International Journal on Applications in Information and Communication Engineering
Volume 1: Issue 9 : September 2015, pp 61 – 68 www.aetsjournal.com ISSN (Online) : 2394 - 6237

AN INTEGRATED CROSS-LAYER DESIGN FOR EFFICIENT LIVE MULTIMEDIA TRANSMISSION IN MOBILE AD-HOC NETWORKS

P. THANGAVEL , S. MOHANASUNDARAM

Abstract— Mobile ad-hoc network is becoming nontrivial to modern communication system because of the ubiquity of portable mobile devices. But, MANETs does not efficiently support real-timemediastreaming since it has large resource requirements andhard timing constraints for data delivery.The main aim of this study is to enhance the quality of live media streaming by means of cross-layer architecture. Cross-layer frameworkdiffers from a conventional layered architecture where each layer of the architecture performs autonomously. In this work, we develop an integrated cross-layer design (IXLD) for real-time multimedia streaming over MANETs. This novel technique enables knowledge sharing among various layers of the architecture and optimizes end-to-end performance of media streaming by utilizing layer-specific. This paper has explored the keyfactorsexploited in cross-layer interactions to enhance the quality of multimedia transmission. Extensive experiment results illustrate that our IXLD can enhance the end-to-end performance of multimediatransmission over MANETs regardless of channel and network dynamics.

Keywords— cross-layer design; MANET; QoS; rate adaption; video transmission;

I. INTRODUCTION

Mobile ad-hoc network (MANET) is a group of autonomous wireless computing devices which cooperate with each other to construct a mesh network without using any fixed infrastructures like base-stations or wireless access points. Hence, MANET is very flexible and extremely compelling for applications where fixed communication infrastructure is very costly to install, cannot be installed rapidly, or is merely not practical. There are a number of mission-critical application domains for MANETs like temporary information sharing in a video conferencing, highway or building automation, communication for disaster recovery and military actions, and intelligent transportation. The decentralized infrastructure, multi-hop routing, channel and network dynamics, signal interference and other features unique to MANET imposes some daunting technical difficulties in supporting real-time multimedia transmission. Moreover, related to the other conventional paradigm, MANET agonizes from the resource constraints in processing capacities, energy, and data rate.

The communicationmedia in the wireless network is fundamentally a capacity-limited broadcast channel;as a result, the mobile devices interfere with each other.The quality of transmissionmediafluctuates over time owing to channel vagaries (e.g. signal fading, node interference, shadowing,and multipath effects, etc.). Network topologies may change hastily and unpredictably as hops leave outorjoin in the network randomly. Additionally, as new links are established and others disappear, transmitting data packets from one hop to another may frequently change. These network dynamics makes extremely hard to deliver the required Quality of Service (QoS) for real-time applications where a best-effort service is not sufficient(e.g. live mediatransmission). Moreover, these issues have stimulatedample investigations on performance evaluation of MANET for live multimedia transmission.

Real-time transmission of video over MANET requires high data rates and stringent delay constraints as data packets need to be received in a timely manner to ensure nonstop media playout. Ifdata packets arrived late or lost, the quality of pictureseverely deterioratesdue to error propagation to succeeding frames of the video. Since video streaming places a demand for higher bandwidth it aggravates the network congestion considerably. Therefore, it is essential to consider the potential impact of each video user on the network statistics and assure that the network is not operating beyond its capacity. Unfortunately, most of the conventional QoS provisioning approaches designed for infrastructure networks have revealed to be insufficient, even if DiffServ and IntServ frameworks can still be employed to accomplish and regulate traffics using marking, queuing, and discarding policies [1]. Hence,

P. Thangavel , Department of Information Technology , Institute of Road and Transport Technology , Erode, Tamilnadu, India, (Email : thangasirtt@gmail.com).
S. Mohanasundaram , Department of Information Technology , Institute of Road and Transport Technology , Erode, Tamilnadu, India , (Email ID :smohanirtt@gmail.com).

QoS management for streaming videos in MANET imposes an extremely stimulating challenge and ruins an open issue.

Even though the conventional layering principles have been offering services to communication engineers for the last three decades, it could not deal with the development of highly complex multimedia applications with stringent quality constraints**.** Therefore, an innovative cross-layer design is essential to overcome the limitations of rigid architectures and to enable interaction between non-contiguous layers. Demand for service quality in real-time applications is pushing the investigators in the arena of ad-hoc networks to bring revolutions. QoS is defined as a set of services guaranteed by the network to its users. The absence of the central administrator, frequent link breakage and limited bandwidth make communication in MANET particularly challenging.

In view of these issues, it is very difficult to satisfy a specified level of QoS in MANET. Most of the techniques proposed for performance optimization in MANET rely on inflexible layering principle, which diminishes designing complexity, establishes interoperability and facilitates simple and rapid implementations. Nevertheless, conventional layering architecture restricts the overall performance of the network due to the deficiency of coordination between non-adjacent layers.

We believe that one promising scheme to resolve the aforesaid issues in the video streaming over MANET is the so-called framework "cross-layer" design (XLD) [2]. The primary idea of XLD is to preserve the activities related to the original layers but to permit synchronization, sharing state information and joint optimization of protocols across various layers.XLDs rely on any violation or modification of the sharp boundaries of traditional layered architecture. The violation of layering principles includes unification of more than one layer, the establishment of novel interfaces and facilitating interaction between various protocols stack. Protocols utilize the state information flowing throughout the stack to adjust their performance consequently. The interdependency across different layers introduces the benefit of explicit layer cooperation in the protocol stack, to handle the meagre performance of communication links and nodes, high BER, energy conservation, QoS, etc. This new paradigm implements stack wide interdependencies and hence enables us to distribute useful information throughout the stack.

Modern researches show that careful exploitation of XLD yields a high possibility of optimization and better end-to-end performance gain by smart interactions between non-adjacent layers. Hence, it is the best choice for adynamic real-time environment to realize the certain decisive impact on network performance such as energy conservation, an adaptation based on the service contract and so forth. Nevertheless, there is still a deficiency of XLDtechniques to directly support real-time video streaming. The key objective of this study is to explore a new XLD framework to address aforesaid issues and making live mediatransmission in MANETs a favorable application domain. In this context, we deploy a XLD that integrates adaptation across all layers: dynamic rate adaptation, capacity and flow assignment, scheduling and application layer rate allocation techniques.The proposed technique syndicates the following features:

- Provision to reallocate link capacities dynamically according to link state information (LSI)
- Provision for capacity and flow assignment (CFA) to achieve an optimal flow rate
- Provision to implement stream-based multipath routing as well as intelligent packet scheduling to balance network congestion and distortion of live video streams

The rest of this paper is organized as follows: The following Section provides substantial relevant approaches aiming to support multimedia applications over MANETs. The overall structure of the proposed IXLD architecture is discussed in Section III. Adaptive link layer techniques are discussed in Section IV. Joint allocation of capacity and flow is explained in Section V.Congestion-distortion optimization technique and determination of the optimal operating rate is explained in Section VI. As a final point, we conclude this paper in Section VII.

II. RELATED WORK

To support multimedia applications over MANETs,the networking and video coding communities came with new suggestions that are already successfully employed. For live multimediatransmission, it is obvious that the partition procedure of channel and source coding stated in Shannon's information theory [3] does not hold. Thus, the combinedchannel and source coding approaches have been developed to solve the problems of the communication channel. But, these have not yet delivered an integrated solution to this issue [4]. However, these notions have intenselysought to stimulate the media communities in the development of video coding standard such as H.264, which includes a very flexible syntax appropriated for hard real-timeapplications [5].

The art of multimedia transmission over MANETs is still in its early stages, particularly when addressed through a XLD framework. Of late, most of the studies take only a few layers into account.The achievable capacity of an ad-hoc network hinges on signal interference, traffic flow and the number of nodes in the network. As the number of hopsin MANET increases, interference upsurges, decreasing the achievable bandwidth. Li et. al examines the achievable capacity of a static ad-hoc network through simulations and analysis [6]. The author studies 802.11 MAC layer interactions, their impact on channel capacity, and the scaling performance of per node capacity as networks grow.

Byung Joon Oh and Chang Wen Chen develop a cross-layer design based on multichannel MAC protocol with Time Division Multiple Access (TDMA) for reliable delivery of H.264 encoded video streams. The proposed framework centered on two major modules to design a multi-channel MAC protocol. In the first module, Maximum Latency Rate (MLR) is considered as the quality measure to categorize the video traffic [7]. The traffic with the lower value of MLR from the PHY layer is considered as a better link quality in the MAC layer. In the second module, by correlating the knowledge of MAC layer utilization and buffer size in the NET layer, they achieve a considerable enhancement in the performance of congestion-aware routing protocol.

Navaratnam et al. investigate the influence of channel contention on the behavior of the TRANS layer. They introduce a novel Link Adaptive Transport Protocol (LATP) to increase the QoS metrics of video streaming applications [8]. The LATP utilizes cross-layer interaction to achieve efficient load control in the TRANS layer for end-to-end flows. According to the knowledge of channel contention gained from the MAC layer, the LATP regulates the transmission rate at the TRANS layer. Experimental results reveal that the LATP provides an efficient means to increase the QoS performance measures and fairness for real-time applications with strict performance constraints.

Mao et.al developed a novel XLD architecture with multi-stream coding to perform path multiplicity in an 802.11 network for multimedia streaming[9]. Schaaret. al proposed another adaptive XLD for increasing the reliability and effectiveness of media streaming by adjusting data rate, dependability, and latency constraintsaccording to the channel statistics and application demands [10]. Lin Xiao et. al proved that capacity and flow can be assigned together as a linear convex function over the traffic flow and design variables to reduce network congestion [11].Wu et al. performed this joint allocation with MAC layer scheduling techniquesby implementing a comprehensive cross-layer optimization [12]. Considerableinvestigations still need to be carried outin this direction to discover and use cross-layer communications in live video transmission in MANETs.

III. AN INTEGRATED CROSS-LAYER DESIGN

The objective of this research work is to design a cross-layer architecture to stimulate the overall performance of the video streaming in MANET. Cross-layer techniques enable the user to break up or modify the sharp boundaries of traditional layered architectures. The violation of layering architectures entails many adaptation capabilities like merging of some contiguous layers, designing of interfaces and enabling information flow among different layers. They allow different layers to interchange state information or to synchronize their operation to provide a decisive impact on the network performance. Moreover, recent research reveals that cautious implementation of XLD produces a high possibility of performance optimization by expediting cooperative interaction among different layers.Hence, flexible and intelligent XLD is the only choice to fulfil users' QoS expectations of delay-constrained applications like live media streaming. On the other hand, the existing XLDs are expensive and provide increased design complexity and overhead for unpredictable topology changes due to randomly moving mobile nodes.

To realize preferred optimization goal, there is a necessity to share locally available information between various layers which is called state information. Theproposed IXLD architecture utilizes state information such as channel condition (e.g. collision level, channel fading, modelling etc.),traffic parameters (e.g. type of traffic, information of the transmission rate, inter-arrival time of packets, data segmentation, etc.) and resource information (e.g.multi-user scheduling, battery exhaustion rate, buffer-space, resolution, type of antennae used, etc.) throughout the stack to adjust their behavior respectively and this will increase the overall performance of the network.

In this framework, each layer is not oblivious of the other layers, however, communicates with them to select its optimumoperating mode. The major technical challenges in XLD belong to characterizing the required information that should be shared among layers. For instance, the link layer may be pigeonholed by variablesindicating the channel condition, like maximum

International Journal on Applications in Information and Communication Engineering
Volume 1: Issue 9 : September 2015, pp 61 – 68 www.aetsjournal.com ISSN (Online) : 2394 - 6237

bandwidth, or LSI such as Bit Error Rate (BER) or signal-to-interference-plus-noise ratio (SINR). Likewise, the network (NET)layer and MAC layer might share the requiredflow rates and sustainable link capacities.

The system model of the proposed IXLD with its interaction at different layers is given in Figure 1. Adaptive link layer techniques are implemented to increase the throughput under channel dynamics. This expands the capacity region. Every point in this region denotes a potential allocation of various capacities. According to LSI, the MAC layer finds the most suitable point by allocating frequency bands, time slots, or codes. The MAC and NET layers jointly find the set of flows in such a way that to reduce network congestion. In order to determine an optimal CFA, these two layers share suboptimal solution iteratively. In the transport layer (TRANS layer), congestion-distortion optimized scheduling (CDOS) technique is implemented to regulate the transmission of data streams. As a final point, the APP layer finds the most competent encoding rate.

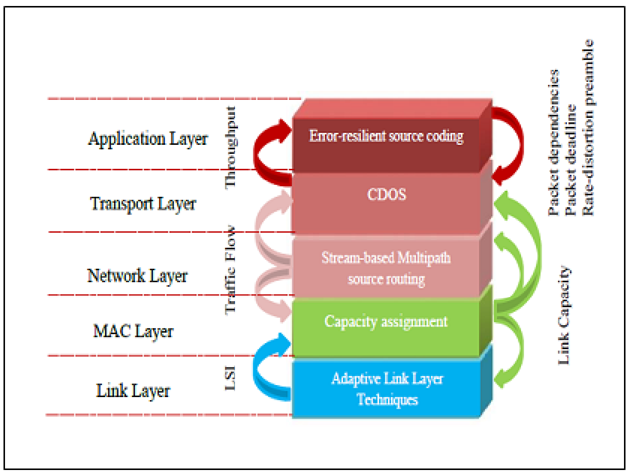

Figure 1: IXLD framework for real-time video streaming over MANET.

In the following sections, we discuss the implementation details of IXLD framework to integrate adaptive link layer techniques, capacity and flow assignment, scheduling and rate allocation to enhance the quality of live video transmission.

IV. DYNAMIC RATE ADAPTATION

Rate adaptation is a procedure to regulate the data bit-rate dynamically according to channel conditions. Recently, several studies dealing with optimal data rate adaptation for MANET in the presence of simultaneous interfering transmissions. But, it is observed that performance does not increase linearly as the data rate rises even in a single-hop communication link. This is owing to the rate-independent overhead at the Link and MAC layers. Furthermore, this overhead becomes a great issue as the sending rate increases since the communication time of the useful data decrease proportionally.

Most of the studies aimed at optimizing the data rate based on channel impairment only, with a few exceptions. Some approaches utilize the received signal strength to select the data rate. But, these approaches are restricted by many factors such as contention-related issues, asymmetric communication link, fluctuation in the medium access time, etc. One of the key objectives of this work is to select the most appropriate data rate according to the present channel conditions using an adaptive modulation technique.

The multi-rate data encoding characteristic and adaptive modulation ability of multimedia services are integrated to guarantee a better quality of service. It is an effective approach to increase the throughput by adapting time-varying channelparameters including the type of modulation, symbol rate, coding, target BER,transmitter signal strength, and combinations of these variables. According to these parameters, the most appropriate modulation and/or data rate is determined.

In this work, an adaptive link layer methodisimplemented to increase channelcapacity. First, we use current LSI and SINR as layer-specific information about the channel dynamics. Based on this information, the transmitting node selects the most suitable size of the packet to optimize channel capacity. Besides, for fixed packet size, the link layer variables like constellation size and symbol rate are considered to derive maximum throughput. Indeed, the packet error rate (PER) is linearly increased with packet size. Hence, the larger packet causes higher PER and link capacity is restricted by frequent retransmissions. When the size of the packet is small, the communication overhead is increased considerably. The optimum packet length (L_{opt}) which maximizes link capacity is derived as follows:

$$L_{opt} = \frac{S_{head}}{2} + \frac{1}{2}\sqrt{{S_{head}}^2 - \frac{4bS_{head}}{\ln(1-P_{se})}} \qquad (1)$$

In Equation 1, S_{head} is the header size,P_{se} is the probability of symbol error and b is the number of bits/symbol. The value of P_{se} will rely onSINR and type of modulation [13]. The process to optimize the size of the packet along with link layer variablesgenerates the following criterion:

• For higher channel gain,the maximum symbol rate should be employed with the highest constellation size.

International Journal on Applications in Information and Communication Engineering
Volume 1: Issue 9 : September 2015, pp 61 – 68 www.aetsjournal.com ISSN (Online) : 2394 - 6237

The resultant optimal packet size increases as the channel quality enhance.

• The error rate should be reduced by enabling redundant transmissionand reducing the symbol rate or using a larger distribution factor. In both the case, a packet is transferred over aprotractedtime period.

If all the design variables are optimally selected, then we can calculate channel throughput (τ) as below:

$$\tau = B\log_2\left(1 + \frac{SINR}{\vartheta}\right) \qquad (2)$$

where$B$ is the linkthroughput and ϑ is a link layer parameter. Figure 2 shows the throughput performance of packet length optimization for different channel conditions, where a persistent gap from Shannon capacity is noticed. A suitable coding method is used to bridge the gap. In MANET, the communication link should be shared betweenseveral sender-receiver pairs viacommunicationprotocolwhichharmonizes medium access across mobile devices.

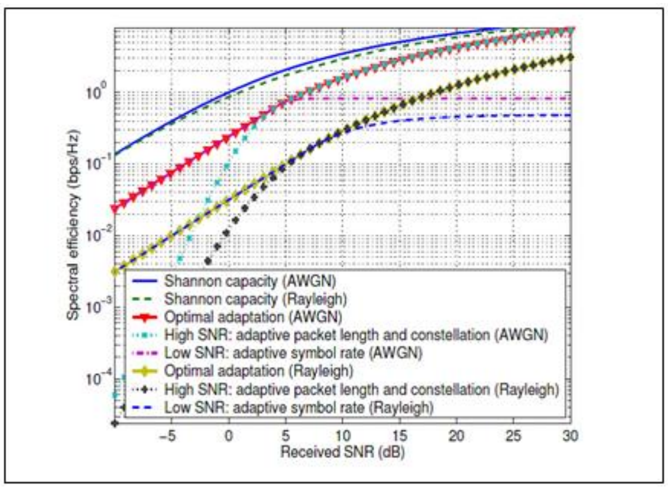

Figure 2: Throughput performance comparison

By bearing all kind of communication approaches among source-destination pairs in mind, one can easily calculate a feasible capacity region that describes the throughputs that are realizable among each sender-receiver pair. Upon additional examination, only a few of these approaches are pertinent, in which optimal throughput is accomplished. For a limited size MANET (e.g., network with tens of active hosts), the capacity zone can be calculated precisely [14]. An example of the possible capacity zone that indicates all the rate pairs concurrently among two source-destination pairs is given in Figure 3. The utilization of efficient approachcan expand the realizable capacity zone. The channel capacity and traffic rateassignment can be optimized within this zone so that flowdemands can be satisfied with minimum congestion.

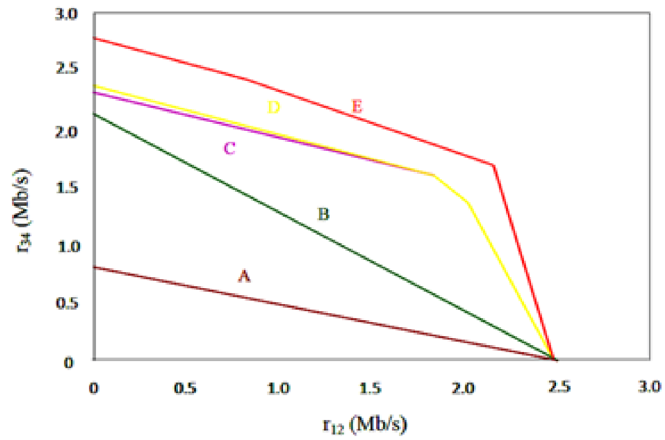

Figure 3:An example capacity zone.
(A) Single-hop routing without spatial reuse.
(B) Multi-hop routing without spatial reuse.
(C) Multi-hop routing with spatial reuse.
(D) Two-level power controladded to (C).
(E) Consecutive interference eliminationadded to (C).

V. CAPACITY AND FLOW ASSIGNMENT

The problem of CFA in MANET comprises the combinedallocation of communication links, sharing of link capacity, and determining the flows on different links (i.e., traffic requirements and routing) to enhance the performance of the network. Given the network configuration and flow demands, the NET layer allocates flows to an individual link.In our proposed model, CFA is optimized to minimize the congestion in the network due to multimedia streams. In order torealize the improvedvideo quality, resources should be assigned to achieveminimum latency with the maximum throughput. As stated in [15], we suggest considering the CFA problem to minimize network congestion (Δ) and maximize throughput is aconvex function.The congestion can be defined as:

$$\Delta(C,F) = max\left(\frac{F_{ij}}{C_{ij}}\right) \qquad (3)$$

In (3), C_{ij} and F_{ij}denotes the channel capacity and flow on the communication link (i,j) respectively. Optimum value C and F are calculated byminimizing Δ over all possible $C$and F.Optimal solutions provideeffectiveutilization of resources to supportbetter-quality links. Usually, the data streamfrom a transmitter to anintended destination is divided into more than one route to deliver higher throughput via spatial reuse. Multipath routing has uncorrelated loss patterns whichdecrease the possibility of video interruption. However, the number of links utilized by this technique may be unfortunately high.Hence, the utilization of a largenumber of links generatesadditional contention in

International Journal on Applications in Information and Communication Engineering
Volume 1: Issue 9 : September 2015, pp 61 – 68 www.aetsjournal.com ISSN (Online) : 2394 - 6237

the MAC layer, and the routing overhead is also increased.

To evaluate the benefits of XLD, a framework with oblivious layers is taken into account where CFA is optimized autonomously. Bidirectional links are formed between adjacent hops and its channel throughput is maximized. Then, the flow assignment is calculated for this fixed capacity by minimizing $\Delta(C,F)$in Equation 3. Interestingly, some links are assigned to traffic flow, though they do not support such traffic.

Unfortunately, this leads to poor resource utilization. In an efficient XLD, irrespective of the multiple routes, high throughput can be achieved constantly as resources are only assigned to livecommunication links.

The performance of the proposed IXLD and the model with the oblivious layers for multimedia transmissionthrough three different routes is shown in Figure 4. In either case, the datastreams are encoded at the maximumachievablethroughput and transferredthrough the User Datagram Protocol (UDP). The peak signal-to-noise ratio (PSNR) is measured to reflect the video quality.The proposed IXLD can achieve an improved throughput (i.e. around 1.8 Mb/s), whereas the framework with the oblivious layers can only accomplish 240 kb/s.

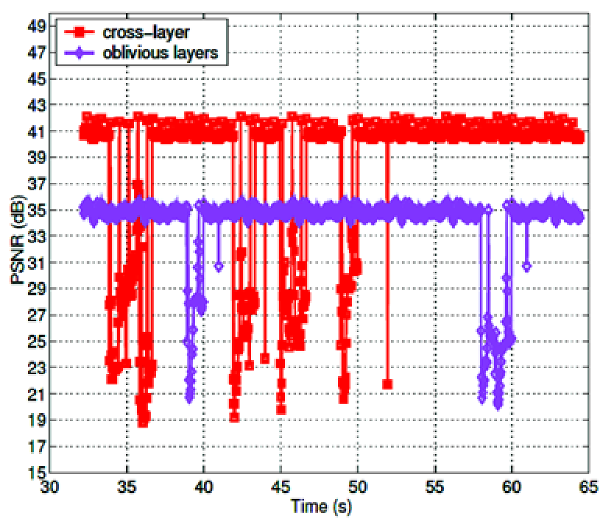

Figure 4: PSNR performance of media transmission for IXLD and design with the oblivious layers.

VI. SCHEDULING AND RATE ALLOCATION

The further performance enhancement of the video streaming can be achieved by implementing an efficient packet scheduling technique at TRANS layer. Losses in the communication link due to node mobility, interference, and collisions are unavoidable. The packet loss and delayed packets at video decoder lead to error propagation to succeeding frame segments, which interprets into the distortion in video quality experienced by end users. The quality degradation due to packet losses mainly produced by link failures is demonstrated in Figure 4.

These packet losses may be alleviated, or at least mitigated, by appropriate scheduling technique at the TRANS layer. Conventional TRANS layer protocols (e.g. TCP) deliver reliable communication but are oblivious of packet priority and latency constraints. In IXLD, unnecessary transmissions may be circumvented by considering delay limitations at APP layer. Priority-based advanced techniques are also available in the literature [16] which finds optimum schedules according to the packet priority. The scheduling at the TRANS layer targets to provide substantial video quality improvements at the receiver side. In a congestion-limited environment, it is convenient to implement CDOS to reduce the transmission latency [17]. It is intrinsically adaptive to fluctuating channel dynamics. The CDOS finds the most significant packets and transfers them in an order toreduce the network congestion. For instance, I frames (which encode spatial redundancy and carry the most significant video information) are transferred with the highest priority, while B frames (which carry only differential information about preceding and succeeding I or P frames and encode temporal redundancy) might be discarded, and only frames with the highest priority are retransmitted. Furthermore, the CDOS evades packet transmission in large torrents as this raises the queuing delay significantly. The flow assignment is optimized according to thechannelthroughputas well as the bandwidthrequired by the application, irrespective of any delayconstraints. For live media transmission, when the transferred rate outdoes a predefined value, self-congestion leadsto considerable latency to satisfy the hardreal-time restraint, and ultimately the media quality experienced by end users reduces. With autonomous layers, the best data rate is predicted by innovative approaches like TCP-friendly rate control [18] according to state information. In our IXLD optimization, the APP layer finds the bestdata rate for media transmission, according to current network conditions, delay constraints, and rate-distortion characteristics.

In [17], the authors develop a framework that reflects the effect of both packet drops and encoder quantization owing to network congestion on the service quality of the multimedia application. This framework can be implemented to find the maximum achievable data rate. Figure 5 illustrates the decoded video quality which encoded at various rates and transferredthroughdifferent routes. When the encoding rate reaches its highest value

International Journal on Applications in Information and Communication Engineering
Volume 1: Issue 9 : September 2015, pp 61 – 68 www.aetsjournal.com ISSN (Online) : 2394 - 6237

(i.e. 350 kb/s) the quality of the media content decreases and the total delay increases. If the latency is trivial, then the efficiency deprivation be falls below channel throughput, as even a small rise in queuing delay affects the loss rate considerably. The optimal data rate corresponding to the maximum video quality is also depicted in the figure.

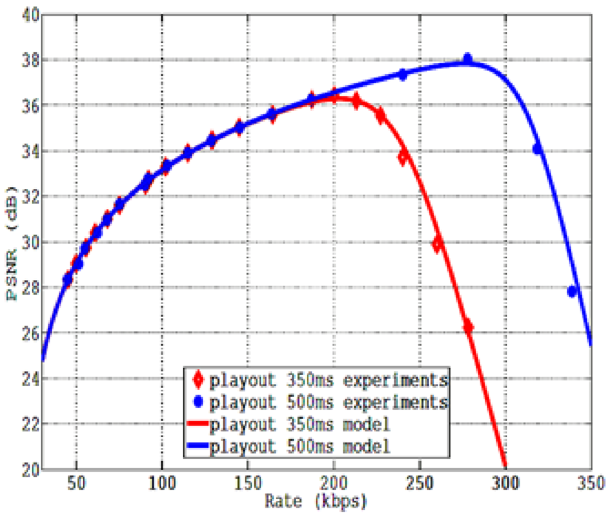

Figure 5: Data rate versus PSNR performance for various playout deadlines.

VII. CONCLUSION

The exceptional features of MANETs call for innovative paradigms that move away from traditional layering architecture. The combined optimization enables efficient communication and effective resource allocation. At the same time, the increasing intricacy in optimization may be high-priced for real-world applications. In order to achieve an acceptable trade off between the design complexity and performance gain, it is essential to preserve the abstraction of layering while permitting interaction among non-contiguous layers. The improved performance gains are promising for multimedia applications like video conferencing. In this paper, we discussed IX LD architecture for live media transmission, which preserves a traditional layered architecture and finds the significantstate information to be shared among contiguous layers. Adaptive link layer technique that modifies packet length, constellation size, and symbol ratebased on channel fluctuations isutilized to increase the data rate, which in turn extends the attainable capacity zone.

The MAC and NET layers jointly optimize the CFA to enhance the overall quality of multimedia content in a wide margin. By implementing an intelligent pack scheduling technique, TRANS layer safeguards the media transmission from packet drops and guarantees timely reception of the data packets without triggering any unnecessary network congestion. Then the APP layer finds the best data rate for media transmission, according to current network conditions, delay constraints, and rate-distortion characteristics. Extensive experiment results illustrate that our IXLD can enhance the end-to-end performance of multimedia transmission over MANETs regardless of channel and network dynamics.

References

[1] X. Hannan, C. K. Chaing, S. K. G. Winston, "Quality of Service Models for Ad Hoc Wireless Networks", in M. Ilyas (Ed.), Handbook of Ad Hoc Networks, CRC Press, New York, 2003 (Chapter 28).

[2] S. Shakkottai, T. S. Rappaport; P. C. Karlsson, "Cross- layer design for wireless networks, " Communications Magazine, IEEE, vol. 41, no. 10, pp. 74, 80, Oct 2003]

[3] Shannon, C and Weaver, W (1949) Mathematical Theory of Communication. Urbana: University of Illinois Press

[4] B. Girod and N. Farber, "Wireless Video," in A. Reibman and M.-T. Sun, Eds., Compressed Video over Networks, Marcel Dekker, 1999

[5] ITU- T Rec. H.264/ISO/IEC 14496-10(AVC), "Advanced Video Coding for Generic Audiovisual Services," 2003

[6] P. Gupta and P. Kumar, "The capacity of wireless networks," IEEE Trans. Information Theory, vol. 46, no. 2, pp. 388–404, Mar. 2000.

[7] Byung, JO, & Chang, WC, 2009, 'A Cross-Layer Approach to Multichannel MAC Protocol Design for Video Streaming Over Wireless Ad Hoc Networks', IEEE Transactions on Multimedia, vol. 11, no. 6, pp. 1052 – 1061.

[8] Navaratnam, P, & Cruickshank, H, 2008, 'A link adaptive transport protocol for multimedia streaming applications in multi hop wireless networks', Mobile Networks and Applications archive, Springer Science, Article no.34, pp. 246-258.

[9] S. Mao, S. Lin, S. Panwar, Y. Wang, and E. Celebi, "Video transport over ad hoc networks: multistream coding with multipath transport," IEEE Journal on Selected Areas in Communications, vol. 21, no. 10, pp. 1721–1737, Dec. 2003

[10] M. van der Schaar, S. Krishnamachari, S. Cho, and X. Xu, "Adaptive cross-layer protection strategies for robust scalable video transmission over 802.11 WLANs," IEEE Journal on Selected Areas of Communications (JSAC), vol. 21, no. 10, pp. 1752 – 1763, Dec. 2003.

[11] Lin Xiao, M. Johansson, and S. Boyd, "Simultaneous routing and resource allocation via dual decomposition," IEEE Transactions on Communications, vol. 52, no. 7, pp. 1136–1144, July 2004.

[12] Y. Wu, P. Chou, Q. Zhang, W. Zhu K. Jain, and S-Y. Kung, "Network planning in wireless ad hoc networks: a cross-layer approach," IEEE Journal on Selected Areas on Communications, submitted October 2003.

[13] T. Yoo and A. Goldsmith, "Throughput Optimization using Adaptive Techniques," in preparation

[14] S. Toumpis and A. J. Goldsmith, "Capacity Regions for Wireless Ad Hoc Networks," IEEE Trans. Wireless Commun., vol. 2, no. 4, July 2003, pp. 736–48.

[15] T. Yoo, E. Setton, X. Zhu, A. Goldsmith, and B. Girod, "Cross-layer design for video streaming over wireless ad hoc networks,"

in Multimedia Signal Processing Workshop (MMSP), Sienna, Italy, October 2004, pp. 99–102.

[16] P. A. Chou and Z. Miao, Rate-distortion optimized streaming of packetized media," Microsoft Research Technical Report MSR-TR-2001-35, Feb. 2001

[17] E. Setton, X. Zhu, and B. Girod, "Congestion-optimized scheduling of video over wireless ad hoc networks," IEEE International Symposium on Circuits and Systems (ISCAS'05), to appear, 2005.

[18] M. Handley, S. Floyd, J. Pahdye, and J. Widmer, "TCP friendly rate control (TFRC): Protocol specification," RFC 3448, Jan. 2003.