allocation	37
2.2.1(b)	Power Control and Energy issues	38
2.2.1(c)	Relay Selection	41
2.2.1(d)	Node Density and Mobility	43
2.2.1(e)	Spatial Frequency Reuse	44
2.2.1(f)	Multiple-Objective Target Orientation	45
2.2.2	Review of Existing C-MAC Protocols	46
2.2.3	Summary	57
 CHAPTER THREE: NETWORK LIFETIME-AWARE COOPERATIVE MAC PROTOCOL FOR WIRELESS AD-HOC NETWORKS		
3.1	Introduction	59
3.2	Proposed LEA-CMAC Protocol	60
3.2.1	Network Model	61
3.2.2	Protocol Description	63
3.2.2(a)	Frame Structure of LEA-CMAC Protocol	64

3.2.2(b)	Operations at the Source Node	66
3.2.2(c)	Operations at the Relay Node	69
3.2.2(d)	Operations at the Destination Node	72
3.3	Relay Selection Backoff Scheme	74
3.4	Proposed Network Lifetime and Energy Model	75
3.5	Network Lifetime Optimization Analysis	77
3.5.1	Formulation of the Network Lifetime Optimization Problem	78
3.5.2	Solution to the Formulated Optimization Problem	80
3.5.2(a)	Solution using Symmetric Policy	81
3.5.2(b)	Solution using Asymmetric Policy	82
3.5.2(c)	Algorithm for the Optimized Transmit Power of the Proposed LEA-CMAC Protocol	82
3.6	Performance Analysis	86
3.6.1	Cooperative Region Analysis	86
3.6.2	Saturation Throughput	89
3.7	Results and Discussion	90
3.8	Summary	105
 CHAPTER FOUR: ENERGY HARVESTING COOPERATIVE MAC PROTOCOL FOR WIRELESS AD-HOC NETWORKS		
4.1	Introduction	107
4.2	Proposed EH-CMAC Protocol	109
4.2.1	Network Model	109
4.2.2	Wireless Energy Harvesting Mechanism	111
4.2.3	Proposed EH-CMAC Protocol Description	112
4.2.3(a)	Direct Transmission Mode	113
4.2.3(b)	Cooperative Transmission Mode	114
4.2.3(c)	EH-enabled Cooperative Transmission Mode	114

4.2.3(d)	Source Node Operation	115
4.2.3(e)	Relay Node Operation	118
4.2.3(f)	Destination Node Operation	121
4.3	Relay Selection Backoff Scheme	122
4.4	Power Allocation Analysis	124
4.4.1	Outage Probability QoS Requirement Analysis	124
4.4.1(a)	Cooperative Transmission with Outage Probability QoS Requirement	120
4.4.1(b)	EH-enabled Cooperative Transmission with Outage Probability QoS Requirement	121
4.4.2	Transmit Power Optimization Analysis	128
4.4.2(a)	Cooperative Transmission with Transmit Power Optimization	124
4.4.2(b)	EH-enabled Cooperative Transmission with Transmit Power Optimization	125
4.4.3	Algorithm of the Optimized Power Allocation for the Proposed EH-CMAC Protocol	127
4.5	Performance Analysis	133
4.5.1	Proposed 3-D Markov Chain Model	133
4.5.2	Throughput Analysis	138
4.6	Results and Discussion	139
4.6.1	Performance with Outage Probability QoS Requirement Technique	141
4.6.2	Performance with Optimization Technique	154
4.7	Summary	165
CHAPTER FIVE: CONCLUSION AND FUTURE WORK		
5.1	Summary of Thesis Contributions	168
5.2	Future Work	169
REFERENCES		171

APPENDICES

Appendix A: Derivation of the Power Allocation for the LEA-CMAC Protocol

Appendix B: Derivation of the Power Allocation for the EH-CMAC Protocol

LIST OF PUBLICATIONS

LIST OF TABLES

	Page
Table 2.1 Summary of CMAC reviews.	33
Table 2.2 CMAC protocols with power adjustment and energy issues.	39
Table 2.3 Relay selection information parameters.	42
Table 2.4 Summary of some existing CMAC protocols	52
Table 3.1 Relationship between data-rate and transmission range (Shamna & Lillykutty, 2017).	86
Table 3.2: Simulation parameters for the network model.	91
Table 3.3 Comparison of the network lifetime of each simulated protocol with the CoopMAC protocol.	104
Table 3.4 Network lifetime performance of the proposed LEA-CMAC protocol.	105
Table 4.1 Simulation parameters for the network model.	140
Table 4.2 Comparison of Transmisson power allocation.	165

LIST OF FIGURES

	Page
Figure 2.1	Cooperative communication wireless network. 12
Figure 2.2	(a) Frame structure and (b) PHY layer mechanism of TS relaying scheme. 16
Figure 2.3	(a) Frame structure and (b) PHY layer mechanism of PS relaying scheme. 19
Figure 2.4	Legacy 802.11 MAC packet transmission (IEEE Standard, 1999). 26
Figure 2.5	(a) Proactive relaying and (b) Reactive relaying method. 30
Figure 2.6	Existing research contributions in target objective orientation for CMAC protocols. 57
Figure 3.1	The flow diagram of the methodology for the proposed LEA-CMAC protocol. 60
Figure 3.2	(a) Network model, (b) relay node optimization policy mechanism for data packet transmission. 61
Figure 3.3	Packet transmission for LEA-CMAC protocol. 63
Figure 3.4	Frame format for (a) RTS, (b) CTS, (c) HRF and (d) MAC Protocol Data Unit header (Shamna & Lillykuty, 2017). 66
Figure 3.5	Flow chart of the source node operations. 68
Figure 3.6	Flow chart of the relay node operations. 71
Figure 3.7	Flow chart of the destination node operations. 73
Figure 3.8	Optimized transmit power allocation for LEA-CMAC protocol. 85
Figure 3.9	Coverage region. 87
Figure 3.10	Throughput against packet length of simulated protocols at $N = 50$. 92
Figure 3.11	Throughput of simulated protocols with a varying number of nodes at $L = 256$ bytes and 1024 bytes. 93
Figure 3.12	E2E delay of simulated protocols with varying number of nodes at $L = 256$ bytes and 1024 bytes. 94
Figure 3.13	Energy consumption of simulated protocols with varying number 95

	of nodes at $L = 1024$ bytes.	
Figure 3.14	Packet delivered of simulated protocols with a varying number of nodes at $L = 1024$ bytes.	96
Figure 3.15	Network lifetime of simulated protocols with a varying number of nodes at $L = 1024$ bytes.	97
Figure 3.16	Energy efficiency of simulated protocols with a varying number of nodes at $L = 1024$ bytes.	98
Figure 3.17	Energy efficiency of simulated protocols with varying packet length at $N = 50$ and 100 .	100
Figure 3.18	Network lifetime of simulated protocols with varying packet length at $N = 50$ and 100 .	100
Figure 3.19	Energy efficiency of simulated protocols with varying packet length at $N = 100$.	102
Figure 3.20	Network lifetime of simulated protocols with varying packet length at $N = 100$.	102
Figure 3.21	Energy efficiency of simulated protocols with varying nodes at $L = 1024$ bytes.	103
Figure 3.22	Network lifetime of simulated protocols with varying nodes at $L = 1024$ bytes.	103
Figure 3.23	Network lifetime of the proposed LEA-CMAC protocols against number of iterations at $N = 50$ and $L = 1024$ bytes.	105
Figure 4.1	The flow diagram of the methodology for the proposed EH-CMAC protocol.	108
Figure 4.2	Network model.	110
Figure 4.3	Block diagram of the network model mechanism.	111
Figure 4.4	PHY Layer EH mechanism of the proposed EH-CMAC protocol at the relay terminal.	111
Figure 4.5	Packet transmission for EH-CMAC protocol.	113
Figure 4.6	Flow chart of the source node.	117
Figure 4.7	Flow chart of the relay node.	120
Figure 4.8	Flow chart of the destination node.	122
Figure 4.9	Power allocation for EH-CMAC protocol utilizing optimization technique.	133

Figure 4.10	3-D Markov chain model for proposed EH-CMAC protocol with the modified part highlighted in the box.	135
Figure 4.11	Transmission power of EH-CMAC protocols against outage probability with EH factors set at $\alpha = 0.3$ for TS-EH-CMAC, $\vartheta = 0.5$ for PS-EH-CMAC and $v = 3$.	142
Figure 4.12	Energy consumption of EH-CMAC protocols against distance with a different value of α , ϑ and $v = 3$.	143
Figure 4.13	Energy efficiency of EH-CMAC protocols against distance with $\alpha = 0.3$, $\vartheta = 0.5$ and $v = 3$ utilizing outage probability QoS technique.	145
Figure 4.14	Energy efficiency of EH-CMAC protocols against path loss factor with $\alpha = 0.3$, $\vartheta = 0.5$ and $d = 200\text{m}$ utilizing outage probability QoS technique.	146
Figure 4.15	Throughput of EH-CMAC protocols with varied number of nodes at $L = 1024$ bytes with $\alpha = 0.3$ and $\vartheta = 0.5$ utilizing outage probability QoS technique.	147
Figure 4.16	E2E delay of EH-CMAC protocols with varied number of nodes at $L = 1024$ bytes with $\alpha = 0.3$ and $\vartheta = 0.5$ utilizing outage probability QoS technique.	148
Figure 4.17	Energy consumption of EH-CMAC protocols with varied number of nodes at $L = 1024$ bytes with $\alpha = 0.3$ and $\vartheta = 0.5$ utilizing outage probability QoS technique.	150
Figure 4.18	Network lifetime of EH-CMAC protocols with varied number of nodes at $L = 1024$ bytes with $\alpha = 0.3$ and $\vartheta = 0.5$ utilizing outage probability QoS technique.	151
Figure 4.19	Energy efficiency of simulated protocols with varying number of nodes $L = 1024$ bytes with $\alpha = 0.3$ and $\vartheta = 0.5$ utilizing outage probability QoS technique.	152
Figure 4.20	Energy efficiency of simulated protocols against packet length with $\alpha = 0.3$ and $\vartheta = 0.5$ utilizing outage probability QoS technique.	153
Figure 4.21	Network lifetime of simulated protocols against packet length with $\alpha = 0.3$ and $\vartheta = 0.5$ utilizing outage probability QoS technique.	154
Figure 4.22	Transmission power of EH-CMAC protocols against number of iterations with $\alpha=0.3$ and $\vartheta=0.5$ utilizing optimization technique.	155
Figure 4.23	Energy consumption of EH-CMAC protocols against distance with $\alpha = 0.3$ and $\vartheta = 0.5$ utilizing optimization technique.	156

Figure 4.24	Energy efficiency of EH-CMAC protocols against distance with $\alpha = 0.3$, $\vartheta = 0.5$ and $v = 3$ utilizing optimization technique.	157
Figure 4.25	Energy efficiency of EH-CMAC protocols against path loss factor with $\alpha = 0.3$, $\vartheta = 0.5$ and $d = 200\text{m}$ utilizing optimization technique.	158
Figure 4.26	Throughput of EH-CMAC protocols with varied number of nodes at $L = 1024$ bytes with $\alpha = 0.3$ and $\vartheta = 0.5$ utilizing optimization technique.	159
Figure 4.27	E2E delay of EH-CMAC protocols with varied number of nodes at $L = 1024$ bytes with $\alpha = 0.3$ and $\vartheta = 0.5$ utilizing optimization technique.	159
Figure 4.28	Energy consumption of EH-CMAC protocols with varied number of nodes at $L = 1024$ bytes with $\alpha = 0.3$ and $\vartheta = 0.5$ utilizing optimization technique.	160
Figure 4.29	Network lifetime of EH-CMAC protocols with varied number of nodes at $L = 1024$ bytes with $\alpha = 0.3$ and $\vartheta = 0.5$ utilizing optimization technique.	161
Figure 4.30	Energy efficiency of EH-CMAC protocols with varied number of nodes at $L = 1024$ bytes with $\alpha = 0.3$ and $\vartheta = 0.5$ utilizing optimization technique.	162
Figure 4.31	Network lifetime of simulated protocols against packet length with $\alpha = 0.3$ and $\vartheta = 0.5$ utilizing optimization technique.	163
Figure 4.32	Energy efficiency of simulated protocols against packet length with $\alpha = 0.3$ and $\vartheta = 0.5$ utilizing optimization technique.	164

LIST OF ABBREVIATIONS

ACK	Acknowledgement
ADC MAC	Adaptive distributed cooperative medium access control protocol
AF	Amplify-and-forward
AI	Artificial intelligence
AWCN	Additive white Gaussian noise
CLMAC	Cross-layer cooperative medium access control protocol
CMAC	Cooperative medium access control protocol
CoopMAC	Cooperative medium access control protocol
CoRe-MAC	Cooperative relaying medium access control protocol
COMAC	Cross-layer cooperative medium access control protocol
CRBAR	Cooperative relay-based rate adaptation protocol
CTS	Clear-to-send packet
CSMA/CA	Carrier sense multiple access/collision avoidance
DCMAC	Distributed cooperative medium access control protocol
DEL-CMAC	Distributed energy-adaptive location-based cooperative medium access control protocol
DF	Decode-and-forward
DIFS	Distributed coordination function inter-frame spacing
DO	Dual objective
DTMC	Discrete-time Markov chain
EAP-CMAC	Energy-aware cross-layer cooperative medium access control protocol
EECO-MAC	Energy-efficient cooperative medium access control protocol
EE-CR	Energy-efficient cooperative relaying protocol

EH	Energy harvesting
EH-CMAC	Energy harvesting cooperative medium access control protocol
EI	Energy information
ETH	Eager-to-help packet
E2E	End-to-end
GC-RS	Group contention-based relay selection
HRF	Helper-ready-to-forward packet
HRTC	Helper-ready-to-cooperate
IEEE	Institute of electrical and electronics engineers
II	Interference indicator
IP	Information processing
KKT	Karush Kuhn-Tucker
LAN	Local area network
LC-MAC	Link utility-based cooperative medium access control protocol
LEA-CMAC	Lifetime extension-aware cooperative medium access control protocol
LETPO	Lifetime extension transmission power optimization
LI	Location information
LQI	Link quality information
MAC	Medium access control layer
MANET	Mobile ad-hoc network
MAPE	Monitor, analyze, plan and execute
MATLAB	MATrix LABoratory
MO	Multiple objective
MIMO	Multiple-input-multiple-output
MRC	Maximum ratio combining

NACK	Negative acknowledgement
NAV	Network allocation vector
NCAC-MAC	Network coding-aware cooperative medium access control protocol
NCCARQ-MAC	Network coding cooperative automatic repeat request medium access control protocol
NCS-CR	Network coding supported-cooperative retransmission
NET	Network layer
P-CR	Pure-cooperative retransmission
PHY	Physical layer
PI	Power information
PNC	Physical network coding
PO-CMAC	Power optimized cooperative medium access control protocol
PO-MAC	Optimized-power cooperative medium access control protocol
PO-PS-CMAC	Power optimized power-splitting energy harvesting cooperative medium access control optimized
PO-TS-CMAC	Power optimized time switching-energy harvesting cooperative medium access control optimized
PS	Power splitting
PS-EH-CMAC	Power-splitting-energy harvesting cooperative medium access control
QoS	Quality-of-service
QSI	Quality of service information
RBAR	Receiver-based rate adaptive protocol
rDCF	Relay-enabled distribution coordination function protocol
REI	Residual energy information
RF	Radio frequency
RRS-MAC	Rapid relay selection cooperative medium access control

RTS	Ready-to-send packet
SA-RS	Splitting algorithm-based relay selection
SIFS	Short inter-frame spacing
SII	Signal interference information
SINR	Signal-interference-noise ratio
SNR	Signal-to-noise ratio
SO	Single objective
TDMA	Time division multiple access
TS	Time switching
TS-EH-CMAC	Time-switching energy harvesting cooperative medium access control protocol
TWT	Two-way relaying
VCS	Virtual carrier sensing
WANET	Wireless ad-hoc network
WLAN	Wireless local area networks
WSN	Wireless sensor network
2rcMAC	Two-relay cooperative medium access control

LIST OF SYMBOLS

α	Time switching ratio
$A_{l_x, l_y}(d)$	The overlap area or cooperative region
$b_{i,j,k}$	The steady-state probability of the 3-D Markov model
$b(t)$	The stochastic process of the residual suspension time k .
β	Unit time
BU_r	The backoff function at the i th relay
C_{S,r_i}	The channel capacity at the i th relaying
$C_{r_i,D}$	The channel capacity at the destination
CW_{min}	The minimum contention window size
δ	Propagation delay
d	The distance between two terminals
d_{S,r_i}	The distance between S and r_i
$d_{r_i,D}$	The distance between r_i and D
D	Destination terminal
D_{RTS}	RTS duration time
D_{CTS}	CTS duration time
D_{HRF}	HRF duration time
D_{HRTC}	HRTC duration time
D_{DATA}	DATA duration time
ε	Step size
ξ	The conditional collision probability
e	The minimum residual energy in the network after cooperation
E_o	The initial energy of all nodes

E_s	The residual energy at the source
E_{r_i}	The residual energy at the i th relay
$E_{r_i}^C$	The estimated energy to be consumed by i th potential relay nodes when cooperating
E_s^D	The estimated energy consumed for direct transmission
$E_{r_i}^C$	The estimated energy to be consumed by the relay node cooperating
E_{min}	The minimum residual energy in the network
$E\{\cdot\}$	The expectation operator
f_x	The fractions of the S to D pairs with direct transmission rates of x Mbps
$Flag_1$	To determine if cooperation is required
$Flag_2$	To select the type of cooperation
h_{S,r_i}	The independently distributed Rayleigh fading channel gain between S and r_i
$h_{r_i,D}$	The independently distributed Rayleigh fading channel gain between r_i and D
$\mathcal{L}\{\cdot\}$	Lagrange function
l_x	Transmission range of x Mbps
L	Packet length
L_H	PHY-MAC header
$\lambda, \mu, z, u, \sigma, \rho$	Lagrange multipliers
m	Maximum retry limit
η	Energy efficiency conversion coefficient
n	Number of iterations
$n_{r_i}(t)$	Additive white Gaussian noise at the i th helper terminal.
$n_{r_i}(t)$	Additive white Gaussian noise at the destination terminal.
N	Number of relays

N_o	Noise power of AWGN channel
ϑ	Power splitting ratio
p_c	The probability of collision in the transmitting nodes
p_e	The probability of transmission error in the transmitting nodes
P	The power factor in PS relaying
P_S	The maximum transmit power at the source terminal for EH
P_t^D	Transmit power for the direct link
P_t^S	Transmit power at the source node
$P_{t\max}$	Fixed transmit power
P_{tr}	The probability that the channel medium is busy
P_s	The probability of successful transmission for each mode
P_e	The probability of unsuccessful transmission due to error in the other node
P_c	The probability of collision transmission in the other node
$P_t^{r_i}$	Transmit power at the i th relay node
$P_{r_i}^{TS}$	Retransmission power at the relaying node for TS relaying
$P_{r_i}^{PS}$	Retransmission power at the i th relaying node for PS relaying
P_{TX}	Processing power at the transmitter
P_{RX}	Receiving power
P_S^{*C}	The optimal transmit power at the source
$P_{r_i}^{*C}$	The optimal transmit power at the i th relaying node
P_{out}	The outage probability of the direct link
P_{out}^{X-EH}	The outage probability for a DF reactive relaying at the destination
$p_{5.5,5.5}(d)$	The probability that a helper terminal located in the coverage area
$P_{5.5,5.5}$	The probability that there exists at least one helper terminal that would support a dual-op transmission with (x, y) Mbps rate

P_S^{DT}	The probability of successful Legacy 802.11 MAC
$P_S^{CoopMAC}$	The probability of successful CoopMAC
$P_S^{PO-CMAC}$	The probability of successful PO-CMAC
$P_S^{TS-EH-CMAC}$	The probability of successful TS-EH-CMAC
$P_S^{PS-EH-CMAC}$	The probability of successful PS-EH-CMAC
$P_S^{PO-TS-CMAC}$	The probability of successful PO-TS-CMAC
$P_S^{PO-PS-CMAC}$	The probability of successful PO-PS-CMAC
r_i	The i th relay terminal
R_{th}	Threshold transmission rate
R	Transmission rate
$R_{S,D}$	Data-rate between source and destination
R_{coop}	Data-rate of the cooperative transmission mode
$R_{X-EH-Coop}$	Data-rate of the EH-enabled cooperative transmission mode
$s(t)$	The stochastic process of the backoff time
S	Source terminal
τ	The stationary packet transmission probability
\mathbb{T}	Saturated throughput
T	Block time
T_{RTS}	The transmission time of the control frames RTS frame
T_{CTS}	The transmission time of the control frames CTS frame
T_{HRF}	The transmission time of the control frames HRF frame
T_{DATA}	The transmission time of the data packet
T_{ACK}	The transmission time of the control frames ACK frame
$T_{\max BO}$	The maximum backoff for the relay nodes
$T_{ACK\ timeout}$	ACK timeout

T_e	Duration of unsuccessful transmission due to error
T_s	The average transmission time
T_x	The average packet transmission time for S to D pairs with a data-rate of x Mbps
$T_{LEA-CMAC\ OH}$	LEA-CMAC overhead
T_{OH}	Legacy 802.11 MAC overhead
T_c	The collision time
\bar{T}_s	The average of the T_s observed by other nodes in the network
\bar{T}_e	The average of the T_e observed by other nodes in the network
\bar{T}_c	The average of the T_c observed by other nodes in the network
T_s^{DT}	The duration of successful Legacy 802.11 MAC
$T_s^{CoopMAC}$	The duration of successful CoopMAC
$T_s^{PO-CMAC}$	The duration of successful PO-CMAC,
$T_s^{TS-EH-CMAC}$	The duration of successful TS-EH-CMAC
$T_s^{PO-TS-CMAC}$	The duration of successful PO-TS-CMAC
$T_s^{PS-EH-CMAC}$	The duration of successful PS-EH-CMAC
$T_s^{PO-PS-CMAC}$	The duration of successful PO-PS-CMAC
$\psi_{r_i}^{TS}$	The harvested energy at the i th relay node for TS
$\psi_{r_i}^{PS}$	The harvested energy at the i th relay node for PS
$u(t)$	The stochastic process of the residual suspension time k
ν	Path-loss exponent
$x(t)$	The normalized information symbol from S , with $E\{ x(t) ^2\} = 1$,
$\hat{x}(t)$	The re-encoded signal
X	The subset of TS and PS
$y_{r_i}(t)$	The received signal at the i th helper terminal

$y_D(t)$	The received signal at the destination terminal
γ_{S,r_i}^{TS}	The instantaneous received SNR at the i th relay nodes for TS relaying
$\gamma_{r_i,D}^{TS}$	The instantaneous received SNR at the destination nodes for TS relaying
γ_{S,r_i}^{PS}	The instantaneous received SNR at the i th relay nodes for PS relaying
$\gamma_{r_i,D}^{PS}$	The instantaneous received SNR at the destination nodes for PS relaying
γ_{th}	Threshold SNR