Chapter 2
A Novel Cross-Layer Architecture for Video Streaming Over MANET

Priya Jumnani and Mukesh Zaveri

Abstract Video streaming is one of the prominent applications of Mobile Ad Hoc Network. Due to high rate requirements, less resource, and severe delay constraints, maintaining real-time media traffic such as audio and video in presence of dynamic network topology is difficult. To cope with this, we propose a cross-layer design (CLD) to optimize the overall performance of video streaming services over MANET. Our CLD jointly controls the video transmission rate, delay constraint, congestion, and resource constraint in order to maximize the received video quality and the performance of the network. When compared with conventional techniques in MANET, our algorithm results in average end-to-end delay, average energy consumption, and the packet loss is considerably reduced with increase in high throughput and good delivery ratio.

Keywords Cross-layer design • MANET • Rate adaptation • Link failure • Congestion control • Energy efficient • MPEG

2.1 Introduction

A Mobile Ad hoc Network is a wireless network consisting of mobile devices that self-configure to form a network without the aid of any established infrastructure. With the rapidly growing popularity of video streaming applications over MANET, the demand for resources efficiency and robustness in the network increases. Due to heterogeneity, dynamism, and unpredictability of

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R. Maringanti et al. (eds.), *Proceedings of Ninth International Conference on Wireless Communication and Sensor Networks*, Lecture Notes in Electrical Engineering 299,
DOI: 10.1007/978-81-322-1823-4_2,

wireless ad hoc network, QoS demands in terms of delay limitation, bandwidth requirement, and loss tolerance are difficult to guarantee. To cope with this, many cross-layer approaches have been proposed that take into account the specific mobile characteristics.

In cross-layer architecture, layers exchange information and jointly optimize in order to improve the overall performance [1]. Cross-layer design (CLD) exploits layer dependencies and therefore allows us to propagate required parameters throughout the protocol stack [2, 3]. It allows us to make better use of network resources by optimizing across the boundaries of traditional network layers. Hence, it is especially well suited to video streaming application over MANET where the characteristics vary over time. There are many cross-layer designs for different optimization purpose for multimedia communication [4, 5]. Different cross-layer designs focus on different optimization purposes and different QoS metrics, which are delay, priority handling, resource constraint, etc.

While previous work often succeeded in showing the benefits of applying CLD, it often lacked providing solution for handling multiple issues to perform the QoS video transmission over ad hoc network [6, 7]. The cross-layer designs provide individual solution for flow control, admission control, link failure, routing overhead, power conservation, energy minimization, and congestion control. There is no complete and combined solution for the above issues for wireless multimedia applications. In this paper, we propose a cross-layer design framework to provide a combined solution for rate adaptation, link failure management, congestion control, and energy optimization. To achieve high performance under varying conditions, nodes need to adapt their transmission rate dynamically. For addressing the link failure problem, the received signal strength from the physical layer can help to determine the link quality. Links with low signal strength are discarded from the route selection. Routing overhead is improved by minimizing the frequency of recomputed routes by determining whether the packet loss was the result of congestion or node failure causing to compute a new route. For congestion control, the queue length of the nodes can be estimated and notified to the network layer. This estimation of the buffer can be utilized by the network layer and accordingly the optimal path is selected. To achieve energy efficiency, energy metric is used to estimate the remaining energy of the node. This information is then used by network layer to select the energy efficient route.

The paper is organized as follows. Section 2.2 presents the related work done. Section 2.3 presents a detailed description of our proposed architecture. Section 2.4 presents the simulation results and the conclusions are given in Sect. 2.5.

2.2 Related Work

There are numerous research works going on in this area. Rate adaptation strategy falls under two categories, statistics-based and channel quality-based approaches [8]. The [9] approach estimates the channel quality based on successful data transmissions or failures. Using this estimation, it adjusts the data transmission mode in steps. An easy way to obtain the necessary information on wireless channel conditions is to maintain statistics about the transmitted data like the Frame Error Rate/Bit Error Rate (FER/BER), or retry ratio, or the achieved short-term/long-term average throughput. The channel quality-based approach estimates the channel quality based on the measured SNR or SSI instead of the statistics and adjusts the data transmission mode by using the predefined threshold lookup table. Channel-based schemes [10] are further classified into sender based, receiver based, and hybrid adaptation techniques.

Several rate adaptation techniques have been proposed in all cases. Among the existing, some are discussed here. Auto Rate Fallback based on frame loss ratio adjusts the rate based on the number of consecutive successful transmissions. But in ARF [11], frequent collision problems occur. To overcome the collision problem in the ARF scheme, the collision-aware rate adaptation scheme (CARA) is proposed. The key concept of the CARA scheme is that the sender combines adaptively the RTS/CTS exchange with the clear channel assessment (CCA) functionality to differentiate frame collisions from frame transmission failures caused by channel errors. However, a fundamental limit of statistics-based approaches is that they classify channel conditions as either "good or bad." This binary decision provides the direction to adapt the transmission mode, but does not suffice to select the appropriate mode immediately. This leads to a slow step-by-step accommodation to large changes in channel conditions and introduces the risk of oscillation during stable channel conditions. Unlike, the statistics-based approaches, channel quality-based approaches can directly measure the channel conditions and adjust the data transmission mode. An example is the receiver-based auto rate (RBAR) [12] scheme which performs rate adaptation at the receiver instead of the sender.

Link failure management schemes are generally based on the physical layer parameter in order to predict the quality of the link. One of the techniques proposed make use of signal strength as a metric to predict link quality at the network layer. With the incorporation of link layer and transport layer, the proposed Link Adaptive Transport Protocol [13] which provides a systemic way of controlling transport layer offered load for multimedia streaming applications, based on the degree of medium contention information received from the network. In [14] is proposed a cross-layer design that uses a metric known as link residual time (LRT) that is computed based on the received power observed at the physical layer. The value of LRT can be used to estimate the longevity of the link and denotes the remaining time for which the link can be used for packet transmission. LRT values can be used in higher layers to make better decisions for hand-off, scheduling, and routing packets.

The research on congestion for MANET is still ongoing and there is a need for new techniques. Congestion aware routing technique has been proposed by using several metrics such as MAC layer utilization, contention and channel interference, queue length, mobility parameter, etc., to increase throughput of the network. Some of the protocols are discussed here. Congestion Adaptive Routing Protocol (CRP) [15] uses additional paths, called bypass, for bypassing the potential congestion area to the first noncongested node on the primary route. For increasing the performance of network, Congestion aware routing plus Rate Adaptation [16] is proposed which uses two metrics to measure congestion information; average MAC layer utilization and Queue length. To handle delay constraint, Congestion Aware Routing protocol is designed for Mobile ad hoc networks (CARM) [17] based on metrics that incorporate data rates, MAC overhead, and buffer delay to control congestion. For load balancing a new protocol [18], Congestion Aware Scheduling Algorithm for MANET (CARE), is proposed, which decreases the arrival rate at the congested node and balances the load among network.

Energy is the important issue to be addressed because the Ad hoc network has limited resource. Several researches have proposed many algorithms [19] for handling the limited resource in an efficient manner. Energy Efficient MANET Routing Protocols are mainly divided into two categories based on how they minimize the active communication energy, i.e., transmission control approach [20] and load distribution approach [21]. For minimizing energy during inactivity sleep/power-down mode approach has been proposed [22]. Energy efficient routing protocols based on transmission power control find the best route that minimizes the total transmission power between a source–destination pair. The specific goal of the load distribution approach is to balance the energy usage of all mobile nodes by selecting a route with underutilized nodes rather than the shortest route. The sleep/power-down mode approach focuses on inactive time of communication.

2.3 Proposed Cross-Layer Design

2.3.1 Overview

In this paper, we propose a novel cross-layer architecture named DSR-CE, whose aim is to provide a combined solution for rate adaptation, link failure management and reduced routing overhead, congestion control and energy efficient for dealing with issues like packet loss, delay, power constraint, and QoS. In DSR-CE, Physical, MAC, and Network layers cooperate with each other to fulfill the task of QoS provision to video streaming application. Our main contribution is to provide the solution for the following critical issues for video streaming over mobile ad hoc network.

We first integrate rate adaptation module with link failure module named DSR-RL, which makes use of received signal strength parameter for cross-layer optimization. In rate adaptation module, transmission rate selection selects data rate in the MAC layer based on the channel estimation information from physical layer. To achieve high performance under varying conditions, nodes need to adapt their transmission rate dynamically. To address the link failure problem, the received signal strength from the physical layer can help to determine the link quality. The

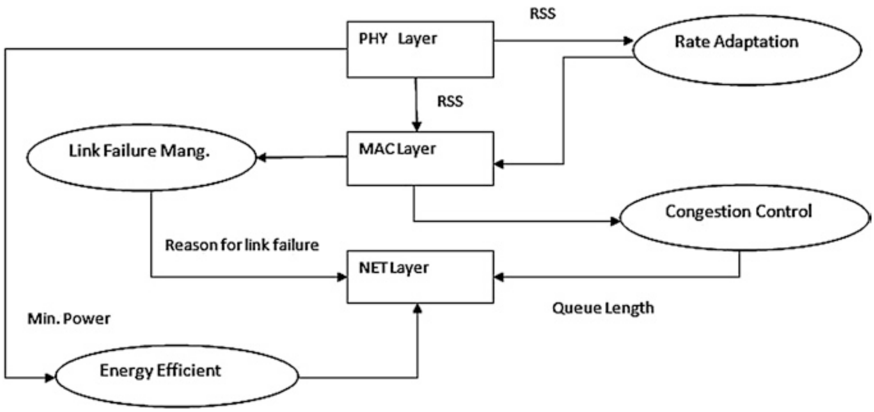

Fig. 2.1 Cross-layer architecture

links with low signal strength are discarded from the route selection. Routing overhead is improved by minimizing the frequency of recomputed routes by determining whether the packet loss was the result of congestion or node failure that caused to compute a new route.

Then, further we modified the design and proposed a new architecture, i.e., DSR-CE which contains solution for congestion and resource constraint also in MANET. For congestion control, the queue length of the nodes can be estimated and notified to the network layer. This estimation of the buffer can be utilized by the network layer and accordingly the optimal path is selected. In energy efficiency module, energy metric is used to estimate the remaining energy of the node from Physical layer. This information is then used by network layer to select energy efficient route. More detailed description of the module is given below. The architecture is shown in Fig. 2.1.

2.3.2 Rate Adaptation

Video applications usually require low error rates. Since video over wireless ad hoc network is already compressed at the available bit rate, errors can ruin the video quality at the receiver. To maintain a constant low error rate, the bit rate of the video bit stream must be adapted to the available bit rate. This would require that physical layer channel information be made available at the MAC layer. Our approach to solve the problem of fluctuating available bit rate makes use of channel state information at the sender to determine at which rate the bit stream is to transfer. The receiver estimates the signal strength of transmission channel using channel model simulation at the physical layer. The parameter used for channel estimation in our scheme is received as power indication P_r, which is calculated as

$$P_r = \frac{P_t * G_t * G_r * H_t * H_r * \lambda^2}{(4 * \pi * d)^2 * L} \tag{2.1}$$

where, P_t and P_r are signal power at receiver and transmitter, G_t and G_r are gain for a signal to a node from the transmitter and receiver, H_t and H_r are height of the transmitter and receiver, is wavelength, d is distance between the transmitter and receiver and L is system loss. Then the received signal strength is mapped to a transmission data rate based on threshold-based technique [23] at the MAC layer. In this approach, the rate is chosen by comparing the channel information based on series of thresholds related to available M-QAM modulation schemes. The receiver sends the determine bit rate to the sender. On receiving the current rate from the receiver, the physical layer at the sender adjusts its transmission rate accordingly. Other neighbor nodes that hear the packet will update the information in their network allocation vector (NAV) and hold their transmission until current transmission gets completed.

2.3.3 Link Failure Management

In ad hoc wireless networks, we deal with nodes that have different power capabilities; hence, there is a considerable likelihood to transmit with different power levels. The link asymmetry arises when a node with high power transmits to a lower power node, and the high power-node cannot sense an ongoing transmission triggered by the low power node. Thereby, the hidden terminal problem is exacerbated, which provokes more false link failures, increasing the time that route discovery process is launched. Normal DSR interprets a link failure (in MAC layer) as a broken link, even when caused by congestion at receiver. The received signal strength of neighboring nodes can be used to detect the reason for lost packets, distinguishing between congestion and broken links due to mobility, because in broken links due to mobility, the receiver is not reachable. The reason for unsuccessful communication is sent to the routing layer. The routing layer should interpret that communication to destination was not possible, not because of a broken link but rather congestion; therefore, route maintenance is not needed. If that is not the reason delivered to the routing layer, a route maintenance process is required. We calculate and use the average signals of nodes to stop retransmitting packets when destination is not reachable because it moved away. The proposed scheme will make DSR distinguish between both situations, avoiding the route error process when the link error at MAC layer is due to congestion and not due to mobility of nodes causing broken links. When MAC layer is not able to communicate to a neighboring node, MAC layer informs to the routing layer not only that there was a problem, but also includes if the neighboring node is still reachable.

2.3.4 Congestion Aware and Energy Efficient Routing

The energy consumption can be reduced by designing routing protocols of these select routes with less energy consumption for end-to-end packet transmission. Congestion aware routing protocol is designed such that it reduces collision and selects the route that avoids congested nodes. We design energy efficient routing and congestion control protocol of MANETs named as DSR-CE. It discovers the route based on energy aware metrics and congestion aware metrics. Here, we use two metrics: queue length for congestion and remaining energy of node. The congestion was assumed to be in existence when queue length was near capacity or when battery level fell below a predefined threshold. The proposed protocol works similar to normal DSR protocol, if the current queue length is less than maximum queue length. When a data packet needs to wait in queue for a longer time, there is a possibility for unexpected delay in transmission or dropping of packets. The number of packets in the queue is a metric reflecting the traffic load of the mobile node. A mobile node with more traffic passing through it usually has more packets in its interface queue. Average queue size indicates the node traffic load in the long term [24]. The calculation of the average queue size is updated every T seconds based on the following equation:

$$\mathrm{len} = \beta * \mathrm{qlen} + (1 - \beta) * \mathrm{qlen}_{\mathrm{sample}} \tag{2.2}$$

where qlen denotes the average queue length and $\mathrm{qlen}_{\mathrm{sample}}$ the current queue length which is constant and set to 0.3 in our simulations. Communication is the main source of energy consumption for a mobile node. Nodes consume energy while transmitting data to a desired destination when forwarding data while acting as intermediate nodes between source and destination nodes, or receiving data destined to them. Hence, we calculate energy metric as power consumed with the following equation:

$$E_n = P_{\mathrm{tx}} - P_r + P_{\mathrm{th}} + P_m + P_{\mathrm{over}} \tag{2.3}$$

where E_n denotes the total energy consumed by node, P_{tx} is power consumed in transmission mode, P_r is power consumed in reception mode, P_{th} is receiving power threshold, P_m is power consumed in idle mode, and P_{over} is power consumed in overhearing mode. When an intermediate node receives a route discovery (RREQ) packet, the following steps are undertaken by the algorithm: Node checks the source node's energy level E_s, source node ID, which was advertised in the network, and the destination node ID. It saves all attributes in its route cache. It calculates whether its queue length cost from equation exceeds the threshold value, i.e., the maximum queue length. If the queue length cost is more than the threshold, it will not forward the packet to any other intermediate node and will not participate in the routing process. The busy node simply drops the RREQ packet, hence the discovered route simply omits the congestive nodes. If the queue length cost is less than the threshold, it appends its node ID, energy level and forwards the packet to its neighboring nodes. When destination node receives the RREQ message it will calculate the mean value of all the values of E_n of all the nodes and send an RREP message to the node whose E_n value is nearest to the mean value. If the route discovery broadcast is not the first one (i.e., if it is another communication period, T), the node will check its route cache to see if there exist routes to the destination. In case there is one, it chooses the one with shortest hop and with minimum total energy to the destination with congested free nodes.

2.4 Simulation Results

In this section, we illustrate the feasibility and effectiveness of the proposed CLD for video streaming, i.e., DSR-CE (DSR with rate adaptation, link failure management, congestion control, and energy efficient) in the NS-2 simulator and compare it with DSR-RL (DSR with rate adaptation and link failure management) and DSR under varying background traffic load, different frame rates [25], different video sequences, and different mobility scenarios based on various performance metrics,viz., network and QoS metrics. We test the accuracy of design for different network varying environment. For analyzing the dynamic behavior of ad hoc network, static and mobile scenario with different mobility of 1–10 m/s are taken for experiment. We use IEEE 802.11 as MAC layer protocol. It has the functionality to notify the network layer about link breakage. In our simulation, 50, 75, 100 mobile nodes move in a 500 m * 500 m rectangular region for 200 s simulation time. All nodes have the same transmission range of 250 m. The background traffic is simulated using CBR packets with fixed size of 1,024 bytes.

For video traffic, the encoded packet traces of different video sequence of both QCIF format (176 * 144) and CIF (352 * 288) such as Akiyo, Foreman, Mother Daughter, News, Hall, High-way, Bridge, and Football are used [26]. To test the effect of rate adaptation, we vary offered load by changing the CBR packet rate from 10 packets/second to 60 packets/second and video sequence at a frame rate of 10, 20, and 30 fps. An analysis of the performance based on mobility is performed by varying the pause time of the node from 20 s (high mobility) to 100 s (low mobility). The number of nodes is taken as 50 (small area network), 100 (large area network) and the maximum number of connections as 20, 40 with different video sequences (low and high resolution).

2.4.1 Network Level Evaluation

It indicates the efficiency of the tested protocols for indicating perceived performance of network. We analyzed how well our design performs in different networking environments using the following metrics.

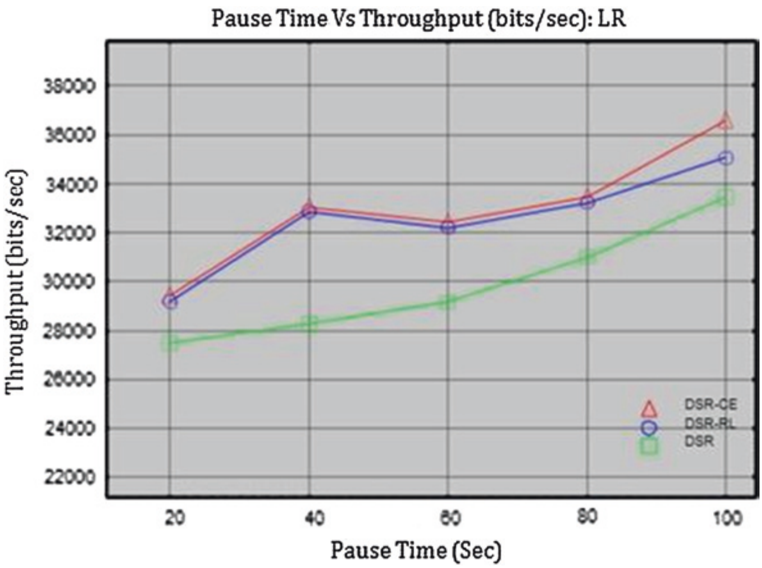

Fig. 2.2 Throughput for network of 50 nodes for low resolution video

1. *Throughput*: In case of high mobility, DSR-CE, DSR-RL increases the overall throughput of the network. The number of link errors in DSR-CE, DSR-RL is decreased compared to normal DSR, because of the high reduction of routing packets, achieving higher overall throughput. In DSR, the length of the route fluctuates between high and optimal values, due to a large amount of route errors and the consequent new routes found. By reducing route errors and congested free route in DSR-CE, the length of the routes becomes optimal and constant (Figs. 2.2, 2.3).
2. *Delivery Ratio*: Packet delivery ratio of DSR is less compared to DSR-CE, DSR-RL because the number of packets dropped is more in DSR. Due to link failure management, less number of packets can be dropped which results in good packet delivery ratio (Figs. 2.4, 2.5).
3. *End-to-End Delay*: The delay of DSR-RL, DSR is almost similar because in case of congestion both schemes wait for a certain period of time before they send the packets that introduce more congestion hence it introduces delay; while in case of DSR-CE, it finds out the congested free path, hence the probability of congestion is reduced (Figs. 2.6, 2.7).
4. *Energy Consumption*: DSR-CE outperforms DSR under different traffic loads, which is mainly due to the benefit of power control in the Network layer. The excess packets inevitably introduce more collisions to the network, wasting more energy. DSR-CE chooses alternative routes, avoiding the heavily burdened nodes and thus alleviating the explosion in average energy consumption (Fig. 2.8).

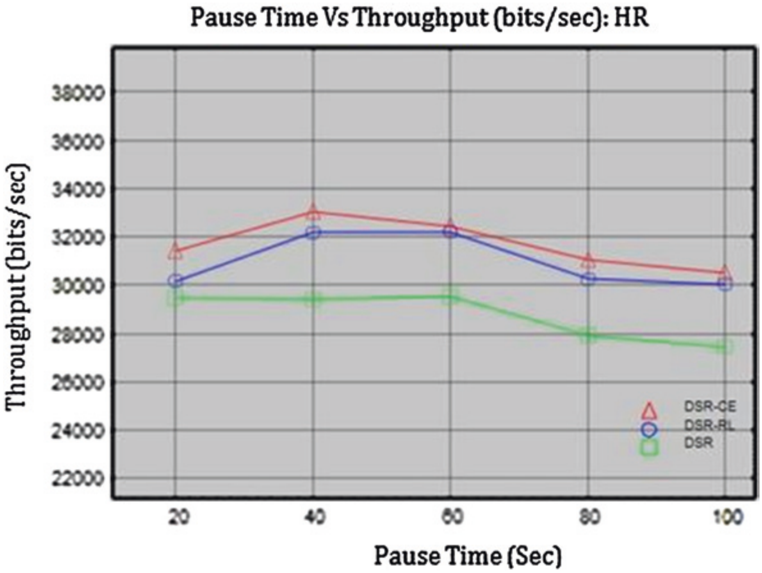

Fig. 2.3 Throughput for network of 50 nodes for high resolution video

Fig. 2.4 Packet delivery ratio for network of 50 nodes for low resolution

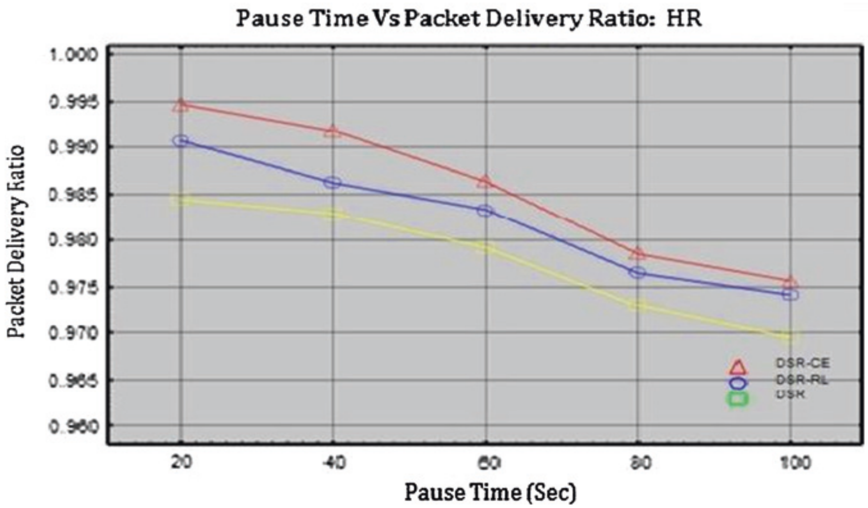

Fig. 2.5 Packet delivery ratio for network of 50 nodes for high resolution

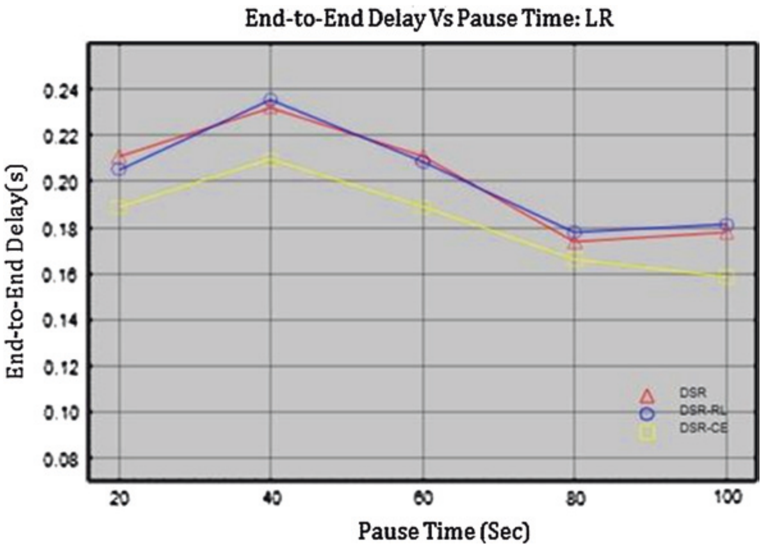

Fig. 2.6 End-to-end delay for network of 50 nodes for low resolution video

2.4.2 Quality of Experience Measurement

Measure of network parameter results in control of resource but for maintaining user satisfaction we need QoS parameter. Quality of experience is the overall acceptability of an application or service, as perceived subjectively by end-users. QoE assessment divided into two different ways: subjective and objective.

Fig. 2.7 End-to-end delay for network of 50 nodes for high resolution video

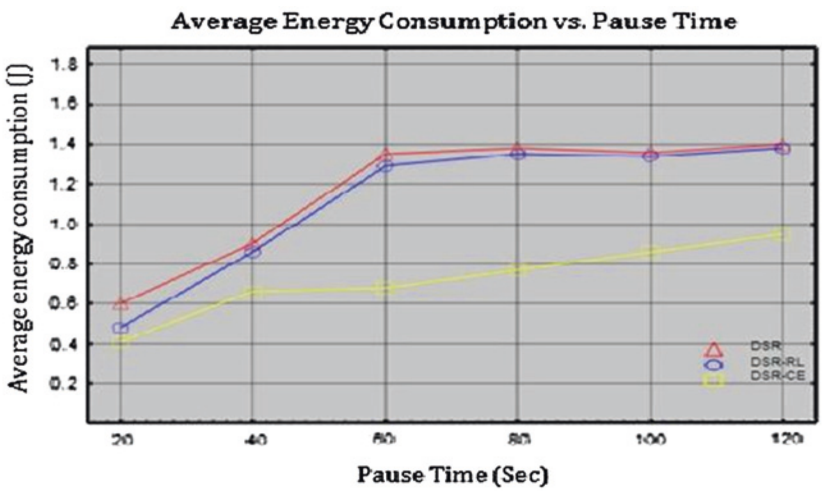

Fig. 2.8 Energy consumption versus pause time

1. *PSNR*: From the result as shown in table, we observe the average PSNR of DSR-CE outperforms DSR-RL by 0.9 dB and DSR by 1.6 dB. We see that, DSR-CE and DSR-RL have lower end-to-end delay compared to DSR, while DSR-CE has the lowest packet loss rate 0.0028. DSR-CE can balance the traffic over multiple paths to avoid the congestion occurs which lead to lowest packet loss probability and improve the robustness of wireless transmission. To quantify the improvement that our algorithm produces on

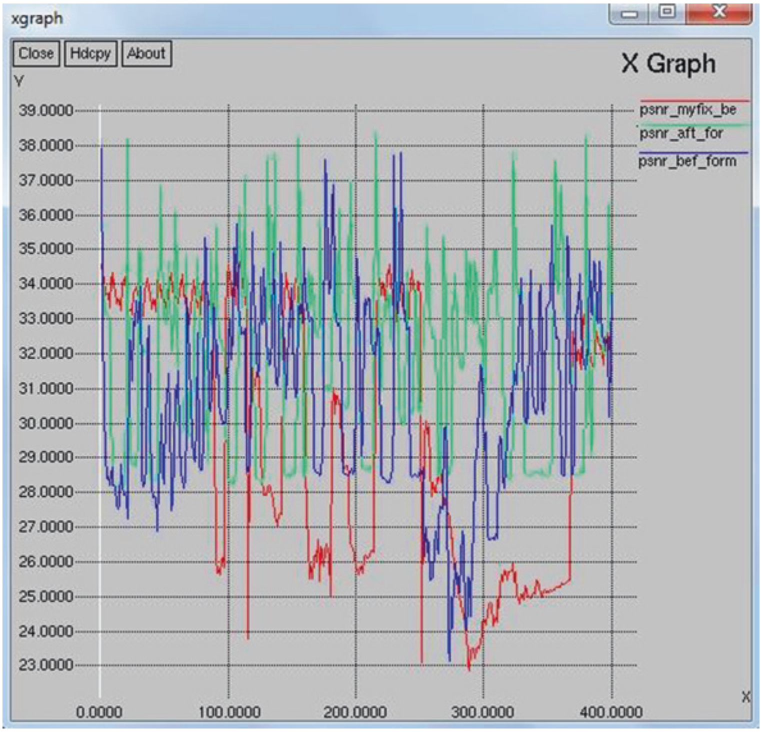

Fig. 2.9 PSNR of video transmission after simulating in DSR-CE, DSR-RL, and DSR

Table 2.1 PSNR, delay and loss rate

	Packet loss rate	Delay (s)	Average PSNR(dB)
DSR-CE	0.0028	0.0548	33.458
DSR-RL	0.0045	0.0879	32.516
DSR	0.076	0.1457	31.795

steaming video, we calculate the PSNR of each frame once before our algorithm has been implemented and once after our algorithm has been implemented. Figure 2.9 shows the PSNR fluctuation received after transmission of video through DSR-CE, DSR-RL, and DSR (Table 2.1).

2. *Subjective Assessment*: To illustrate the perceptual video quality delivered by different approaches, we observe the quality of a video in YUV Viewer which gives results of the distortion and delay occurred during transmission. From Fig. 2.10 it can be seen that quality of video improves when transmitting through DSR-CE, DSR-RL as compared to DSR. DSR introduces distortion and delay in receiving frame which degrades the quality of video. DSR-CE has better performance because it can reduce delay and distortion by avoiding or relieving the congestion.

Fig. 2.10 Screenshots of received foreman video sequence with (**a**) DSR-CE, (**b**) DSR-RL, (**c**) DSR

2.5 Conclusion

Based on the analysis of ongoing efforts, cross-layer design appears to be a suitable approach for future contributions to the framework of wireless network that address emerging issues related to ever-higher performance, energy consumption, and mobility. We have designed a cross-layer design-based architecture to provide a combined solution for link failure management, rate adaptation, congestion control, and energy efficiency. Performance of DSR-CE is compared with DSR-RL and DSR. It increases the QoS of video in terms of PSNR as well as subjective quality. By simulation results, we have shown that the DSR-CE reduce average end-to-end delay, average energy consumption, and packet loss with increase in high throughput and good delivery ratio.

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http://www.springer.com/978-81-322-1822-7

Proceedings of Ninth International Conference on
Wireless Communication and Sensor Networks
WCSN 2013

Maringanti, R.; Tiwari, M.; Arora, A. (Eds.)
2014, XV, 266 p. 135 illus., Hardcover
ISBN: 978-81-322-1822-7