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Cross Layer Design for QoS support in MANET

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Abstract— With the aim to provide soft QoS in multihop networks, various solutions in form of layered protocol stack exist but they resulted in lower performance of the overall architecture. Layered OSI and TCP/IP model are unable to provide all the services necessitated by MANETs due to lack of coordination among layers. The strict layered design was opposed by MANETs because of their time varying unstable links and the mobility of nodes. These issues make way to cross layer design violating traditional boundaries among layers for performance gain. Cross layer design is based on the concept where the different layers exchange information and maintain their original functionalities in addition to allowing coordination, interaction and joint optimization of protocols crossing different layers. The paper aims to gather motivation behind current cross layer design paradigm to enable soft QoS support in MANETs, illustrates some representative examples and draw conclusions for future research directions. The aim of the survey is to investigate the current cross-layer design research developments in addressing the QoS, security and energy efficiency issues in wireless networks.

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Index Terms— QoS architecture, Cross Layer, QoS, MANET

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1 INTRODUCTION

THE concept of Quality of Service (QoS) in communication systems is closely related to the network performance of the underlying routing system. ITU's definition of Quality of service [1] states that Quality of Service is the collective effect of service performance which determines the degree of satisfaction of a user of the service. Fig 1. shows the four building blocks introduced in [1]: quality of service, serveability, trafficability performance, and dependability. QoS can be provided, in some form or the other, at different layers of the protocol stack.

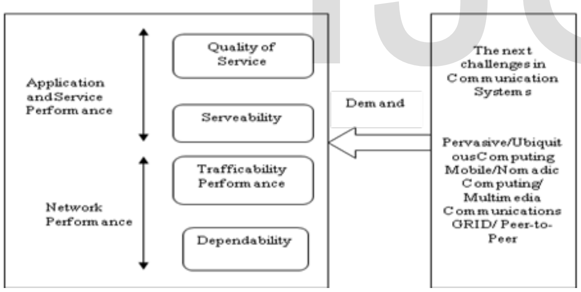

Fig 1 . Main QoS building blocks according to ITU [1]

2. CROSS LAYER CONCEPT

It may be required to accept new approaches in which the protocols can be designed by violating the reference layered architecture allowing direct communication between protocols in non adjacent layers. Such violation of a layered architecture is termed as cross-layer design (CLD) sometimes called Delayered model .

Cross-layer feedback means interaction of a layer with any other layer in the protocol stack. A layer may interact with layers above or below it. *Weak Cross-layering*: enables interaction among entities at different layers of the protocol stack; it thus represents a generalization of the adjacency interaction concept of the layering paradigm to include "non-adjacent interactions". *Strong cross-layering*: enables joint design of the algorithms implemented within any entity at any level of the protocol stack where cross-layering optimization can lead to loss of individual features related to different layers. Potentially, strong cross-layer design may provide higher performance at the expense of narrowing the possible deployment scenarios and increasing cost and complexity. An alternative notion is "evolutionary approach" for "weak cross-layering" and "revolutionary approach" for the "strong cross-layering" [2].

The cross layer design (CLD) approach is a new dynamic area of research into MANET networks. This approach provides new possibilities to increase the performance and adaptability of MANET [3]. Evolutionary approach to cross layer design is based on extending the layered structure to maintain compatibility with existing systems and networks. Examples are Layer Triggers, Event Helix Protocol, MobileMan Project, Joint Secure Channel coding and designing a mobile broadband wireless access network. Revolutionary approach is not based on extending the layered structure. Hence, it is free from any existing implementation. Examples are wireless sensor networks (WSNs) and Shannon Mappings. Evolutionary approach to Cross Layer Design is based on extending the layered structure to maintain the compatibility with existing systems and networks.

Cross Layer Design(CLD) involve mainly the combination of Network-Transport, Physical-MAC-Network combinations. Hence, their functionalities are also limited. There is no complete CLD solution covering issues like - fault tolerance, congestion control, energy minimization, flow control and power conservation. The main drawback of poorly framed cross-layer design are unstable system (tightly coupled protocols), uncontrolled stack design and erroneous implementation which degrades their performance. If proper care is not taken for CLD, it can create loops through unintentional interactions between different layers of the system. As future design improvements are impossible, it will be difficult to find out exactly how a new modification will affect the overall system operation.

Layer triggers are widely used in both wired and wireless network because of their low cost and ease of implementation and compatibility with original strict layered structure. Prede-

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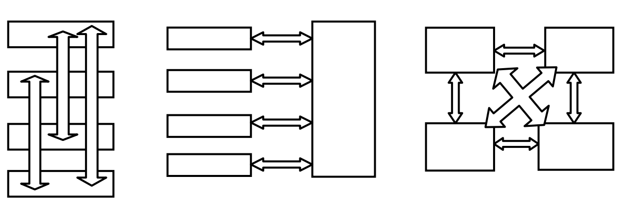
fined signals used to notify special events between protocols are named as layer triggers. For example - The Explicit Congestion Notification (ECN) bit. Event Helix Protocol Design – It is based on incorporating cross layer design principles used in CLD protocols. It uses standardized interface between different layers, and is able to decouple the individual protocol layers. In Event helix design, layers can be inserted or removed without changing the implementation details of individual layers. For example encryption need not be supported by application, instead and IP security layer is inserted between the Network layer and Data Link Layer.

MobileMan project [16] design goal is to maintain the benefits of a modular architecture without modifying each layer's core function for a robust upgrade environment. In this project, authors aim to avoid duplicating efforts for collecting internal state information, increased local interaction among protocols, minimized remote communications leading to saving network bandwidth. Joint Secure Channel coding (JSCC) - shares information between source coder, the channel coder and utilizes soft information from the Physical Layer. Shannon mapping is a common JSCC technique. Designing a Mobile Broadband Wireless Access Network- The scheduler having rich set of cross-layered information is the focal point for achieving any Cross Layer Design Optimization.

Cross layer designs avoid duplicating efforts to collect internal state information leading to a more efficient design. Cross layer design are based on knowledge derived from wireless networking, signal processing and information theory fundamentals. Hence, CLD are capable enough to slove the accessibility problem in ad hoc networks. Multiple cross-layer design are expected to come in near future to serve as combined solution for different QoS issues in MANETs.

There are three different cross layer designs [3]: Direct Communication between two adjacent layers, Shared database and Heap architectures of completely novel approaches as shown in Fig 2. In Direct Communication, shared variables, internal packets or layer triggers may be used. In shared database approach, methods exist to retrieve/insert data from/into the common database. Heap architectures exploit new abstractions for protocol information sharing. The specific characteristics of MANET leads to problems that the CLD is trying is solve, when the solutions can be divided into the following areas [3, 4]:



(a) Direct Communications (b) Shared database (c) New abstraction

Fig 2. Different types of cross layer design for MANET

Adaptation and self organization

The system may be called adaptive if they can adjust to dynamically changing topology, shared medium contention, varying traffic patterns and distributions while keeping their organization as much as possible intact. Due to presence of decentralized autonomous entities operating in dynamic environment, MANET nodes spontaneously create a globally coherent pattern out of local interactions.

Mobility

In mobility models, nodes exhibit behavior as per definition of underlying mobility model and this greatly impacts overall network configuration and capacity.

Energy Control or power Control

Power constraint is the most suitable metric to be adopted by a routing decision in MANET. Hence, the need arises to develop a cross layer design for Power conservation.

Different QoS requirements

Delay, jitter, system buffer, network/system bandwidth and error rate are different QoS constraints. Bandwidth, latency, jitter and loss are network layer QoS. Different traffic behaviors have their specific QoS requirements.

Security

Security aims to eliminate multiple layers of encryption and security attack. Security represents one of vital QoS dimension.

3 Cross Layer Signaling Architectures

Cross layer design is a way of achieving information sharing between all the layers in order to obtain highest possible adaptively of any network. This is required to meet the challenging data rates, higher performance gains and Quality of Service requirements for various real time and non real time applications. CLD is a cooperation between multiple layers to combine the resources and create a network that is highly adaptive. We provide an overview of different cross signaling architectures:

A. *Interlayer Signaling Pipe-*

Implementation of cross-layer signaling is revealed by Wang et al. [5] as interlayer signaling pipe, which allows propagation of signaling messages layer-to-layer along with packet data flow inside the protocol stack in bottom-up or top-down manner (Fig 3). Signaling information is inserted into a specific section of packet structure. Whenever a packet is generated by the protocol stack or successfully received from network interface, a corresponding packet structure is allocated. This structure includes all the packet related information such as protocol headers and application data as well as internal protocol stack information such as network interface id, socket description, configuration parameters and other. Moreover, employment of *packet structures* does not violate existing functionality of separate layers of protocol stack.

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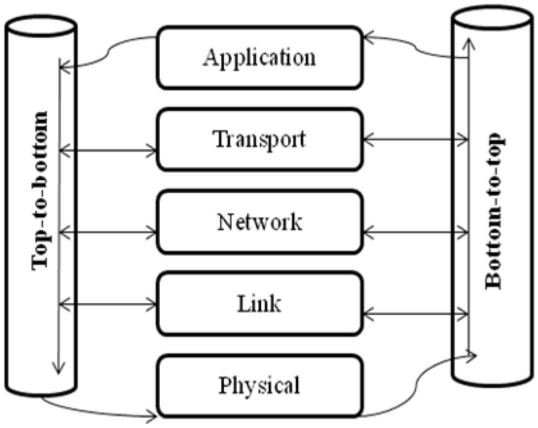

Fig 3: Interlayer Signaling Pipe in Cross-Layer Signaling Architectures

B. Direct Interlayer Communication:

It is proposed in [5] aims at improvement of interlayer signaling pipe method by introducing signaling shortcuts out of band. Fig. 4 shows the Direct Interlayer Communication. Internet Control Message Protocol (ICMP) [6,7] is available for core signaling method.

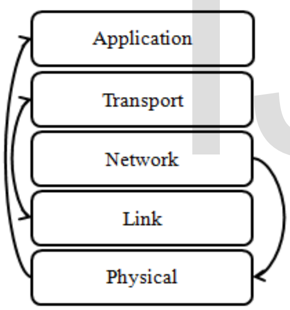

Fig 4: Direct Interlayer Communication in Cross-Layer Signaling Architectures

C. Central Cross-Layer Plane

In this scheme, Central Cross-layer Plane is implemented in parallel to the protocol stack. In [8], the authors propose a shared database that can be accessed by all layers for obtaining parameters provided by other layers and providing the values of their internal parameters to other layers. This design assists in information exchange between layers but does not implement any active control functions such as tuning internal parameters of the protocol layers shown in Fig 5.

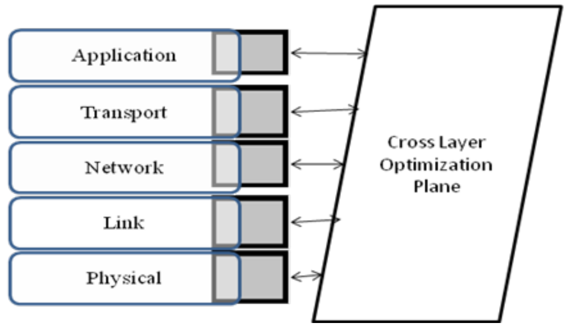

Fig. 5 : Central Cross-Layer Plane in Cross-Layer Signaling Architecture.

D. Network wide Cross-Layer Signaling:

Several optimization proposals exists which perform cross-layer optimization based on information obtained at different protocol layers of distributed network nodes. This helps in propagation of cross-layer signaling information in the entire network to add another degree of freedom in how cross-layer signaling can be performed as shown in Fig.6.

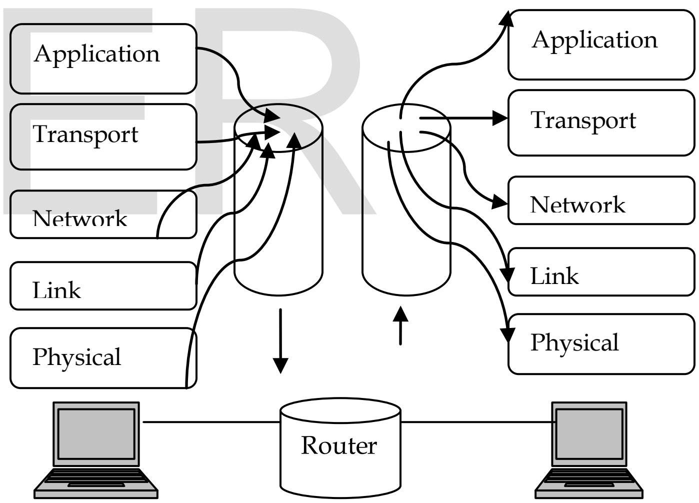

Fig. 6 Network-wide Cross-Layer Signaling in Cross-layer Signaling Architectures

One of the early examples of Cross-network cross-layering is the Explicit Congestion Notification (ECN) presented in [9]. It realizes in-band signaling approach by marking in-transit TCP data packet with congestion notification bit. The structure of the traffic class field is illustrated in Fig.7 where Differentiated Services Code Point (6 bits) provides various code sets to mark the per-hop behavior for a packet belonging to a service class. ECN (2 bits) allows routers to set congestion indications instead of simply dropping the packets. This avoids delays in retransmissions while allowing active queuing management. In [10] comparison of cross layer

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schemes used for QoS provisioning is provided.

0	5 6	7
DSCP		ECN

Fig. 7. Traffic class field.

Framework for QoS Multicast (FQM) to support QoS multicast applications for MANETs is proposed in [11]. It a load balancing framework. The cross layer design uses the passive listen method which is an efficient way to estimate the available bandwidth with no overhead. The first component of the framework is a new and efficient routing protocol for finding multiple paths meeting the QoS requirements and maintaining these paths. Second, cross layer bandwidth estimation is used to estimate the available bandwidth. Third, classifier, shaper, dynamic rate control and priority queue work together to support high priority real-time traffic.

The integrated mobile ad hoc QoS framework (iMAQ) [8] is a cross layer architecture to support transmission of multimedia data over MANET. A model of the framework is shown in Fig. 8. At each mobile node, coordinating layers share information and collaborate to provide QoS assurances to the multimedia traffic.

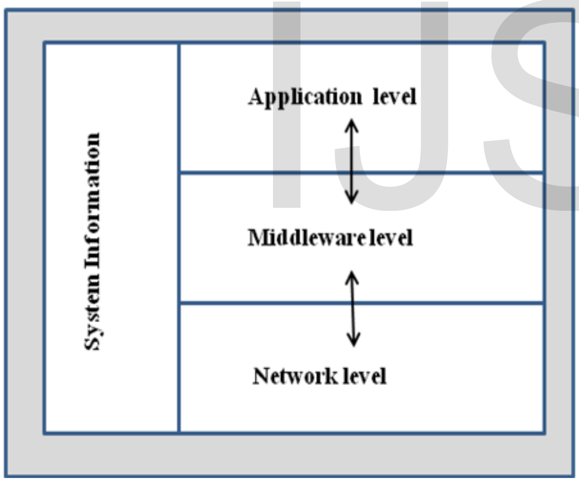

Fig. 8. The iMAQ framework model.

FQMM also provides QoS support to mobile ad hoc networks by a cross-layer distributed network model over any types of MAC and routing protocols. Modular QoS architecture [12] supporting real time applications in MANET environment as shown in Fig 9. The purpose is to provide a flexible framework offering end-to-end QoS support to ad hoc networks that is both efficient and easily deployable with currently available technology.

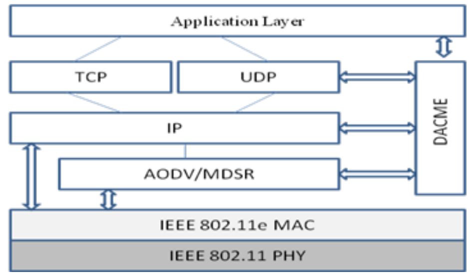

Fig 9. Diagram of QoS Architecture including cross-layer interactions.

4 QoS Support with Cross Layer Design

Evolution of cross-layer design on multihop wireless networks are indirect result of current technological developments of wireless community like cooperative communications and networking, opportunistic transmission and real time systems etc.

4.1 Interaction among multiple layers and the cross-layer-design framework-

Cross-layer design can contribute to improve the system performance [13],[14],[15]. Inter-layer interactions and relative performance issues in MANETs were studied by a working group of Internet Engineering Task Force [17]. This study was focused on interlayer interaction
metrics mainly for information exchange between the lower layers, network layer and transport layer.

- Interaction between Physical Layer, Link layer, Network Layer and Transport Layer exists as follows: Signal-to-noise ratio from physical layer and the interference level from link layer may be applied for route selection at network layer and control the size of TCP window at transport layer.
- Power control and modulation adaptation in PHY layer will determine the overall system topology.
- Routing and admission control will have strong impact on flow distribution.
- The traffic volume in each communication link will be determined by congestion and rate control in Transport Layer.

4.2 Cross Layer Network Capacity Planning-

Network capacity planning involves deployment of cost-effective communication infrastructure for providing adequate coverage, throughput and QoS support for network services. Different design goals for network capacity planning schemes are: maximizing system throughput, minimizing end-to-end delays and minimizing the total energy consumption. The goal of network planning problem [18] is to minimize a cost function for fulfilling transport layer communication demands by allocating physical and MAC layer resources.

4.3 Joint routing and Rate Allocation for media streaming-

Ad hoc Multipath Streaming Protocol (AMTP) [19] can efficiently differentiate categories of packet losses as it can accurately detect different network states. AMTP contributes to maximize aggregate end-to-end throughput by selecting multiple maximally disjointed paths with best QoS. For video streaming over ad hoc networks, the presence of multiple streams affect each other performance [20] for every chosen rate and route by the system creating the need for joint optimization of rate allocation and route selection for all streams in the network.

4.4 Joint channel assignment and routing-

QoS-aware routing decisions depend on network topology. Hence, channel assignment directly affects routing. For better results, channel assignment should be dynamically adjusted according to the traffic status and traffic demand of each link, which is determined by a cross-aware routing algorithm. This states that routing and channel assignment are tightly coupled and should be jointly optimized for performance improvement.

4.5 Joint scheduling and rate adaptation for opportunistic transmission-

Opportunistic medium access and auto rate(OMAR) [21] efficiently utilize the shared medium in 802.11 based ad hoc networks by taking into consideration the features like diversity, distributed scheduling and adaptively. Each node with certain number of links is encouraged for forming a cluster and act as cluster head to locally coordinate multiuser communications. For each cycle of data transmission, it is the responsibility of cluster head to initiate medium access, followed by cluster members making medium access decisions in a distributed manner on observed channel conditions.

Cooperative Scheduling [22] is used to exploit multiuser diversity and time diversity for MANETs. It represents an opportunistic and cooperative scheduling scheme to approximate the optimal scheduling introducing the aspect of cooperation like Scheduling decision making requires exchange of average data rates supported, QoS factors and contention relationship between two-hop neighboring nodes.

4.6 Joint rate control, admission control and scheduling for service differentiation

It is essential to have a joint design among transport layer (for rate control), network layer (for admission control) and link layer (for scheduling) to achieve service differentiation,. SoftMAC [23] employs "coarse-grained" control mechanism to coordinate and regulate network load and packet transmission of both real time and best effort traffic among neighboring nodes in a distributed manner. The objective is to reduce collision rate and keep channel busy time below appropriate level, to ensure acceptable VoIP quality. It consists of three modules:

1) Distributed admission control module to regulate "admissible" VoIP traffic and "reserve" bandwidth along its path.

2) Rate Control Module – controls transmission of best effort traffic to make sure that collision probability and impact to real time traffic on other nodes is under control.

3) Priority queuing module ensure non-preemptive priority to VoIP traffic at each node.

4.7 Joint rate control, admission control and scheduling for service differentiation

Traditional layering network approach [24] which separates routing, scheduling and power control is inefficient for providing QoS support for ad hoc networks. In [25] the issue of coupling routing with access control has been addressed. A joint scheduling and power control algorithm [26] states that a joint design among power control, scheduling and routing is essential. [27] considers a time-division multiple access (TDMA) based ad hoc network where all nodes share the bandwidth by occupying different time slots. For scheduling process, link metrics are used to assign slots to the links. Priority is given to links that have larger queue length and block less traffic from neighboring links. Authors come to conclusion that re-routing decision should be iteratively with joint power control and scheduling for some unbalanced topology to achieve significantly larger throughput and less delay. In [28] traffic demand rate matrix is required to determine the data rate on each link for routing decisions. Authors have proposed duality approach for finding the optimal scheduling and power control.

4 Conclusion

Research activity is still going on to design cross layer architecture for MANETs as they need to deliver QoS guarantees to real time services, being competitive alternative to cellular networks. Some open research issues are: the complexity of implementing cross layer design, performance gains by "best" cross layer design, effect of different factors on cross-layer design need, real systems based on Cross layer design, nodes cooperation for cross layer design and security concerns associated with cross layer designs.

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