Solving Hidden Terminal Problem in Cognitive Networks Using Cloud Technologies

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Abstract—**Hidden terminal problem is one of the well-known problems when a node is visible from the access point but cannot communicate through it. The problem occurs in ad hoc networks as well as cognitive networks. The clear solution is not discussed in cognitive networks. In this paper, we proposed a method to solve the hidden terminal problem through cloud computing. The idea is that the cloud can store the status of cognitive network, compute, reorganize, and make available the current state of cognitive networks for future decisions. Further, we discussed the role of cloud computing in hidden terminal problems and a solution using the blackboard technology. The simulations were presented to cognitive radio network cloud and discussed the packet transfer and handshaking. The proposed cognitive network model using cloud technologies eliminates the overheads of request to send and clear to send. Further, implementation of cognitive networks through cloud technologies minimizes the problem of sudden entry of primary user.**

Keywords: Hidden Terminal; Cognitive Networks; Cloud computing; spectrum mobility; spectrum holes.

I. INTRODUCTION

The software defined radio and cognitive radio brought significant attention in telecommunications technology [1, 2]. The cognitive radio has the capability of changing its parameters depending upon the environment that it operates. Therefore, the cognitive capability and reconfigurability makes the cognitive radio (CR) detects the licensed user and identify the unused spectrum (spectrum holes or white spectrum). In recent years, the underutilization of licensed spectrum and introduction of digital broadcasting TV, the FCC (federal communications commission) regulations allowed access to TV white spaces [3]. The recent FCC regulations encouraged international organizations to define cognitive radio standards on TV white spaces.

The CR is a promising technique to detect and utilize the spectrum holes (unused spectrum) efficiently [4]. The process includes spectrum sensing, spectrum management, spectrum sharing, and spectrum mobility. In spectrum sensing, the CR must detect primary (licensed) user through sensing methods including matched filter detection, energy detection, and feature detection. The spectrum management includes characterization, selection, and reconfiguration of the spectrum. The management further includes channel selection, modulation selection, bandwidth setting, observation time setting, transmission time setting, and power setting. The spectrum sharing helps in preventing spectrum overlapping when multiple cognitive radios are involved in intranet. The spectrum mobility deals with the handoff (transfer of connection to another unused spectrum band) in CR networks. The handoff involves the connection lost due to mobility and the quality of service. Further, the hidden terminal problem (HTP) happens in spectrum mobility. The HTP can be solved using the cloud with cognitive radio networks.

A cognitive radio network (CRN) is a group of cognitive radios connected to verify the concepts, algorithms, and protocols. The CRN improves the performance of spectrum utilization and helps smooth the transmission of packets. The tools for total functionality require a significant amount of computing resources in a real time environment. Cloud computing is an alternative to minimize the computing resources and improve the performance. The cloud works like another intelligent agent equipped with all CRN states, policies, and concurrent actions.

In wireless communications, CRN uses knowledge representation, machine learning, genetic algorithms, and game theory techniques for efficient resource (spectrum) utilization. The CRN detects the current network conditions, plans the successive actions, and act on those decisions. Further, the CRN system learns from the history of decisions, actions, and uses the knowledge to improve the decisions. Since CRN uses the previous knowledge and improves the current decisions, game models are very useful in the prediction of network conditions.

The cognitive radio mostly uses the first two OSI model layers (Open Systems Interconnection), whereas the CRN covers all layers. The basic functions learning, reasoning and adapting to current network conditions are required to create end-to-end optimum performance. The CRN makes the decisions to meet the network needs as a whole rather than individual network component. The CRN improves the robustness, usability, security, and human interaction for operation and communication.

The remaining paper discusses the hidden terminal problem and cognitive networks, the role of the cloud to solve the hidden terminal problem, recent developments, problem formulation, simulations, conclusions, and future research.

II. HIDDEN TERMINAL PROBLEM AND COGNITIVE NETWORKS

The hidden terminal problem occurs when a node is visible from the access point but cannot communicate to the nodes within communication distance. A star network is the best example. One of the well-known hidden node problems in wireless networks is a three node problem as

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shown in Figure 1. For example, a user tries to transmit the information from node A to node C. The node A cannot hear the transmission from node C by sensing the medium. Similarly, node C cannot sense the transmission from node A; therefore, they try to communicate and collide at node B. The third example is provided through Figure 2 (waiting forever). The node A is communicating to node D through node B and node C (Figure 2). In the beginning, the node A assumes that channel 2 is free. Once the packet reaches node B it understood that node C is in communication with node D for channel 2. That is node C sends the request for communication (RTS: request to send) to node B for channel 2. The node B is waiting to get the signal clear to send (CTS) from node C for channel 2. Both nodes are waiting for channel 2 at node B and cannot move further. This is a waiting forever problem. The RTS/CTS mechanisms implemented in the MAC (medium access control) protocol helps to eliminate the hidden terminal problem with time overhead.

The RTS/CTS problem further introduces the exposed terminal problem (Figure 1) in wireless communications. For example, if node B is transmitting to node A and node C tries to transmit to node D. The node C and node B are in the transmission range of each other. Therefore, after carrier sense, transmission of node C interferes with the transmission of node B. Further, node D can still receive the transmission of node C without interference, if the nodes C and B are synchronized with the same packet size and data rate (IEEE 802.11 RTS/CTS) [8]. If the nodes are not synchronized, the neighboring node may not hear the CTS during transmission and exposed terminal problem may occur.

The unsuccessful transmissions are proportional to number of hidden or exposed terminals from the transmitting terminal. The RTS/CTS implemented in IEEE 802.11 solves the problem with the conditions explained above. A similar problem occurs if the presence of the primary signal cannot be detected by cognitive radios due to interference or noise of neighboring cognitive radios (hidden node). The RTS/CTS may not help in such cases. The cognitive radios can solve the problem in a cooperative spectrum sensing. Cognitive radios sense the spectrum holes at each hop and utilize the opportunity of allocating the channels in an optimum manner. In a multi-hop cognitive network (MUCON), users can use different frequencies depending upon the availability of spectrum. In MUCON, a common control channel is used to control the available channels. The number of channels available at each hop depends upon the presence of the primary user (PU), because the complete path of the primary user is dedicated. Therefore, the number of channels available to the secondary user or cognitive user (SU/CU) is fixed. In the current problem, the number of channels available is variable at each hop due to collaborative activity of the cognitive network users. The unshaded part of nodes A, B, C, and D in Figure 2 shows the available channels.

The spectrum sensing is used to detect the presence of the PU in the frequency band. The unused spectrum (spectrum holes) detected by the CU helps the control channel to allocate the needed spectrum to CU on the communication path. Further, the energy detectors are used to detect the presence of PU and determine the current status of PU in the geographical area.

The design of cognitive radio (CR) in spectrum sensing poses more challenges since it requires sensing the spectral environment and flexibility to adapt transmission parameters. The design of CR must detect the weak signals and strong signals. The possible solutions include notch filtering, banks on radio frequency (RF) chip, and spatial filtering RF beam forming through adaptive antenna arrays.

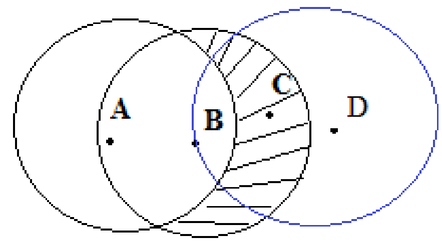

Figure 1. Hidden and exposed node problem

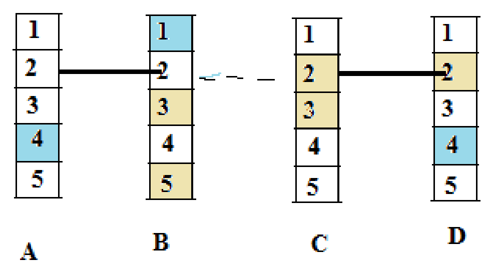

Figure 2. Hidden Node Problem

III. Role of Cloud to Solve Hidden Terminal Problem

The current challenges in cognitive radio networks are storing vast amount of information, processing for real time decisions, and handoff situation during the transfer of information packets at various CRN nodes. Storing and processing the information requires a vast amount of computational capabilities. Further, knowing the current state of channels of the nodes in advance makes the transmission of information easy. But, the change in node status (availability of channels) during the transfer of information requires additional capability. The IEEE 802.11 RTS/CTS solves the hidden terminal problem to a certain extent in wireless communications, but the same cannot be applied in cognitive networks due to the sudden entrance of the primary user. The cloud is very useful (come out of the current bottlenecks) to minimize the storage, save the status of channels and complex computations at node level. Since the channel status at each node is stored in the cloud, the HTP problems will never arise.

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The current computing facilities have limited access to resources, financial limitations to purchase packages, problems of portability, and maintenance. To overcome these limitations an emerging concept called cloud computing entered into the technological market. The cloud concept simplified the user needs by eliminating the purchase and maintenance of systems and packages. The advantages are enormous, and security is a basic issue. Paying for the resources you use is the fundamental advantage. This eliminates the purchase of special equipment, packages, other related software, and maintenance. The user can store all the information and use it anywhere in the world without carrying the work related resources. Since the resources can be stored, maintained, executed, and made available on the real-time basis, the concept extended to cognitive radio networks to use spectrum efficiently without any obstructions. Further, the cloud concept eliminates the hidden terminal problem due to the storage of all CRN information at one place and the availability of the current status to all nodes.

CR (portable or non-portable) functions require a cloud due to the intensive computations and vast storage. The functions include signal detection and environment awareness; large amount of data storage, processing and sharing; learning; collect data from various CR nodes and make available to all CR nodes. To facilitate these functions a prototype needs to be built. The prototype must have capabilities of collecting, processing in real time and interacting with nodes for all updates at a central place called cloud as shown in Figure 3. The CRN nodes are connected with cloud to store, plan, update status, and transfer information from a source node to the destination node. This process helps to eliminate the RTS/CTS process at nodes. Further, it saves lot of battery, processing time and hand shaking (or handoff) for mobile devices. The overhearing will be avoided in wireless networks and eliminates the hidden node problem.

Cloud computing avoids the common control channel (CCC) in CRN. The need of a dedicated CCC problem in CRN will be avoided by connecting the nodes of CRN to cloud and allow cloud to take care of the activities of CRN including the HTP. In cloud connection, we do not need to use the time intervals for the available channels. The available channels and frequencies are registered in the cloud and cloud activities are dedicated to transferring the user information to the destination. Therefore, no special protocols or controls are required.

The CCC was discussed in [5] using an example with cognitive nodes and unawareness of the channel set on successive node. In Figure 2, A, B, C, and D are four cognitive nodes in the network. The shaded parts are the channels that occupied. The initial handshake from node A to node B communicated through the control channel is channel 2. Further, node A is unaware of the available channels in node B and vice versa. If the user from node A wants to transmit the information to user (s) at node B, the nodes A and B should negotiate with their channel set with the control structures called RTS/CTS to reserve the channel for communication (we are not discussing a dedicated channel). This problem of negotiating will be eliminated using cloud, since the available channels are registered in the cloud. Therefore, most of the communications and waiting for CTS signal will be eliminated using cloud. Further, the best channel will be selected and quality of service maintained using cloud.

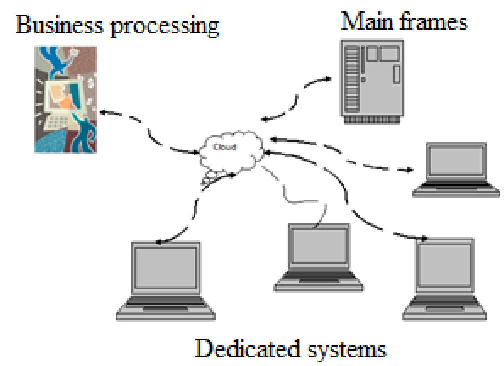

Figure 3. CRN Test-bed and Cloud

IV. REVIEW OF RECENT DEVELOPMENTS

The authors in recent literature [6 - 10] discussed the HTP in ad hoc networks. The literature includes the hidden vs. exposed terminals, solutions to HTP, minimizing the effect of deafness and HTP in wireless and ad hoc networks, and the role of RTS/CTS in IEEE 802.11 to eliminate HTP. The concepts were extended to CRN to solve HTP in CRN [5, 11]. The cloud concept helps CRN to allocate the resources efficiently at node level compared to traditional tools [12-14]. The solution to HTP is the extended opportunity of cloud.

In CRN primary user detection and transferring the packets on multi-hop cognitive radio network (MCRN) are known problems. Further, HTP is another problem that was solved using RTS/CTS in IEEE 802.11 protocol. The RTS/CTS implementations take time and computational resources. The authors in [5] introduced an alternative MAC protocol on MCRN to avoid common control channel through simulations using NS2 package. The idea is good but consumes more computational resources and time. The HTP with the mathematical model and simulations through NS2 was discussed in [9]. Biswas et al. [15] used cooperative spectrum sensing in dynamic CRN to detect primary user and collect the spectrum holes for efficient use of unused spectrum. Zang et al. [16] proposed a fast spectrum sensing algorithm with minimum cognitive radios to perform the cooperative spectrum sensing with minimum errors.

Jayasuria et al. [7] discussed the hidden vs. exposed terminals and concluded that RTS/CTS degrade the performance. The MAC protocol for multi-hop networks was studied in [17] by proposing pair-wise ID (identity detection) countdown. The hidden terminal problem using directional antennas was studied in [10]. They claimed the performance does not depend on network topology and network pattern. Further, the experimental study of Hidden terminal problem was discussed in [6, 18]. In [6], hidden terminal jamming problem presented in IEEE 802.11 for ad hoc networks was discussed. They claimed that signal differential 2dB is sufficient for the stronger transmission and effectively jam a weaker signal. In [18], the impact of hidden nodes in both infrastructure and multi-hop an ad hoc network was studied. The authors claim that RTS/CTS degrade the throughput and may not solve the hidden node problem.

The cognitive networks and using game models for resource allocation was discussed in [19-23]. The role of cognitive radios, the cognitive networks, and standardization of large scale wireless networks were the main theme of these papers. The cloud did not have any role of these networks. The recent developments and timely papers in [12 - 14] open the doors for new research using cloud for CRN. Further security is a big issue in implementing CRN in cloud. The channel allocation in CRN, status of cognitive nodes, and hand shaking in moving devices will be solved easily with cloud.

V. SOLUTION TO HIDDEN TERMINAL THROUGH CLOUD

The CRN cloud (CRNC) is a centralized global data structure consisting of a set of knowledge sources (CRN nodes) called intelligent agents. These agents are self sufficient to detect the primary signal and spectrum holes and store the current status on the cloud. Further, the nodes continuously update their information on the CRNC. The design is similar to the blackboard technology to maintain the current state of nodes.

Figure 3 shows that each node in the CRN is connected to the cloud (CRNC). Let us discuss the transfer of packets from node A to node D in the Figure 2. Each node in the CRN is connected to the cloud and the nodes update their status at cloud. The cloud software executes the status of free channels in each node connected from node A to node D and secures the free channels. The cloud software decides the channel in each connected node to transfer the packets. Further, if the primary user enters at any time, the cloud decides the alternate action of assigning the channel or stores the packets in its buffer till it finds the free channel to transfer the packets to the destination. The same facility will not be possible without cloud organization. For example, if the primary user enters (to use the channel) suddenly, the current data transfer on the channel used by secondary user must be stopped and wait for alternate channel. In CRNC, the free channels are available at each node in the cloud knowledgebase. The cloud software connects the free channel to transfer the data without delay. Therefore, delay time is less in CRNC since it maintains the current channel states and does not require RTS/CTS. Further, if a node cannot connect or is disconnected, the status is stored at cloud and the system administrator is notified. In CRNC if any node could not be connected or disconnected the information will never be lost. The information is forwarded through an alternate path or stored till the node is available (connected).

Each node in CRNC contributes towards a solution without knowing the status of other nodes in the network. The solution model contains the control structure, nodes involved in the current solution, CRNC knowledgebase, query processor, and database access as shown in Figure 4. The query processor takes the request from the CRNC node, verifies the status of each node in the path (source to destination) from database, uses the facts and rules from knowledgebase, and selects best possible path. This process eliminates the RTS/CTS at each node as well as hidden node problem. Therefore, the CRNC process saves time since we eliminate the RTS/CTS and noise interruption (hidden terminal problem). In CRNC, the decision is taken at a global level (in the cloud) and eliminates the problems at each node including processing time, waiting time for clearance of path, interference of nodes in communication distance, and request for a channel to send packets to successive nodes. Two cases arise in the current situation. The case 1 deals with mobile devices and Case 2 with fixed devices.

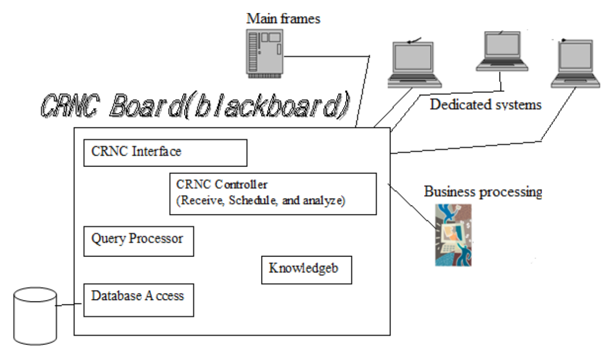

Figure 4. CRNC Architecture

Case 1 deals with mobile devices communications. Once the device opens the communication, the device is registered in the cloud along with the destination device. As the source and destination devices change their current status, the CRNC changes its connection status on real time, since handshaking is needed at any time to any one or both the devices.

Case 2 deals with stable devices. Once the device enters in contact or is ready to communicate, it enters the requests in cloud with a source and destination address. The cloud triggers the respective nodes to update their current status.

One solution is that the information will be sent to cloud from the source node and a destination node copies from cloud. Therefore, we can eliminate even transfer of packets through each node, since the packets are in the cloud and destination address is known. The loss of packets will be minimized when connecting through cloud. Further, the destination will be triggered as soon as the packets are ready to send from the source. The destination node copies from the cloud. This is possible because, any change in the cloud database (blackboard) is triggered to all related CRNC nodes. Therefore, the hidden terminal problem, overhearing, and processing will be eliminated automatically. The purpose will be served if we can achieve the control strategy and real time performance.

The second solution is that the connections required to transfer the information will be calculated and assigned through the cloud database. Once the channels are assigned at each node, the node status will be updated at cloud and the packets will be transferred. As soon as the packets are transferred from each node the channels will be freed and cloud status will be updated.

VI. SIMULATIONS

CRNC scheme eliminates the following requirements which are needed in CRN [5].

- We do not need maintain two radios to be equipped with each node for control signals and receiving/transferring.
- If a new node enters in the network, it registers in cloud only. It does not notify its neighbors.
- If a primary user enters at any node or node status changes the node need not inform to its neighbors.
- The node need not send the communication to its neighbor about its intension to communicate.

Using the above assumptions, sample simulations were completed using MATLAB language. Initially, we assumed five nodes connected in CRNC. The statuses of all nodes are available in the cloud for process. The channels are assigned randomly (0 means busy). Two cases were discussed.

In case 1, if a user in node A wanted to transfer the information to a user in node D, the node status will be verified and updated on the CRNC board. Once the request comes to cloud from node A to transfer packets to the destination node D, the cloud controller triggers node A and node D and lock the needed channels to transfer the information. The channel update (at each node) will be done after completion of the task. Further, if we want to transfer the packets through each connected node in the path, we need to follow a different procedure.

The available channels in all nodes in the path will be verified and assigned the needed channel (s) in each node and mark them as busy. In this case, the first available channels are 2 in node A, 1 in node B, 1 in node C, 1 in node D, and 1 in node E. These channels will be locked and information packets will be transmitted. The channels will be freed after the completion of the task.

In the case 2, the user in node A is making conversation with the user in node E. But A is moving towards B. The CRNC knows that user in node A is close to node B and handshaking is required. The CRNC scheduler searches for a free channel in B. As soon as the user enters in node B's boundary the handshaking will take place and channel in node B will be assigned. The channels will be free after completion of the task.

The CRNC design eliminates the RTS/CTS problem as well as hidden node problem because the status of nodes and allocation of channels was done at CRNC board. Since the decisions were taken at CRNC, the overhearing and packet loss were eliminated automatically. Further, processing in each node, waiting time for allocation of channels, and reservation of channels (RTS/CTS) and other overheads will be eliminated with the implementation of CRNC.

MATLAB OUTPUT

Case 1: Fixed terminals
send packet A to D
cloud status
trigger A and D

Available Channels in node A	0	2	3	0	5
Available Channels in node B	1	2	0	4	5
Available Channels in node C	1	2	3	0	0
Available Channels in node D	1	2	3	0	0
Available Channels in node E	1	2	0	4	0

Assigned Channel in node D (first available channel) 1
Channel in node D copies and exits

Case 2: Moving Terminals
Channel in node A moving and calling through the channel in node E
The updated CRNC cloud status

Available Channels in node A	0	2	3	0	5
Available Channels in node B	1	2	0	4	5
Available Channels in node C	1	2	3	0	0
Available Channels in node D	1	2	3	0	0
Available Channels in node E	1	2	0	4	0

assigned Channel in node A i = 2
assigned Channel in node D i = 1
Hand shaking channel in A j = 2
Hand shaking with channel in B k = 1

Task completed
cloud status

Available Channels in node A	0	2	3	0	5
Available Channels in node B	1	2	0	4	5
Available Channels in node C	1	2	3	0	0
Available Channels in node D	1	2	3	0	0
Available Channels in node E	1	2	0	4	0

VII. CONCLUSIONS AND FUTURE RESEARCH

In the proposed CRNC structure, the interface is connected to CRN nodes and CRNC board (blackboard). The controller receives messages from CRN nodes, schedules messages, and conducts appropriate actions. The knowledgebase consists of a set of production rules and inference engine to operate those rules. The scratch space (work space) stores the current state of messages for processing.

The hidden node problem and dynamic spectrum allocation are very important in cognitive radio networks. The hidden node problem will be eliminated by using cloud, since CRNC board has current status of CRN nodes. Further, the changes will be triggered automatically using the blackboard structure. The structure of CRNC provides the use of two mobile devices, one mobile device and one fixed device, both fixed devices and/or multiple devices with fixed and mobile devices.

The cost factor related to computing and communications, storage is not provided in this paper.

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These are application dependent. Further, power optimization at node level depends upon the quality of services and time varying state of wireless communications [24, 25]. The cloud helps better power savings [25].

The future work involves the security issues for CRNC, and possible solutions.

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REFERENCES

[1] Mitola, J. and Maguire, G. Q., “Cognitive Radio: Making software radios more personal”, IEEE personal Communications, vol. 6, no. 4, pp. 13-18, 1999.

[2] Mitola, J., "Cognitive Radio – An Integrated Agent Architecture for Software Defined Radio", Ph.D. Dissertation, Royal Institute of Technology, Kista, Sweden, May 8, 2000

[3] FCC, Second report and order and memorandum opinion and order, FCC 08-260, 2008 (last access July 1012).

[4] Akyildiz, I. Lee, W. and Chowdhury K., “CRAHNs: Cognitive Radio ad hoc Networks”, Ad Hoc Networks, vol. 7, pp. 810-836, 2009.

[5] Kondareddy, Y. R. and Agrawal, P., “Synchronized MAC Protocol for Multi-hop Cognitive Radio networks”, IEEE International Conference on Communications (ICC’08), pp. 3198 – 3202, 2008.

[6] Ware, C. Wysocki, T. and Chicharo, J., “On the Hidden Terminal jamming Problem in IEEE 802.11 Mobile Ad hoc Networks”, IEEE International Conference on Communications (ICC), Helsinki, Finland, 2001, pp. 261-265.

[7] Jayasuriya, A. Perreau, S. Dadej, A. and Gordon, S., “Hidden Vs. Exposed Terminal Problem in Ad hoc Networks”, Proceedings of the Australian Telecommunications, Networks and Architecture Conference (ATNAC 2004), December 2004, Sydney, Australia.

[8] Fullmer, C.L. and Garcia-Luna-Aceves, J.J., “Solutions to Hidden Terminal Problems in Wireless Networks”, Proceedings of the SIGCOMM’97 conference on Applications, technologies, architectures, and protocols for computer communication, 1997, pp. 39-49.

[9] Jeong, J. Kim, H. Lee, S. and Shin, J., “An Analysis of Hidden Node Problem in IEEE 802.11 Multihop Networks”, Sixth International Conference on Networked Computing and Advanced Information Management (NCM), Seoul, S. Korea, 2010, pp. 282-285.

[10] Gossain, M. P. Cordeiro, C. and Agrawal, D. P., “Minimizing the Effect of Deafness and Hidden Terminal Problem in Wireless ad hoc Networks using Derectional Antennas”, Wireless Communications & Mobile Computing - Wireless Ad Hoc Networks: Technologies and Challenges, vol. 6, Issue 7, November 2006, John Wiley and Sons Ltd. Chichester, UK, pp. 917-931.

[11] Reddy, Y. B., “Spectrum Detection in Cognitive Networks by Minimizing Hidden Terminal Problem”, ITNG 2012, April 16-8, Las Vegas.

[12] Ge, F. Lin, H. Khajeh, A. Chang,C. J. and Eltawil, A.M., “Cognitive Radio Rides on the Cloud”, Military Communications Conference, MILCOM 2010, October 2010, 1448 – 1453

[13] Chen, Z. Zang, C. Lin, F., Yu, J. and Lie, X., “Towards a Large-Scale Cognitive Radio Network: Testbed, Intensive Computing, Frequency Agility, and Security”, International Conference on Computing, Networking and Communications (ICNC), 2012, Feb. 2 2012, pp. 556 - 562

[14] Ko, C. Hang, D. H. and Wu., S., “Cooperative Spectrum Sensing in TV White Spaces: When Cognitive Radio Meets Cloud”, IEEE INFOCOM 2011, pp. 683-688.

[15] Biswas, A. R., Aysal, T.C., Kandeepan, S., Kliazovich, D., and Piesiewicz, R., “Cooperative Shared Spetrum Sensing for Dynamic Cognitive Radio Networks”, IEEE International Conference on Communications, Dresdan, Germany, June 2009, pp. 1-5.

[16] Zhang, W. Mallik, R. K. and Letaief, K. B., “Cooperative Spectrum Sensing Optimization in Cognitive Radio Networks”, IEEE International conference on Communications, Beijing, China, 2008, pp. 3411-3415.

[17] You, T. Hassanein, H. and Yeh, C., “PIDC – Towards an Ideal MAC Protocol for Multi-hop Wireless LANs”, International conference on Wireless Networks, Communications and Mobile Computing, June 2005, pp. 13-16.

[18] Ng, P. C. Liew, S. C. Sha, K. A. and To, W. T., “Experimental Study of Hidden-node Problem in IEEE 802.11 Wireless Networks”, ACM SIGCOMM, August 2011, Toronto, Canada.

[19] Thomas, R. W. DaSilva, L. A. and MacKenzie, A. B., "Cognitive networks", Proceedings of the First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, Baltimore, MD, USA, November 8–11, 2005.

[20] Fortuna, C. and Mohorcic, M."Trends in the development of communication networks: Cognitive networks", Computer Networks, 2009.

[21] Song, L., "Cognitive Networks: Standardizing the Large Scale Wireless Systems", 5th IEEE Consumer Communications and Networking Conference (CCNC), 2008, pp. 988-992.

[22] Balamuralidhar, P. and Prasad, R., "A context driven architecture for cognitive nodes", Wireless Personal Communications 45 (2008), pp. 423–434.

[23] Song, L. and Hatzinakos, D. "Cognitive networking of large scale wireless systems". International Journal of Communication Networks and Distributed Systems 2 (4): 2009, pp. 452-475.

[24] Khajeh, A. Cheng, S. Y. Eltawil, A. and Kurdahi, F., “Power management for cognitive radio platforms,” in IEEE Global Telecommunications Conference, GLOBECOM 2007, pp. 4066 -4070.

[25] Amin, K. Kim, M. Dutt, N. Eltawil, A. M. and Kurdahi, F. J., “Cross-Layer Co-Exploration For Mobile Multimedia,” in proceedings of IEEE Workshop on Embedded Systems for Real-time Multimedia (ESTIMedia’08) in part of ESWEEK, pp. 13-18.