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Cross-Layer Standards for Reconfigurable Systems

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Abstract:

In recent times, university and polytechnic campuses and institutional offices information communication supported by WLAN or WiMAX technology is not enough. As communication efficiency is desired in centralized cognitive radio (CR) with improved interactions between PHY, MAC and transport layers. With specific objective of developing reconfigurable infrastructure to increase number of served users, without corresponding increase in bandwidth (cost), formulated reconfigurable/infrastructure CR network model is conceived. Vertical handover between heterogeneous technologies (Wi-Fi, 3G, 3.5G, 4G, Zigbee, Cellular etc) is addressed by IEEE 802.21 standard and legacy IEEE 802.11 but layered architecture of protocol design cannot provide optimum performance. Wireless Regional Ad-hoc Network (WRAN) and Mobile Ad-hoc NETwork (MANET) as main technologies supporting CR wireless networks' scalability enables cross layer (CL) designs. Though the CLdesigns violates layered protocol, CR CL offer standards, which supports seamless roaming and smooth handovers required in reconfigurable models. Discussing the characteristic features of various CL frameworks presented in this research, legacy IEEE 802.11 WLAN-based built-in chipset interfaces provide standardizations enhance network scalability offered by reconfiguration and interoperability capabilities of HPR in extending served users. Also, improved CL standards compensates for performance tradeoff between wider coverage and slower speeds of transmission using optimized routing, media access and PHY layer techniques. These functions yield high capacity links for users to engage ubiquitous computing while maximizing allocated spectrum.

***Keywords* — cross-layer, cognitivewimax, reconfigurable radio system, sensing, vertical handover, wran .**

I. INTRODUCTION

An increasing number of wireless technologies and growing number of wireless providers of different sizes have in fact built a heterogeneous wireless network of worldwide coverage since over a decade [1]. Reconfigurable Communication System (RCS) model, otherwise called Cognitive Radio System (CRS) consist of Hardware Processing Resources (HPRs) standardized by IEEE802.22WG [2]. With wireless networks' requirement of *guaranteed* Quality of Service (QoS) or *best-effort* Quality of Service, advancement in CL design help maintained ubiquitous access and scaling. More so, communication efficiency sought in centralized cognitive radio (CR) is aided by CL functions and capabilities. CL approach implementable at base stations offer no changes to parameters in the end system [3]. While guaranteed QoS is provided for PUs in CRN, [4] stipulated that best-effort QoS is provided for SUs, as they employ the unused spectrum of PUs for their communication in CRN.

Reconfigured network models deliver higher speed Internet access by managed handovers.

Development of mobile devices (CPU, storage and memory) and use of mobile networks (Ad-Hoc, Wi-Fi, WiMAX, 3.5G and 4G) make it more convenient and desirable for Internet users to be connected everywhere. Existing network standards including GSM, CDMA, LTE, WiFi, WiMAX, Fiber Optics and others does not provide for interoperation and dynamic access to wireless networks. This limitation is a major drawback, which also inhibit optimal usage of spectrum and subsequent reduction of served users. Specific capabilities of cognitive infrastructures, including reconfigurable radio system (RRS) are cognition and reconfiguration [5], which assist users' practical implementation of dynamic spectrum access (DSA). To extend number of served users in heterogeneous wireless environment, RRS is modeled to implement reconfiguration over HPRs.

In academic environments, users are serviced with distinct means of Internet access and the frequency spectrum is constantly in use by two major categories of users. The first set of users called primary users are licensed users (LUs) while the second set are called secondary unlicensed users (UUs). Based on the concept of mobility and roaming, users directly registered with their home networks are therefore licensed users but user leaving home network for foreign network is a secondary user at the foreign location. Access to the web for various functions of browsing, chatting, searching, file transfers and other content-based activities imagines profitable access and continued qualitative service. Users at foreign location, identified as SUs [6] are also called CR users [7]. In agreement with [8], [9] posted that CRN elements,with built-in intelligence and cognitive capabilities embedded in SUs, flexibly adapt transmission and reception parameters to provide space for unlicensed secondary users (SUs). Hence, they dynamically access licensed spectrum allocated to primary users (PUs)enabling full implementation of CR CL standardizations [6].

Vertical handovers in wireless networking includes automatic switching from one technology (e.g. IEEE 802) to another (e.g. cellular technology) without service interruption. For reconfigurable models, specific radio functions necessary for effective handover are captured and summarized in [10] as cognitive functions. These functions are defined as spectrum sensing, spectrum allocation, spectrum sharing and spectrum mobility, described in [11] and [12] as cognition cycle.

Problem Statement. In wireless networks, layered architecture of protocol design cannot provide optimum performance of increased network capacity [13]; high end-to-end throughput or reduced interference and power consumption [14]. Also, growing number of wireless technologies and providers, plus increasing need to serve many users, call for the design of CL protocols because CRCL require defined interoperability. A key challenge to employ cognitive-radio cross-layer (CRCL) standardization is to compensate for the tradeoff between wider coverage and slower speeds, being major limitations in layered abstraction worth consideration as identified in [15]. Developed in [6], CRN model simulation provided proofs of reconfiguration with formulated dynamic algorithms (open shortest path forwarding routing protocol) to offer solution to problems enumerated in [14].

II. LAYERED STRUCTURES - REVIEW

Modularity in network protocol design enables interoperability and flexibility, using layering paradigms. Layered architecture facilitate built-in standardization but CRCL architecture facilitates interoperability [4]. Traditionally, system architectures follow strict layering principles, which sometimes inhibits interoperability, flexibility, and efficient implementations. ISO reference model, illustrated the layering approach supporting IEEE 802 standards [16]. Also, [9] in resonance with [15] viewed CL design with network coding as an optimization technique for multi-user cognitive radio systems. Developed in 1980s, standardization of network architectures using layering approach is depicted in Fig. 1. Layered architecture follows abstraction principle where the internal parameters of protocols inside layer n are hidden to the remainder layers n-1, $n+1$. Inter-layer communication are limited to procedure calls and responses between adjacent layers. This enables any layer n make use of services provided by layers below *n-1, n-2,…* and making services available to layers *n+1, n+2,…* above.

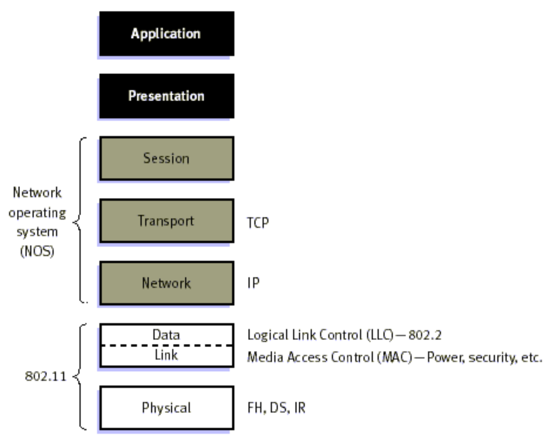

Fig. 1 Layered architectural support for CL

IEEE 802 WG [17] defined PHY and DLL/MAC as the legacy IEEE 802.11 standards and later initiated IEEE802.22 WG to standardize worldwide unlicensed operation in TV broadcast bands with target application of wireless broadband data access to rural/remote areas [18]. IEEE802.22 (WRAN) has performance comparable to Digital Subscribers Line (DSL) and cable modems because it enables point to multipoint implementation for data traffic BTS. All standard addresses the needs of PHY and MAC layers and IEEE later established the IEEE1900 project as standards targeted at DSA and CR, which later evolved into IEEE standards Coordinating Committee on Next Generation Radio and Spectrum Management (SCC-NGRSM).

A. Fundamentals of Reconfigurable Radio System (RRS)

RRS is a generic term for radio systems including Software Defined Radio (SDR) within the Cognitive Radio System (CRS) [19]. Defined in [20], [21] and simulated in [6], CRS, characterized with Hardware Processing Resources (HPRs) employs a technology of sensing to make its radio system obtain knowledge of operational and geographical environment, based on established policies and internal states, and dynamically, autonomously adjust operational parameters and protocolto learn results and achieve predefined objectives [5]. RRS enables reconfiguration for each Radio Access Technologies (RATs) in the heterogeneous environments to exploit International Mobile Telecommunication (IMT) and GSM bands. IMT and GSM bands are licensed spectrums allocated to IMT and GSM systems to increase the efficiency of radio resource management in intra-operator communications [7], [22].

B. Software Defined Radio (SDR)

SDR is radio transmitter/receiver, which employs the technology of enabling RF operating parameters (frequency range, modulation type, output power, bit rate etc) be set/altered in software according to systems'/users' specifications or application needs [6].

Reference [23] also demonstrated the techniques of SDR in providing *software control* of variety of modulation techniques in wideband or narrowband operations. Communication security functions and waveform requirements of current wireless systems evolves various CL standards over a broad frequency range [24]. As multiband, multistandard, multiservice and multichannel system, CR waveform functionalities reconfigures to provide continuous service delivery through software in CRS implementations [6], [25].

C. Architecture of Cognitive Radio Network (CRN)

CRN, formed by a collection of CR-enabled SUs (generic mobile devices MDs), Base Stations (BTSs) or Access Points (APs) and Internet backbone. Each CR is equipped with cognitive functions to perceive current network conditions, plan, decide and act to achieve end-to-end goals. [7] classified CRN as infrastructure, ad-hoc and mesh architectures and are generally equipped with: (i) cognitive capability - ability to sense the environment; (ii) self-organized capability - ability to analyze and learn sensed information and (iii) reconfigurable capability - ability to adapt to the environment. CRN learns from these adaptations to make decisions of basic signal-processes. Cognitive architectural layers, shown in fig. 2 (appendix) established the need for efficient coordination of decision variables at lower PHY/DLL/MAC layer to achieve guaranteed QoS at upper layers of network and application [6].

D. Cognitive cycle functions defined

Four CR-specific functions implemented in additional to signaling functions of coding/decoding, modulation/demodulation, switching, routing etc includes: s*pectrum sensing* function enables CR user determine which portions of allocated spectrum are available by monitoring and identifying those appropriate for communication; s*pectrum allocation* function enables CR user select best unoccupied band and operating over it using different policies based on QoS assumption; s*pectrum sharing* function enabled sharing between PU and SU with spectrum coordination for collision avoidance between multiple CR users and interference with PU; and s*pectrum mobility* function of ensuring unlicensed CR users give priority to PU's need of spectrum, moving to another spectrum hole whenever PU requires currently occupied spectrum band for communication.

Information sharing between all CR layers defined in [25] and upheld by CL is discussed in [24]. As shown in fig. 2, existence of PU around CR-enabled transceiver is detected by interaction of the two lower levels (PHY and DLL) in spectrum sensing and sharing. Appropriate spectrum (hole) is allocated to SU based on decision variables (including sensed information, routing metrics, transport, cognitive application requirements (best-effort QoS), power and acceptable interference level) when PU is inactive. SU moves transmission to another channel to continue its transmission any moment PU needs to transmit. This is the principle used in spectrum mobility [6].

Infrastructure CRN are centralized architecture with separate BTS for SUs and PUs. Though infrastructure-less CR Ad-Hoc Network (CRAHN) enable communication in ad-hoc mesh modes and Internet access through mesh routers enable Cognitive wireless mesh networks (CRWMN) self-organize and self-configure while operating. In distributed architectures implemented in [26], cognitive nodes (CN) implements spectrum overlay or underlay approach to dynamically access spectrum [20]. Information availability at network layer initiates hand-offs and completion events for handovers.

III. CL DESIGN TARGETS AND SPECIFICATIONS

Legacy IEEE 802.11 standard is defined for two main components - APs and BTSs as Internet backbone for wireless communication [17]. Some CL design works based on published CR standards offer pointers to effective utilization of wireless spectrum as major application of cognitive systems. Need for spectrum utilization efficiency was vital and introduction of unlicensed SU in CRN to make use of the vacant part of spectrum without interfering operations/transmission of PU stimulated the need to fashion out the following guidelines to achieve improved CL design specifications:

a. TCP performance: this has been an issue in wireless networks and it motivates designers to seek CL solution. Proposed CRCL solutions having close interaction between transport and MAC/PHY layers in order to improve the communication efficiency in a CRN client is aimed as a guideline to boost transmission speed.

b. sensing: with the sensing of incumbent signal taken as most important task in all CR paradigms, standards are required to set the requirements for detection accuracy and acceptable interference. This will enable designers access reliable sensing using collision avoidance (CSMA/CA) mechanism at the MAC layer with spectrum sensing (SpSe) implemented as a Markov chain model. Proposed method is compatible with IEEE 802.22 and ECMA-392 standards.

c. PU protection: major of PU protection is another specification for sensing performance in CR over TVWS. Proposed in [27], the work investigates a CL mechanism of using cross layer cognitive engine (CLCE) within IEEE 802.22 standard framework to share information between MAC and PHY layers, so sensing measurements can influence spectrum access decisions. CLCE forms a basis of an enhanced detection algorithm to outperform existing PU detection algorithms applied to IEEE 802.22 WRAN standard [10].

d. Cognitive radio ad hoc (CRAHN): this guideline aimed for application in sensor networks, machine-to-machine (M2M) communications and Internet of things (IoT). Multi-hop CRAHNs handles issues (like collision due to channel contention) affecting network performance among different links at the MAC layer. CLMAC schemes enable multi-hop CRAHNs to ensure interactions providing optimum operating point for CR users against three barriers of. congestion, collision and interference [28]. Proposed CRCL PHY/MAC protocol optimized framework suggested in [6] achieve energy efficiency and contention fairness according to specifications of IEEE 802.22 standard defined for CRS.

A. *Cross-Layer Approach for RRS*

CL approach is protocol design implemented by the violation of a reference layered architecture [21]. Violation of layered architecture encompass creating new interfaces between layers, redefining the layer boundaries, designing protocol at a layer based on details of how another layer is designed, joint tuning of parameters across any two of the layers or other techniques.

Three architectural approach used for the CL design are m*erging layer* technique (adjacent layers merged into a single layer with optimum functionality of initial layer adopted) done on NET and Transport layer while adopting NET; *new interface* technique (information exchange between non-adjacent layers using newly created interface) and *parallel calibration* technique (parameter calibration in some layer using parallel structure as shared interface) as done on MAC mobility and NET routing to provide cross-interaction between DLL and NET layers as shown in fig. 3 (appendix).

IV. IMPROVEMENT ON STANDARDIZATION BY CRCL DESIGN

CRs enhance information sharing between all layers. CL design techniques shown in fig. 3 offer several ongoing CR standardization activities and workings aimed at considering derived CRCL standards, as violations to layered protocols. Standards also set requirements, specifications, guidelines and characteristics to be observed consistently by designers and manufacturers usually do not specify algorithms, methods or protocols for this purpose. Designers are not confined to use any algorithm (or method) provided the specified requirements of the respective standard is attained.

Various CL design approaches had been implemented for different concerns. For transmission efficiency of high-bandwidth traffic driven for planned QoS while implementing underlay CRN to guarantee PU protection, CL distributed control algorithm is speculated to maintain service guarantee of reliability, latency and data rate. Therefore, for the suitability of this research, some CRCL standardizations for the working of CRAHNs, MANETs, WRAN, TVWS etcare named among many others.

CL between PHY, DLL/MAC and NET is effected on centralized CRN to maximize throughput on PHY layer’s adaptive modulation and coding (AMC) while DLL/MAC layer’s adaptive frame size (AFS) is handled in underlay technique shown in fig. 3(i and iv). Earlierdesigned CL optimization framework for Call Admission Control (CAC) strategy for spectrum sensing on PHY layer, simultaneously enabled tuning sensed spectrum to minimize dropping rate at MAC as shown in fig.3(ii).Reference [29] also implemented CL approach’ on CR-based Connection Admission Control provides guarantee QoS to heterogeneous traffic in WiMAX using Adaptive Coding and Modulation information. CognitiveWiMAX system operates under many spectrum assignments, improving system capacity [4] and procedures of CL design between PHY, DLL and NET jointly optimizes user need, routing, media access and layer functions to deliver improvement in standardizations outlined in 1 to 7.

1) Wireless Radio Ad-Hoc Network: WRAN (IEEE 802.22)

WRANIEEE 802.22 standard defined CL design between PHY-MAC for centralized cognitive radio PHY-MAC layer standard developed to exploit vacant TV spectrum bands. TV white spaces (TVWS) is fashioned to provide wireless broadband access everywhere [17]. IEEE 802.22 networks operates in point to multipoint basis making CRN divisible into cells and each one comprising of BTS with estimated coverage of radius 17 km to 100 km [10].

CL interaction enable WRAN end users, called customer premise equipment (CPEs) provide PU protection in cognitive networking while implementing spectrum sensing. Geolocation database provisions PU-SU coexistence on same transmission band.

***2)* WhiteSpace Standard: WSS (IEEE 802.11af, White-Fi)**

IEEE presented another standard called *White-Fi* to exploit the TVWSs in another scenario using personal and portable devices an. IEEE 802.11af adapts the current IEEE 82.11 standards to make use of the TVWSs between 54 and 750 MHz but smaller transmission range up to 1 km was considered [17]. These modifications occur mainly in PHY and MAC of legacy IEEE 802.11 standard.

***3)* Vertical Handover in Heterogeneous Network standard: VHHN (IEEE 802.21)**

Problem of vertical handovers between heterogeneous technologies is being addressed by another CL *IEEE 802.21* standard. Vertical handover, an automatic switching from one technology to another without service disruption is advertised efficiently under CRCL. Metrics, which initiate vertical handover is evaluated in [6] and [30] for optimization while switching between IEEE 802, cellular technology or WiMAX technologies. Received signal strength (RSS), application need (user preference), network conditions, application types, cost etc. are factors considered in different layers of*IEEE 802.21* [8].

IEEE 802.21 standard provide an explicit CL entity introduced and deployable as a framework for CL signaling at higher levels to interact with lower layers and provide session continuity, riding on the interoperability of the standard. IEEE 802.21 technology creates a mid-layer between layers 2 and 3 called layer 2.5 media independent handover (MIH) to provide upper layer services enabling users communicate with protocols of lower DLL and PHY layers [31].

***4)* Microwave standard or CognitiveWiMAX: (IEEE 802.16h)**

Worldwide interoperability for Microwave Access (WiMAX) is dented as IEEE 802.16 standard in 2009 but in its second amendment in 2012, it was denoted by IEEE 802.16h and some cognitive mechanisms for license-exempt operation of WiMAX networks for frequencies below 11GHz was introduced. WiMAX network enable coexistence of licensed users and unlicensed users sharing the same frequency band.

***5)*CognitivePHY-MAC: (IEEE 802.16n)**

Proposed as another variant of *cognitive PHY-MAC* framework to achieve two major goals of enabling coexistence among license exempt (LE) systems based on IEEE 802.16 standards only and facilitate the coexistence of such systems with primary users (licensed system of any other technology) type. Two modes of operation of uncoordinated coexistence mechanisms and coordinated co-existence is allowed. Multiple CR networks coexist in the same region, reducing generated interference as the networks are classified as neighbour features in mesh architectures.

***6)* Television Band Devices: TVBD (IEEE 802.11ag)**

TVBD standardization is application in Medical Body Area Networks where it is required to either have a geolocation capability or be professionally installed in a specified fixed location where list of available channels from an authorized database is retrievable. Fixed TVBDs can only operate on channels that are not adjacent to an incumbent TV signal in any channel between 2 and 51 except channels 3, 4, and 37. Portable devices such as PC and mobile devices are restricted to channels 21 – 51.

***7)* Wireless Home: (ECMA-392 – MUX)**

ECMA International as an industry association is dedicated to the standardization of information and communication technology (ICT) and consumer electronics (CE) ECMA-392 standardized as CL approach between MAC-PHY operation in TV White Space [32]. Target applications including wireless home and business network access over TV White spaces, similar to IEEE 802.11af but characterized with merging adopts link scheduling MAC function to dynamically allocate channel in overlay approach.

Major difference between standards *IEEE 802.11af* and *ECMA-392* are mechanisms of incumbent protection and supported bandwidth utilization [17]. In addition to acquisition of available channels through a database, ECMA-392 additionally supports spectrum sensing functionality because it enables a periodic check of incumbent signal presence over white spaces. IEEE 802.11af does not engage periodic checks. Also, ECMA-392 standard specifies a MAC-sub-layer-PHY layer sharing for portable cognitive wireless networks using session management protocol. Sub-layer, another CRCL entity enables coexistence of concurrent active higher layer protocols within single device. MAC sublayer routes outgoing and incoming service data between corresponding higher layers and two lower layers

A. DISCUSSIONS AND EVALUATION

CL techniques for transmission of high-bandwidth content over current network devices (mobile node, AP, BTS) combines mobile and cellular networks while operating over licensed and TVWS spectrums. IEEE 802.22 standard consideration of two sensing (fast sensing and fine sensing) techniques define specifications for each type corresponding to sensing durations suggested in [33].

CRS implement spectrum management functions with some other functions to enable CL interactions inherent to more than one single layer. These functions influence different layers to stabilize operations. CoMP technology formulated and investigated in [23] provided another proven offer of *multiplied link capacity* with signal maximization signifying extension of bandwidth with insignificant minimal interference. Cognition cycle, eliminates adjacent co-channel users' interferences with resultant increase in spectral usage, directly compensating for increased served users

Achievable within imminent operations of CRS/RRS, HPRs and CRCL standardization, cognitive functionalities supporting CR (IEEE 802.11af or IEEE 802.22) networks' implementation of vertical handover equip RRS model with participatory CRCL capability and efficiency at derived layers between application, network, transport, data link and physical layers.Mobility management functionality also provides session continuity resulting from vertical handover in the network layer. CL-based approaches shown in fig. 2 enables fewer handover delays, less packet losses, higher throughputs, and better/guaranteed QoS.

V. CONCLUSION

With the problem of vertical handover addressed by VHHN IEEE 802.21 standardization and DCA of CRCL-design involving PHY-MAC-NET and application functions, interoperability is enhanced in CRN HPRs. Built-in intelligence and cognitive capability of RCS, flexibly adapt transmission and reception parameters to provide more space for unlicensed SUs to transmit. Communication efficiency is therefore attained in centralized CRN with highly provisioned spectrum-aware communication paradigm features. Also, secured end-to-end transmission offer of TCP enables many SUs to communicate reliably over unoccupied TVWS bands [34].

In this research, various architectures of CRN,RCS fundamentals and CRCL design targets offerstandardizations based on legacy IEEE 802.11 and IEEE 802.22 specifications. Improvements made on existing CL standardization outlined also justify CRCL design offer of spectrum mobility advantage in DLL, fast sensing in PHY, efficient routing and handover in NET. These approach jointly optimize layer functions, yielding high capacity links. In addition, the various interactions (between PHY, MAC, transport and NET layers) does not change any parameter in SUs' end systems while facilitating the smooth handover, aided by fast PHY layer sensing.

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APPENDIX

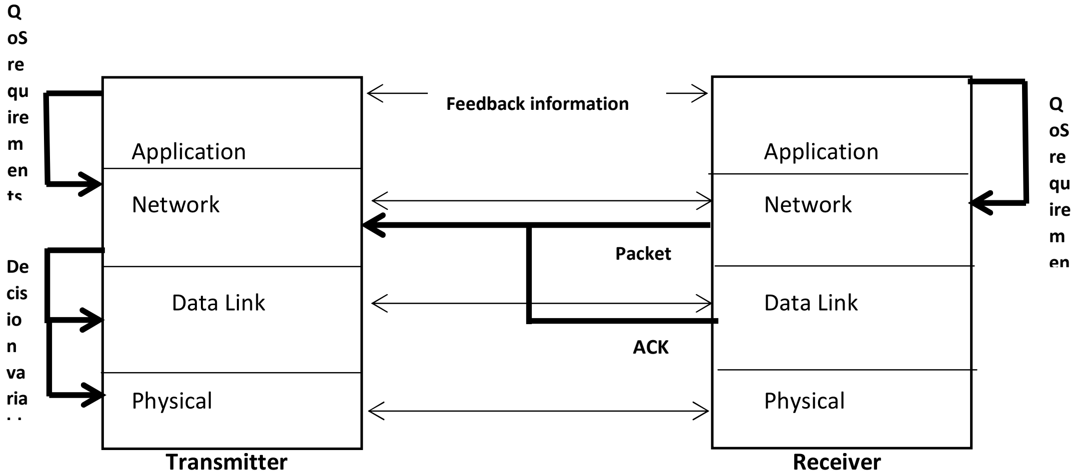

Fig. 2 Architectural layers in CRN

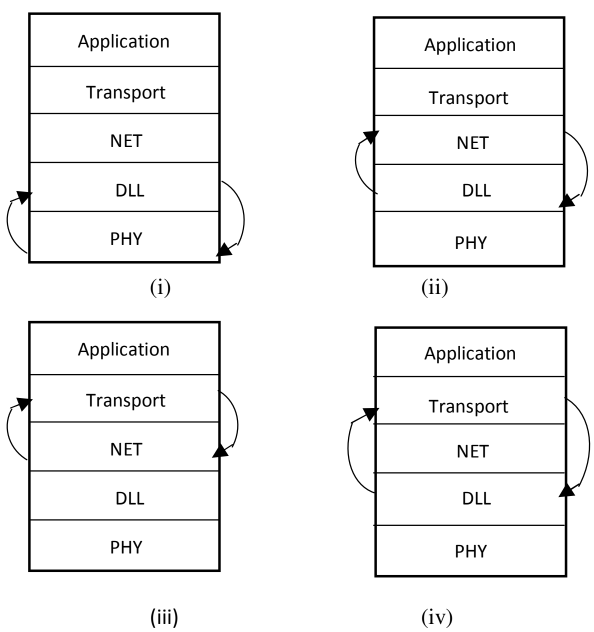

Fig. 3 Cross-layer design (adopted from [4])