Dedicated to

My beloved family

Declaration

I certify that

- The work contained in the thesis is original and has been done by myself under the general supervision of my supervisors.
- The work has not been submitted to any other institute for any degree or diploma.
- I have followed the guidelines provided by Tezpur University in writing the thesis.
- I have conformed to the norms and guidelines given in the Ethical Code of Conduct of the university.
- Whenever I have used materials (data, theoretical analysis, and text) from other sources, I have given due credit to them by citing them in the text of the thesis and giving their details in the references.

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This is to certify that the thesis entitled **"Collaborative Approaches to Overlay Spectrum Sharing in Cognitive Radio Networks"** submitted to Tezpur University in the Department of Computer Science and Engineering under the School of Engineering in partial fulfillment of the award of the degree of Doctor of Philosophy in Computer Science and Engineering is a record of research work carried out by **Meenakshi Sharma** under my supervision and guidance.

All helps received by her from various sources have been duly acknowledged. No part of this thesis has been submitted else where for award of any other degree.

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The Committee recommends for award of the degree of Doctor of Philosophy.

Signature of Principal Supervisor Signature of External Examiner

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Meenakshi Sharma

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Glossary of Terms

5G	Fifth-Generation
3G	Third-Generation
AWGN	Additive White Gaussian Noise
AF	Amplify and Forward
BS	Base Station
bps	bits/second
CCC	Common Control Channel
CR	Cognitive Radio
CRN	Cognitive Radio Network
CSS	Cooperative Spectrum Sharing
CSSC	Cooperative Spectrum Sharing and Communication
CSI	Channel State Information
DF	Decode and Forward
DPS	Dynamic Power Splitting
DSA	Dynamic Spectrum Access
D2D	Device to Device
EE	Energy Efficiency
EH	Energy Harvesting
FCC	Federal Communication Commission
GSM	Global System for Mobile Communication
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
ID	Information decoding
MAC	Medium Access Control
Mb	Megabits
MHz	MegaHertz
MIMO	Multiple Input Multiple Output
M2O	Many-to-One
NP-HARD	Non-Deterministic Polynomially Hard

O2O	One-to-One
O2M	One-to-Many
PU	Primary User
PS	Power Splitting
QoS	Quality of Service
RF	Radio Frequency
SDR	Software Defined Radio
SNR	Signal-to-Noise Ratio
SU	Secondary User
sec	seconds
Avg.	Average
no.	Number
coop.	Cooperative
comm.	Communication
SWIPT	Simultaneous Wireless Information and Power Transfer
TDMA	Time Division Multiple Access
TS	Time Switching
TV	Television
VANET	Vehicular Ad-hoc Network
WRAN	Wireless Regional Area Network

Symbols and Notations

$\mathcal{M}$	Set of PUs
$\mathcal{N}$	Set of SUs
M	Number of primary users
N	Number of secondary users
T	Total access time of PU band
α, β	Time allocation factors
W	Bandwidth of PU band
γ	Bandwidth allocation factor
F	Number of frames in a PU band
P_{PT}	Transmission power of PU
P_{ST}	Transmission power of SU
$h_{PT,ST}$	Channel gain between PT and ST
$h_{ST,PR}$	Channel gain between ST and PR
$h_{PT,PR}$	Channel gain between ST and PR
$DV_{PT,ST}$	Decoding vector used by ST to obtain PT's signal
$EV_{ST,PR}$	Encoding vector used by ST to transmit PT's signal towards PR
$d_{PT,PR}$	Euclidean Distance between PT and PR (in m)
$d_{PT,ST}$	Euclidean Distance between PT and ST (in m)
$d_{ST,PR}$	Euclidean Distance between ST and PR (in m)
$d_{ST,SR}$	Euclidean Distance between ST and SR (in m)
TR_{PT}^{max}	Maximum transmission range of PT (in m)
$SNR_{PT,ST}$	SNR received at ST from PT
$SNR_{ST,PR}$	SNR received at PR from ST
$SNR_{PT,PR}$	SNR received at PR from PT
N_0	Noise power
$\sigma_{N_0}^2$	Noise variance
R_{PT}^{tar}	Targeted transmission rate of PU

RC_{PT}^{tar}	Targeted resource constraint (in terms of time × bandwidth) of PU
RC_{ST}^{max}	Maximum PU resource (in terms of time × bandwidth) used by SU for relaying PU service
RC_{ST}^{rel}	Allotted PU resource (in terms of time × bandwidth) to SU for relaying PU service
RW_{ST}^{min}	Reward constraint (in terms of time × bandwidth) of SU on behalf of relaying PU service
RW_{ST}	Allotted reward (in terms of time × bandwidth) to SU on behalf of relaying PU service
$R_{T_1}^{max}$	Maximum possible decoding rate at ST during T_1 duration
$R_{T_1}^{prop}$	Achieved decoding rate at ST during T_1 duration in proposed scheme.
$EH_{T_1}^{max}$	Maximum possible energy harvesting at ST during T_1 duration
$EH_{T_1}^{prop}$	Achieved harvested energy at ST during T_1 duration in proposed scheme.
HP_{ST}^{prop}	Achieved harvested power at ST in proposed scheme.
$R_{T_2}^{prop}$	Instantaneous achievable rate at PR during T_2 duration in proposed scheme.
$R_{T_3}^{prop}$	Instantaneous achievable rate at SR during T_3 duration in proposed scheme.
TP_{ST}^{ava}	Total power available at ST after energy harvesting.
C_{PT}^{coop}	Cooperative capacity achieved by PU during cooperation with SU
C_{PT}^{direct}	Capacity achieved by PU via direct transmission
EN_{ST}	Energy consumption of SU
ER_{ST}	Expensive rate of SU
C_{ST}	Total capacity achieved by SU during secondary communication
$P_n(\alpha, \beta, \xi)$	Penalty function set by PU for SU
t_{PT}	Tuple of cooperative SUs that prefer PT
PA_{list}	Priority access list
$EH_{T_1}^{prop}$	Achieved harvested energy at ST during T_1 duration through proposed scheme.
$R_{T_1}^{prop}$	Achieved decoding rate at ST during T_1 duration through proposed scheme.

HP_{ST}^{prop}	Achieved harvested power at ST through proposed scheme.
TP_{ST}^{ava}	Total power available at ST after energy harvesting.
U_{PU}	Utility of PU
U_{SU}	Utility of SU
GU_{SU}	Gross Utility of SUs
OU_{SN}	Overall utility of secondary networks
SAT_{ST}	Average satisfaction of SUs
$\%P_{ST}$	Percentage of SUs participated in coop. communication
Th_{ST}^{FI}	Throughput fairness index of SUs
λ	Per frequency transmission power rate of an ST
τ	Energy consumption rate of ST
ϕ	Gain per unit of data transfer achieved at the Maximal Ratio Combining output
ω	Negligible value ≈ 0
δ_{ST}	Amplifying factor at ST
ρ	Power splitting factor
η	Energy conversion efficiency
x, y	Power allocation factors
π	Partition of SUs