Literature Survey on Cross-Layer Design Architecture for Bandwidth Management in Mobile Ad-hoc Networks

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ABSTRACT
In a Mobile Ad-hoc Network, the wireless nodes usually self-configure to exchange information without the help of any centralized infrastructure or administrator. There is high mobility and rapid deployment of the mobile nodes. Hence, there is need for multi-hop transmission where nodes can forward other nodes information. A Cross-layer design allows interaction between the layers above or below it. The strict layered architecture may not be the best model for wireless network. It is difficult to optimize the network performance according to different situation without interaction among the different layers. In dynamic network, there is a need for different layers to cooperate closely to meet QoS requirements of the mobile application. This goal can be achieved when the routing layer share the link quality information, channel bandwidth information of the MAC layer. For making decision, the same information may be used by different layers like the link and channel state, topology information and location for the nodes are used by the routing and application layers to compute routes. In this paper, the benefits of cross-layer feedback on mobile nodes and a representative survey are discussed.

General Terms
Mobile Ad-hoc Network, Cross-layer design, Quality-of-service

Keywords
Cross-layer feedback, MAC layer, channel bandwidth information

1. INTRODUCTION
TCP/IP is the protocol suite designed for the wired network. It is also deployed in wireless nodes like in 2G, 3G and beyond. This is done to increase the interoperability with the existing Internet. TCP is an end-to-end protocol, wherein the sender sends the packet and waits for an acknowledgement for sending additional packets. A missing acknowledgment is interpreted as an indication of packet loss due to congestion in the network. However, in mobile wireless environments packet losses could occur due to poor wireless channel conditions and disconnections. The wired networks are based on layered architecture for the purpose of modularity. [1] The wireless network, are dynamic since the links are variable and the mobile nodes are constrained by energy and resources.
TCP is not suitable for ad hoc networks due to reduction in the TCP throughput. Several methods have evolved to enhance the protocol stack over mobile wireless networks like TCP k-SACK, TCP Jersey, TCP-Casablanca, I-TCP, Snoop and Copas.

The layered protocol stack does not function efficiently in mobile wireless environment. To improve the performance of these protocol stacks, there is a need for cross-layer feedback. Cross-layer feedback optimization may be implemented at the intermediate nodes or mobile hosts. The cross-layer feedback in the mobile host is focused since it is believed that the changes on the end devices are easier to implement than in the network. [2] Cross-layer feedback on mobile nodes is intended to enhance application performance and user satisfaction.

To further enhance the performance of the mobile nodes it becomes necessary to incorporate dynamic user requirements in the protocol stack. A large fraction of the battery power is consumed by the network interface, it is imperative that the various protocol layers adapt and collaborate to optimize power consumption.[3] Cross-layer feedback means the sharing of information among the layers of the protocol stack. Some of the examples of cross-layer feedback are:-

I. TCP packet loss information being communicated to the application layer to enable application adaptation.
II. Delay or loss constraints of the application communicated to the link layer to enable link layer to adapt its error correction mechanism.
III. Application priorities communication to the TCP to widen its receiving window.
IV. Link/MAC layer tuning the transmit power of the physical layer based on the bit error information from the physical layer and vice versa.

2. Different layer interactions
The cross-layer feedback refers to the interaction among the different layers. The information exchange among the different layers is discussed as follows:

2.1 Function of physical layer
The information available in this layer are bit-error rate, transmit power, coding and modulation used. The main function of this layer is transmission of raw bits with minimum bit errors using a suitable power level. It defines the physical specifications for devices and the relationship between the transmission medium and the device.

Interactions of physical layer with:
(a) Application layer: The application layer is the interface layer with the network and the users. This layer can adapt to the physical layer parameters to provide Quality of service to the applications. The requirements of the users vary, some are delay sensitive and some are not. Hence,

the required throughput, acceptable packet loss, acceptable delay variation, delays tolerance, etc can be adapted in accordance to the available transmission power and bit-error rate.

(b) Network Layer: The bit-error rate on an interface can be used as the guiding information for selecting the appropriate interface.

(c) Data Link Layer: The transmit power for packet transmission becomes optimal when the packet length and bit-error rate information is known to the link layer. The physical layer may adapt its modulation and coding depending on the battery status.

2.2 Function of Data Link Layer

The information available in this layer is the forward error correction schemes, frame length, handoff-related events, number of retransmitted packets and point in which the medium is available for transmission. The function of this layer is collision avoidance, fragmentation, improving link reliability through Automatic Repeat Request and forward error correction.

Interaction of data link layer with:

User: The link throughput information can be used by the users to decide about the applications that can be run. By looking into this information, the users can expect the application performance.

(a) Application layer: Different frames of the application layer are treated as per requirements of the traffic pattern. Some of the frames may be delay sensitive and some may not. Based on this the frames may be categorized according to priority. Delay sensitive frames are given higher priority, so the forward error correction and automatic repeat request may be improved for high reliability requirement. This idea is based on multi-service link layer [1,3] for Quality of service in the internet, that adapts the link layer services based on the traffic class.

(b) Transport layer: There is need for TCP retransmission when channel conditions are poor. Retransmission of the link layer results into delays and reduction in throughput. It is seen in [4, 5] that increased in the MAC level retransmission, decreases the power consumption.

(c) Network layer: The hand-off in Mobile-IP depends on the detection of network change at the IP layer. The Mobile-IP is used for IP hand-off whenever the mobile devices change sub-nets. Hand-off in the Mobile-IP depends on the detection of a network change at the IP layer. Link layer hand-off information can be used to reduce the hand-off latency for Mobile-IP. [3 ,5, 6]

(d) Physical Layer: Based on current channel conditions the error control mechanisms at the link layer may be adapted to reduce the transmission errors. The adaptation of error control mechanisms at the link/MAC layer along with transmit power control at the physical layer can help in substantial reduction in power consumption and improvement in throughput. [5, 6, 7]

2.3 Function of Network Layer:

The function of this layer is IP hand-off, routing, selecting the network interface and addressing to maintain IP connectivity in foreign networks. [7]. The core function of the network layer is to acquire a route based on the addressing. The information available at the network layer are the network interface currently in use and Mobile-IP hand-off initiation and completion events.

Interaction of Network layer with:

a) Application or user layer: An application could control its sending rate based on Mobile-IP hand-off indications. A device may have multiple wireless network interfaces that can provide different levels of service. Depending on the application or user needs, the network layer could select an appropriate network interface.

b) Transport: Mobile-IP hand-off delay may lead to reduced throughput due to the TCP retransmission time-out (RTO) and back-off mechanism. TCP can be informed about the event of Mobile-IP hand-off to reduce the retransmission latency. Depending on the hand-off conditions, this helps in reducing TCP retransmission latency by up to 75% and improving throughput by up to 25% [1,2,4,8]

c) Data link layer: The information available in the data link layer is current FEC and number of frames. This information may be used by the network layer for routing the frames with reduced delay and retransmission.

d) Physical Layer: The battery power of this layer may be used by the network for successful transmission of frames through optimum path, by reducing the power consumption and interference.

2.4 Function of Transport layer:

The transport is concerned with the establishment of end-to-end connection over the network. The information available with TCP is round-trip time, receiver window, congestion window, throughput, maximum transmission unit, number of packet lost, etc.

Interaction of Transport layer with:

a) Application or User Layer: The user can add priorities to their applications where more bandwidth would be assigned to it. The information about impending disconnection can be used by TCP to increase its retransmission time-out value. TCP may provide packet loss and good put information. The applications may indicate their Quality of Service requirements to TCP, based on this information TCP may manipulate the receiver windows. The packet loss information may be provided to the application layer to adjust their sending rate.

b) Network layer: The information Mobile-IP hand-off delay that leads to reduced throughput can be used sent to the TCP to adapt accordingly. The currently used network interface information may be sent to the TCP.

c) Data link layer: TCP and the data link layer may exchange retransmission information about frame length, number of retransmitted frames to reduce collision for reliable transmission. The TCP may accordingly readjust the sender and receiver window.

d) Physical Layer: The bit-error rate, transmit power and modulation/coding details of this layer can be used by the transport layer protocols. The information from the physical layer can be used by the TCP to reduce retransmissions and frame length as per the available battery power.

Function of Application layer:

The application layer may transmit to other layers about the applications QoS requirements like acceptable packet loss, delay tolerance, jitter, acceptable delay variations, etc. The users may deal with real time data and non real time data. Different types of coding are applied on the multimedia data. Information about the channel condition may be adapted to perform the coding.[8,9] From the above discussion, the channel condition of the physical layer and data link layer are crucial for improving application performances. It becomes essential to tune the data link error control mechanisms based on the QoS requirements of the applications to improve application throughput.

3. Literature Survey on different cross-layer design architectures

3.1 An Efficient Cross-Layer Architecture for Wireless Protocol Stack (ÉCLAIR):

The main components of this architecture are the Tuning Layers (TL) and the Optimization Sub-System (OSS) [17,18, 20]

3.1.1 Tuning layer:

This layer provides necessary Application program interface to the POs for manipulating the protocol data structures and interactions among the layers. [10, 11,12]The TLs provide an interface to the POs for registering for events. Multiple POs can register for the same event with a TL. The TL monitors the protocol for events for which the POs have registered. On the occurrence of an event, the TL notifies the registered POs. The functionalities for manipulating protocol data structure is built in the TLs, hence no modification is required in the existing protocol stack. Due to the addition of the Tuning layer, inclusion of new cross-layer feedback algorithms with minimum intrusion becomes feasible. For the purpose of portability, each TL is subdivided in to a *generic tuning sub-layer* and an *implementation dependent access sub layer.*

The *generic tuning sub-layer* provides an implementation independent interface to a specific protocol. For effecting a protocol optimization a PO would invoke the API provided by the generic sub-layer of a protocol tuning layer. The generic sub-layer would in-turn invoke the API of the implementation specific access sub-layer. The MAC tuning layer provides an interface for 802.11, CDMA MAC and GPRS. Transport Tuning Layer provides an interface for various transport protocols. The *implementation dependent access sub-layer* provides implementation specific interface for a protocol. This layer has the knowledge about a protocol implementation in a particular operating system and is used to manipulate or monitor the values in that protocol's data structure for events.

3.1.2 OSS Layer:

This layer executes concurrently with the existing protocol stack and does not increase the stack processing overhead. The OSS is the cross-layer engines that contain many protocols Optimizers (PO). [13,14]The POs take input from various layers and decides on the optimizing action to be taken to be taken to reduce packet losses and power consumption. The PO contain the algorithm for a given cross-layer optimization. On the occurrence of event at every layer, the optimization action is undertaken. [21] The POs interact with various layers for state information, events and optimization actions.
Tuning Layer

3.1.3 Limitations of ECAIR:

There is creation of multiple modules for the purpose of monitoring and adaptation. This requires interactions between the modules through APIs. This results in high time overhead.

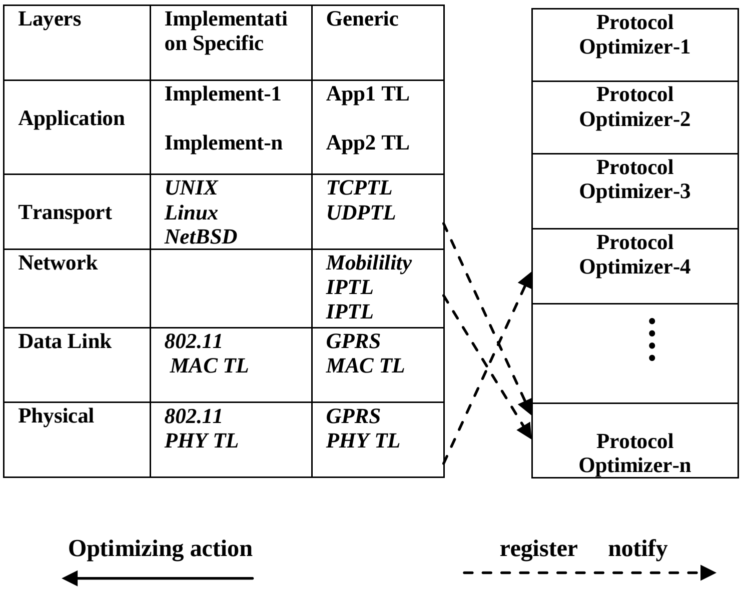

Fig. 1. ÉCLAIR Architecture details

3.2 Direct Communication based Cross-Layers Architecture: [19]

In this cross-layer architecture, the runtime information sharing in between the layers is to allow communicating between the layers. The variables of at one layer become visible to the other layers at runtime. Different ways exist for the layer to communicate with one another. The protocol headers may be used to allow flow of information between the layers. [17, 19] Alternately, extra interlayer information could be treated as internal packets. Cross-layer Signaling Shortcut (CLASS) is an architecture where two layers communicate directly. In this architecture only few cross-layer information exchanges are implemented. [15, 18, 20] Many issues like managing shared memory spaces between the layers are to be resolved.

3.2.1 Merits of the Cross Layer Signaling Shortcuts (CLASS).

- Non-neighboring layers of the proposed stack exchange information without processing at adjacent layers, so fast signaling information delivery to the destination is possible.

- Bidirectional signaling is possible since the CLASS messages are not related to data packets.

3.2.1Limitations of Cross Layer Signaling Shortcuts (CLASS)

The cross-layer design was designed for increasing the cross-layer feedback speed. The cross-layer feedback is built into the layer, so the layers need to be modified to adapt to each new cross-layer algorithm. Each layer is needed to generate events for informing other layers. Both of these modifications increase the processing overhead on the layers and results to reduction in the stack processing speed. This architecture demands direct communication between the layers, it introduces dependency among the interacting layers.[15,16] This would lead to increase in the task of maintaining the cross layer feedback implementation**.**

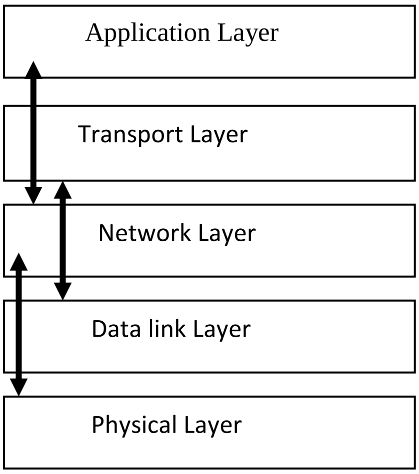

Fig. 2. Direct Communication between layers

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3.3 Shared Database Cross-Layer Architecture[9]

In this approach a new layer like, a common database is framed that can be shared by all the layers. This database is used for providing storage and retrieval of information by all the layers. An optimization program can interface with the different layers at once through the shared database. New interfaces between the layers can be realized through the shared database but the main challenge of this architecture is the design of the interaction between the different layers. An example of shared database cross-layer architecture is the MobileMAN project. The MobileMAN project [CMT04] aims to exploit a full cross-layer design for MANETs. The architecture presents a core component, Network Status (NS) that works as an information repository. The layer separation is achieved by means of standard interfaces to access the network repository. Two possible interactions models are *synchronous* and *asynchronous*. Synchronous communications take place when there is request for private data which is on-demand in nature. A protocol layer issues a query for private data retrieval and waits for the result. Asynchronous interactions characterize the occurrence of specified conditions, to which protocols may be willing to react.

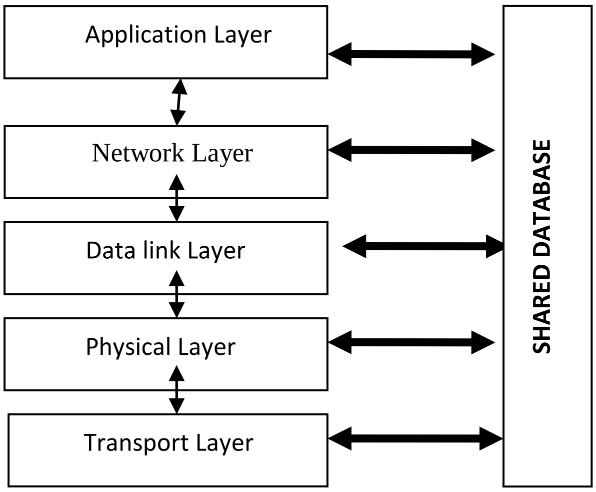

Fig. 3. Shared Database Cross-Layer Architecture

3.4. MobileMan: A Full Cross-Layer Architecture [18]

The reference architecture of MobileMan is a full cross-layer design but at the same time layer separation exists. Cross-layering is exploited in this architecture by information sharing among all the layers in the protocol stack. Some of the network functions like security, QoS, energy management, etc are cross-layer by nature. These functions need to be handled through information sharing between the protocol layers. The main feature of this approach is that, within the layered architecture, the protocols of the different layers cooperate by sharing network-status information while still separating the layers. *Network status (NS) is* the core component in this architecture.

3.4.1 Network Status:

It is a central repository of information, where from all the layers in the protocol stack collects. [17, 18,19] Each layer can access the *NS* to share its data with the other layers. By having the *NS* being accessible to all the layers, duplication efforts may be avoided and leads to a better system design. The layers in MobileMan are separated by standardizing their access to the *NS.* The read and write operations of the layers in the protocol stack has to be defined. The interaction between the *NS* and the layers are placed beside the normal layer behavior, this allows optimization without compromising the expected normal functioning. Replacing a network-status-oriented protocol with its legacy counterpart will therefore let the whole stack keep working properly, although at the cost of penalizing functional optimizations.

There are five access methods to the repository:-

I. The *seize* and *access* method: It permits insert and retrieval of information from the repository.
II. The *subscribe* method: A protocol declares its interest to receive notification of a specific event.
III. The *notify* method: A protocol to insert data in the repository to notify event occurrences.
IV. The *Monitor* method: A protocol for data gathering and monitoring of the repository.

3.4.2 Advantages of MobileMan architecture

The main merits of the MobileMan are:-

- Full compatibility with the existing strict-layering as there is no modifications to the core functions of the protocol stack.
- Maintains modular architecture.
- Provides robust upgrade environments, which permit the addition or removal of protocols belonging to different layers from the stack without modifying the operations at the other layers.
- Improved local and global adaptation.

3.4.3 Limitations of MobileMan Architecture

- The creation of the Network Status component requires substantial modifications in the protocol stack.
- It makes difficulty to add new cross-layer optimizations to the stack.
- Dependency occurs between the Network Status component and the protocol. So, modifications in the NS component require all the protocol layers to be modified. This increases overhead.
- There is increased stack processing overhead as the protocol executes additional code for monitoring the network status and determining appropriate action.

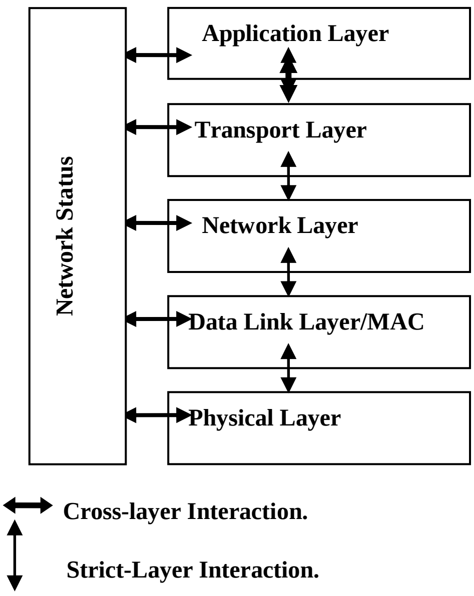

Fig. 4. MobileMan Cross-Layer Design Architecture

3.5 ICMP message passing based cross-layer Architecture: [16]

Internet Control Message Protocol (ICMP) messages are the standardized way of signaling event information from one layer to other layer. It involves operation with protocol headers: IP Header and ICMP.

Different methods of signaling using the ICMP messages are:-

3.5.1Packet Headers: signaling pipe

The network layer information may be added as additional header in the IPv6. [15, 16, 17] The interlayer signaling pipe stores the cross layer information in the wireless extension header (WEH). This method makes use of IP data packets as in-band message carriers with no need to use a dedicated internal message protocol. IP packet can be processed from layer to layer, it is not easy for higher layers to access the IP level header. Protocol adaptation is built into the protocol. Hence, the time overhead is low. Interlayer Signaling pipe architectures require the modification of one or more protocol layers to gather environment information and transmit it to other layers via the protocol stack. Environment information is detected at appropriate protocol layers and assembled into cross-layer packets, which are injected into the protocol stack in the direction of the recipient layer. The recipient layer recognizes the cross-layer packet, reads the environment information contained therein and utilizes the information to influence its own decision-making.

IPv6 header **Next Header** =WEH **……**	**WEH header** **Next Header = TCP Inter-layer info ……**	**TCP** **Header + payload**

Fig. 5. Cross-layer information with extension header

The signaling pipe is bottom to top approach. Although the ISP is implemented within the mobile host, network nodes and the corresponding host can read the information if they are WEH-aware.

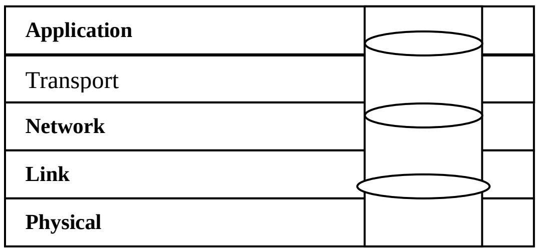

Fig. 6: Signaling pipeline in Mobile Host

3.5.2Limitations of Signaling Pipe

The Protocol stack needs to be modified, to introduce adaptations and feedback. This results in poor maintainability and high data path delay.

3.5.3 ICMP Messages:

The ICMP messages are encapsulated in the IP packet and passed from layer to layer. Since a message could be generated from any layer and then terminated at a higher layer, cross-layer signaling is[18,20] carried out through these selected "holes", rather than the "pipe". The ICMP messages encapsulated by IP packets have to pass by the network layer even if the signaling is only desired between the link layer and the application layer. The cross-layer communication is carried out through selected holes and not through general pipe. So, this method is flexible and efficient.

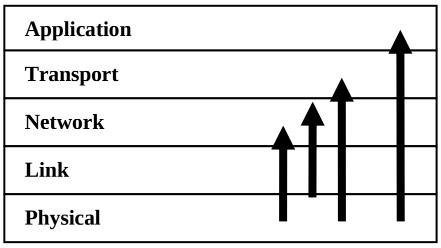

Fig. 7: Holes in Mobile Host

3.5.3 Local Profiles

The Cross-layer information is abstracted from the related layers and stored in a separate profile inside the mobile host. The other layers that are interested can select profiles to fetch desired information.[18, 19] This method is flexible since profile formats can be tailored to specific layers that can access the information directly. But this is not suitable for time stringent tasks. This method is not suited for time stringent task.

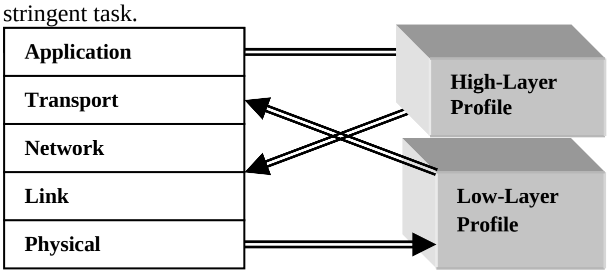

Fig. 8. Local Profiles in Mobile Hosts

3.5.4 Network Service:

A third party maintains a Wireless Channel Information (WCI) server. The channel and link information from the physical and data link layers is gathered, abstracted and managed in the WCI. As a network service, it is complementary to the former schemes within a MH although some overheads in the air is incurred and interfaces have to be defined among the MH, the WCI server and application servers.

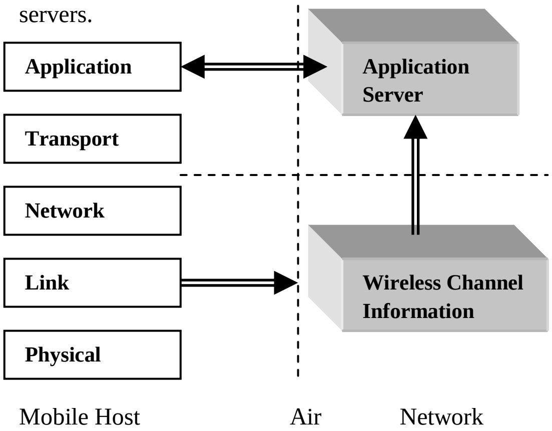

Fig. 9. Interface of Mobile host and WCI Server.

3.5.5 Limitations of ICMP message passing based cross-layer Architecture

- The message passing is only in the upward direction. The upper layers cannot communicate with the lower layers. Therefore, it does not enable any-to-any layer feedback in general.
- The architecture does not provide mechanism for defining adaptation for layers below the transport layers. It requires modifications to the protocol stack to introduce application and transport action tables and new ICMP handler.
- The protocol layers needs modification to introduce new APIs in the protocol stack to support adaptation. A new variable has to be introduced to allow modifications in the protocol behavior. These modifications lead to difficulty to ensure correctness and increased effort for stack code maintenance.
- The cross layer feedback overhead is higher since the messages are encapsulated in ICMP messages. The adaptations of the transport layer are based on the actions stated by the application. Therefore, the transport protocol is adapted for each application separately and there is no mechanism to have a common adaptation for all the transport layer sessions.

3.6 Layer Manager based Cross-layer Architecture[17]

The cross layer manager is exposed to the events and state variables of the protocol layers. The management algorithms to perform the cross layer information processing use these events. The cross layer manager uses the state variables to query and set the protocol internal state. To extract the benefits of cross-layer design the concept of coordination plane was introduced. [13] A coordination plane is a cross-section view of the protocol stack on which interlayer coordination algorithms are applied and it solves a set of problems of the same kind. Four coordination planes were been identified:

(a) Wireless link adaptation: includes cross issues, bit error rate and error rate adaptability.
(b) Mobility: includes the problems created by mobility scenarios.
(c) Security: Includes elimination of multilayer encryption.
(d) QoS: includes distribution of QoS requirements.

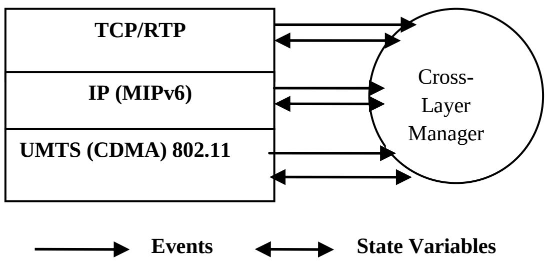

Fig. 10. Interlayer Coordination model.

3.6.1 Limitations of Layer Manager based Cross-layer Architecture:

1) The layers are to generate events to feed to the cross layer manager. This leads to slow down of layer execution.

2) Further, the cross layer manager is dependent on the protocol implementation since it reads and updates state variable information of a protocol.

4. Evolutionary & Revolutionary approach to Cross Layer design

The CLD approach to network stack design is historically a big shift in how one designs a communication system. Not only does the applications, protocols and hardware need to be reimplementation to be able to support the new extensions, but the whole concept of CLD challenges everything engineers and researchers know about network protocols, layers, stack design and system construction. While CLD might seem revolutionary instead of evolutionary at first, there are implementations available today which tries to incorporate some of the key elements of the CLD philosophy into existing protocols and layers

The evolutionary approach gives priority to compatibility with existing system than to the performance. The evolutionary aspect targets to enhance the existing system so that it becomes interoperable with the existing system. Most cross layer designs are evolutionary since it is important to think for end users and commercial vendors. This simple yet effective cross layer design solutions are most popular as they are compatible with the existing system. In several aspects there is no need for all layer interaction but only two or three layer interaction so it makes sense to extend the existing system. This method has been adopted by Mobileman project.

The revolutionary aspect of cross layer design approaches is to build a new system without extending the existing system. Most cross layer designs are evolutionary since it becomes difficult for commercial vendors to market. A revolutionary approach can however be applied to highly specific problems where backwards capability is not important. Wireless sensor network environment applies this method. Joint Source Channel Coding (JSCC) with Shannon's mapping are the revolutionary approach to cross layer design. In ISCC the source coding and channel coding are treated differently. Source coding aims to remove redundancy using an efficient representation of the source signal. Channel coding involves adding redundancy to achieve error free transmission in noisy environments. JSCC allows the coder exploit the changes in the channel conditions or variations of the source contents. As a result, it is adaptive and robust systems and give better performance when operating under delay constraints or time varying channels.

5. Conclusion

In this paper a representative survey of existing research on cross layer feedback optimizations. As new wireless networks are deployed, to enhance the performance of the protocol stacks multiple cross layer feedback algorithms would be required. These algorithms would need to be easily integrated with the existing stack. Introduction of cross layer feedback should not impact the correctness, efficiency, and maintainability of the existing protocol stack. It has been shown that the existing approaches to cross layer feedback implementation impact the runtime efficiency and have poor maintainability. The design goals for cross layer feedback architecture are efficiency, rapid prototyping, minimum intrusion, portability and any-to-any layer communication. Existing approaches to cross layer feedback do not address all the design goals. In the ongoing cross-layer versus legacy-layer architecture debate, the ad hoc research community recognizes that cross-layering can provide significant performance benefits, but also observes that a layered design provides a key element in the Internet's success and proliferation. Strict layering guarantees controlled interaction among layers because developing and maintaining single layers takes place independently of the rest of the stack. On the other hand, an unbridled cross-layer design can produce spaghetti-like code that is impossible to maintain efficiently because every modification must be propagated across all protocols. Further, cross-layer designs can produce unintended interactions among protocols, such as adaptation loops, that result in performance degradation.

Future work on cross layer design approach may to replace traditional layered structures completely. However this might not even be possible because of the demand for compatibility with every other network using the IP. It is therefore, observed that for task specific purposes, revolutionary approach is beneficial. By leaving out the redundant parts of the layered architecture and also the redundant protocols, it is possible to obtain an optimized and power efficient system to specific problems. Greater development cost and a delayed time-to-market will be out weighted by the many advantages a system-wide CLD provides.

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