*IRACST – International Journal of Computer Networks and Wireless Communications (IJCNWC), ISSN: 2250-3501*
*Vol. 2, No. 1, 2012*

# Cross-Layer Design for wireless mesh networks

B.Nandini[1]
[1](Asst.Prof, Dept of CSE, Telangana University, Nizamabad, A.P, India.)
Anand Tumma[2]
[2](academic consultant, Dept of CSE, Telangana University, Nizamabad, A.P, India.)

***Abstract*:**

**Cross-Layer Design has recently become the new hype in wireless communication systems. Cross-Layer Design has a great potential in future wireless communication Systems. Cross-layer design for quality of service (QoS) in wireless mesh networks (WMNs) has attracted much research interest recently. Several key technologies spanning all layers, from physical up to network layer, have to be exploited and novel algorithms for harmonic and efficient layer interaction must be designed.**

Keywords: Wireless ad hoc networks, osi-iso layer, cross layer design, Wireless mesh networks, QoS.

## I. Introduction

Wireless mesh networks (WMNs) is a relatively new and promising key technology for next generation wireless networking that have recently attracted both the academic and industrial interest [1]. Mesh networks are expected gradually to partially substitute the wired network infrastructure functionality by being able to provide a cheap, quick and efficient solution for wireless data networking in urban, suburban and even rural environments. Their popularity comes from the fact that they are self-organized, self- configurable and easily adaptable to different traffic requirements and network changes. Mesh networks are composed of static wireless nodes/mesh routers (WMR) that have ample energy supply. Each node operates not only as an conventional access point (AP)/Internet gateway (IGW) to the internet but also as a wireless router able to relay packets from other nodes without direct access to their destinations [2]. The destination can be an internet gateway or a mobile user served by another AP in the same mesh network. Moreover, some nodes may only have the backhauling functionality, meaning that they do not serve any mobile user directly but their purpose is to forward other APs packets. Mesh networks must meet a number of technical requirements. First of all, they must meet the high capacity needs of the access nodes that have to forward the accumulated traffic of their underling users. Furthermore, they have to cope with multiple strict quality-of-service (QoS) requirements of the end user applications, including end-to-end (ETE) packet delay, throughput, and packet-error-rate (PER). Finally they must provide a large enough effective communication range to ensure that no APs (or groups of APs) are isolated from the Internet gateways. Such technology enablers include but not limited to multi-hopping, various multiple antennas techniques, novel medium access control (MAC), routing and connection admission control algorithms. Unfortunately, most of the current work on WMNs protocol analysis and design is mainly based on a layered approach. This layered architecture by providing modularity and transparency between the layers, led to the robust scalable protocols in the Internet and it has become the de facto architecture for wireless systems. However, the spatial reuse of the spectral frequency, the broadcast, unstable and error prone nature of the channel and different operational time scales for protocol layers, make the layered approach suboptimum for the overall system performance of WMNs. For instance, bad resource scheduling in MAC layer can lead to interference that affects the performance of the PHY layer due to reduced signal-to-interference-plus-noise-ratio (SINR) and ultimately deteriorates the overall network performance. These are primarily why cross-layer design for improving the network performance has been a focus of much recent work. In a cross-layer paradigm, the joint optimization of control over two or more layers can yield significantly improved performance.

Caution needs to be exercised though, since cross-layer design has the potential to destroy the modularity and make the overall system fragile. Other important challenges that have to be taken into account during the design of cross-layered solution for WMNs is the different operation time-scales between coding, scheduling and routing algorithms; especially in the case that system performance estimations in different layers have to be performed. Moreover, since WMNs have to support a wide variety of applications and services, there are multi-constrained QoS requirements that have to be jointly satisfied by the cross-layer approach.

## II. Traditional ISO-OSI/TCP/IP Layer design

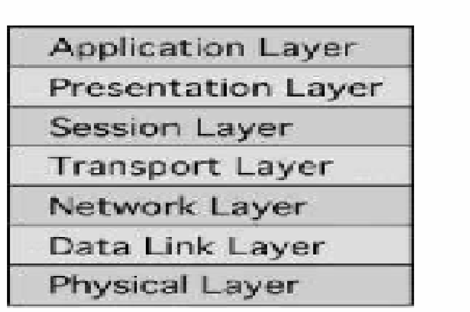

Figure 1 : The OSI reference model

The International Organization for Standardization (ISO) began in the early 1980s to work on an open set of protocols that would enable multi vendor computers to interact and communicate with one another. This work eventually led to the design of the Open Systems Interconnection (OSI) network stack, which was sought to become the building block of all network based communication worldwide. The OSI model was by many considered as the ultimate model for worldwide interoperability, however as time has showed, the OSI model remained just that: A model by which other implementations are compared against. The predecessor to the Internet, the DARPAnet, was developed by the US Defense Dpt. in the 1960's and was based on the Internet Protocol (IP). Specifications and interoperability were created second to allow others to participate in the network. While using the standardized OSI protocols undoubtedly would have been a good idea at that time, the IP implementation was easy, quick and cheap. The IP allowed the Internet to grow rapidly at the grass root level. As the governments around the world started participating in the Internet growth, it was expected that the IP was to be replaced by the OSI protocols, however this never happened. The ISO OSI model remains today as a reference model, by which other implementations are compared to and it describes and outlines the different levels of networking protocols and their relationship with each other. The OSI model consist of 7 layers as shown in Figure 1. As we shall see throughout this tutorial, a rigid and strict layer definition turns out to be perhaps the most fundamental identity of the traditional design approach. The most fundamental challenge in any network reference design, is how to allocate the available resources among the different network users. The traditional approach to network stack design has always been to treat the different layers as separate entities, and then perform layer specific operations on these entities to achieve an operational network stack with acceptable performance. Since the main goal of the OSI model was to allow multi vendor computers to interact and communicate (transmit pure data traffic), the term QoS was not thought off and thus not an issue in the design process. Resource handling and sharing followed a First-In First-Out (FIFO) pattern, or perhaps better described as a "best-effort" service. To minimize congestion in the network, each network entity adapted its transmission rate accordingly, and this worked for the most part. The layered network stack approach has been extremely successful over the last three decades, and the design principles have been widely adopted throughout various implementations and applications worldwide.

The traditional way of designing a wireless Manet or cellular network architecture has been to identify each process or module and then assign them roles or requirements. Since each process or module has been treated separately, this approach has in many ways caused the research communities to split into different groups, where each group focus their resources on solving their problem the best possible way. What other research communities are doing, is not really important, as long as the job is done. This is of course a bit exaggerated, but none the less illustrates the problem in an efficient manner.

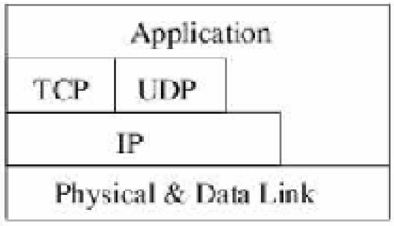

Figure 2: TCP/IP and UDP in a network stack

## III. Features Demanding Cross-Layer Design

Several characteristics pertaining to WMNs make cross layer design more indispensable for WMNs than that in other multi hop wireless networks such as mobile ad hoc or wireless sensor networks.

1) No clean-slate protocol architecture: By optimization decomposition, a new protocol architecture that is quite different from the existing standard protocol stack can also result. The well-known TCP/IP protocol stack has been widely adopted for most applications of WMNs. Thus, how to make the layered-protocol architecture derived from optimization decomposition and the TCP/IP protocol stack match with each other is a technical challenge. It is highly possible that no match can be achieved in several cases. Thus, in order to further improve the network performance without abandoning the TCP/IP protocol stack, the cross-layer design becomes indispensable.

2) Advanced physical-layer technologies: Many advanced physical-layer technologies have been adopted for WMNs in order to support applications that have high bandwidth demand. These technologies fall into several major categories.

a) Multirate-transmission technology: This is achieved by having multiple options of modulation, coding, and power-control schemes. Different transmission rate usually results in different transmission range and interference range. With multirate-transmission technology, the same physical layer can support a different transmission rate, depending on the link quality and the environment. In a single-hop wireless network, link-adaptation protocols, which are a type of simple cross-layer design schemes, can satisfy the need for maximizing throughput. In WMNs, however, merely the link adaptation is not enough, since links within multiple hops are related to each other. Thus, in WMNs, link adaptation becomes network wide rather than a one-hop mechanism. Thus, link adaptation is inevitably cross-related to routing and topology control. Such cross-relationship between different protocols reflects the necessity of cross-layer design.

b) Advanced antenna technology: Directional antennas and the advance versions, such as smart antennas, can significantly reduce interference between nodes that are close to each other. Such techniques certainly increase the network capacity but also require additional algorithms in upper layers to coordinate the antenna direction or beam forming. In a single-hop wireless network, a control algorithm located in the MAC layer, i.e., MAC/physical cross-interaction is enough. However, in WMNs, routing needs to be considered together, since different beam forming or antenna direction impacts the routing path and vice versa. In other words, routing, MAC, and physical layers all need to work together. A more advanced antenna technology is multiple input and multiple output (MIMO). In a node using MIMO, advanced signaling processing technology is employed to achieve an optimal balance between link reliability and link capacity. MIMO on a point-to-point or point-to-multipoint setup has been well researched. However, taking advantage of MIMO in WMNs usually requires a network wide-scheduling scheme.

c) Multi channel or multi radio technology: Multi channel operation (either single- or multiple-radio) can significantly reduce the interference between nodes in a multi hop network.

To utilize such a technology, an additional algorithm (dynamic channel allocation) must be developed in the MAC layer. This algorithm also needs to be aware of the interference from external networks. Since varying channels in different hops potentially impact the optimal routing path that can be selected, both MAC and routing protocols must work together to take advantage of the multi channel technology. It should be noted that the above three classes of physical layer technologies are usually integrated, which further intensify the challenge in protocol design in upper layers. For example, the multi rate transmission can happen in a physical layer using MIMO and multi channel operation. For a WMN with so many advanced physical-layer features, it is more challenging to reoptimize both MAC and routing protocols.

3) Imperfect MAC: MAC has always been a critical part in all wireless networks. Many solutions are available. However, none of them is perfect because of the following two major factors: 1) The wireless medium is always imperfect in nature, and 2) the MAC itself has no guaranteed performance. In the second factor, a typical example is CSMA/CA, which is a best effort protocol and cannot provide any guarantee for delay, collisions, etc. Such unpredictable performance of the MAC can severely limit the performance of a routing protocol. For example, routing messages may not be able to send out in a congested CSMA/CA-based WMN, which in turn impacts the capability of a routing protocol. This issue is even worse in WMNs, because the performance of MAC is not just a matter of single-hop networking but multi hop. Research can be carried out to constantly improve the MAC protocols for WMNs. However, as a matter of fact, if routing is not taken into account, optimal performance can only be achieved locally. Consequently, in order to achieve the ultimate goal of perfect MAC, routing must be considered as an integral part of MAC. In this sense, MAC and routing protocols in WMNs are so closely related that they should be put together as two modules in one layer or even just one module in the same protocol layer. A typical example is the upcoming IEEE 802.11s standard for 802.11 WMNs, in which MAC and routing have been put together into the same MAC layer. However, we have also noticed that the optimal interactions between MAC and routing have not been exploited yet in IEEE 802.11s.

4) Mixed traffic types with heterogeneous QoS: WMNs are expected to support a large variety of services that consist of many traffic types with heterogeneous QoS requirements. In order to deliver such services in WMNs, transport layer, routing, and MAC protocols need to cooperate smoothly; otherwise, either service quality is not ensured or the network resources may be wasted. For example, it is always preferable to use separate transport layer protocols for VoIP, video, and data traffic. For VoIP and video traffic, finding a reliable routing path is obviously not the goal, since a path does not guarantee the quality of VoIP or video, no matter how reliable the path can be. Thus, finding a routing path must consider bandwidth allocation. This problem has been researched as a QoS-routing topic. However, when more advanced Physical-layer technologies are considered; it becomes more than a QoS-routing problem and has to involve tight routing/MAC cross-layer design. For example, variation of bandwidth demand on a given routing path or change of a routing path can trigger reallocation of time slots, channels, antenna directions, etc., on all links related to the given routing path or vice versa. Based on the above analysis, we know that cross-layer design is imperative for WMNs.

## IV. Cross Layer Design*:*

As shown in Figure4, the CLD approach to network architecture is located where the three communities intersect. Listed below are some of the fields the different research communities traditionally have focused on solving:

### *General Methodology of Cross-Layer Design*

Cross-layer design can significantly improve the network performance [6]–[8]. It can be performed in two ways:

- loosely coupled and
- tightly coupled cross-layer design.

In the loosely coupled cross-layer design, optimization is carried out without crossing layers but focusing on one protocol layer. In order to improve the

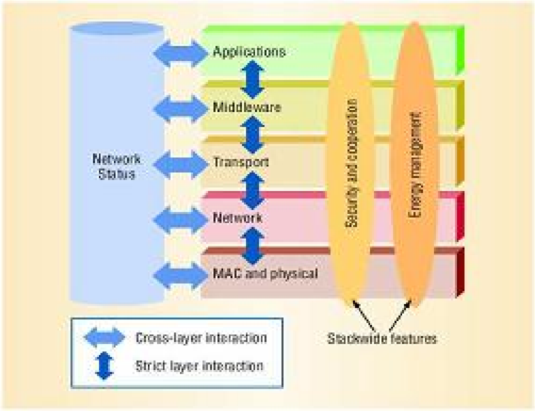

Figure 4: cross-layered network stack

Performance of this protocol layer, parameters in other protocol layers are taken into account. Thus, information in one layer must be passed to another layer. Typically, parameters in the lower protocol layers are reported to higher layers. For example, the packet-loss rate in the MAC layer or channel condition in the physical layer can be reported to the transport layer so that a TCP protocol is able to differentiate congestion from packet loss. As another example, the physical layer can report the link quality to a routing protocol as an additional performance metric for the routing algorithms. It should be noted that information from multiple layers can be used on another layer to perform cross-layer design. With such information, there are two different methods in utilizing such information. The first one is the simplest case of cross layer design, in which the information in other layers works just as one of the parameters needed by the algorithm in a protocol layer. The performance of this algorithm is improved because a better (more accurate or reliable) parameter is used, but the algorithm itself does not need a modification. For example, the physical layer can inform TCP layer of the channel quality so that TCP can differentiate real congestion from channel-quality degradation and, thus, can carry out congestion control more intelligently. In the second method, based on the information from other layers, the algorithms of a protocol have to be modified. For example, if a MAC protocol can provide a routing protocol about its performance, the routing can perform multi path routing to utilize spatial diversity. However, the change from a single-path routing to multi path routing needs a significant modification in the routing protocol rather than just a parameter adaptation. In the tightly coupled cross-layer design, merely information sharing between layers is not enough. In this scheme, the algorithms in different layers are optimized altogether as one optimization problem. For example, for MAC and routing protocols in a multi channel time-division multiple-access (TDMA) WMN, time slots, channels, and routing path can be determined by one single algorithm. Due to optimization across layers, it can be expected that better performance improvement can be achieved by the tightly coupled cross-layer design than the loosely coupled scheme. However, the advantage of the loosely coupled design is that it does not totally abandon the transparency between protocol layers. An extreme case of tightly coupled cross-layer design is to merge different protocol layers into one layer. According to the concept of “layering as optimization decomposition,” this kind of design tries to improve the network performance by relayering the existing protocol stack. Merging multiple protocol layers into one layer keeps the advantage of tightly coupled cross-layer design. Furthermore, it can also eliminate the overhead in cross-layer information exchange. Interestingly, merging multiple protocol layers is not just a theoretical concept but has been seriously considered in real practice. For example, in the upcoming 802.11 standards for mesh networks, the routing protocol is being developed as one of the critical modules in the MAC layer. Such a merge between routing and MAC layers provides a great potential to carry out optimization between MAC and routing within the same protocol layer. Cross-layer design can be realized between multiple layers or between just two layers. Given a protocol stack, cross layer design can be based in any combination of two protocol layers.

## V. Conclusion

In this paper we discussed about Several characteristics pertaining to WMNs make cross layer design more indispensable for WMNs than that in other multi hop wireless networks such as mobile ad hoc or wireless sensor networks. We also discussed about 2 general methods of performing cross layer design.

## References

[1]. Zhang, Q., Zhang, Y.Q.: Cross-layer design for QoS support in multihop wireless networks. The Proceedings of IEEE 96(1), 64{76 (2008)

[2]. Akyildiz, I.F., Wang, X.:A survey on wireless mesh networks. IEEE Communications Magazine 43(9), S23{S30 (2005)

[3] R. Bhatia and M. Kodialam, “On power efficient communication over multi-hop wireless networks: Joint routing, scheduling, and power control,” in *Proc. IEEE Annu. Conf. INFOCOM*, 2004, pp. 1457–1466.

[4] U. C. Kozat, I. Koutsopoulos, and L. Tassiulas, “A framework for crosslayer design of energy-efficient communication with QoS provisioning in multi-hop wireless networks,” in *Proc. IEEE Annu. Conf. INFOCOM*, 2004, pp. 1446–1456.

[5] M. Chiang, “To layer or not to layer: Balancing transport and physical layers in wireless multihop networks,” in *Proc. IEEE Annu. Conf. INFOCOM*, 2004, pp. 2525–2536.

[6]. Cross-Layer Design in Wireless Mesh Networks Ian F. Akyildiz, *Fellow, IEEE*, and Xudong Wang, *Member, IEEE*

## About Athours

**B.Nandini,** Working as Assistant Professor in the department of Computer Science and Engineering, Telangana University, Nizamabad, AndhraPradesh, India. Completed B.Tech from JNTU, Hyderabad. Doing P.hD from JNTU, Hyderabad. Research Area is Wireless Mesh Networks.

**Anand Tumma,** Working as Assistant Professor(contract) in the department of Computer Science and Engineering, Telangana University, Nizamabad, AndhraPradesh, India. Completed MCA from Osmania University, Hyderabad.