List of Figures

1.1 Mobile Data Traffic Globally (EB per month) [4]. 1
1.2 D2D communication system. 2
1.3 A two-hop relay-assisted cooperative D2D communication system model. 3
1.4 DAF relay-assisted, two hop cooperative D2D system. 15
1.5 PA-DAF relay-assisted, D2D cooperative wireless communication system. 16
1.6 EH relay-assisted, two hop cooperative D2D system. 17
1.7 Relay-assisted C-SSS systems. 19
1.8 Thesis Organization. 20

2.1 DAF relay-assisted, two-hop cooperative D2D system. 22
2.2 FASER as a function of relay transmit power (Mean channel power gains of all links = 1, ${\sigma_n}^2 = 1$, $\mathcal{K} = 0$ dB, $d_0 = 100$ m, and $d = 150$ m.). 31
2.3 FASER as a function of mean channel power gain ($P_{r_1} = P_{r_2} = 1$ dB, ${\sigma_n}^2 = 1$, $\mathcal{K} = 0$ dB, $d_0 = 100$ m, and $d = 150$ m.). 32
2.4 FASER and its upper bound as a function of relay transmit power (Mean channel power gains of all links = 1, ${\sigma_n}^2 = 1$, $\mathcal{K} = 0$ dB, $d_0 = 100$ m, and $d = 150$ m.). 32
2.5 Average spectral efficiency and its bounds as functions of relay transmit power (Mean channel power gains of all links = 1, ${\sigma_n}^2 = 1$, $\mathcal{K} = 0$ dB, $d_0 = 100$ m, and $d = 150$ m.). 33
2.6 Average energy efficiency and its bounds as functions of relay transmit power (Circuitry Power $P_c = 15$ dBm, Mean channel power gains of all links = 1, ${\sigma_n}^2 = 1$, $\mathcal{K} = 0$ dB, $d_0 = 100$ m, and $d = 150$ m.). 34
2.7 FASER as a function of relay transmit power for ORSP and PRSP (Mean channel power gains of all links = 1, ${\sigma_n}^2 = 1$.). 34

3.1 PA-DAF relay-assisted, D2D cooperative wireless communication system. 36
3.2 FASER as a function of relay transmit power ($P_{\text{th}} = 15$ dB, mean channel power gain = 1, and $\sigma_n^2 = 1$.). 57

3.3 FASER as a function of relay transmit power for higher order modulation scheme and comparison between exact and upper bound plot for the proposed varying $\mathcal{G}_\beta$ case ($P_{\text{th}} = 15$ dB, mean channel power gain $= 1$, and $\sigma_n^2 = 1$.). 58
3.4 FASER versus relay transmit power for different P_{th} values (Mean channel power gain $= 1$, and $\sigma_n^2 = 1$.). 59
3.5 FASER as a function of mean channel power gain ($P_r = 5$ dB, $P_{\text{th}} =$ 15 dB, and $\sigma_n^2 = 1$.). 60
3.6 FASE as a function of relay transmit power (Mean channel power gain $= 1$, and $\sigma_n^2 = 1$.). 60
3.7 FASE as a function of mean channel power gain ($P_r = 5$ dB, $P_{\text{th}} =$ 15 dB, and $\sigma_n^2 = 1$.). 61
3.8 FAEE as a function of relay transmit power ($P_{\text{th}} = 15$ dB, mean channel power gain $= 1$, and $\sigma_n^2 = 1$.). 61
3.9 FAEE as a function of mean channel power gain ($P_r = 5$ dB, $P_{\text{th}} =$ 15 dB, and $\sigma_n^2 = 1$.). 62

4.1 EH multi-relay assisted, green cooperative D2D system model. . . . 64
4.2 Illustrating a timeslot in the time-switching based energy efficient relaying policy. 66
4.3 Rayleigh fading plus path loss model (absence of shadowing): $\overline{\mathcal{EH}}_{\max}$ as a function of mean channel power gain ($\upsilon = 0.4$, $d = 1$ m, $\eta = 0.8$, and $P_s = 0$ dB.). 82
4.4 Outage probability as a function of source transmit power ($\upsilon = 0.4$, $p_0 = 0.2$, $d = 1$ m, $\eta = 0.8$, average channel power gain of all links $=$ 1, $\mathcal{D} = 1$ m, and $\sigma_d = 1$.). 83
4.5 FASE as a function of source transmit power ($\upsilon = 0.4$, $d = 1$ m, $\eta = 0.8$, average channel power gain of all links $= 1$, $\mathcal{D} = 1$ m, $L = 2$, and $\sigma_d = 1$.). 84
4.6 FASE as a function of source transmit power ($\upsilon = 0.4$, $d = 1$ m, $\eta = 0.8$, average channel power gain of all links $= 1$, $\mathcal{D} = 1$ m, $L = 2$, and $\sigma_d = 1$.). 86
4.7 FASE as a function of average channel power gain of $R_{\mathbb{S}} - D$ link ($\upsilon = 0.4$, $d = 1$ m, $\eta = 0.8$, $P_s = 4$ dB, $\mathcal{D} = 1$ m, $L = 2$, and $\sigma_d = 1$.). 87
4.8 FASE as a function of source transmit power for various values of L ($\upsilon = 0.4$, $d = 1$ m, $\eta = 0.8$, average channel power gain of all links $=$ 1, $\mathcal{D} = 1$ m, and $\sigma_d = 1$.). 87

4.9 FAEE as a function of source transmit power ($\upsilon = 0.4$, $d = 1$ m, $\eta = 0.8$, average channel power gain of all links = 1, $P_c = 15$ dBm, $\mathcal{D} = 1$ m, $L = 2$, and $\sigma_d = 1$.). 88
4.10 FAEE as a function of source transmit power ($\upsilon = 0.4$, $d = 1$ m, $\eta = 0.8$, average channel power gain of all links = 1, $P_c = 15$ dBm, $\mathcal{D} = 1$ m, $L = 2$, and $\sigma_d = 1$.). 89
4.11 FAEE as a function of average channel power gain of $R_{\mathbb{S}} - D$ link ($\upsilon = 0.4$, $d = 1$ m, $\eta = 0.8$, $P_s = 4$ dB, $P_c = 15$ dBm, $\mathcal{D} = 1$ m, $L = 2$, and $\sigma_d = 1$.). 89
4.12 FAEE as a function of source transmit power for various values of L ($\upsilon = 0.4$, $d = 1$ m, $\eta = 0.8$, average channel power gain of all links = 1, $P_c = 15$ dBm, $\mathcal{D} = 1$ m, and $\sigma_d = 1$.). 90
4.13 FASE and FAEE as a function of source transmit power ($\upsilon = 0.4$, $d = 1$ m, $\eta = 0.8$, average channel power gain of all links = 1, $P_c = 15$ dBm, $\mathcal{D} = 1$ m, $L = 2$, and $\sigma_d = 1$.). 90

5.1 IC-PA-DAF relay-assisted underlay C-SSS model. 93
5.2 FASE as a function of relay transmit power ($I_{\text{th}} = 10$ dB, mean channel power gain = 1 (for all links), $d = 1$m, $D = 1$m, $\nu = 2.7$, $\sigma_d^2 = 1$, $\sigma_D^2 = 1$). 103
5.3 FASE as a function of mean channel power gain ($I_{\text{th}} = 10$ dB, $P_r = 6$ dB, $d = 1$m, $D = 1$m, $\nu = 2.7$, $\sigma_d^2 = 1$ and $\sigma_D^2 = 1$). 104
5.4 FAEE as a function of relay transmit power ($I_{\text{th}} = 10$ dB, $P_c = 15$ dBm, mean channel power gain = 1 (for all links), $d = 1$m, $D = 1$m, $\nu = 2.7$, $\sigma_d^2 = 1$, $\sigma_D^2 = 1$). 104
5.5 EH based IC-PA-DAF relay-assisted C-SSS. 105
5.6 Illustration of timeslots in TSP. 107
5.7 FASE as a function of source transmit power ($\tau = 0.4$, $d_s = 1$ m, $\eta = 0.8$, average channel power gain of all links = 1, $D_s = 1$ m, $L = 2$, and $\sigma_d = 1$.). 116
5.8 FASE as a function of average channel power gain of $\mathrm{R}_{\mathbb{S}}^{\mathrm{s}} - \mathrm{D}_{\mathrm{Rx}}^{\mathrm{s}}$ link ($\tau = 0.4$, $d_s = 1$ m, $\eta = 0.8$, $P_s = 4$ dB, $D_s = 1$ m, $L = 2$, and $\sigma_d = 1$.). 116
5.9 FASE as a function of source transmit power for various I_{th} value($\tau = 0.4$, $d_s = 1$ m, $\eta = 0.8$, average channel power gain of all links = 1, $D_s = 1$ m, $L = 2$, and $\sigma_d = 1$). 117

5.10 FAEE as a function of source transmit power ($\tau = 0.4$, $d_s = 1$ m, $\eta = 0.8$, average channel power gain of all links = 1, $D_s = 1$ m, $L = 2$, $P_c = 15$ dBm, and $\sigma_d = 1$). 117
5.11 FAEE as a function of average channel power gain of $\mathrm{R}_{\mathbb{S}}^{\mathrm{s}} - \mathrm{D}_{\mathrm{Rx}}^{\mathrm{s}}$ link ($\tau = 0.4$, $d_s = 1$ m, $\eta = 0.8$, average channel power gain of all links = 1, $D_s = 1$ m, $L = 2$, $P_s = 4$ dB, $P_c = 15$ dBm and $\sigma_d = 1$). 118
5.12 FAEE as a function of source transmit power for various L and I_{th} values ($\tau = 0.4$, $d_s = 1$ m, $\eta = 0.8$, average channel power gain of all links = 1, $D_s = 1$ m, $L = 2$, and $\sigma_d = 1$). 118
5.13 FAEE versus FASE trade-off ($\tau = 0.4$, $d_s = 1$ m, $\eta = 0.8$, average channel power gain of all links = 1, $D_s = 1$ m, $P_c = 15$ dBm, $L = 2$, and $\sigma_d = 1$). 119

List of Tables

1.1 Comparison of conventional and hybrid relaying policies. 5

2.1 Cooperative D2D transmission protocol. 24
2.2 Performance comparison of PRSP and ORSP in high SNR regime. . . 35

3.1 Transmission protocol for the cooperative D2D system with PA-DAF relays. Relay selection policy selects the relay i ($i = 1$ or $i = 2$.). . . . 39
3.2 Relay selection criterion in PRSP when frequency-flat Rayleigh fading channels is assumed. 41
3.3 Complexity comparison of the proposed policy with respect to benchmark policy. 54
3.4 Simulation parameters for PA-DAF relay-assisted cooperative D2D communication system. 55

4.1 Simulation parameters for green cooperative D2D communication system. 81

5.1 Simulation parameters for N-EH relay-assisted C-SSS model. 102
5.2 Simulation parameters for EH relay-assisted underlay C-SSS model. . 115

List of Acronyms/Abbreviations

2G	Second Generation
4G	Fourth Generation
5G	Fifth Generation
3GPP	Third Generation Partnership Project
AAF	Amplify-and-Forward
AWGN	Additive White Gaussian Noise
C-SSS	Cooperative Spectrum Sharing System
CRS	Cognitive Radio System
CSI	Channel State Information
D2D	Device-to-Device
DAF	Decode-and-Forward
dB	Decibel unit
EHRS	Energy Harvesting based Relay Selection
EH	Energy Harvesting
EB	Exabyte
FASER	Fading Averaged Symbol Error Rate
FASE	Fading Averaged Spectral Efficiency
FAEE	Fading Averaged Energy Efficiency
IC-PA-DAF	Interference-Constrained Power-Adaptive Decode-and-Forward
i.i.d	Independent and Identical Distribution
LTE	Long Term Evolution
LTE-A	Long Term Evolution Advanced

MIMO	Multi-Input and Multi-Output
mmWave	Millimeter Wave
ML	Maximum Likelihood
MPSK	M-ary Phase Shift Keying
MQAM	M-ary Quadrature Amplitude Modulation
OC-EHRS	Outage-Constrained Energy Harvesting based Relay Selection
ORSP	Opportunistic Relay Selection Policy
PRSP	Probabilistic Relay selection Policy
PA-DAF	Power-Adaptive Decode-and-Forward
PHY	Physical
PU	Primary User
RF	Radio Frequency
RRS	Random Relay Selection
RGF	Relay Gain Function
SWIPT	Simultaneous Wireless Information and Power Transfer
SNR	Signal Power to Noise Power Ratio
SU	Secondary User
SDG	Sustainable Development Goals
TSP	Time-switching Protocol
UE	User Equipment
VLC	Visible Light Communication