Quest Journals
Journal of Electronics and Communication Engineering Research
ISSN:2321-5941 Volume1 ~ Issue 4 (2013) pp: 15-21
www.questjournals.org

Research Paper

Cross Layer Design Approaches, Schemes and Optimization Methodologies for Cognitive Radio Networks: a Survey

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Received 20 December, 2013; **A**ccepted 30 December, 2013© The author(s) 2013. Published with open access at **www.questjournal.org**

ABSTRACT: - *Wireless technology has seen a tremendous advancement in recent times. Overnight new researches are made and fascinating outcomes are accomplished. But it's never imperative that such a technological growth in wireless system has offered numerous challenges to the research community. For improvement in the performance of wireless networks 'cross-layer designing' was coined. Many issues arouse for cross layer design. The situation became even tougher with new paradigm 'cognitive networks'. Since cognitive networks are limited in performance by challenges in spectrum sensing, sharing, mobility, end to end Qos etc, a cross-layer design is worth pursuing. In this paper, we present an insight to cross-layer design first. Secondly, we introduce some of the approaches proposed in the literature followed by a short overview on classical optimization methodologies for cross-layering. Finally, an extensive survey on different schemes for performance enhancement is performed taking several recent works in literature. Tabulation is made systematically for quick reference.*

Keywords: - *Cognitive radio networks, cross layer design, optimization.*

I. INTRODUCTION

Cross-layer design refers to protocol design by exploiting the interdependence of protocol layers to obtain performance betterment. This is in a way different from layering, where the protocols at the different layers are designed independently. Hence, "Protocol design by the violation of a reference layered communication architecture is cross-layer design with respect to the particular layered architecture". The examples of violation of a layered architecture include creating new interfaces between layers, redefining the layer boundaries, designing protocol at a layer based on the details of another layer, joint adjustment of parameters across layers etc. This kind of design certainly imposes many constraints on the processing at other layers!!. Cross-layer design is defined as a protocol design methodology. However, a protocol designed with this methodology is also termed cross-layer design.

The migration from conventionally used wired to wireless networks expanded the network research intensively. There is huge number of applications designed. To support such a variety of applications, there is an ever growing effort to optimize the performance of the wireless networks. However during the transition from wired to wireless only a few protocols at the lower layers in the protocol stack were replaced with new protocols for wireless networks. So in a way the higher layers remained ignorant of the fact that now they are operating without a wire. This lack of knowledge about this communication novelty and different behavior of a new physical layer (PHY) consequently caused wrong notions at the higher layers. In order to cope with these problems an idea of cross layer information exchange was coined in the research community. The idea behind cross layer information exchange is to use various parameters from different layers for joint optimization of protocols across the communication stack. The cross-layer architectures proposed in the literature are mainly based on three possible approaches [19]:

II. CROSS LAYER APPROACHES

1. *Merging approach* - adjacent layers are merged together in order to accomplish a specific goal
2. *Streaming approach* - where even non-adjacent layers may exchange information using dedicated interfaces

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3. *Parallel approach* - where the cross-layer interaction is realized through a parallel structure that acts as a shared database of the system state.

A. *Merging cross-layer architecture*

The merging cross layer approach is the simplest of three. It usually comprises user-centric, evolutionary and targeted cross layer optimization approaches. The most representative example of a merging architecture consists in bringing together the physical and the data link layer for efficient link adaptation. The advantages of the merging cross layer optimization architecture lies in its ease of implementation and limited variation of the layered protocol stack. But the performance improvement that can be obtained with this approach is limited.

B. *Streaming cross-layer architecture*

In the streaming approach we need to form a new interface at each layer in addition to those already existing between adjacent layers. As a consequence of which this cross-layer schemes are termed as *direct cross-layer communications*. A typical block of streaming architecture is shown in Figure 1 taken from [19]. Every layer in this cross layer scheme must exchange control information with a some of the other layers by means of an appropriate control function. The pros of the streaming cross-layer architecture are in the reduced complexity and the liberty to optimize parameters using information from non-adjacent layers.

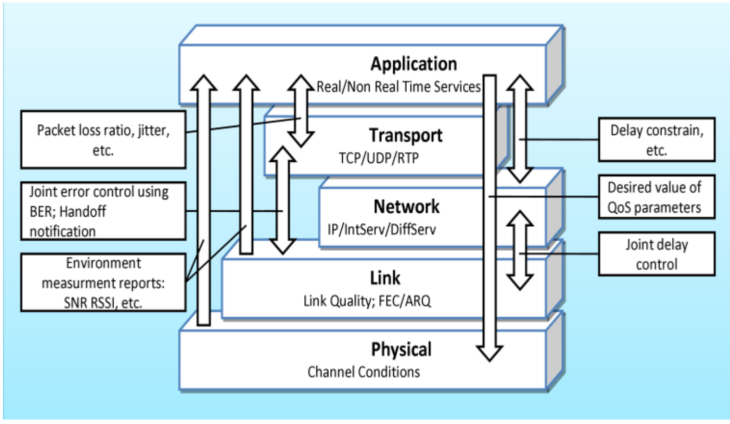

Figure1. Streaming cross-layer architecture

C. *Parallel cross-layer architecture*

This architecture introduces a shared database for all the protocol layers, thereby avoiding direct inter-layer talk. This database can be accessed by every layer that requires its utility. System architectures based on this approach are becoming popular day by day since it is suitable for addressing many of the challenges. Figure2 proposes an architecture where all layers communicate with a single control plane that performs cross layering in a unified way according to optimization criterion. In this case the control plane, which becomes the core of the network node, can actually be used to create a new abstraction of the network functionalities and hence the layered structure loses its original meaning.

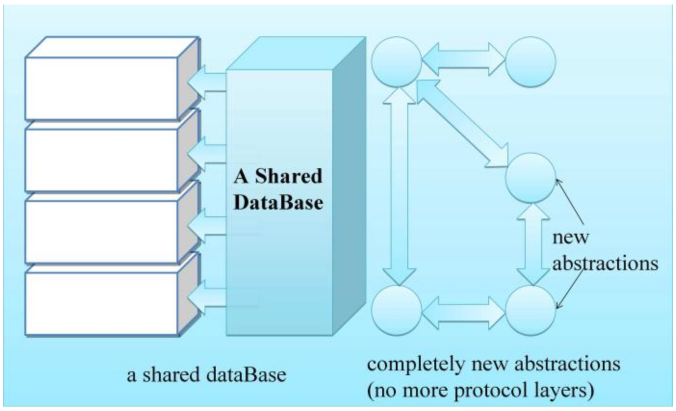

Figure2: *Parallel cross-layer architecture*

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III. OPTIMIZATION METHODOLOGIES

In any system, optimization is the ultimate goal of researchers. If the cognitive radio's performance needs to be satisfying, it must perform optimizations in an intelligently efficient, cognitive way, dealing with many input parameters. Therefore, powerful optimization techniques are promising candidates for optimization methodologies. Four optimization methods have been selected to be shortly presented in this paper, due to their capability for fulfilling specific optimization tasks [20].

A. *Simulated Annealing*

Simulated annealing (SA) can deal with multidimensional optimizations where traditional numerical methods might not be fast and scalable enough if applied to the full dataset [20]. Simulated annealing, as in [21], belongs to the random search algorithms where a random walk through the solution space governs the search towards an optimal solution. It mimics the natural processes of controlled cooling of a material. The advantage of SA is that it is a simple and highly efficient method for finding the optimal or acceptably good solution, which can be combined with other methods to improve the final result.

B. *Genetic Algorithms*

Genetic algorithm is a heuristic stochastic optimization and global search methodology, based on the principles of natural selection. The common constituents of GAs are: "chromosomes" representing radio parameters in case of CR, genetic operators of crossover and mutation, evaluation function to determine the "score" i.e. fitness of a chromosome, and selection function that chooses the chromosomes that will survive to the next generation based on their scores. Thus, at each step the algorithm selects chromosomes from the current population that will serve as a base (parents) to create chromosomes of the next generation (children). Crossover function combines two parent chromosomes to form children for the next generation. Mutation function makes changes to individual parents to form children. [22] provides details **of** a distributed genetic algorithm **(CA)** based cognitive radio engine model for disaster communications and its implementation **in** a cognitive radio test bed using programmable radios.

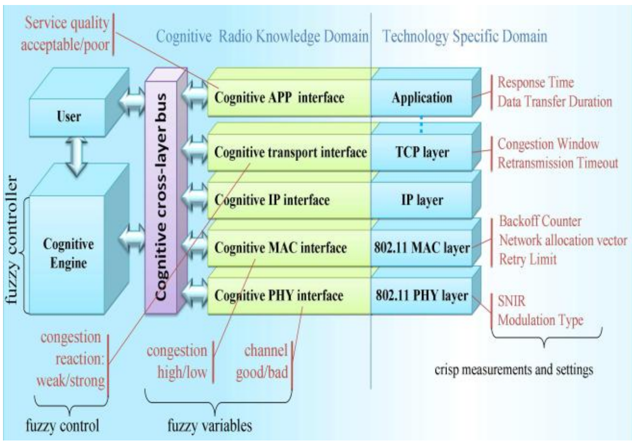
C. *Neural Networks*

Artificial neural networks (NN) offer an effective data modeling mechanism able to model complex relationships and to learn these relationships by training. Frequently a Multilayer Feed forward NN (MFNN), a supervised network that requires a known desired output in order to learn is used [23]. Learning in this case is a process of determining the optimal combination of network weights (internal parameters) so that the network approximates a given function (input/output relationship).

D. *Fuzzy Logic*

In fuzzy logic (FL) is based on reasoning close to humans which make decisions based on often imprecise and approximate input information. It uses the important notions of membership functions, linguistic variables, a rule base and an inference procedure. Fuzzy logic is a promising research topic for cross-layer optimization in wireless networks. For example, [24] proposes Fuzzy Logic as an effective means of meeting these challenges, as far as both knowledge representation and control implementation are concerned and it is shown how it can be used for generic knowledge representation of cross-layer information and building controllers in CR.

Figure3. ***Fuzzy Logic***



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IV. CROSS LAYER SCHEMES

As mentioned, most of the classical cross layer schemes address specific problems rather than providing a general system optimization. Accordingly, the survey will include many cross layer design schemes that intend for performance improvements in many forms. Here we present the cross-layer schemes proposed in literature, not all but the recent ones that are aimed at improving the cross layer performance at the application layer, the transport layer, the network layer and. MAC & Physical layer in the following manner :

A. *Joint Physical and MAC layer schemes*

Scheme [2] presents a cross-layer design scheme for TCP performance improvement over CR networks by jointly optimizing Spectrum sensing, access decision, the physical-layer modulation and coding scheme, and the data-link layer frame size in CR networks to maximize the TCP throughput. They have formulated the CR system as a POMDP to obtain the optimal policy. Simulation results have shown that low-layer design parameters have significant impact on the TCP throughput in CR networks, and the TCP throughput can be substantially improved in the proposed cross-layer design scheme. In [4], they propose the cross-layer based opportunistic multi-channel medium access control (MAC) protocols, which integrate the spectrum sensing at physical (PHY) layer with the packet scheduling at MAC layer, for the wireless ad hoc networks. It also proposes two collaborative channel spectrum-sensing policies, namely, the random sensing policy and the negotiation-based sensing policy, to help the MAC protocols detect the availability of leftover channels. Thesis [5] studies the performance of both opportunistic spectrum access and spectrum sharing cognitive radio networks using cross-layer design approaches in order to provide reliable and optimum packet transmission at the medium access control (MAC) layer with quality of service (QoS) guarantees, to optimize the secondary user (SU) performance given the primary user (PU) protection and to realize the impact of imperfect spectrum sensing at the MAC layer. The reliable and optimum packet transmission at the MAC layer with QoS guarantees is accomplished by the combination of adaptive modulation with hybrid automatic repeat request (HARQ) protocol in OSA CRNs.

In [7], the cross layer design approach and challenges for cognitive radio functionalities to enhance its efficiency in dynamic spectrum access management are discussed. Spectrum sensing and scheduling challenges as well as spectrum shaping challenges are described for the implementation in cross layer design. Appropriate techniques in enabling multimedia application over cognitive radio are addressed. Finally, the proposed cross layer design architecture for the CR MB-OFDM system is presented.Paper [8] presents a first in-depth comparative study on different factors effect QoS which include system performance, power interference, wireless channel conditions, services priorities and fairness constraints. A cross-layer scheduling algorithm which could optimize system performance and control power interference is proposed. An optimal Channel Sensed Multichannel Cognitive MAC (OCSM-CMAC), a QoS driven cross layer system for the joint optimization of different network parameters along the network protocol stack for the improved video transmission is presented In [9].The results of the proposed OCSM-CMAC scheme demonstrate that improved PSNR and delay performance is achieved under the optimal channel sensing scheme compared to the random sensing scheme.

In scheme [10], an optimal TCP throughput based channel access scheme in CR networks, and the TCP performance improvement from a cross-layer perspective is accomplished. Simulation results show the TCP throughput can be improved substantially compared with the existing approach that maximizes physical layer throughput. In [16], the functional concept of Cognitive Resource Manager (CRM) is presented providing cognition of the environment to optimize the allocation and exploitation of radio resources, to improve the access to these resources and to ensure mobility control in the opportunistic system. Few selected algorithms for distributed power control that implement parts of the functionalities of the CRM while considering specific QoS constraints and protection of incumbent users are discussed. In [17], a prime focus on adaptively scheduling spectrum sensing and data transmission so that negative impacts to the performance of the CR network are minimized is made. It shows how optimal sensing/transmission scheduling policies can be obtained and proves some important structural properties of such optimal policies.

B. *Joint Physical , MAC and Network layer schemes*

The scheme [1] proposes a lagrangean relaxation based heuristic (LRH) to jointly consider channel assignment, power allocation, and routing to minimize network energy consumption in the cognitive radio networks. Such cross-layer design problem has been completely formulated as a mixed integer non-linear programming (MINP). The simulation results indicate that the proposed LRH outperforms the two approaches and obtains a significant power gain. In [6], a cross-layer opportunistic spectrum access and dynamic routing

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algorithm for cognitive radio networks is proposed, called ROSA (ROuting and Spectrum Allocation algorithm). Through local control actions, ROSA aims at maximizing the network throughput by performing joint routing, dynamic spectrum allocation, scheduling, and transmit power control.

In [11], they present a cross-layer protocol of spectrum mobility and handover in cognitive LTE networks. With the consideration of the Poisson distribution model of spectrum resources, a cross-layer handoff protocol with the minimum expected transmission time is developed in cognitive LTE networks. Simulation results illustrates the proposed handoff protocol significantly reduces the expected transmission time and the spectrum mobility ratio. Paper [14] proposes a joint distributed power control, routing and MAC protocol for cognitive radio networks and we obtain performance tradeoffs via analysis and simulation. Finally in thesis [18], they first investigate research challenges specific to DCRN MAC design and present an overview of current state-of-the-art DCRN MAC protocols. Then propose a MAC protocol called OMC-MAC to address major research issues in DCRN. Next, a resource allocation scheme based on cross-layer interaction between MAC and network layers to minimize network wide resource wastage in multi-hop DCRN is proposed.

C. *Schemes based on TCP performance*

An analysis of TCP performance in IEEE 802.22 Wireless Regional Area Network (WRAN) based on Cognitive Radio Networks is presented in [12] and it also proposes two approaches to improve the networking performance. The first approach makes base station resort to local recovery of lost frames between CRN base station and its clients, while the second approach implements a modified split TCP connection in which the base station sends crafted acknowledgements back to an Internet-side host on behalf of the corresponding CRN client to boost transmission speed. Simulation results show that the proposed mechanisms result in improvement in TCP performance by as much as 20 times and conserve bandwidth by reducing retransmission overheads. In [13], a cross layer distributed mechanism using CR triggers and freeze TCP to optimize TCP over cognitive radio networks for trains is proposed. The results show that our mechanism can improve the link utilization efficiency as compared to standard TCP.

D. *Application driven Physical and MAC layer schemes*

In [3], several key design considerations at the physical, MAC and application layer that need to be considered in cross layer design framework for C-UWB are proposed. At the physical layer, analysis on Multi-band orthogonal Frequency Division Multiplexing (MB-OFDM) under several UWB channel conditions is presented. Signal-to-noise ratio (SNR) condition and sensing time are taken into account as bridging parameters between the physical layer and the media access control (MAC) to optimize wireless resource allocation. Some preliminary result on the impact of resource allocation at the MAC to the video quality is also analyzed. Finally in [15], an application-driven Multiuser resource allocation and packet scheduling concept for wireless video streaming is shown. This work takes into account the time-varying nature of the wireless channels, as well as the importance of individual video packets, to develop a cross-layer resource allocation and packet scheduling scheme for multiuser video streaming over wireless networks. Our simulation result show that the proposed scheme performs significantly better than a conventional content independent scheme of video transmission.

The schemes discussed above are tabulated to form an easy insight as follows**:**

Protocol /scheme	Cross layer aspects	Advantages
1) Mixed Integer Non-linear Programming (MINP)	power control, channel assignment, and routing	minimizes network energy consumption while maintaining data rate requirements
2) Partially observable Markov decision process (POMDP)	spectrum sensing, access decision, modulation and coding scheme, frame size	maximizes the TCP throughput in CR networks
3) Cognitive Ultra Wideband (C-UWB)	SNR ,sensing time and resource allocation	optimizes wireless resource allocation, supports high data rate as well as BER improvement
4) collaborative channel spectrum-sensing policies with *M/GY* /1-based queuing model	spectrum sensing, the packet scheduling	Improve the delay-QoS provisioning over cognitive radio wireless networks.
5) 1.adaptive modulation with hybrid automatic repeat request	opportunistic spectrum access and spectrum sharing	reliable and optimum packet transmission with qos provisioning and realization of imperfect

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(HARQ) protocol 2. iterative sub gradient method 3.CSMA/CA		spectrum sensing
6) ROSA (ROuting and Spectrum Allocation algorithm)	routing, dynamic spectrum allocation, scheduling, and transmit power control	Throughput maximization with bounded BER guarantees.
7) Multi-band OFDM based UWB system	Detection and shaping the transmitted signal spectrum	allows peaceful coexistence between the primary and secondary systems
8) cross-layer scheduling algorithm	power interference, adaptive modulation and coding	Guarantees QoS requirements of real-time and non-real-time traffic
9) Optimal Channel Sensed Multichannel Cognitive MAC (OCSM-CMAC)	MAC scheduling delay , physical modulation	improved PSNR and good delay performance
10) Optimal channel access scheme (TCP throughput based)	Channel access, modulation and coding scheme, frame size	TCP throughput improves substantially
11) cross-layer protocol of spectrum mobility and handover in C- LTE networks	Transmission time, hand-off	reduces the expected transmission time and the spectrum mobility ratio
12) TCP performance in IEEE 802.22 based WRANs	Packet losses, transmission speed	Improves TCP performance by 20 times and conserves bandwidth by reducing retransmission overheads
13) CR triggered TCP freezing scheme to optimize TCP performance	Link layer trigger, connection manager application at application layer	improves the link utilization efficiency compared to standard TCP.
14) Hierarchical cross-layer distributed framework for integrating power control, channel allocation and routing	Power control, channel allocation, routing	reduces energy consumption, while providing QoS (BER, end-to-end delay and through-put)
15) application-driven Multiuser resource allocation and packet scheduling concept for wireless video streaming	Resource allocation and packet scheduling	minimizes the distortion of the received video sequences
16) Cognitive Radio Manager (CRM).	Resource allocation, sharing and mobility	optimizes the allocation and access to resources and ensures mobility control
17) Adaptive Joint Scheduling of Spectrum Sensing and Data Transmission in CRN	spectrum sensing, data transmission	Helps to attain sensing requirements while throughput loss or transmission delay is minimized
18) resource allocation in DCRN	Resource allocation and routing	minimizes network wide resource wastage in multi-hop DCRN

V. CONCLUSION

Literature survey conveys that, a clear notion of cross-layer design is clearly formulated in the research community. The practical approaches and methodologies are made out. A lot of work has been done on improving the performance of cognitive radio networks with cross layering approach. As far as the implementation of a whole system with all necessary optimization is concerned, still a long way appears to be existing. Timely surveys on the literature and modular implementations will provide path for faster accomplishment. This survey is made with the recent literature resources available. This can be extended and made better with more inclusions in future.

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