The Art of Using Cross-Layer Design in Cognitive Radio Networks

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Abstract. Cognitive Radio Networks (CRNs) have been obtained a significant focusing due to the ability of this technology to dissolve the issues of spectrum overcrowding and underutilization. In a CRNs, the secondary user (SU) is equipped to discover and use abandoned licensed channel, however, they must be desertion the channel if any interference is brought to the primary user (PU) who holds the channels. For that, the dynamic spectrum access (DSA) in CRNs is considered as an important application that allows for SU to use the licensed band in a dynamic way. Nevertheless, there are several challenges on CRNs such as interference, channel selection, routing, and etc. Cross-layer design can provide effective solutions in order to counteract these challenges. To this aim, in this paper, we have studied the existing related work about applying a cross-layer design in CRNs and how the upper layers and the lower layers parameters can optimize with the helping of a cross-layer. Finally, we have explained the implementation challenges of cross-layer design on CRNs.

Keywords: Cross-layer design · Cognitive radio network
Secondary users

1 Introduction

Radio spectrum is considered as precious resources for wireless communications. The spectrum resources, in ancient wireless networks, are used by a fixed spectrum policy that holds the licensed spectrum to the PU [1]. In recent decades, the request on the spectrum resource is being increased, and that called to change the policy of using the licensed spectrum [1,2]. Accordingly, the Federal Communication Committee (FCC) has enabled new rules for dynamically assigning the spectrum [3]. Subsequently, the CR employs to resolve spectrum limitation issues

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through discovering the existence of spectrum holes and used it in a dynamic way [4]. However, CR is suffering from some challenges such as (interference, channel section, spectrum allocation, mobility, etc.) and that bearing on CR [5]. Hence, these challenges and problems can break down the performance of the CRNs [5,6].

Therefore, to make CR user can work efficiently, CRNs have to adopt a cross-layer style. For instance, to share the spectrum holes parameters with network layer, cross-layer will apply through combining getting spectrum sensing data which provide the physical layer and the spectrum schedule through a link-layer to the network layer. Combining these layers can help the network layer to discover the best routing path. For that, the cross-layer structure can provide different solutions for CR challenges and that it can help to optimize network performance.

Thus, this paper studies and discusses the previous related work about cross-layer design. In parallel, we explained how to apply the cross-layer methods in environments of CRNs, and how that can reflect positively on the CRNs and the layers performance. Also, we described the implementation challenges of cross-layer design on CRNs.

The rest of the paper is organized as follows: Sect. 2 explains why cross-layer design is considered as a solution for wireless and CR communication. Section 3 proposes different framework designs for the cross-layer. Section 4 describes how to apply the cross-layer in CR and how can that improve the performance it. Section 5 explains how we can develop the cross-layer framework to be more efficient with the environment of CR and how can benefit from the layer's parameters. Besides, it clarifies the challenges of cross-layer design and summarizes the way of sharing between five layers. Finally, Sect. 6 concludes the paper.

2 Why Cross-Layer Design

In an actual network, every layer in the network stack model has realized a different functional protocol that is interdependent with each other. It makes the process of interaction between these layers is complicated [8]. In spite of the network model drove up to dissolve the issues of designing the basic network functionalities, but it also creates restrictions on optimization of the network performance. From this point of view, the layered network structure has a major disadvantage by making it as a rigid network structure [8], which means the layers in the network stack just care about its functionality and its neighbor layers, and that makes the layers to disregard the interaction with other layers. For that, the ignore interaction between non-contiguous layers can lead to sub-optimal network performance [9]. For instance, it is difficult to enhance QoS and a management mobility in the layered structure due to that it needs to create the interaction between different layers. In reality, the network structure stack is suffering from the limitations and the non-interaction designing between the upper and lower layers. For that, this is called to break the constraints of the traditional network layer stack and optimize the network performance by using a cross-layer method.

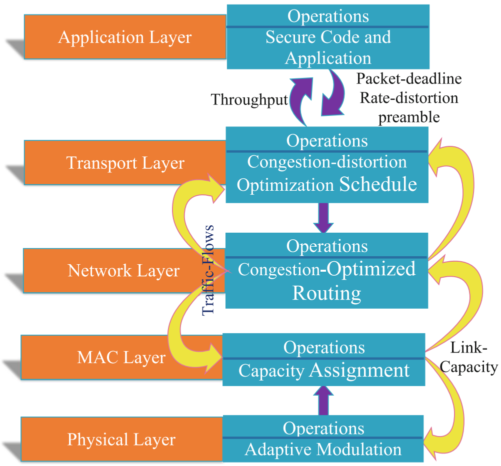

Fig. 1. Cross-layer design framework with information exchange between different layers [14].

In more details, Fig. 1 displays a design of a substitution of a cross-layer framework, where the data transfer between different layers. At link-layer, adaptive modulations are assigning to increase the rate of the link according to the channel conditions. This expands the achievable ability region of the network [10]. At every point of this operation, it refers to a potential giving of the various link-ability. According to the information state (facilities) of the link, MAC and the upper layer, choose from the capacity region at one point through applying the codes, time slots, or frequency bands for each of the links. Thus, the network layer operates together with the MAC layer to define the sequences of network flows that reduce the congestion.

Thus, solving for capability assignments and network flow are changed iteratively between two middle layers which represent a cross-layer framework (network and MAC layer). The process of congestion control and retransmission packet are defined at the transport layer. Lastly, the application layer establishes the most efficient encoding average.

3 A Proposition of Cross-Layer Design

The cross-layer style is a combine-style between upper and lower layers to improve many or all layers under assumed resource restriction. Cross-layer makes to use the cooperation between the protocol layers and evades unwanted interactions to amelioration the network performance in case of the designed is duly [11]. The cross-layer style will integrate data interchange between various layers (not necessarily neighbor layers), adaptivity at every layer to the existing data, and varieties into every layer to confirm it [12]. In generally speaking, this section will review different cross-layer design to boost the efficiency and performance of the network within a cross-layer style as shown in Fig. 2.

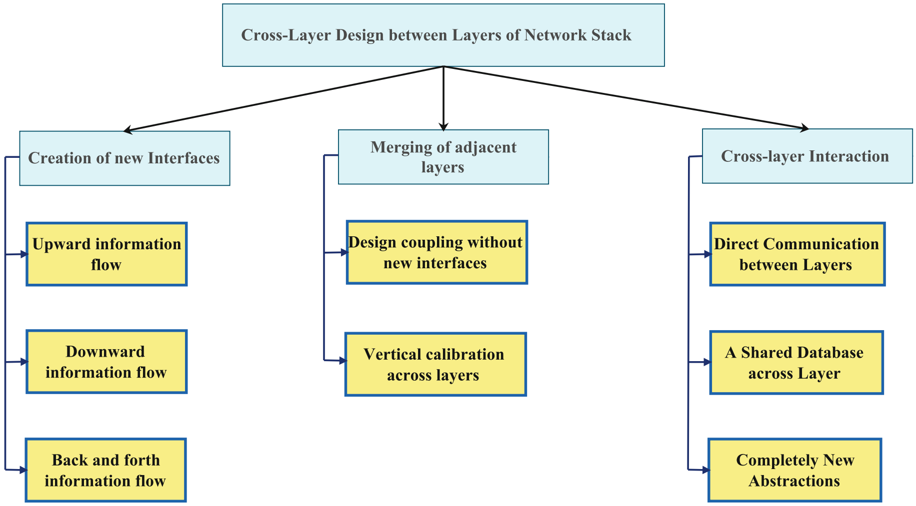

Fig. 2. A proposition of cross-layer design.

3.1 Motivation of Creates a New Interface

The new interfaces area is utilized for taking part among layers at run-time. The style of creating a new interface is a violation the network layer structure due to the traditional architecture is not supported that. We tend to distinguish this category into three sub-types according to [11].

Upward information flow. It refers to the case of following a layer protocol information in a lower layer to higher layers at the runtime according to create a new interface from the lower to a higher layer, as shown in Fig. 3(A). For instance, the loss of packet from the TCP receiver protocol to transport layer from the TCP sender can palpably converse the TCP transmitter to resend the packets if there is any damage in the packet.

Downward information flow. It refers to the case of following a layer protocol information in a higher layer to lower layers at the runtime according to create a new interface from the higher to a lower layer, as shown in Fig. 3(B). As shown, the link-layer will receive information from application layer regarding the delay requires. Also, the link-layer will then deal with packets from delay-sensitive at the applications with more importantly.

Back and forth information. In this class, there are two-layers employed at the same time to perform many functions, and this collaborate executes at the run-time. Usually, the iterative loop is obvious in between a couple of layers, with information flowing back and forth in between them as showcased in Fig. 3(C)

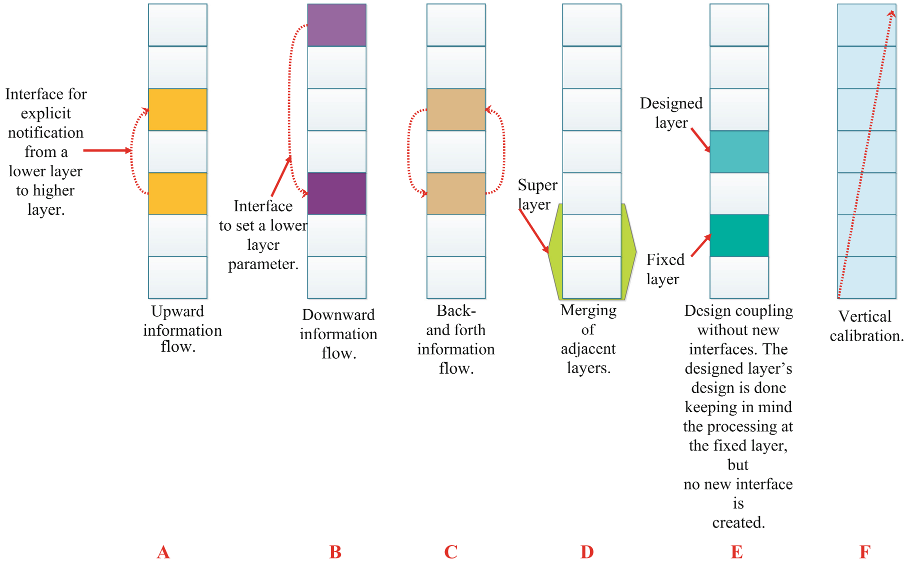

Fig. 3. Clarify the various kinds of cross-layer design suggestion. The rectangular boxes appear the protocol layers [11].

Obviously, the network structure, in this case, has included a couple of new interfaces.

3.2 Merging of Adjacent Layers

Another design of cross-layer is a meeting of adjoining layers. The amid this design, union of enterprises given by the principal layers is called a super-layer. This structure does not need to bother with any creation of new communication interfaces. They make a super-layer can connect with other parts of the stack through the use of interfaces that currently include the underlying stratified style, Fig. 3(D) shows the case of combined neighbor layers.

Design Coupling without New Interfaces. For this type, it includes the conjugation of two or a lot of layers while not building any additional the new interfaces at run-time. This category explains in Fig. 3(E) it's insufferable to switch one layer without creating a matching change to another layer.

Vertical Calibration across Layers. For this type, in light of the fact that the name proposes, the parameter that extends crosswise over layers at runtime is adapted, as represented in Fig. 3(F). The execution of utilization layers relies on the contribution of shifting parameters of the layers under it. It is supposed the mutual harmony that it can assist to acquire superior performance than the individual layer parameters.

3.3 Implementing Cross-Layer Interactions

Based on cross-layer interaction, and enforcement that it can be separated into three categories, as explained below.

Direct Communication between layers. The combine of runtime information enables the layers to be able to connect directly with each other, as came out in Fig. 4(a). In this case, the phenomenon of communication is transparent, and that making the parameters of one layer is available to another layer at runtime. Thus, there are a lot of methods that enable the layers to be able to connect with one another by protocol header or further information header.

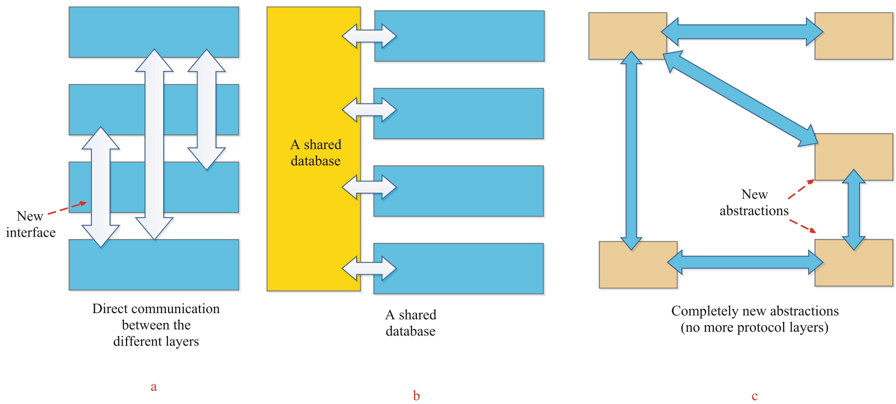

Fig. 4. Clarify the various kinds of cross-layer design suggestion. The rectangular boxes appear the protocol layers [11].

A Shared Database across Layers. As the name recommends, in this type, the database can reach it by every layer, as outlined in Fig. 4(b). The joint database is considered as a new layer that supplies the administration of capacity/recovery of information to/from every one of the layers. This class is appropriate for the vertical building as specified in the previous area as mention it. However, this structure has a disadvantage due to this design requires creating new interfaces between the stack on the network layer and the database.

Completely New Abstractions. In this class, there is regularly a new abstraction with no more protocol layers, that we have explained it in schematically organize as shown in Fig. 4(c). This class offers adaptability during run-time and design and that because of the wealthy interaction between the network layers stack.

4 Cross-Layer Design for Cognitive Radio Networks

As illustrated in Fig. 5, this part describes the map of cross-layer design in CRNs and discuss some related works to explain why CRNs ought to implement the cross-layer design between these layers.

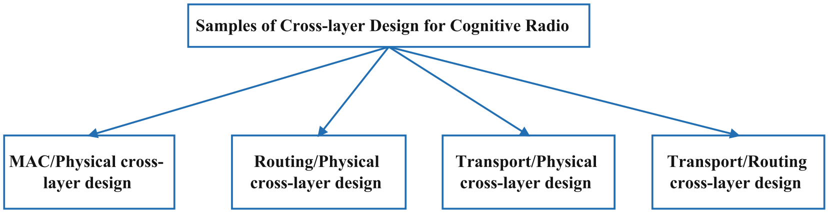

Fig. 5. Cross-layer design for CRNs

MAC/Physical cross-layer design. Cross-layer design between the physical and MAC generally used in CRNs due to combining these two layers contribute to the efficiency of this type of network (CRNs). In another word, the MAC layer has to be able to adjust the provider connection resources and modify the configuration of user mobility. The superior physical layer strategies, which include standard categories inclusive of a couple of coding and modulation schemes, superior antenna strategies, MIMO and OFDM technologies and extremely wide bandwidth, offer a terrific capacity of enhanced overall to reduce of delay, throughput and packet loss [12]. Overall, utilizing channel expertise at MAC layer enable to a utilization of the channel and outcomes overall in an efficient performance.

In [13], the author deal with combined of both the spectrum sensing at the physical layer and the cognitive protocol at the link layer to augment spectrum effectiveness whereas restricting the interference probability to PU. In [14], the author applied method of cross-layer style on pragmatic multi-channel MAC protocols, that incorporate between the physical layer for sensing process for spectrum at and the packet tabulation at MAC layer. In traditional CR protocols, the idle waiting for time-lots might involve a high average of the packet and loss, and poor quality of service outcomes for SU. To get over this drawback, in [15], The author proposed a cross-layer structure and applied the scheduling algorithm to reduce the rate of packet delay of the SU under restrictions on transferring rate power which sends by the SU and delay rate of the packet for the PU. Besides, the allocation algorithm for a useful resource is as well recommended to designate the SU channels at which the overall throughput of the CRNs increased.

In [16], the author recommended a cross-layer design as an arranging approach with reliable interference control at the link-layer for a couple of SU with a variety of QoS necessities. In CRNs, most vital elements are throughput enhancement and reduce power usage. Nevertheless, the conflicted case occurs while the throughput is increasing and the power decreasing where each other in a sensible state of affairs. To solve this problem, in [17], the author introduced a cross-layer strategy for combined link scheduling and power control in CRNs. Via this technique, the throughput, enhanced rate enables without extreme transmit powers.

Routing/Physical cross-layer design. The approach of cognitive radio provides a dynamic change of underlying radio community parameters of the physical layer. This dynamic control guarantees overall performance enhancement contrasted with traditional radios with static source assignment style. In [18], the author suggested a cross-layer promoting platform to collectively style the spectrum take part and flowing routing with interference challenges in CRNs. They can develop a promoting issue in the form of mixed-integer linear programming (MILP) to offer an intelligent routing.

Transport/Physical cross-layer design. For the multi-hop features in the wireless network, the ability of a link is time-various as an outcome of the elements which consist of interference, variable channel quality, then on. The phenomenon packet loss in wireless network appears for causes such as channel error, congestion, or node quality [19]. In order to enhance CR end-to-end procedure, the variable link capability ought to be taken into consideration.

For a long time, the artwork of combine between the physical layer and the transport layer for wireless networks has been investigated [19]. The bearing on strategies in the literature may be labeled towards a couple of classes. Within the primary class, the TCP protocol for congestion-control is confident to improve through the data that obtained from the physical layer into consideration. As an example, we can apply a significant information from the physical layer to distinguish the phenomenon of packet loss because of the congestion or bad link. However, rather than passively taking movement most efficiently in TCP, TCP and the physical layer can manipulate and enhanced collectively, these types of strategies belong to the second classification, which includes excess complex algorithms and additional sophisticated protocols, and achievements [18].

Many several parameters may be managed within the physical layer. It is tough and incorrect to possess by one management procedure to include the all of the optimization parameters. A useful method is to specialize in one parameter or two parameters within the procedures and suppose that alternative parameters are fastened. As an example, consideration facility management due to the significant method of harmonizing the physical-layer performance [20]. The routing direction is believed to be fastened in shared power control and congestion algorithmic. Once congestion appears, a technique attempts to avoid congestion and search a better routing path.

Transport/Routing cross-layer design. In CRNs, the transport layer also is suffering from congestion and low response issues in CRNs. However, there is a little bit of research that has been focused on transport-layer dilemmas in a cognitive radio setting [21]. In [22] the author revealed that the protocols within the transport layer are very slow to reply quickly. That means the protocol of transport-layer are not able to offer a powerful process, and not reliable to utilizing in CRNs. For this reason, the author diagnosed the necessities of protocols for the transport layer in CRNs and proposed a novel modular structure for supplementing the transport layer. In more details, by intending on using the cross-layer model through providing a new module to the existing layered community structure for incorporating cognitive capabilities between transport and network layer, and that will increase growth throughput for CR user. In including, this examine confirmed that during cognitive radio networks cut-up of the delivery layer from different layers is viable and protocols for the layered architecture can utilize available bandwidth correctly.

5 Develop Cross-Layer Approach and Challenges

A lot of research has been done to develop the prototype of communication in CRNs since 15 years [23]. However, CR user requests many complex operations to perform new features [23]. Precisely, for a CR is important to detect the surroundings and framework of functionality, distinguish the relevant attributes of this circumstance, make a decision founded on them, and eventually connect suitably. However, the issue in cross-layer design in CRNs that how to make an efficient cross-layer design and how integrated between the layers parameter in a manner consistent with requirements CRNs.

Meanwhile, a cross-layer design can develop through taking part a variety of protocol layer starting from the application layer and ended to physical layer [24]. For instance, the process of merging different layers in one layer that it can reduce the overhead in term of cross-layer information interchange [24]. However, to boost the network efficiency and increase the users interests, sharing between the layers of routing, MAC, physical, transport, and application become indispensable part, where the transport layer protocol is measured in the congestion control part, physical and MAC layers are identify in the arranging and sensing part, and routing is regarded in the fundamental interaction among congestion control and scheduling, and application layer is considered in QoS part [23].

As shown in Table 1, every layer in the network layer stack has a variety of parameters and features. For that, every layer can supply different information about the network environments [24]. In CRNs, there are new functions that have been added to the layers in network stacks due to the nature of dynamic spectrum access in CRNs [25,27]. For that, SU needs to discover the surrounding environment to be able to transfer the information with low-cost routing, and without making any interference with the PU [26,31]. In addition, to explore the unused spectrum in a reliability way [24,32]. Notwithstanding, the border of network layer stack has to violate to design a practical cross-layer model able to draw new horizons of managing the operations in CRNs.

The cross-layer violates the traditional layered structure through permitting for communication directly between layers or combine between distant layers [26], significantly for wireless networks. The cross-layer style provides a solution key to enhance network functionality [24]. Even so, the cross-layer style is

Table 1. Parameters and functions of the network layers stack

Layers	Parameters	Functionality of layers in CRNs
Application-Layer	Source coding rate, Buffer priority, Packet arrival rate	The principal function of Cognitive Radio Application Layer is to handle disputes between different applications when a new contact is created
Transport-Layer	Congestion control, Traffic patterns, Packet-loss,	The transport layer in cognitive radio employs to draw the way for QoS at the application layer and the and lower layers and also to initiate transport layer connection
Network-Layer	Network topology, End-to-End delay, Metric of routing, Packet size, Routing cost	The network layer in Cognitive Radio can supply two important services, namely Routing and Flow/admission control
Link-Layer (MAC)	Frame size, Medium Access Feedback, Control channel-related information	The link-layer in cognitive radio enable to saving the parameters and interfaces starting at link-layer radio to higher layers protocols of cognitive radio
Physical-Layer	Transmitter power, Spreading type, Channel state information, External interference and SINR, Operation mode, RSSI	Physical Layer in Cognitive Radio can supply two primary functions, namely the communication service and sensing services

debatable as a result of it violates traditional style principles of the network layer stack. In spite of being debatable in methods of the networking community, but it also has advantages of using a cross-layer style [30].

In other words, a cross-layer style proposals should be holistic [23]. As an example of developing a cross-layer design, In [24], the author proposed a new cross-layer design by using a planned to utility optimization drawback (GUOP) in CRAHNs with various restrictions of parts of the physical layer to the appliance layer. It is entirely different from the reverse cross-layer style. By calculative in an associate reiterative circle in between and all over layers with data flowing back and forth performing arts completely a variety of activities, the planned COVD is in a position to resolve the five-layers concerned networking drawback globally and optimally. For that, mix five-layer represent is made a replacement behavior for the cross-layer designs, and overcomes the challenges of participating between the layers stack.

From another perspective, the challenges of cross-layer implements in modularity design, protocol ability, system complexity, and compatibility between layers [23–25]. Once returning to the particular execution of the previous designs, the changes of protocols in multiple layers will affect on reusable of the software system, balancing protocol model and adaptability to different applications [27]. Through cross-layer fashion, the quality operating approach in the protocol stack is betterment [27]. Though, a wireless network with cross-layer style might also be contradictory with different platforms [29]. Therefore, inter-operation between totally different networks is tough to keep up. That it always requires noting that such problems typically do not exist in a very superimposed style theme [19]. To avoid these issues, exchange ought to be created amongst the functionality improvement via cross-layer style and profit loss of superimposed style [23,24].

The art of cross-layer design has rules to initiate the design through break the limitation of the network layer stack and create new interfaces to pass and integrate the information of every layer to other layers [28]. The features of cross-layer design have represented a solution for many challenges, especially in CRNs [14,24]. Nevertheless, the researchers in cross-layer design need to meet future challenges of design cross-layer pattern that must agree with the features and issues CRNs technology.

6 Conclusion

This paper studies and investigates the cross-layer design from various perspectives by relying on the revision of previous studies to clarify methods of designing cross-layer. Moreover, to explain how to apply cross-layer in CRNs, and to demonstrate the ability of these ways to solve the problems that face up the CRNs. However, the cross-layer design also has different challenges while implementation, therefore, it also discusses the challenges of implement a cross-layer in CRNs.

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