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Cross Layer Design Approach in Wireless Mobile ADHOC Network Architecture

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Abstract: Traditional Wired network uses protocol architectures follow the principle of stack layered implemented by ISO/OSI model. ISO/OSI model was developed to support all the standardization of the network architecture using layered model. Initially wireless network also adopts the traditional stack layered architecture from the wired networks. This Layered architectures are not efficiently cope up with the dynamically changing environment in the wireless-dominated next-generation communications with a wide range of Quality of Service (QoS) requirements. Wireless network performance can be degraded due to the adaptation of the protocols from layered architecture and Transmission control protocol/ Internet Protocol (TCP/IP), which was designed originally for wired network. However, lack of coordination between layers limits the performance of such architectures due to the specific challenges posed by wireless nature of the transmission links. In this paper a new cross layer design is adopted in wireless mobile Adhoc network in order to overcome the network performance problems. Since nowadays wireless networks are becoming very popular technology. In the Mobile Adhoc network, cross-layer design allows the protocol that belong to different layers which cooperate in sharing network-status information while still maintaining the layers separation at the design level. Cross-layer design has been proposed to maintain the functionalities associated to the original layers but to allow coordination, interaction and joint optimization of protocols crossing different layers.

Keywords: Wireless mobile ADHOC network Architecture, QoS, Cross Layer Design, TCP/IP, ISO/OSI

I. INTRODUCTION

Nowadays Wireless networks are becoming very popular technology in the world. Hence it is very important to understand the architecture for this kind of networks before deploying it in any application. But we are very much familiar with wired technologies. Growing interest and penetration of wireless networking technologies are underlining various challenges in the design and optimization of communication protocols. The ISO/OSI protocol architectures follow strict layering principles, which ensure interoperability, fast deployment, and efficient implementations. However, lack of coordination between layers limits the performance of such architectures due to the specific challenges posed by wireless nature of the transmission links. This is due to the infrastructure less wireless Adhoc network nodes with its dynamic nature. To overcome such limitations, cross-layer design has been proposed. Its core idea is to maintain the functionalities associated to the original layers but to allow coordination, interaction and joint optimization of protocols crossing different layers.

This may be required to accept new approaches in which protocols can be designed by violating the reference layered architecture allowing direct communication between protocols in nonadjacent layers Such violations of a layered architecture have been termed as cross-layer design (CLD) or sometimes called as Delayered model.

II.ISO/OSI TCP/IP PROTOCOL STACK PRINCIPLES

Presently the design of network architectures is based on the layering principle, which provides an attractive tool for designing interoperable systems for fast deployment and efficient implementation. ISO/OSI model [1] was developed to support standardization of network architectures using the layered model. The main concepts motivating layering are the following:

- Each layer performs a subset of the required communication functions
- Each layer relies on the next lower layer to perform more primitive functions
- Each layer provides services to the next higher layer
- Changes in one layer should not require changes in other layers

Such concepts were used to define a reference protocol stack of seven layers, going from the physical layer (concerned with transmission of an unstructured stream of bits over a communication channel) up to the application layer (providing access to the OSI environment). A protocol at a given layer is implemented by a (software, firmware, or hardware) entity, which communicates with other entities (on other networked systems) implementing the same protocol by Protocol Data Units (PDUs). A PDU is built by payload (data addressed or generated by an entity at a higher adjacent layer) and header (which contains protocol information). PDU format as well as service definition is specified by the protocol at a given level of the stack. The same concepts are at the basis of the de-facto standard protocol stack on the Internet, namely the TCP/IP protocol stack [2]. The main advantage deriving from the layering paradigm is the modularity in protocol design, which enables interoperability and improved design of communication protocols. Moreover, a protocol within a given layer is described in terms of functionalities it offers, while implementation details and internal parameters are hidden to the remainder layers (the so-called “information-hiding” property). The TCP/IP (Transmission Control Protocol/Internet Protocol [5]) protocol stack has been standardized for connecting to the Internet, using wire line devices (example desktop PCs). This protocol stack is also being deployed on mobile wireless nodes (3G and beyond [8, 6]), to ensure interoperability with the existing Internet. The architecture and implementation of a TCP/IP stack is layered [3]. In a layered stack, a layer does not share information about its state with any other layer. For example, layers such as TCP or IP are not aware of disconnection or handoff at the lower layers. This leads to inefficient functioning of the layered stack in mobile wireless environments [4, 7]. On a mobile device, this inefficient functioning would lead to poor user experience, decreased throughput, decreased battery life, etc. We highlight this inefficiency of a layered stack.

III.CROSS LAYER DESIGN

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. We list a few examples of cross layer feedback for each layer:

Physical: Channel condition (example, bit-error rate) status from the physical layer can be used by the link layer to adapt the frame length [12]. Also, physical layer transmit power can be tuned by Medium Access Control (MAC) layer to increase the range of transmission [14].

Link / MAC layer: The number of retransmissions at the link layer can serve as a measure of channel condition. TCP may re-estimate its retransmission timers based on this data. The link layer may adapt its error correction mechanism based on the Quality-of-Service (QoS), that is, acceptable delay, packet losses, etc. Requirements of the application layer [21].

Network: Mobile-IP hand-off begin/end information can be used at TCP to manipulate its retransmission timer [10]. Mobile-IP layer could use link layer hand-off events to reduce its hand-off latency [19, 20].

Transport: Packet loss data from TCP can help the application layer adapt its sending rate. Link layer and TCP retransmission interference [11] can be reduced by making the link layer adapt its error control mechanisms based on TCP retransmission timer information.
Application: An application could use information about channel conditions from the physical layer to adapt its sending rate [16]. Also, an application could indicate to the user the throughput it requires versus the available throughput.

User: A user may define application priorities which can be to mapped to proportional receiver window values within TCP [17, 18]. Besides the feedback between protocols at different layers, as indicated above, feedback could also be between protocols within the same layer. This would be required in scenarios such as vertical hand-off [9], when a mobile device moves across heterogeneous networks. In such scenarios, multiple interfaces and hence protocols within the same layer, for example 802.11 [13] and GPRS [15] protocols within MAC and Physical layers, would need to coordinate the hand-off. As new wireless networks are deployed, various cross layer feedback optimizations would be required to enhance the performance of the existing protocol stacks. These cross layer optimizations would require easy integration with the existing stack. Thus an appropriate architecture is required for implementing cross layer feedback. In the following sections, we present an overview of existing approaches to cross layer feedback implementation and list the proposed design goals for a cross layer architecture. Several cross-layering approaches have been proposed so far [22 - 25]. In general, on the basis of available works on the topic, two approaches to cross-layering can be defined here:

- 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; in this case, individual features related to the different layers can be lost due to the cross-layering optimization. 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 notation is “evolutionary approach” for the “weak cross-layering” and “revolutionary approach” for the “strong cross-layering” [26].

IV. CROSS-LAYER SIGNALLING ARCHITECTURES

The large variety of optimization solutions requiring information exchange between two or more layers of the protocol stack raises an important issue concerning implementation of different cross-layer solutions inside

TCP/IP protocol reference model, their coexistence and interoperability, requiring the availability of a common cross-layer signalling model [27]. This model defines the implementation principles for the protocol stack entities implementing cross-layer functionalities and provides a standardized way for ease of introduction of cross-layer mechanism inside the protocol stack. In [28], Raisinghani et al. define the goals the cross-layer signalling model should follow. They aim at rapid prototyping, portability, and efficient implementation of the cross-layer entities while maintaining minimum impact on TCP/IP modularity. In this framework, several cross-layer signalling architectures have been proposed by the research community. While the following paragraphs will provide an overview and comparison between the most relevant solutions, it is important to note that research on the topic is far from being complete. In fact, up to now, just of few of cross-layer signalling proposals were prototyped and none of them is included into current operating systems.

A. Interlayer Signalling Pipe.

One of the first approaches used for implementation of cross-layer signalling is revealed by Wang et al. [29] as interlayer signalling pipe, which allows propagation of signalling messages layer-to-layer along with packet data flow inside the protocol stack in bottom-up or top-down manner.(Fig.1.) An important property of this signalling method is that signalling information propagates along with the data flow inside the protocol stack and can be associated with a particular packet incoming or outgoing from the protocol stack. Two methods are considered for encapsulation of signalling information and its propagation along the protocol stack from one layer to another: packet headers or packet structures.

- Packet headers can be used as interlayer message carriers. In this case, signalling information included into an optional portion of IPv6 header [30], follow packet processing path and can be accessed by any subsequent layer. One of the main shortcomings of packet headers is in the limitation of signalling to the direction of the packet flow, making it not suitable for cross-layer schemes which require instant communication with the layers located on the opposite direction. Another drawback of packet headers method is in the associated protocol stack processing overhead, which can be reduced with packet structures method.

- Packet structures. In this method, signalling information is inserted into a specific section of the packet structure. Whenever a packet is generated by the protocol stack or successfully received from the 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 descriptor, configuration parameters and other. Consequently, cross-layer signalling information added to the packet structure is fully consistent with packet header signalling method but with reduced processing. Moreover, employment of packet structures does not violate existing functionality of separate layers of the protocol stack. In case the cross-layer signalling is not implemented at a certain layer, this layer simply does not fill / modify the corresponding parts of the packet structure and does not access cross-layer parameters provided by the other layers. Another advantage of packet structure method is that standardization is not required, since the implementation could vary between different solutions.

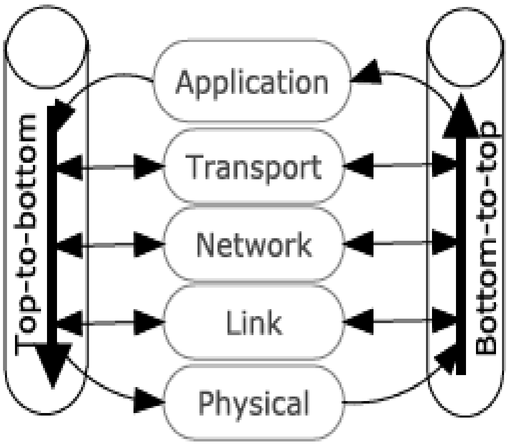

Fig. 1 Interlayer Signalling Pipe in Cross-layer Signalling Architectures.

B. Direct Interlayer Communication

It is proposed in [29] aims at improvement of interlayer signalling pipe method by introducing signalling shortcuts performed out of band. In this way, the proposed Cross-Layer Signalling Shortcuts (CLASS) approach allows non-neighbouring layers of the protocol stack to exchange messages, without processing at every adjacent layer, thus allowing fast signalling information delivery to the destination layer. Along with reduced protocol stack processing overhead, CLASS messages are not related to data packets and thus the approach can be used for bidirectional signalling. Nevertheless, the absence of this association is twofold since many cross-layer optimization approaches operate on per-packet basis, i.e. delivering cross-layer information associated with a specific packet travelling inside the protocol stack.

One of the core signalling protocols considered in direct interlayer communication is Internet Control Message Protocol (ICMP) [31, 32]. Generation of ICMP messages is not constrained by a specific protocol layer and can be performed at any layer of the protocol stack. However, signalling with ICMP messages involves operation with heavy protocol headers (IP and ICMP), checksum calculation, and other procedures which increase processing overhead. This motivates a "lightweight" version of signalling protocol CLASS [29] which uses only destination layer identification, type of event, and related to the event data fields. Fig.2 shows the Direct Interlayer Communication.

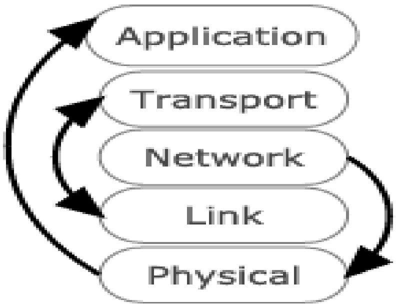

Fig. 2 Direct Interlayer Communication in Cross-layer Signalling Architectures.

However, despite the advantages of direct communication between protocol layers and standardized way of signalling, ICMP-based approach is mostly limited by request-response action - while more complicated event-based signalling should be adapted. To this aim, a mechanism which uses call-back functions can be employed. This mechanism allows a given protocol layer to register a specific procedure (call-back function) with another protocol layer, whose execution is triggered by a specific event at that layer.

C. Central Cross-layer Plane

Central Cross layer plane implemented in parallel to the protocol stack is probably the most widely proposed cross-layer signalling architecture. In [33], 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 database is an example of passive Central Cross-Layer Plane design: it assists in information exchange between layers but does not implement any active control functions such as tuning internal parameters of the protocol layers.

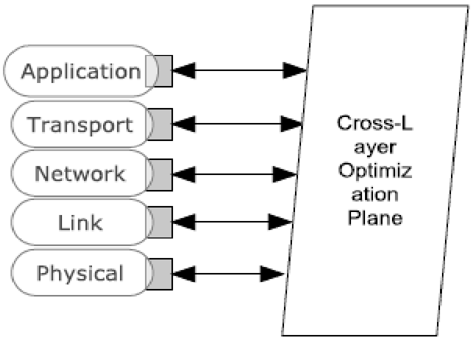

Fig. 3 Central Cross-layer Plane in Cross-layer Signalling Architectures.

Similar approach is presented by the authors of [34], which introduces a Central Cross-layer Plane called Cross-layer Server able to communicate with protocols at different layers by means of Clients. This interface is bidirectional, allowing Cross-layer server to perform active optimization controlling internal to the layer parameters.(See Fig.3.)

Another approach, called ECLAIR, proposed by Raisinghani et al. in [28] is probably the most detailed from the implementation point of view. ECLAIR implements optimizing subsystem plane, which communicates with the protocol stack by means of cross-layer interfaces called tuning layers. Each tuning layer exports a set of API functions allowing read/write access to the internal protocol control and data structures. These API can be used by protocol optimizers which are the building blocks of the optimizing subsystem plane.. Similar goals are pursued by Chang et al. [20] with another architecture falling into Central Cross-Layer Plane category. It assumes simultaneous operation of multiple cross-layer optimization approaches located at different layers of the protocol stack and aims at coordination of shared data access, avoiding dependency loops, as well as reduction of the overhead associated with cross-layer signalling. To this aim, an Interaction Control Middleware plane is introduced to provide coordination among all the registered cross-layer optimizers implemented in different layers. The main difference of this cross-layer architecture proposal with other proposals of this category is that signalling information propagates along the protocol stack with regular data packets - making it a unique combination of Central Control Plane and interlayer signalling pipe approaches.

D. Network-wide Cross-Layer Signaling

Most of the above proposals aim at defining cross-layer signalling between different layers belonging to the protocol stack of a single node. However, several optimization proposals exist which perform cross-layer optimization based on the information obtained at different protocol layers of distributed network nodes. This corresponds to network-wide propagation of cross-layer signalling information, which adds another degree of freedom in how cross-layer signalling can be performed, as shown in Fig.4.

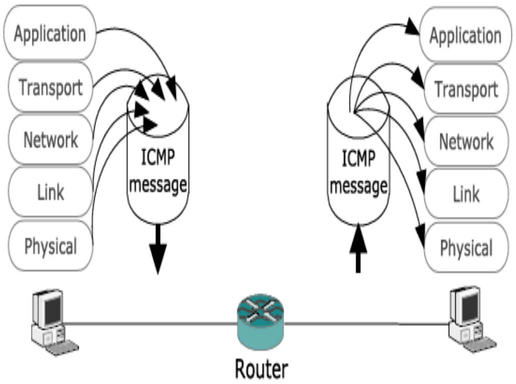

Fig. 4 Network-wide Cross-layer Signalling in Cross-layer Signalling Architectures

Among the methods overviewed above, packet headers and ICMP messages can be considered as good candidates. Their advantages, underlined in the single-node protocol stack scenario, become more significant for network-wide communication. For example, the way of encapsulating cross-layer signalling data into optional fields of the protocol headers almost does not produce any additional overhead and keeps an association of signalling information with a specific packet. However, this method limits propagation of signalling information to packet paths in the network. For that reason, it is desirable to combine packet headers signalling with ICMP messages, which are well suited for explicit communication between network nodes.

One of the early examples of cross-network cross-layering is the Explicit Congestion Notification (ECN) presented in [35]. It realizes in-band signalling approach by marking in-transit TCP data packet with congestion notification bit. However, due to the limitation of signalling propagation to the packet paths this notification need to propagate to the receiver first, which echoes it back in the TCP ACK packet outgoing to the sender node. This unnecessary signalling loop can be avoided with explicit ICMP packets signalling. However, it requires traffic generation capabilities form network routers and it consume bandwidth resources.

An example of adaptation of Central Cross-Layer Plane-like architecture to the cross-network cross-layer signalling is presented in [36]. This suggests the use of a network service which collects parameters related the wireless channel located at the link and physical layers, and then provides them to adaptive mobile applications.

A unique combination of local and network-wide cross-layer signalling approaches called Cross-Talk is presented in [19]. Crosstalk architecture consists of two cross-layer optimization planes. One is responsible for organization of cross-layer information exchange between protocol layers of the local protocol stack and their coordination. Another plane is responsible for network-wide coordination: it aggregates cross-layer information provided by the local plane and serves as an interface for cross-layer signalling over the network. Most of the signalling is performed in-band using packet headers method, making it accessible not only at the end host but at the network routers as well. Cross-layer information received from the network is aggregated and then can be considered for optimization of local protocol stack operation based on the global network conditions.

Main problems associated to deployment of cross-layer signalling over the network, also pointed in [37], include security issues, problems with non-conformant routers, and processing efficiency. Security considerations require the design of proper protective mechanism avoiding protocol attacks attempted by non-friendly network nodes by providing incorrect cross-layer information in order to trigger certain behaviour. The second problem addresses misbehaviour of network routers. It is pointed out that in 70% of the cases, IP packets with unknown options are dropped in the network or by the receiver protocol stack. Finally, the problem with processing efficiency is related to the additional costs of the router's hardware associated with cross-layer information processing. While it is not an issue for the low-speed links, it becomes relevant for high speeds where most of the routers perform simple decrement of the TTL field in order to maintain high packet processing speed.

V. COMPARISON

A comparison of different cross-layer signalling methods through the comparison of their essential design and deployment characteristics is presented in Table I Such features include:

- Scope defines cross-layer approach operation boundaries. Solutions which limit their operation to a single protocol stack are more flexible in the choice of signalling techniques: they can use internal protocol stack techniques such as packet structures or call-back functions, thus avoiding processing related overhead and the need for standardization effort.

- Propagation latency parameter describes the delay associated with signalling message delivery. It becomes essential for signalling performed across the network, where the delay corresponds to the delay of communication links and time messages spend in router buffers. For local signalling methods, the delay is usually several orders of magnitude lower than for network-wide cross-layering. However, signalling using interlayer signalling pipe method is slower than direct interlayer communications due to layer-by-layer processing. Moreover, interlayer signalling pipe can only afford asynchronous reaction to the event occurred, while direct communication allows instantaneous reaction.

- Communication overhead parameter is more essential for network-wide communication and describes the amount of network resources needed for signalling. Encapsulation of signalling information into packets headers does not require any additional network resources in case reserved fields are used, or corresponds to just minor increase in case optional packet header fields are involved. On the contrary, ICMP messages require a dedicated effort for their delivery from the network, consuming considerable amount of network resources – including also protocol (ICMP and IP headers) overhead. The communication overhead for local signalling corresponds to the amount of operations (CPU cycles) required to deliver the message from one layer to another. This parameter is different from processing overhead, which includes message encapsulation and processing. The highest communication overhead for local communications is associated with interlayer signalling pipe due to subsequent processing at several protocol layers before message delivery.

- Processing overhead is the amount of processing power required for message creation, encapsulation, extraction, and analysis. Medium processing effort is required for signalling messages transmitted using packet headers and packet structures inside the protocol stack (mainly needed for allocation of memory and data copy procedures). Higher processing overhead is required for ICMP message creation, which involves execution of ICMP and IP layer functions of the protocol stack. For network-wide signalling, the overhead of packet headers method is medium. The procedures at the end nodes are similar to packet headers signalling performed locally, while no additional effort associated with signalling information delivery is taken. This is due to the fact that signalling information is encapsulated into the regular data packet and is being delivered along with it.

- Direction of signalling is an important characteristic which defines the applicability of the signalling approach to the chosen cross-layer optimization scheme. The schemes which do not rely on regular traffic flow (or out-of-band) signalling are packet path independent, providing a faster reaction to an event. This reaction can be preformed also in synchronous way, while packet path dependant signalling provides only asynchronous reaction. The speed and flexibility of path independent signalling comes at the expense of the additional communication resources. Nevertheless, path independence cannot be only considered as an advantage: many cross-layer optimization algorithms require signalling information associated with a specific packet transmitted through the network - making path dependant signalling more attractive in such cases. In order to implement packet association in non-path dependant approaches, a unique identification or a copy of the packet associated with the transmitted signalling information should be attached to the message. A good example of this technique is "Time Exceeded" ICMP message sent by a router for a packet dropped due to expired TTL, which includes IP header and part of data of this packet.

- Requires standardization parameter specifies whether standardization effort is needed for the cross-layer signalling method which is considered to fully support effective deployment. Standardization is required for signalling performed over the network while standardization of network protocols which are used solely inside the protocol stack of the single node is still desirable but can be avoided. This positions internal protocol signalling methods based on packet structures or call-back function is less dependent on standardization bodies and thus more flexible for the deployment form the implementation point of view as well as time wise.

TABLE I.

COMPARISON OF THE CROSS-LAYER SIGNALLING METHODS.

Cross-Layer Signaling Method	**Scope**	**Propagation Latency**	**Communication overhead**	**Processing overhead**	**Direction of signaling**	**Requires standardization**
Interlayer Signaling Pipe						
Packet Headers	Local	Medium	High	Medium	Path dependant	√
Packet Structures	Local	Medium	High	Medium	Path dependant	×
Direct Interlayer Communications						
ICMP messages	Local	Low	Medium	High	Path independent	√
Callback functions	Local	Low	Low	Low	Path independent	×
Central Cross-layer Plane	Local	Low	Low	Low	Path independent	×
Network-wide Cross-layer Signaling						
Packet Headers	Local/Network-wide	High	Low	Medium	Path dependant	√
ICMP messages	Local/Network-wide	High	High	High	Path independent	√

Cross-Layer Signaling Method
Interlayer Signaling Pipe Packet Headers Packet Structures
Direct Interlayer Communications ICMP messages Callback functions
Central Cross-layer Plane
Network-wide Cross-layer Signaling Packet Headers ICMP messages

VI. CONCLUSION

we addressed the need for a Cross Layer approach in wireless mobile Adhoc Networks. Cross layer feedback is essential for improving the performance of layered protocol stacks deployed over mobile wireless networks. We compared various Cross layer signaling architecture's parameters/metrics and understands its merits and demerits. This research work has providing the basic requirement of cross layer design in mobile networks. In the Mobile Adhoc network, cross-layer design allows the protocol belong to different layers which cooperate in sharing network-status information while still maintaining the layers separation at the design level. Cross-layer design has been proposed to maintain the functionalities associated to the original layers but to allow coordination, interaction and joint optimization of protocols crossing different layers. Also the limitations in ISO/OSI, TCP/IP layered protocols are eliminated and the performance is improved by adopting cross layer design in wireless mobile Adhoc networks.

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