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ABSTRACT

Data Communication Networks find their extensive utility in national security, commerce, education sector, social media interactions, voice telephony, Internet usage and multimedia streaming. Further, in recent times there has been an exponential growth in the number of its users and their demands. On the other side, with extensive developments in the field of microelectronics, wireless transmitters and receivers have become very popular and hence increased demand for electromagnetic spectrum usage. Since much of the spectrum has been licensed to wireless networks, spectrum scarcity is an unavoidable consequence. However, a recent survey of licensed networks [1] shows that a large portion of spectrum is underutilized. If only one can have a mechanism to identify the underutilized spectral bands and utilize them effectively, there is a large free electromagnetic spectrum out there for future applications. Cognitive Radio (CR) technology addresses the issues and techniques of utilizing the otherwise underutilized spectral bands and the networks based on cognitive radio concepts are inevitable consequences.

To have efficient communications over cognitive radio based networks, cognitive radios must have low probability of false alarms and missed detections, and they also must avoid interference among themselves and more importantly with the licensed or primary users. In this thesis enhanced spectrum sensing scheme was proposed and incorporated in cognitive cell radio environment for increasing the capacity and to minimize the interference. Conventional spectrum sensing methods have the problem of missed detections and false alarms if there is little variation in the environment. As the secondary user has to sense the spectrum all the time, it has the past spectrum information with it. In the proposed enhanced spectrum sensing with the help of past spectrum information the

decision is made about primary users presence or absence and applied it in different traffic scenarios to check for improved throughput. We also investigated on Hybrid spectrum sharing scheme which will improve the throughput of both primary and secondary users.

To administer cognitive radio network operations, a cognitive cell radio environment is considered. To increase the capacity and to minimize the interference in the network our first contribution [T4], enhanced spectrum sensing was proposed and incorporated. Then, to evaluate the performance of the proposed enhanced spectrum sensing in real world scenarios, easily available spectrum analyser was used for sensing the spectrum. Performance of spectrum sensing was characterised by both accuracy and efficiency, and more importantly the time taken to make a decision and also the complexity involved in doing so. We also proposed a simple detection technique based on a peak excursion threshold. The results show that proposed method works well and is amenable for practical implementation [T6].

In our second contribution, analysis was done on how a mobile Cognitive user can relay the packets with good probability of detection and without causing interference to primary user to benefit the wireless infrastructure. The scenario considered in this work is as follows: The cognitive user who is away from base station has to decide whether to connect to a base station directly or to form a two hop connection via cognitive user relays. Enhanced spectrum sensing which is proposed in our first contribution is used to get ideal vacant bands and two important performance metrics are derived. Investigations were carried out on the probability of establishing a route and the expected duration that a route or connection can be sustained. The results were published in [T7].

In our third contribution, studies were made on the advantage of having collaboration between cognitive enabled small cell network and primary macro-cell. Different from the existing works, at spectrum sensing stage enhanced spectrum sensing is applied to avoid probability of false alarms and missed detections which has impact on spectral efficiency. Later power control optimization for secondary users known as Hybrid spectrum sharing is used for further improvement of spectral efficiency. Furthermore, the failed packets of Primary users are taken care by high ranked relays so as to decrease the average Primary user packet delay by 20% when compared between assisted Secondary user method and non-assisted Secondary user method [T1].

In our fourth contribution, we have applied all the algorithms and studies which we made in our previous contributions in the IoT application and we have developed an efficient routing algorithm for Cognitive radio enabled IoT applications. With the recent emergence and its wide spread applicability, Internet of Things (IoT) is placing pressure on network resources and most importantly on availability of spectrum. Spectrum scarcity is the issue to be addressed in networking within IoT. Equipping the IoT devices with cognitive radio capability will lead to a new dimension called cognitive radio enabled IoT devices. To achieve ON-demand IoT solutions and interference free communications cognitive radio enabled IoT devices will become an effective platform for many applications. The results were published in [T2].

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List of Symbols

$x(n)$	Input signal
$w(n)$	Additive white Gaussian noise (AWGN)
$y(n)$	Received Signal
n	Index for number of samples
N	Number of samples
M	Energy detector output/Decision metric
H_0	Primary user is not present
H_1	Primary user is present
P_D	Probability of detection
P_{md}	Probability of missed detection
P_F/P_{fa}	Probability of False alarms
λ	Threshold
σ^2_w	*Signal Variance*
σ^2_w	*Noise Variance*
$\chi^2{}_2N$	chi square distribution with 2*N* degrees of freedom
$x_*(n)$	Conjugate of input signal
$S(f,\alpha)$	Cyclic spectral density
α	Cyclic frequency
$R_y^\alpha(\tau)$	Cyclic autocorrelation function
$T_i(Y_i)$	Test statistic of ith sensing event
P	Power ratio
R_{ex}	Peak excursion
T_{sw}	Sweep time
R'_{ex}	Threshold
N_{fa}	False alarms
$\overline{R}_s$	Average Signal power ratio
$\overline{R}_n$	Average Noise power ratio
ΔR	Difference of average signal and noise strengths
y_n	n^{th} sample in the spectrum
(r,Θ)	Location Coordinates
Υ_1	SNR of base station
Υ_2	SNR of relay station
T_{2h}	Time required for two hop transmission

T_{ref}	Time required for direct transmission
A	Area of feasible region
L	Length of the perimeter of feasible region
f(k)	Feasible region decision
f '(k)	Derivative of f(k)
ρA	Mean
$\mathbb{E}[\nu]$	Average speed of the CU relays
$\mathbb{E}[\mathcal{M}]$	Average number of relays move out of region / unit time
$\mathbb{E}[N]$	Average number of CU relays in the feasible region
$\mathbb{E}[\tau]$	Average relay sustenance time
$P^{v}_{s,n}$	CSC can transmit with high power
$P^{o}_{s,n}$	CSC can transmit with low power
$R_{v,n}/R_{o,n}$	$R_{v,n}/R_{o,n}$The feasible capacity of sub channel n when sensing outcome is idle and when it is active in small cell
$g_{ss,n}$	Where $g_{ss,n}$ is the channel gain of sub channel *n* between small cell user and Cognitive small cell base station
$g_{ms,n}$	Where $g_{ms,n}$ is the channel gain of sub channel n between macro cell base station and Cognitive small cell base station
${p^0}_{m,n}$	Transmit power of macrocell basestation on sub channel n
p_{av}	Maximum average transmit power of CSC Users
Γ	Maximum average interference power
g and h	Instantaneous channel gains
${\sigma^2}_n/{\sigma^2}_p$	Variance of noise and signal
$L\ (p, \nu, \mu)$	Supremum of lagrangian
$g(\ \nu, \mu)$	Lagrange dual function
λ, μ	Lagrangian multipliers
$\lambda_{i,k}$ and $\mu_{i,k}$	Rate of PU i using k and PU i not using k Respectively
N_0	Thermal Noise
V_k	Transmission rate

B	Channel bandwidth
S	Packet size
TTD_P	Transmission time delay over path P
TSP_P	Delivery success probability

List of Abbreviations

AMM	Alternative Mode Monitoring
AODV	Adhoc on Demand Distance Vector
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BS	Base Station
CAF	Cyclic Autocorrelation Function
CDNs	Cognitive Device Networks
CED	Conventional Energy Detector
CR	Cognitive Radio
CRNs	Cognitive Radio Networks
CSC	Cognitive Small Cell
CSD	Cyclic Spectral Density
CSS	Conventional Spectrum Sensing
CU	Cognitive Users
DSDV	Destination Segmented Distance Vector
EED	Enchanced Energy Detector
ESS	Enhanced Spectrum Sensing
FBSs	Femtocell Base Stations
FCC	Federal Communications Commission
FFT	Fast Fourier Transform
GSM	Global System for Mobile Communication
HMM	Hidden Markov Model
HSS	Hybrid Spectrum Sensing
IMI	Initial Mode Identification
IOT	Internet Of Things
ISM	Industrial Scientific &Medicine
MBS	Macrocell Base Station
MC-MR	Multichannel Multi Radio
MUSIC	Multiple Signal Classification