COMPLETION REPORT

PART - 1

1. Title of the project : *MAC Protocols Design for Cognitive Radio Networks*

2. Implementing Organisation : *Tezpur University, Napaam,Tezpur - 784028, Assam, India*

3. DIT Sanction No. and Date : *No 14 (2)/2012-CC&BT, Dated 08/03/2013*

4 (a) Total Budget Outlay : Original *Rs.72.84 Lakhs only* Revised, if any *N/A*

(b) Duration of project : *2 years; Extended to 3 years*

(c) Date of completion and reasons for delay, if any : *31-03-2016 (Unavailability of technical manpower)*

5. Total funds spent under various approved budgetary Heads/actual expenditure. Reasons for deviation, if any (as per enclosed Table 1) : *Provided in Table 1*

6. Details of equipment/assets acquired out of DIT funds with the name of equipment, sources of supply, total cost/whether Indian or imported (as per enclosed Table 2 and 2A) : *Provided in Table 2*

7. Details of manpower associated with the project (as per enclosed Table 3) : *Provided in Table 3*

8. Details of yearwise audited statement of accounts and utilization certificates submitted to DIT (as per G.F.R.19 & 19A) : *Provided in G.F.R. 19 & 19A*

TABLE : 1 HEADWISE BREAK-UP OF EXPENDITURE
(Rs. In Lakhs)

S. No.	Head	Approved Budget Outlay (Rs. in Lakhs)	Expenditure Incurred Upto - 31-03-2015 (a)	Expenditure From 01-04-2015 To 31-03-2016 (b)	Anticipated Expenditure From ---- To-- (c)	Total (d)	Remarks*
1.	Capital Equipment	30.20	29,63,744	52,319		30,16,063	
2.	Software						
3.	Consumable items/components	2.50	1,36,202	1,13,220		2,49,422	
4.	Manpower	20.00	14,80,554	3,98,000		18,78,554	
5.	Travel/Training	5.00	2,40,344	1,18,676		3,59,020	
6.	Contingencies	3.00	1,32,952	1,66,832		2,99,784	
7.	Overheads/, if any	12.14	7,83,011	4,30,989		12,14,000	

* Please indicate deviation from originally approved budget and whether necessary approval has been taken.
(1) Consumable stores approved budget 3.5 Lakh, and the revised budget is 2.5 Lakh.
(2) Manpower approved budget 18.0 Lakh, and the revised budget is 20.0 Lakh.
(3) Contigencies approved budget 4.0 Lakh, and the revised budget 3.0 Lakh.

(1),(2), & (3) are as per Approval vide letter No. 14(2)/2012-CC&BT dated 26.11.2015.

(a) Upto the end of last Financial Year
(b) From the beginning of current Financial Year till date
(c) For remaining period of current Financial Year
(d) Total of (a)+(b)+(c)

TABLE 1 : HEADWISE BREAK-UP OF EXPENDITURE

S.No	Head	Approved Budget Outlay (Rs. In Lakhs)	Expenditure incurred from 08-03-2013 to 31-03-2014 RE FE Total (Rs.)	Expenditure incurred from 01-04-2014 to 31-03-2015 RE FE Total (Rs.)	Expenditure incurred from 01-04-2015 to 31-03-2016 RE FE Total (Rs.)	BE (Rs.)	Remarks
1.	Capital Equipment (FE Comp) *	30.20	29,63,744	Nil	52,319	3,937	
2.	Consumable items / Components (FE Comp)	2.50	61,000	75,202	1,13,220	578	
3.	Duty on Imports	Nil	Nil	Nil	Nil	Nil	
4.	Man power	20.00	6,78,8,56	8,01,698	3,98,000	1,21,446	
5.	Travel/Training	5.00	1,44,459	95,885	1,18,676	1,40,980	
6.	Contingencies	3.00	66,046	66,906	1,66,832	216	
7.	Overheads, if any	12.14	7,68,051	14,960	4,30,989	Nil	
8.	Other expenditure debitable to this project (please specify)	Nil	Nil	Nil	Nil	Nil	
	Total	72.84	46,82,156	10,54,651	12,80,036	2,67,157	

* FE utilised, over and above sanction made by DIT, through OGL facilities may be indicated separately. Please indicate if there is any deviation from originally approved budget and whether necessary approval has been taken

* Total amount sanctioned is Rs.72.84 Lakhs

* Interest Earned during the period is Rs.90,855/-

10/11/16

Chief Investigator
DeitY Project, Tezpur University

Professor
Department of Computer Science & Engg.
Tezpur University

Registrar
Tezpur University

Registrar
Tezpur University

Finance Officer 10/11/16
Tezpur University

Finance Officer
Tezpur University

For SURAJIT CHAKRABORTY & CO.
CHARTERED ACCOUNTANTS

CA. SURAJIT CHAKRABORTY
(Proprietor)
Membership No.- 305054

TABLE 2 : CAPITAL EQUIPMENT PROCURED FOR THE PROJECT

(Rs. In Lakhs)

Sr. No.	Description	Manufacturer/Supplier	Brief Specification	Purchase Order No. and date	Date of Receipt	Total Cost	Duty Paid, if any	Condition * G - Good B ï Bad
1.	Workstation (1 No.)	HP	Z-420, Xeon 6Core E5,32GHz/12 MB L3Cache,16G B MM	TU/11-13/Pur/CSE/2013/2543	02-12-13	2,18000	Nil	G
2.	Server (1 No.)	HP	IBM, X3500M4,Tower,XeonE5 6Core,2.0Ghz /15MB cache,16GB MM	TU/11-13/Pur/CSE/2013/2543	02-12-13	3,67,500	Nil	G
3.	Personal Computer (5 Nos.)	HP	Intel Core i7 3770S, 4Gb DDR3 RAM,Pro630 0MT	TU/11-13/Pur/CSE/2013/1110	09-09-13	2,55,675	Nil	G
4.	Laptop (3 Nos.)	HP	Intel Core i7-4440S,4GB DDR3 RAM	TU/11-13/Pur/CSE/2013/1110	09-09-13	1,89,000	Nil	G
5.	Laptop (3 Nos.)	HP	Intel Core i5-4440S,4GB DDR3 RAM	TU/11-13/Pur/CSE/2013/1110	09-09-13	1,51,200	Nil	G
6.	Printer Laser Jet (1 No.)	HP	Laser Jet Pro 401DN	TU/11-13/Pur/CSE/2013/1108	06-08-13	32,132	Nil	G
7.	UPS Lines in Research Lab and Battery	Orion/ Astra Series	Online 6KVA, 1hr Backup	TU/11-13/Pur/CSE/2013/1111	17-07-13	91,935	Nil	G
8.	USRP (10 Nos.)	Tenet Technotronics, Bangalore	USRP1(6),USRPN210(4)	TU/11-13/Pur/CSE/2013/1109	23-10-13	10,44,450	Nil	G
9.	Daughter Boards (16 Nos.)	Tenet Technotronics,	XCVR2450, RFX2400,Basic Tx/Rx, WBX	TU/11-13/Pur/CSE/2013/1109	23-10-13	4,22,528	Nil	G

		Bangalore						
10.	Antenna (24 nos.) and other Cables	Tenet Technntronics, Bangalore	VERT2450, VERT900, LPBK-KIT,SMA-M/F Cable,MIMO Cable	TU/11-13/Pur/CSE/2013/1109	23-10-13	1,91,324	Nil	G
11	Personal Computer (1 No.)	HP	HP 800 MT Core-i5, 4Gb DDR3 Non-ECC RAM, 500Gb HDD	TU/11-13/Pur/CSE/2015/1509	22-07-15	52,319	Nil	G

Mention condition of equipment purchased. If bad, describe the fault/defect and what action has been taken to repair it?

TABLE 2.A SALE/TRANSFER OF CAPITAL GOODS (WITH PRIOR PERMISSION OF DIT)

S.No	Description	Sale/Transfer S/T	Orgn. To which sold/ Transferred	Sale Value Rs. in lakhs	Funds Refunded To DIT
1. 2.					

TABLE 3 : MANPOWER ASSOCIATED WITH THE PROJECT :

S.No.	Name*	Desig nation	Qualification	% of time devoted to this project	Salary drawn Y/N	Date of joining	Date of leaving	Total average emoluments (monthly)
1.	Nayan Basumatary	PF	M.Tech. (with experience)	100%	Y	June 18,13	Dec, 15	25,000
2.	Hema Kr. Yarnagula	JPF	MTech(GATE)	100%	Y	June 18,13	July, 21,14	20,000
3.	Arijit Nath	PA	BTech(CSE)	100%	Y	June 18,13	Dec, 9, 13	10,000
4.	Chaitanya Buragohain	PA	BTech(CSE)	100%	Y	June 18,13	July, 2, 14	10,000
5	Manashjyoti Kalita	PA	BTech(CSE)	100%	Y	June 18,13	Oct, 16, 14	10,000
6	Geeta Kumari	PA	MCA	100%	Y	Feb, 28,14	May, 1, 15	10,000
7	Prakash Chauhan	JPF	MCA(GATE), 6^{th}months Exp.	100%	Y	August28 ,14	Sept, 15, 15	20,000
8	Purbarag P. Choudhury	PA	BTech(CSE), GATE)	100%	Y	Sept, 01,14	Oct, 8, 15	10,000

- All are recruited staff

* Please indicate as applicable

- (a) Institute Faculty and Staff
- (b) Staff recruited for the project
- (c) Students

FORM G.F.R. 19

(SEE GOVERNMENT OF INDIA'S DECISION 7(B) UNDER RULE 148(3)
Assets Acquired wholly or substantially out of Government Grants
Register maintained by grantee institution

Block Account maintained by Sanctioning Authorities
Name of the Authority_____

1.	Name of Grantee Institution	**Department of Electronics and Information Technology (DeitY), Govt. of India**
2.	Name & Date of sanction	*No 14 (2)/2012-CC&BT, Dated 08/03/2013*
3.	Amount of the sanctioned grant	**Rs. 72.84 Lakhs**
4.	Brief purpose of the grant	**Implementation of Research Project**
5.	Whether any condition regarding the right of ownership of Govt. in the property or other assets acquired out of the grant was incorporated in the grant-in-aid sanction	**No**
6.	Particulars of assets actually credited or acquired	**As per TABLE 2**
7.	Value of the assets as on	**Same as TABLE 2**
8.	Purpose for which utilized at present	**Research work**
9.	Encumbered or not	**No**
10.	Reasons if encumbered	**N/A**
11.	Disposed of or not	**No**
12.	Reasons & authority, if any for disposal	**N/A**
13.	Amount realised on disposal	**N/A**
14.	Remarks	

Form GFR 19-A

Utilisation Certificate

Sl. No.	Letter No. and Date	Amount
1	14(2)/2012-CC&BT dtd.08.3.13	Rs. 50.00 Lakh
2	14(2)/2012-CC&BT dtd.10.3.15	Rs.22.84 Lakh
Total		**Rs.72.84 Lakh**

Certified that out of **Rs. 72,84,000** of Grants-in- aid sanctioned during the period 2013-16 in favour of **Tezpur University** under this Ministry/Department Letter No. given in the margin and accrued interest* of **Rs. 90,855**, a sum of **Rs. 70,16,843** and has been utilized for the purpose for which it was sanctioned and that the balance of **Rs. 3,58,012** remaining unutilised at the end of the year has been surrendered to Government (vide **DD** No. **324653** dated **06-06-2016**) ~~/will be adjusted towards the grants-in-aid payable during the next year~~.

*Interest Earned during the period is **Rs. 90,855/-**

2. Certified that I have satisfied myself that the conditions on which the grants-in-aid was sanctioned have been duly fulfilled/are being fulfilled and that I have exercised the following checks to see that the money was actually utilized for the purpose for which it was sanctioned.

Kinds of checks exercised:

1. Procurement of equipment as per Tezpur University rules.
2. Standard procedures and the Tezpur University rules have been followed in recruiting the project personnel.
3. Accounts are audited by the CAG every year.

10/11/16

Chief Investigator
DeitY Project, Tezpur University
Professor
Department of Computer Science & Engg.
Tezpur University

Registrar
Tezpur University
Registrar
Tezpur University

10.11.16

Finance Officer
Tezpur University
Finance Officer
Tezpur University

For SURAJIT CHAKRABORTY & CO.
CHARTERED ACCOUNTANTS

CA. SURAJIT CHAKRABORTY
(Proprietor)
Membership No.- 305054

PART – II

1. Project work and achievements :

   a. Executive Summary : ***See Annexure-A***

   b. Details covering targets, achievements in quantitative term and reasons for variations, if any on the following:

      i. Scope of the project: *MAC Protocols Design for Cognitive Radio Networks*

      ii. Systems/ Sub-systems with specifications or feasibility report on futuristic studies: *Four protocols for data dissemination, three spectrum sensing schemes, two routing protocols for spectrum sharing and spectrum decision and a power/channel allocation technique have been designed to support MAC protocols design for cognitive radio networks*

      iii. Research papers/Technical Reports brought out: ***See Annexure-B***

      iv. Manpower trained: A total of 8 peoples have worked as project staff; Project fellow (1), junior project fellow (2) and project assistant (5) throughout the project. Some of them are perusing research in premier institutes like IITs and US Universities.

      v. Anticipated know-how transfer to industry

      vi. Technology/Know-how developed (Hardware, software & other details, if any); know-how document available or not: ***See Annexure-C***

      vii. No. of industries shown interest for know-how utilization/ commercialization: *Nil*

      viii. No. of users/interested for taking prototype/finished product.: *Nil*

      ix. No. of industries/users interested in applying the know-how developed for enhanced productivity: *Nil*

2. Additional information

   i) Details of patents registered, if any :*Nil*

ii) Technological spin offs, seeding of a major activity and how the project has helped in enhancing the technological base/capabilities in the country :

iii) Future areas for work : ***See Annexure-D***

Government of India
Ministry of Communications & Information Technology
Department of Electronics & Information Technology
Electronics Niketan, 6 CGO Complex, New Delhi – 110 003

No. 14(2)/2012-CC&BT Dated: 26.11.2015

Subject:- Project on "MAC Protocols Design for Cognitive Radio Networks" by Tezpur University, Tezpur, Assam

Administrative Approval No. 14(2)/2012-CC&BT dated 08.03.2013

In continuation to this Department's letter of even no. dated 08.03.2013, I am directed to convey the approval of the Competent Authority for the redistribution of Rs. 2.00 lakhs to **Manpower Head** (Rs. 1.0 lakh each from **Consumable Stores** head and **Contingencies** head) without any enhancement in the total outlay of the project. The revised break-up of the project outlay after re-distribution of funds is as follows:

(Rs. in Lakhs)

Sl. No.	Head	Approved Outlay	Revised Outlay
1.	Capital Equipment	30.02	30.02
2.	Consumable stores	3.5	**2.5**
3.	Duty on import (if any)	0.0	0.0
4.	Manpower	18.0	**20.0**
5.	Travel / Training	5.0	5.0
6.	Contingencies	4.0	**3.0**
7.	Overheads (if any)	12.18	12.18
	Grand Total	72.84	72.84

This issues with the concurrence of Integrated Finance Division vide OPA No. 38013 dated 10.11.2015 and approval of GC(BMB) vide OPA No. 38013 dated 10.11.2015.

SArora
(Sangita Arora)
Additional Director

To

Dr. Nityananda Sarma
Professor, Department Computer Science & Engineering
Tezpur University
Tezpur, Assam -784 028

Copy to:

1. The Director, Office of the Director General of Audit, Post & Telecommunication, Shamnath Marg, Civil Lines, Delhi-110 034.
2. Pay & Accounts Officer, Pay & Accounts Office, Deity, New Delhi - 110 003
3. Integrated Finance Division, DeitY
4. GC(BMB)
5. Sanction File

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Sr. No: 702016

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STATE BANK OF INDIA
/ DRAWEE BRANCH: MICR CP CENTRE NEW DELHI
/CODE No: 04336

* Hologram ❘❘ ✓ ❘❘ check

⑈324653⑈ 000002000⑆ 000455⑈ 16

R. Hussain
H - 1281

Annexure-A

Executive Summary

For recent development in wireless communication, Cognitive Radio (CR) is emerging as a promising solution to overcome the spectrum scarcity problem for next generation radio communication. A Cognitive Radio Network (CRN) with CR enabled unlicensed nodes allows opportunistic wireless communication by utilizing the unused spectrum portion called spectrum holes in the licensed spectrum bands. To enable efficient spectrum aware CR communication for next generation radio, many challenging issues related to MAC protocol design requiring to solve issues of spectrum sensing, power and channel allocation and medium access control (MAC) layer sensing decision need to be addressed with utmost importance. The MAC protocol design for CR communication is dependent on the performance of sepctrum sesning operations. The challenge in spectrum sensing is to achieve higher detection performance due to the secondary users inabilities to exploit the inherent spatial diversity. The cooperative spectrum sensing (CSS) has evolved as a probable solution to tackle this problem. In context of MAC protocol design, a number of cooperative spectrum sensing approaches have been attempted by researchers. Unfortunately, these approaches could not improve the detection performance beyond a certain limit. The majority of the approaches do not consider cooperation overhead due to reporting time and reporting energy. Also they do not consider using adaptive sensing threshold which is estimated based on secondary user's distance from the primary user. Utilization of detected spectrum holes to maximize the capacity rate needs an efficient and optimal power allocation scheme, designing such a scheme is challenging. A number of water-filling based power allocation approaches have been proposed by the researches, which face challenges in terms of ensuring strict primary protection and the computational overhead to find the water level for optimal solution. To enable MAC level decision about the availability of channel in proactive sensing, the estimation of channel usage pattern of primary user is very essential. In this direction, researchers have proposed tech-

niques to predict the channel availability using Hidden Markov Model (HMM) for interweave mode of access. Developing a model to predict channel availability for underlay mode of access is challenging and not addressed so far. To enable MAC to allow multi-user communication and data dissemination, distributed CR-MAC protocol design with location-aware forwarding and capacity constraint data dissemination are important. In this direction designing MAC sublayer architecture and developing the techniques to allow multi-hop communication, cross-layering information requirement for location awareness and constraint based distributed data dissemination are very challenging and found less interest by the researchers. Furthermore to achieve spectrum sharing and decision, dynamic routing, throughput maximization, interference aware decision framework design are important for success of CR-MAC protocol which have got less attention from the researchers.

We begin by developing a distributed TDMA based CR-MAC protocol for data dissemination for multi-hop ad-hoc communication, using the proposed TDMA protocol a cross-layer based location-aware forwarding solution is developed. To realize the deployment scenario of the proposed DTDM protocol a testbed is setup as a proof of concept. Further a HMM based channel-usage model for MAC layer sensing and a data dissemination ptotocol with capacity contraint channel ranking is developed. A distributed data dissemination protocol is developed to utilize the proposed channel usage model and discover the opportunities in the licensed channel, while tolerating the interference power constraint (IPC). These four protocols address the problem of distributed data dissemination for MAC sub-layer architecture design.

For spectrum sesing solution two co-operative spectrum sensing schemes are developed. We desing a coalitional game theoretic framework for cooperative spectrum sensing for ad-hoc CRNs. It addresses the problem of minimizing the cooperation overhead in terms of reporting time and reporting energy to enhance the detection performance. Furthermore, to improve the detection performance by exploiting the spectral diversity of the SUs, the game theoretic framework is extended for distributed threshold adaptive cooperative spectrum sensing (TACSS). It also addresses the problem of minimizing cooperation overhead due to reporting error and reporting energy.

With the enhanced detection performance next we investigate the technique for spectrum sharing scheme for CR adaptation and spectrum decision. A dynamic virtual backbone based routing protocol for SUs is developed for CR routing. Further a joint routing and channel allocation in multi-hop CRN with network throughput optimization is developed to address the efficient use of the resource. In context to routing an interference aware decison framework for PU protection is also developed for underlay CR communication.

Finally, with the enhanced detection performance of the CSS schemes, efficient dynamic routing schemes next we investigate the technique to make the efficient use of the detected opportunities for maximizing the capacity rate for SUs. A water-filling (WF) based optimal power allocation technique for a single pair of SUs is developed to maximize the capacity rate using OFDMA mode of channel access using underlay communication. The technique finds the optimal water-level while maintaining the average interference power (AIP) tolerance limit of the primary users.

Keywords: Cognitive Radio, Cognitive Radio Network, Capacity rate, Primary user, Secondary user, Game theory, Reporting error, Reporting energy, Nash Equilibrium, Spectrum sensing, Underlay communication, Spectral diversity

Annexure-B

Publications based on the Project Works

Journals

1. Deka, S. K., Chauhan, P. and Sarma, N., "Threshold Adaptive Cooperative Spectrum Sensing for Ad-hoc Cognitive Radio Networks", *IEEE Transactions on Control of Network Systems*, 2015 [under revision].

2. Deka, S. K., Sarma, N. and Yarnagula, H. K., "A Power Allocation Strategy for Underlay Cognitive Radio Networks", *Indian J. Discrete Math., vol.1, no.2, pp.58-75*, 2015.

3. Deka, S. K. and Sarma, N., "A Distributed Power Allocation Technique for Multiuser Ad-hoc Cognitive Radio Networks", *IEEE Transactions on Control of Network Systems*, 2015 [communicated].

4. Deka, S. K. and Sarma, N., "Opportunity Prediction at MAC Layer Sensing for Ad-hoc Cognitive Radio Networks", *Journal of Network and Computer Applications (Elsevier)*, 2016 [Accepted].

5. Yarnagula, H. K., Deka, S. K., Sarma, N., "A Cross-Layer based Location-Aware Forwarding using Distributed TDMA MAC for Ad-Hoc Cognitive Radio Networks", *Wireless Personal Communications, Springer*, 2016 [under review].

6. Nath, A. and Sarma, N., "A distributed solution for cooperative spectrum sensing scheduling for multiband cognitive radio networks", *Journal of Network and Computer Applications (Elsevier)*, 2016 [Communicated].

Conferences/Workshops

7. Iqubal Z., Sarma, N., "Network Throughput Maximization through Joint Routing and Channel Allocation in Multi-hop Cognitive Radio Network", *in the proc. of 3rd IEEE International Conference on Applications and Innovations in Mobile Computing (AIMoC 2016)*, February 10-12, 2016, Kolkata, India.

8. Devi M., Sarma, N., Deka, S. K., "Dynamic Virtual Backbone based Routing in Cognitive Radio Networks ", *in the proc. of IEEE International Conference on Advanced Networks and Telecommunication Systems (IEEE ANTS)*, December 15-18, 2015, Kolkata, India.

9. Deka, D., Deka, S. K. and Sarma, N., "A Capacity Constraint Distributed Data Dissemination Protocol for Ad-hoc Cognitive Radio Networks ", *in the proc. (Springer AISC Series 2016) of International Conference on Information and Communication Technology for Sustainable Development (ICT4SD - 2015)*, July 3-4, 2015, Ahmedabad, India.

10. Bora, K., Baishya, N., Choudhury, N., Chauhan, P., Deka, S. K. and Sarma, N., "Interference Aware Decision Framework for Underlay Cognitive Radio Communication ", *in the proc. of International Conference on Computing and Communication Systems (I3CS)*, April 9-10, 2015, Shillong, India.

11. Deka, S. K., Chauhan, P. and Sarma, N., "Constraint based Cooperative Spectrum Sensing for Cognitive Radio Networks", *in the proc. of 13th IEEE International Conference on Information Technology (ICIT 2014)*, pp. 63 - 68, December 22-24, 2014, Bhubaneswar, India, DOI:10.1109/ICIT.2014.12. (Awarded with "Amiya K Pujari Best Paper Award" for ICIT 2014).

12. Deka, S. K., Sarma, N. and Yarnagula, H. K., "A Power Allocation Strategy for Underlay Cognitive Radio Networks", *in the proc. of National Workshop and Conference on Discrete Mathematics and its Applications (NWCDMA 2014)*, March 10-14, 2014, Kolkata, India.

13. Deka, S. K. and Sarma, N., "A Review on Security Vulnerabilities in Cognitive Radio Networks", *in the proc. of National Workshop on Network Security 2013 (NWNS'13)*, pp. 158-174, March 15-16, 2013, Tezpur, India.

14. Yarnagula, H. K., Deka, S. K.and Sarma, N., "Distributed TDMA based MAC Protocol for Data Dissemination in Ad-Hoc Cognitive Radio Networks ", *in the proc. of 7th IEEE International Conference on Advanced Networks*

and Telecommunication Systems (IEEE ANTS), pp. 1 - 6, December 15-18, 2013, Chennai, India. :DOI 10.1109/ANTS.2013.6802855.

Book Chapters

15. Deka, S. K. and Sarma, N., "Channel-Usage Model in Underlay Cognitive Radio Networks"', *Computer Networks & Communications (NetCom), LNEE, Springer*, Volume 131, pp 115-123, 2013, DOI:10.1007/978-1-4614-6154-8_12.

Anne ure – C

1. A Capacity Constraint Distributed Data Dissemination Protocol for Ad-hoc Cognitive Radio Networks

- In order to perform optimal data dissemination, the issues like (i) spectral diversity and (ii) requirement for strict primary user (PU) protection, need to be addressed effectively. We have developed a Capacity Constraint Distributed Data Dissemination Protocol for Ad-hoc CRN, which includes a weighted channel selection strategy and a scheme to prepare data dissemination schedule based on adopting a neighbor discovery method for a multi-hop Adhoc CRN.
- Simulation has been carried out in order to evaluate the efficacy of the proposed protocol in terms of improving packet delivery ratio, minimizing interference to the PU and reducing the number of redundant messages in the network.
- The simulation is done using *N 2-CRCN* patch
- **Published on Proceedings of International Conference on ICT for Sustainable Development, Springer,2 1**

2. Dynamic Virtual Backbone based routing in Cognitive Radio Networks

- For effective communication in a multi-hop ad-hoc network, it is expected that the path/route via which data packets are transmitted should be stable. In CRN, due to PU activities most of the route remains unstable for SUs communication. Again, due to this dynamics of channel availability, SUs are forced to sense channel repeatedly which incur high cost in terms of time.
- To overcome such kind of issues, a dynamic routing solution for multi-hop ad-hoc CRN has been put forwarded which is based on Virtual Backbone (VB).
- The proposed strategy looks for constructing VB across the network by considering coverage of nodes and relying on common control channels (CCC) for coverage. Concept of Distributed Database Coverage Heuristic (DDCH) is used for construction of VB which only requires the exchange of local information among SUs. The approach focuses on how this DDCH can be employed to generate and maintain the structure in CRN. Next, the inter-connectivity is maintained among the backbone nodes which get created while constructing the backbone infrastructure. Finally, VB gets utilized for performing end-to-end data transmission. Following this strategy, every SU retains updated data about spectrum availability of nodes residing in their coverage.
- Performance of the proposed scheme is evaluated by comparing it with a non CRN based routing solution, AODV, in the designed simulation environment. Also, channel adaptivity characteristic of VBR is analyzed by relating it with AODV. AODV being a MANET routing solution is not concerned much with channel availability for nodes. While analyzing channel adaptivity, AODV is made to implement under two different situations such that each time AODV uses separate channels to carry out routing of data packets.
- Simulation is done using OMNET ++.
- **Published on Proceedings of the IEEE International Conference on Advanced Networks and Telecommunications Systems (IEEE ANTS 2 1), 1 -18 December, 2 1 , Kolkata, India**

3. Network Throughput Ma imi ation through Joint Routing and Channel Allocation in Multi-hop Cognitive Radio Network

- The dynamic transmission characteristics of the primary users make the spectrum availability in Cognitive Radio Network very unpredictable. Since secondary users can only opportunistically access the licensed band, network throughput maximization in such an environment is very challenging that needs to be addressed for effective use of CR technology. Routing and channel allocation when performed independently lead to sub-optimal throughput in multi-hop cognitive radio network (CRN).
- To overcome the issues of independent channel selection and routing, a Joint Routing and Channel Allocation in Multi-hop Cognitive Radio Network have been proposed which maximize the network throughput by scheduling flows with robust routes and channel assignment.
- The optimization problem to maximize network throughput is formulated using Integer Linear Programming (ILP).
- The ILP formulation is evaluated using solver provided by CPLEX and results are obtained. Various test cases are considered to validate the formulation. The result obtained in each test case provides optimal network throughput in the given network conditions and provides an upper bound to the throughput that can be achieved in the considered network.
- **In proc. of IEEE Sponsored Intl Conference on Applications and Innovations in Mobile Computing (AIMoC) 2 1 , February 1 -12, 2 1 , Kolkata, India .**

4. A Power Allocation Technique for Underlay Communication

- The maximization of capacity rate for SUs while ensuring primary protection in underlay communication is a challenging task, and the power allocation techniques used in legacy wireless networks do not work in such a scenario. To address these issues, a power allocation technique for underlay communication has been proposed which uses a water-filling (WF) based scheme in presence of channel state information (CSI) to maximize the power allocation leveraging the capacity rate optimization for transmission.

- The algorithm used handles the issue of computational complexity of classical WF to search the water level without resorting to the binary search mechanism. Using theoretical analysis of the classical water-filling framework, the proposed technique directly computes the final solution considering the average interference power (AIP) constraint of primary user.

- Experimental results show that the proposed algorithm runs much faster compared to the existing classical based algorithm for varying number of sub-channels. The result show that while the interference tolerance power, constrained by the AIP remains within the total transmission power limit of the SU, the proposed algorithm achieves the optimal spectral efficiency in terms of capacity rate. When interference tolerance power value increases close to total transmission power limit of the SU, the capacity rate further improves significantly.

- Simulation is done using MATLAB.

- **Published in Indian Journal of Discrete Mathematics (IJDM), Dec 2 1**

. A Distributed Power Allocation Technique for Multiuser Underlay Communication

- In multiuser environment, secondary users compete to use the available channels for transmission. A distributed solution is desirable to address both the equilibrium condition and maximization of power allocation, while optimizing the capacity rate. Toward this direction, a framework has been developed based on potential game theory which models the optimization problem of distributed power allocation (DPA) for multiuser ad-hoc underlay communication scenario. The proposed framework is based on iterative water-filling (IWF) scheme, where the potential function developed incorporates noise variance, and interference from the primary user as well as other SUs. The proposed framework improves the capacity rate for underlay communication while the game reaches the Nash Equilibrium (NE), proving the convergence behavior of the game according to the potential game model.
- Simulation results show that the game reaches the NE, and at the NE state, the capacity rate depends on the number of secondary transmitters and receivers. Compared to the centralized approach, the proposed technique is found to be more robust to accommodate the dynamic behavior such as interference tolerance and adaptive power allocation of the SUs. Providing channel access to SUs on detected available spectrum while protecting PU is done through proper power allocation technique.
- Simulation is done using MATLAB.
- **Communicated to IEEE Transactions on Control of Network Systems, 2 1**

. A Channel Usage Model for MAC Layer Sensing

- Learning about the channel usage pattern of PUs to predict future channel availability can help alleviate the sensing overhead problem of proactive sensing at MAC layer. In this part of the work, two important issues of MAC-layer sensing have been investigated for underlay mode CRNs. These are - i) how to estimate and model the channel usage pattern of PUs, while tolerating interference from SUs, and ii) how to use learnt channel usage patterns for discovery of opportunities. Accordingly, a Hidden Markov Model (HMM) based channel usage pattern of PUs is proposed for use by the SUs to predict the spectrum opportunity. The proposed model uses estimated interference power constraint (IPC) in determining the impact of interference due to the presence of SUs to protect the PUs from harmful interference. Using the model, a formulation deriving the availability metric (AM) for a license channel is developed, which helps in deciding and selecting the best channel by an SU for its transmission needs.
- Experimental results show that the trained HMMs are statistically stable and accurate, which can be used for predicting future channel availability, provided the same IPC condition prevails for a certain period. It is also observed that the availability metric (AM) of the channel sequences generated by the trained HMMs are effective in selecting a suitable channel for transmission.
- Simulation is done using MATLAB
- **Communicated to Ad Hoc Networks (Elsevier) , 2 1**

7. Interference Aware Decision Framework for Underlay Cognitive Radio Communication

- In CRN, protecting the primary user from harmful interference due to underlay mode communication by SUs is the key. Depending on the possible interference produced by the SUs based on their position and transmission power level, the decision to select the SUs for communication is an interesting problem. In order to minimize the interference to PU, a decision framework is required, which dynamically form the cluster of SUs to take part in communication according to their positional priorities.
- The main contribution of this work is to design a concentric circle based decision framework, which clusters the SUs into three different zones. It considers the adaptive nature of selecting the power level by the SUs for their transmission and their distances with respect to the PU receiver.
- The analysis and the simulation studies conducted in MATLAB have revealed that the proposed decision framework significantly improves CRN performance in terms of PU protection and number of SUs allowed for communication.
- **In proc. of International Conference on Computing and Communication Systems (I3CS), April 9-1 , 2 1 , Shillong, India .**

8. Implementation of energy-detection based spectrum sensing using test-beds

- The objective of this implementation module is to enable a CR enabled device (SU) to sense a channel and make a decision that whether it is usable or not by using energy detection technique in a real test-bed.
- Spectrum sensing is one the most vital functionality of CR technology and amongst all the spectrum sensing technique, Energy Detection (ED) has been considered as one of the efficient and simple spectrum sensing approach since it does not require any prior information of the channel as well as transmitter (blind detection).
- In our setup, we have modified the existing sample python script to implement spectrum sensing using energy detection. We compute the Threshold (TH) value of the noise by sensing and calculating the average value of the signal power when the channel is assumed to be free i.e., when we do not transmit anything in the channel. Once the TH is computed, we start transmitting data using the channel and compute the power level (P) for that channel. If the value of P is greater than TH, it means channel is busy otherwise free.
- For this implementation, two PCs and two USRP1 devices containing RFX2400 daughter board are used. One PC with a USRP1 device acts as a Primary User (PU) which transmits using the intended channel that SU want to sense and other PC with one USRP1 acts as sensing node (SU).
- ISM band of 2.4GHz is used during the experimentation.
- From the experiment, we observed that environmental factor such as noise have a significant impact on result of the spectrum sensing.

9. Implementation of PU activity (pseudo-random channel switching) sensing in CRN using test-bed

- The main goal of this implementation module is to show how a Cognitive Radio enabled device is capable of sensing a set of channels and opportunistically access the free channel i.e. channels do not occupied by Primary User (PU). This module also enabled a CR device to switch to the next available channel if the current channel becomes re-claimed by the PU.
- In order to implement this module, we have modified some existing python script for sensing and transmission of GNU radio suite.

- For hardware setup, PU transmitter has been configures using one PC with a USRP1 device containing a RFX2400 daughter board and SUs are configured using another PC with two USRP1 devices with one RFX2400 daughter board each.
- ISM band of 2.4GHz is used for experimentation.
- From the experiment, we observed that though the SU can detect the existence of PU accurately and switch to the next available channel accordingly most of the times, it still suffers from miss-detection due to noise uncertainty in the spectrum band and threshold value of the noise level.

1 . Implementation of Basic CSMA in CRN using test-bed

- The main objective of this implementation module is to show how a Cognitive Radio enabled device is capable of sensing the carrier and accordingly transmit data using basic CSMA with random back off time in order to reduce collision. Our implementation is based on the concept of Non-persistent CSMA protocol in which a ready transmitter sense an intended channel and transmit immediately if the channel is sensed to be free otherwise waits for random amount of time and then sense again.
- In software setup, we have modified python script for sensing and transmission in GNU radio suite.
- For hardware setup, we configure 1st SU using one PC with a USRP1 device containing a RFX2400 daughter board which is already tuned in a channel say channel K and the 2nd SU is configured using another PC with two USRP1 devices with one RFX2400 daughter board each which performs carrier sensing.
- ISM band of 2.4GHz is used for experimentation.
- From the experiment, we observed that the probability of miss-detection and false alarm is highly dependent on the chosen sensing threshold and environmental factors like noise, temperature etc.
- This module can be enhanced to implement CSMA/CA.

11. Implementation of Basic TDMA protocol in CRN using test-bed

- The main objective of this module is to simulate basic Time Division Multiple Access (TDMA) scheme using real test-bed.
- In software setup, we have modified the python script in GNU radio suite for transmission and reception functionalities.
- In hardware setup, we configured two SU transmitters using two PCs with one USRP1 device each and another PC as a common SU receiver to both the SU transmitters. Both the SUs transmit their independent data to the common receiver in time slotted manner. The data from different SUs are received in the designated receiver which is buffered independently.
- Each and every SU transmits their own ID with each packet so that the receiver can distinguish them accordingly.
- The module use the system time to synchronize between the two SUs so that they can transmit their data without making any collision.
- ISM band of 2.4GHz is used for experimentation.
- From the experiment, we observed that due to the lack of proper timeout/timer feature in control plane of GNU radio suit, implementation of global synchronization become challenging.

- This module can be enhanced to implement Distributed TDMA and other TDMA based scheme.

12. Implementation of Cooperative Spectrum Sensing (CSS) technique in CRN using test-bed

- The main objective of this module is to implement the technique of Cooperative Spectrum Sensing (CSS) in CRN using real test-bed to overcome the issues of local sensing like fading and shadowing.
- In software setup, we have modified python script in GNU radio suite for sensing, transmission and reception functionalities.
- In hardware setup, we configured one fusion center (FC) using one PC with two USRP1 devices and two SUs with two PCs with three USRP1 devices each having RFX2400 daughter board. The SUs per performed local sensing to the intended channel and send the local sensing decision to the FC. The FC receives the local sensing decision and performed fusion accordingly depending on some fusion rule (AND, OR etc.) and transmitted the final fusion decision to the each of the SU.
- ISM band of 2.4GHz is used during experimentation.
- This module can be enhanced to implement Adaptive CSS.

13. Analysis of some selected relevant DSA techniques through simulation as well as using test bed.

- Based on the study of existing MAC protocols for cognitive radio networks, a CRN MAC protocol is developed. Data dissemination in a CRN is very useful to propagate non-urgent messages in order to limit cost and complexity of the network. MAC protocols in existing legacy wireless networks limit the productive utilization of spectrum holes by secondary users. We developed a Distributed TDMA based MAC protocol for data dissemination in multi-hop ad-hoc CRNs. The developed MAC protocol goals are two-fold - (i) to attain maximum message reachability and (ii) to avoid collision among secondary users in a CRN and hence to improve bandwidth utilization efficiency. Extensive simulations are carried out to show the efficacy of proposed MAC protocol.
- The simulation is done using NS2-CRCN simulation.
- **Published in 7th IEEE International Conference on Advanced Networks and Telecommunication Systems (IEEE ANTS), 2 13**

14. To develop a suitable scheme for spectrum sensing in a cognitive way.

- Development of a Constraint based Cooperative Spectrum Sensing for Cognitive Radio Network.
    - In CR communication, the issues of shadowing, multipath fading affect performance of spectrum sensing function that impacts the detection performance

of secondary users (SUs). Cooperative Spectrum Sensing (CSS) has proven to be an emerging scheme which significantly improves spectrum sensing performance by utilizing spatial diversity of the SUs.

- This work proposes a game theory based coalition model for CSS, where the game has been devised as a non-transferable coalitional game. The main contribution of this work is to consider the constraint during cooperation due to cost involved in reporting time and reporting energy.
- A formulation has been proposed to decide the optimal size of a coalition and a scheme for dynamic selection of coalition head. In the game, the condition to achieve the coalition stability is carried out. MATLAB based simulation has been performed to analyze and study the behavior of the proposed model. Simulation results have shown the efficacy of the proposed model that enhances the sensing performance significantly.
- The framework of this work using CSS is required to develop a CR-MAC protocol.

- **Published on"13th IEEE International Conference on Information Technology (ICIT), 2 14(Awarded with Amiya K Pujari Best Paper Award for ICIT 2 14)**

1 . Development of a Threshold Adaptive Cooperative Spectrum Sensing (TACSS) for Ad-hoc Cognitive Radio Network

- The recent studies have shown that the traditional spectrum sensing technique used for CR is inefficient in terms of detection performance due to issues of spectral diversity. In presence of spectral diversity of the Secondary Users (SUs), Cooperative Spectrum Sensing (CSS) has been proven to be a successful technique which improves sensing performance. However the perfectness of the value of parameters chosen during CSS has significant impact on the performance. The accuracy of the sensing threshold plays a critical role in detection performance.
- In this paper, we propose a model for CSS using coalitional game theory, where the game has been devised as a non-transferable coalitional game.
- A distance based threshold adaptive scheme is also proposed for the CSS.
- A scheme has also been proposed to select the head of the coalition dynamically based on a formulation using the distances among the SUs.
- Also the cooperation constraint due to the reporting error and energy has been considered in the model.
- The efficacy of the proposed model has been observed and analyzed via simulation. MATLAB based simulation has been performed to analyze and study the behavior of the proposed model.

- The analysis results have shown the significant improvement of the spectrum sensing performance of CSS in terms of probability of detection.
- The framework of this work using TACSS is required to develop a CR-MAC protocol.

– **Communicated to IEEE Transactions on Control of Network Systems,**

1 . Propose MAC sub-layer architecture and the new MAC policy.

– Development of A Cross-Layer based Location-Aware Forwarding using Distributed TDMA MAC for Ad-Hoc Cognitive Radio Networks.
  - The contribution of this work is a cross-layer based location -aware forwarding protocol using a distributed TDMA MAC for ad-hoc CRNs.
  - The distributed TDMA based MAC protocol constructs TDMA schedules by exchanging three rounds of control messages over the common control channel (CCC) in a distributed fashion with collision avoidance among SUs as a fundamental goal.
  - The MAC protocol also uses the service of network layer, which classifies the available channels and selects the best ranked channel and passes this information to the MAC sub-layer for effective communication.
  - The location-aware forwarding protocol constructs request zone for making decisions regarding data packet forwarding with highest packet delivery ratio by confining the flooding of packets as a key objective.
  - The proposed CR MAC protocol has been verified through simulation using NS2-CRCN simulator.
  - Simulation results show the efficacy of the proposed cross-layer scheme.

– **Communicated to Wireless Personal Communications , Springer**

Annexure-D

Future Works

In the following, we outline some of the possible directions of future research works based the contributions made in this report.

To implement a cooperative spectrum sensing in real testbed incorporating robustness against noise and interference To implement collision avoidance scheme in onging non persistent CSMA based MAC protocol To implement the proposed DTDM based MAC protocol in real testbed and validation with the simulation results

- The implementation a cooperative spectrum sensing in real testbed incorporating robustness against noise and interference is interesting and is kept for future work.
- The practical implementation of collision avoidance scheme for non persistent CSMA based MAC protocol in testbed is a challenging task and is left for future work.
- To achieve reliable CR based data communication implementation of the proposed virtual backbone based routing scheme,joint routing and channel allocation scheme in real testbed will be interesting work.
- The performance of UPA techniques optimizes the capacity rate considering the full CSI is available to SUs. But, in practice determining the CSI itself is challenging and incorporation of real channel dynamics in terms of CSI into the techniques will enhance the estimation of the power allocation, which is left as part of future works. Further, the consideration of fairness (**?**) to satisfy QoS requirement of the SUs during the DPA technique will give interesting results which is out of the scope of this work and is also kept under future works.
- The proposed channel usage model of PU considers the interference dynamics on the channel in proactive manner. The model with collaboration among

SUs will be more interesting in terms of accuracy, which can accommodate dynamic channel switching behavior as well and this is left for future works.

Form GFR 19-A

Utilisation Certificate

Sl. No.	Letter No. and Date	Amount
1	14(2)/2012-CC&BT dtd.08.3.13	Rs. 50.00 Lakh
2	14(2)/2012-CC&BT dtd.10.3.15	Rs.22.84 Lakh
Total		**Rs.72.84 Lakh**

Certified that out of **Rs. 72,84,000** of Grants-in- aid sanctioned during the period 2013-16 in favour of **Tezpur University** under this Ministry/Department Letter No. given in the margin and accrued interest* of **Rs. 90,855**, a sum of **Rs. 70,16,843** and has been utilized for the purpose for which it was sanctioned and that the balance of **Rs. 3,58,012** remaining unutilised at the end of the year has been surrendered to Government (vide **DD** No. **324653** dated **06-06-2016**) ~~/will be adjusted towards the grants-in-aid payable during the next year~~.

*Interest Earned during the period is **Rs. 90,855/-**

2. Certified that I have satisfied myself that the conditions on which the grants-in-aid was sanctioned have been duly fulfilled/are being fulfilled and that I have exercised the following checks to see that the money was actually utilized for the purpose for which it was sanctioned.

Kinds of checks exercised:

1. Procurement of equipment as per Tezpur University rules.
2. Standard procedures and the Tezpur University rules have been followed in recruiting the project personnel.
3. Accounts are audited by the CAG every year.

10/11/16

Chief Investigator
DeitY Project, Tezpur University
Professor
Department of Computer Science & Engg.
Tezpur University

Registrar
Tezpur University
Registrar
Tezpur University

10.11.16

Finance Officer
Tezpur University
Finance Officer
Tezpur University

For SURAJIT CHAKRABORTY & CO.
CHARTERED ACCOUNTANTS

CA. SURAJIT CHAKRABORTY
(Proprietor)
Membership No.- 305054

TABLE 1 : HEADWISE BREAK-UP OF EXPENDITURE

S.No	Head	Approved Budget Outlay (Rs. In Lakhs)	Expenditure incurred from 08-03-2013 to 31-03-2014 RE FE Total (Rs.)	Expenditure incurred from 01-04-2014 to 31-03-2015 RE FE Total (Rs.)	Expenditure incurred from 01-04-2015 to 31-03-2016 RE FE Total (Rs.)	BE (Rs.)	Remarks
1.	Capital Equipment (FE Comp) *	30.20	29,63,744	Nil	52,319	3,937	
2.	Consumable items / Components (FE Comp)	2.50	61,000	75,202	1,13,220	578	
3.	Duty on Imports	Nil	Nil	Nil	Nil	Nil	
4.	Man power	20.00	6,78,8,56	8,01,698	3,98,000	1,21,446	
5.	Travel/Training	5.00	1,44,459	95,885	1,18,676	1,40,980	
6.	Contingencies	3.00	66,046	66,906	1,66,832	216	
7.	Overheads, if any	12.14	7,68,051	14,960	4,30,989	Nil	
8.	Other expenditure debitable to this project (please specify)	Nil	Nil	Nil	Nil	Nil	
	Total	72.84	46,82,156	10,54,651	12,80,036	2,67,157	

* FE utilised, over and above sanction made by DIT, through OGL facilities may be indicated separately. Please indicate if there is any deviation from originally approved budget and whether necessary approval has been taken

* Total amount sanctioned is Rs.72.84 Lakhs

* Interest Earned during the period is Rs.90,855/-

10/11/16

Chief Investigator
DeitY Project, Tezpur University

Professor
Department of Computer Science & Engg.
Tezpur University

Registrar
Tezpur University

Registrar
Tezpur University

20.11.16

Finance Officer
Tezpur University

Finance Officer
Tezpur University

For SURAJIT CHAKRABORTY & CO.
CHARTERED ACCOUNTANTS

CA. SURAJIT CHAKRABORTY
(Proprietor)
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