Protocol Design for Adaptive Video Transmission over MANET

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Abstract- In this paper, we propose an efficient video data transmission protocol using the cross-layer approach in ad hoc networks. Due to node movement, the MANET is frequently changing path and each path has different transmission rate so that it shows low performance when transmitters select a constant transmission late at the encoding time regardless path condition. So, we need an effective video transmission method that considers physical layer channel statistics, node's energy status, and network topology changes at the same time unlike the OSI layered protocol in that each layer is independent and hard to control adaptively video transmission according to the network conditions. In the proposed CVTP protocol, a source node selects an optimal path using multilayer information such as node's residual energy, channel condition and hop counts to increase path life time and throughput. And a video source can determine an adequate video coding rate to achieve high PSNR and loss packet loss ratio.

1 Introduction

Conventional wireless networks require as prerequisites some form of fixed network infrastructure and centralized administration for their operation. In contrast, the so-called MANET (Mobile Ad hoc Network), consisting of a collection of wireless nodes, all of which may be mobile, dynamically creates a wireless network among them without using any such infrastructure or administrative support. MANET is affected by wireless transmission channel conditions like that interference and fading, so it is necessary to effectively utilize in limited wireless resources. Also MANET is generally running by limited energy, an efficient energy management is required to increase network life time and network throughput.

Because existing MANET uses layered protocol such as OSI (Open Systems Interconnection) reference model, each layer has independent and detached characteristics. It is difficult to adaptively control different layers at the same time and integrated manner so that the existing layered approach shows low performance especially in ad hoc environments in which network conditions and topologies

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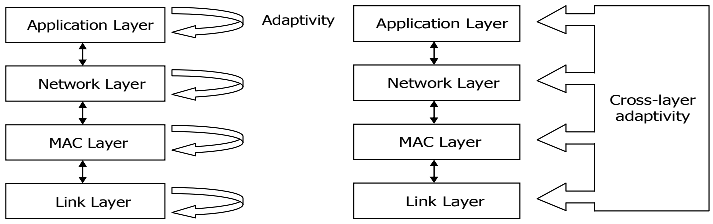
frequently changes. Cross-layer design architecture [1][2] is attractive in ad-hoc networks, because layer information can be easily exchanged and each layer can accommodate other layer's conditions for performance increase in terms of network life time, node's residual energy, data rate, network throughput. A Difference between OSI and cross layer design structure is shown in Figure1.



(a) (b)

Figure 1. OSI layered and adaptive cross-layer structures.

This paper proposes optimum routing path selection and video transmission rate decision methods in MANET environment using the cross-layer design architecture. In the proposed method, we use multilayer information such as node's residual energy, wireless channel condition and hop count. And video source selects a path to the destination based on possible channel speed and its energy stability. In accordance with dynamic path change and node or network status varying, video encoder computes the maximum coding rate and changes quantization parameter (QP) value.

The remainder of the paper is organized as follows. Section 2 explains existing video transmission methods in MANET and cross-layer design architecture. In Section 3 we propose a new cross-layer video transmission protocol (CVTP) for effective video transmission in MANET. Section 4 shows our experimental results and in Section 5 we conclude this paper.

2 Cross Layer Design Approach

In ad-hoc network, there are frequent topology changes due to the node movements and energy shortages. Therefore, packet loss and overdue delivery plentifully occur in such network environments. These characteristics make receivers difficult to correctly decode received video data or continuously display real-time video with high quality. To overcome this difficulty, several cross layer methods which jointly consider various layers including video coding, error control, transport mechanisms, and routing were suggested.

Among various approaches, multipath transport mechanism is a popular field of research. It uses multiple paths from a video source to a destination to transmit a video program. Because multipath transport has advantages such as load balancing, fault-tolerance, and higher aggregate bandwidth, it can be suitable for transmission of real-time video that is burst and delay sensitive. If this mechanism is combined other mechanisms such as video coding or error control, its performance can be improved. For example, in [3][4], multipath transport mechanism is combined with some schemes, which are feedback based reference picture selection, layered coding with selective automatic repeat request (ARQ) and multiple description motion compensation coding (MDMC). First, feedback based reference picture selection scheme can achieve both high error propagation resilience and high coding efficiency by choosing reference frame based on the feedback message and path status prediction. Second, layered coding with selective ARQ, in which base layer and enhancement layers are transmitted over different paths and only base layer is allowed to be retransmitted, can significantly reduce error propagation in the reconstructed frames at the cost of retransmission delay. Finally, unlike the above two schemes, MDMC is a multiple description coding scheme that does not depend on the availability of feedback channel, nor does it incur additional decoding delay.

However, these advantages of multipath transmission mechanism come at the cost of higher coding redundancy, higher computation complexity, and higher control traffic overhead in network. It is because more streams may increase the video bit rate for the same video quality, and delay during traffic partitioning and re-sequencing, and maintaining multiple paths in the dynamic ad hoc network environment involves higher control traffic overhead and more complex routing algorithm.

And some feedback-based mechanism with single path were proposed [5][6]. They control the source bit rate in accordance with hop count information. A crucial factor affecting ad-hoc channel performance is the deterioration of the network throughput as the number of transmission hops increases. As soon as a new route is established, the application layer upon receiving the hop-counts information from a routing layer would be able to adjust QP parameter for effective transmission. This mechanism allows an application layer to adapt itself to changes in a network layer condition. However, this method only considers hop count to adjust video coding rate. In fact, there are several network characteristics that impact on video quality and desirable behaviors such as node's residual energy, path's expected life time, channel speed, hop count, and so on.

3 Proposed Effective Cross-Layer Video Transmission Protocol

In wireless ad-hoc video application, providing good video quality without service breaks or termination for a given video service time is very important. In this paper, we define T_v as the desirable video service time by users and during this time video should be transmitted incessantly. In ad-hoc network, the actual video transmission time through a selected routing path is limited by residual energy level of participating nodes, video transmission rate, channel speeds of all links of the path, and hop count. When a video is transmitted with a constant quality through the selected path by a conventional ad-hoc routing protocol, since some wireless links on the path may not support the source transmission rate, there will be lots of packet retransmissions (or packet losses) and large delay. And even worse some nodes can consume all their energies before the desirable video service time T_v so that the service can be disrupted and the source node needs to find whether there is a new path to the destination or not.

Therefore, in this paper we propose an effective cross-layer design architecture and protocol that can select an optimal path and adaptively determine the adequate video coding rate by means of multilayer information such as node's residual energy, channel condition and hop counts. In the proposed cross-layer video transmission protocol (CVTP), multilayer information between network and physical layers are collected through routing message exchanges and used for selection of optimal and reliable transmission path in routing layer. Also this information is utilized for calculation of adaptive and optimum transmission rate in application layer by means of video encoder that adaptively changes QP value. CVTP consists of three phases: optimum path selection, effective video coding rate decision, and adaptive coding rate adjustment.

a) Optimum path selection

In Figure 2, an example ad-hoc network structure is shown. Source *S* want to communicate with destination *D*, and three candidate paths are currently found via a routing protocol. Path_i means *i*'th path among the all paths from source to destination. In ad-hoc network, each node's residual energy level impacts on the network or path life time. In CVTP, routing messages carry each node's residual energy on a path. A $minREnergy_i$ (minimal residual energy of path *i*) is defined as (1).

$$minREnergy_i = \min\{REneregy_j, {}^{\forall} j \in \mathbf{V}_{path_i}\} \tag{1}$$

where, $REnergy_j$ is the residual energy of node *j*; $\mathbf{V}_{path_i}$ is the set of nodes of path *i*.

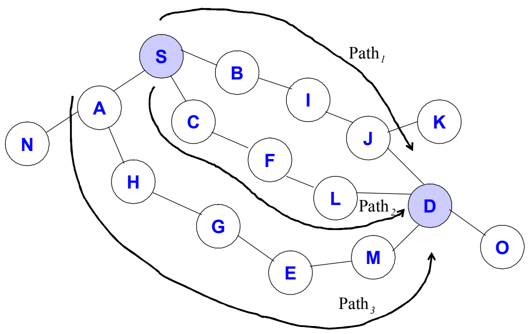


Figure 2. Transmission path selection in MANET.

Links between nodes can have different bandwidth and transmission rates in MANET. Namely, a bandwidth between node *j* and node (*j*+1) can be different from a bandwidth between node (*j*+1) and node (*j*+2). In the proposed CVTP, we have defined $minRate_i$ (minimal rate of path *i*) that indicates the smallest link bandwidth from the all links of path *i*.

$$minRate_i = \min\{Rate_l, {}^{\forall} l \in \mathbf{E}_{path_i}\} \tag{2}$$

where $Rate_l$ is the bandwidth of link *l*; $\mathbf{E}_{path_i}$ is the set of links of path *i*.

To select an optimal path that can provide long path life time and high path bandwidth, we define a total cost function C_i for each routing path *i* as (3). In ad-hoc network, the larger hop count from source to destination, we have the higher probabilities of link or node failure and path partitioning due to node movements. Therefore, as in (3) the path total cost includes hop count, minimal residual energy, and minimal rate of the path.

$$C_i = \omega_h \cdot HOP_i^N + \omega_e \cdot \frac{1}{minREnergy_i^N} + \omega_r \cdot \frac{1}{minRate_i^N} \tag{3}$$

where

$$HOP_i^N = \frac{HOP_i}{\max\left[HOP_p, \ ^\forall p \in \mathbf{P}_{s-d}\right]}, \quad HOP_i = \text{hop count of path } i$$

$$minREnergy_i^N = \frac{minREnergy_i}{\max\left[minREnergy_p, \ ^\forall p \in \mathbf{P}_{s-d}\right]}$$

$$minRate_i^N = \frac{minRaate_i}{\max\left[minRate_p, \ ^\forall p \in \mathbf{P}_{s-d}\right]}$$

$\mathbf{P}_{s-d}$ = set of paths from the source s to the destination d

ϖ = weight

In (3), each path's hop count, minimal residual energy, and minimal rate are normalized with their maximum values among the all possible paths to make them be in an equal dimension. $\varpi_h, \varpi_e, \varpi_r$ are the weights for hop count, energy, and rate, respectively; $\varpi_h + \varpi_e + \varpi_r = 1$. The weights can be adjusted in accordance with each item's importance. The video source node finally selects an optimal path i^* from source to destination that has a minimum total cost C_i.

$$i^* = \arg\min_i \left\{C_i, ^\forall i \in \mathbf{P}_{s-d}\right\} \tag{4}$$

b) Effective video coding rate decision

Once a path is selected, CVTP decides an effective video data coding rate based on channel and node conditions of the selected path. The first goal of this step is transmitting the video data without service disruptions during the desirable video service time T_v. The second goal is providing high video quality (i.e., high bit rate) as possible as the path sustains the desirable service time. We define the number of packets (N_{Pkt}^E) that can be transmitted during T_v with the minimal residual energy of the selected path i^*. N_{Pkt}^E is determined as (5). E_{Pkt} is a sum of the required energies for receiving, processing, and transmitting a packet as (6). Because a source can know the average video packet size $\left(AvgSize_{Pkt}\right)$, we assume that a source node can calculate the required energy to relay a packet in advance. Therefore N_{Pkt}^E is the maximum packet numbers that can be transmitted through the selected path without any node's energy exhaustion.

$$N_{Pkt}^E = \frac{minREnergy_{i^*}}{E_{Pkt} \times T_v} \tag{5}$$

$$E_{Pkt} = E_{Pkt}^{R} + E_{Pkt}^{P} + E_{Pkt}^{T} \tag{6}$$

Also, we define the number of packets $\left(N_{Pkt}^{R}\right)$ that can be transmitted at the minimum rate of the selected path during the service time T_v. Consideration of the minimum link speed of the path is important to the real-time applications. If the source node transmits its video data at higher rate than the minimum rate of the path, then many packets can be delayed and lost at the bottleneck nodes.

$$N_{Pkt}^{R} = \frac{minRate_{i^*} \times T_v}{AvgSize_{Pkt}} \tag{7}$$

In the proposed CVTP, video application layer computes the maximum number of packets to be transmitted during the service time in terms of energy and link bandwidth as (8).

$$N_{Pkt}^{*} = \min\left\{N_{Pkt}^{E}, N_{Pkt}^{R}\right\} \tag{8}$$

Finally, the application layer decides the maximum video coding rate at the encoder with (9). OH_{Pkt} is an amount of a packet overhead in network, data link, and physical layers.

$$maxCRate_{i^*} = \frac{N_{Pkt}^{*} \times \left(AvgSize_{Pkt} - OH_{Pkt}\right)}{T_v} < minRate_{i^*} \tag{9}$$

Coding rate of a sender is controlled by changing QP value and the coding rate is always less than the minimum rate of the selected path.

c) Adaptive coding rate adjustment

In ad-hoc network, because nodes can move and be used as relay nodes for other data flows, the selected path can be partitioned and node failure can be happened due to the energy exhaustion. In the proposed CVTP, source periodically sends a route discovery packet and performs the procedure of (a). Therefore, when the current path is not available any more, a new optimal path can be selected again using Equation (4). If a new path is selected at time *t* after its service starting time, the source node should readjust its maximum coding rate $maxCRate_{i^*}(t)$ based on the new selected path's energy and link rate conditions as (10).

$$maxCRate_{i^*}(t) = \frac{N_{Pkt}^{*} \times \left(AvgSize_{Pkt} - OH_{Pkt}\right)}{T_v - t} \tag{10}$$

In conclusion, CVTP decides an optimum path by means of physical and network layer information that were acquired at routing time and adaptively calculates application layer video coding rate. Therefore, it has advantages that a connection can be continuously and stably maintained during the desirable service time and quality of received video is improved because of little packet losses and delay. The proposed path selection and coding rate decision can decrease frequent path re-establishments due to energy exhaustion of nodes before the expected service time so that routing overhead also can be reduced. Figure 3 shows the functional and procedural structure of the proposed CVPT at the video source node.

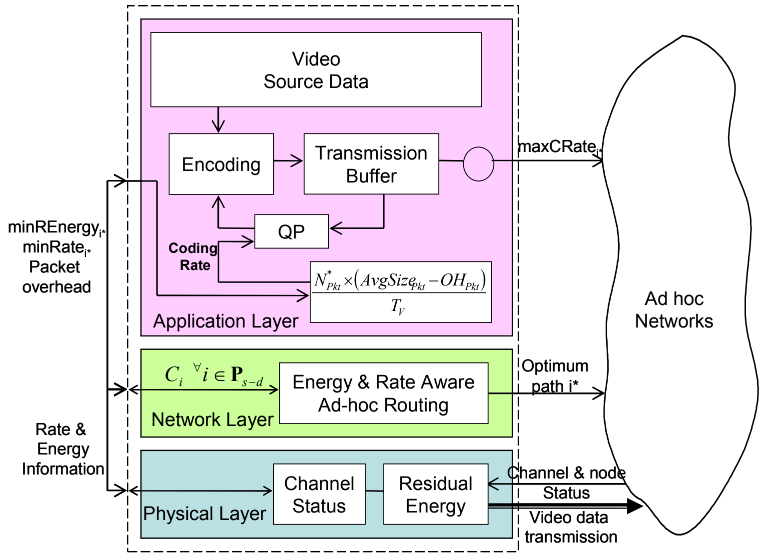


Figure 3. Functional and procedural structure of CVPT.

4 Experimental Results

In this section, we demonstrate performance of proposed CVPT. NS2 (Network Simulator 2) is used to make a simulation environment as Table1. In this experiment sources and destinations are randomly selected and the packet overhead (OH_{Pkt}) is ignored. For CVPT all weights are the same $(\varpi_h = \varpi_e = \varpi_r = 1/3)$.

Table 1. Simulation Environment

Simulation area	600 m × 600 m
Number of nodes	10~35
Buffer size at each node	50 packets
Node velocity	0~30 m/s (0~108 km/h)
Average packet size	512 bytes
Energy of nodes	15~25 kJ (random)
Link bandwidth	50 ~ 80 kbps (random)
Simulation time	300 sec

H.263 codec that it can adaptively change QP value is used for video data compression. The codec is implemented by UBC and the version is TMN5. This codec has simple function of error concealment. For comparison, we implemented two methods that are different from the proposed method on the decision of video coding rate and optimal path selection. For the video coding rate, one method (NgbMin) uses the minimum link bandwidth among the links between a source and its all one hop neighbors. Another method (NgbAvg) uses the average bandwidth between a source and all its one hop neighbors. For the two compared methods, video transmitting paths were determined using the conventional AODV [7] protocol. The source and destination nodes are randomly selected.

Figure 4 shows the video data transmitting rate (i.e., coding rate) changes according to the number of nodes. As increasing number of nodes, the minimum path's link bandwidth and minimum path's residual energy will generally decrease. This means that the required hop count from the source to the destination is increasing and network condition is getting worse by increasing the number of nodes. As we can see, the proposed CVTP adaptively control its coding rate in accordance with channel condition. The video transmitting rate is similar NgbMin and lower than NgbAvg. The large node count, CVTP decreases its rate to reduce possible packet losses on the path.

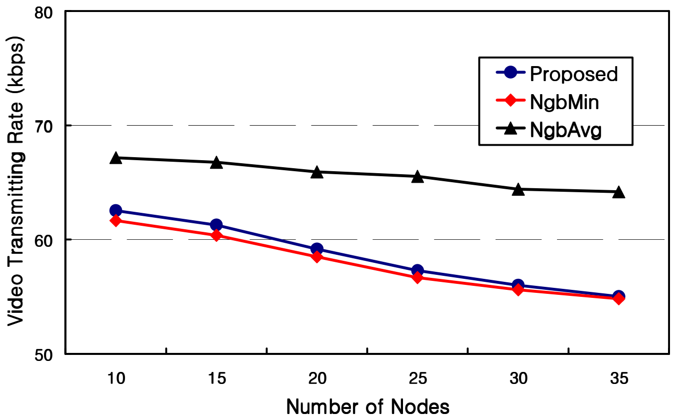


Figure 4. Video data transmitting rates by increasing nodes.

Figure 5 shows the packet loss rate by increasing node numbers. For the small number of node case, there was longer path break time than that of the large number of node case. When the number of nodes is small, if one of the nodes one the path moves out, there is a path break and it takes a long time to recover the path with a new node appearance that interconnects the broken paths. However for the case of the large number of nodes, when a path is broken, because there are many candidate nodes to interconnect the broken paths, shorter path recovery time is required. All packets during the path break time are lost. And as shown in Figure 5 the packet loss ratio of CVTP is also maintained lower level than those of compared methods.

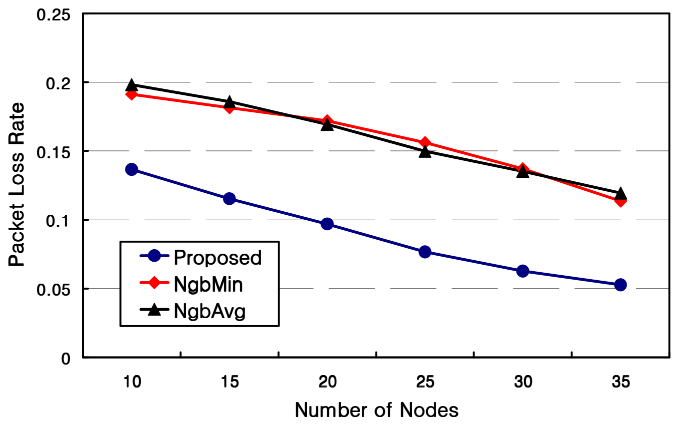


Figure 5. Packet loss ratio by increasing nodes.

Figure 6 shows the average PSNR changes at a decoder according to the number of nodes. The proposed CVTP shows higher average PSNR for all node number conditions than those of the compared two methods. For the larger node number condition, the PSNR differences between CVTP and compared methods are also the larger.

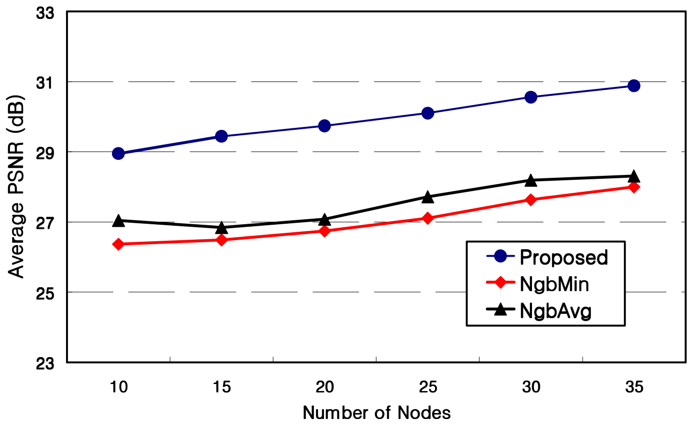


Figure 6. Observed PSNR by increasing nodes.

Figure 7 shows transmitting rate changes of the proposed protocol for one example experiment (20 nodes) during the simulation time. The transmitting rate of CVTP is recomputed whenever path reconstruction is required. As we can see, the CVTP can control transmission rate adaptively based on the new path's channel and energy status.

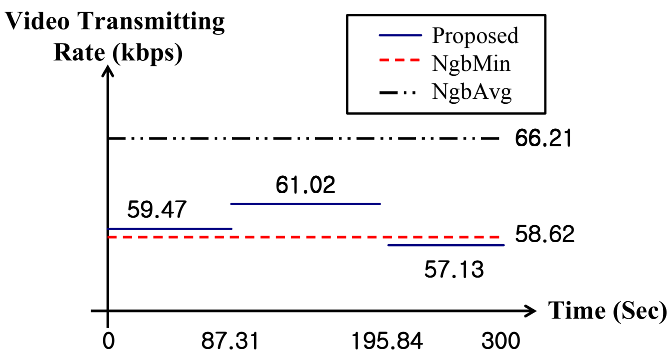


Figure 7. During simulation time, observed video transmitting rate.

5 Conclusion

Video transmission application in ad-hoc network is restrained by node's mobility, frequently topology changes, various node's energy capacity, and transmission path conditions compared with video transmission in general wired or wireless networks. So, in this paper, we propose a new cross-layer protocol for effective video transmission in wireless ad-hoc network. The proposed CVTP decides an optimum path by means of information in terms of minimal residual energy, link bandwidth, and hop count of a path that are collected at routing time. This optimal path selection method can increase path life time and transmission speed. With help of physical and network layer in CVTP a video source adaptively decides its video coding rate for reducing packet losses and at the same time achieving maximum video quality.

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