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A SIMULATION STUDY ON MULTIPOINT-TO-POINT VIDEO STREAMING OVER MOBILE AD HOC NETWORKS

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ABSTRACT

Supporting video applications over infrastructureless mobile ad hoc networks is more challenging than over any other networks due to the absence of fixed infrastructure and rapid changes in network topology. In this paper, we tackle this problem by adopting the concept of multipoint-to-point (M2P) video transmission together with Multiple Description Coding (MDC) scheme. Some modifications have been introduced considering the differences between wired and wireless networks and the Dynamic Source Routing (DSR) protocol is extended accordingly to support M2P video transmission. Simulation study is carried out using NS-2 to demonstrate the performance of the proposed mechanism as compared to point-to-point transmission and the original Dynamic Source Routing protocol. We show that the proposed mechanism outperforms the conventional point-to-point transmission, especially at high mobility.

I. INTRODUCTION

A mobile ad hoc network is a group of wireless devices that organize themselves in a mesh topology to find routes and relay packets from a node to any other node. Recently, mobile ad hoc networks emerge as a promising solution for providing ubiquitous communications and its ability in supporting various multimedia applications, including video applications, has become a topic of intense interest. Video transport requires rigid requirements on bandwidth, delay and jitter. The commonly used low bit rate video compression methods can achieve high compression efficiency and good video quality under error free or nearly free transmission, but the quality drops drastically as the error rate increases. Much research has been done to provide solution for good video streaming in lossy networks, such as path diversity transmission [1, 2], multipoint-to-point transmission [3], and layered video transmission [4] together with error-resilient video coding schemes [5, 6]. These techniques have been proven feasible in many lossy networks but it does not necessarily hold true in mobile ad hoc networks. Video transmission over infrastructureless ad hoc networks experiences greater challenges due to rapid topology changes and higher transmission loss caused by multihop relaying.

Considering the aforementioned problem, some solutions have been proposed to handle video transmission over mobile ad hoc networks. A well-known one is using multistream coding with multipath transport [7, 8]. The Multiple Description Coding (MDC) scheme is used to replace conventional video coding scheme where several independent and equally important video streams (also known as descriptions) are generated in such a way that each description can be decoded to its original video at low but acceptable quality, and any additional descriptions received increases the video quality on top of the minimum level [9]. In order to fully utilize the strength of MDC scheme, these descriptions should be sent at highly disjoint routes to ensure that a single route failure affects only a minimum number of descriptions.

We present another alternative to tackle this problem in this paper. Generally, a mobile ad hoc network has a mesh topology where each node is virtually connected to all other nodes within its transmission range. Therefore, each node can obtain data freely from any node as long as there is a valid route between them. In addition, if the same information is owned by several nodes within the network, a node can retrieve this information at higher rate by downloading it simultaneously from more than one node, using the same concept as peer-to-peer network. Therefore, we propose multipoint-to-point (M2P) transmission for video streaming over mobile ad hoc networks in this paper. Fig. 1 illustrates the feasibility of the proposed mechanism for various video applications. Fig. 1(a) shows video applications such as video-on-demand, live streaming and conferencing. In this case, if node 1, 2 and 3 can receive the video directly from the original video source through an infrastructure wireless or wired network and if they are part of the mobile ad hoc network, they can become the secondary video source for other node in the same mobile ad hoc network. Meanwhile, fig. 1(b) demonstrates download-and-play video applications where the same video is stored at node 1, 2 and 3 in the same network. This phenomenon is the same as file-sharing in peer-to-peer network. On top of M2P transmission, we also use MDC in our proposal to reduce the workload redundancy.

The rest of this paper is organized as follows. In Section 2, our proposed mechanism is presented. Section 3 explains the simulation study using NS-2 and the performance evaluation. Simulation results are presented and discussed in Section 4. Finally, conclusions and future work are given in Section 5.

II. PROPOSED MECHANISM

A. Multipoint-to-Point Transmission

The basic idea of our proposal is to implement concurrent video streaming from several nodes to a single receiver over an ad hoc network. For simplicity, the video sending node is called sender in the rest of this paper. This method has been long implemented in wired networks but this

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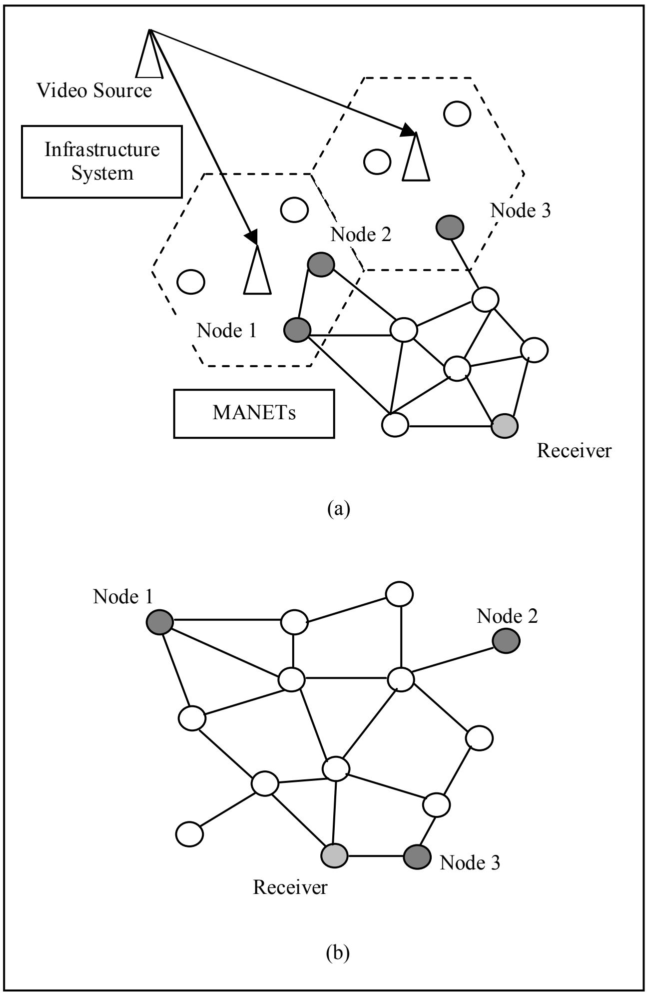

Fig. 1 Multipoint-to-point video transmission over (a) Hybrid Networks, (b) Mobile Ad Hoc Networks

model is not suitable for mobile ad hoc networks. Wired peer-to-peer networks use a greedy mechanism, which enables the receiver to establish many simultaneous connections to achieve highest possible downloading rate. This greedy behavior is not suitable for wireless networks because the same transmission medium is shared by all nodes in the network. Too many connections to a single node can degrade the overall network performance notably. Therefore, we must limit the number of concurrent connections connected to a single node.

In order to avoid duplicated workload, the video is encoded using MDC scheme. MDC scheme is a coding technique that generates several independent and equally important video descriptions in such a way that any subset of received descriptions can be decoded to obtain the original video at an acceptable quality. MDC is more error-resilient because each description is different and totally independent. Furthermore, the likelihood to lose all descriptions altogether during transmission is very small. All these features make MDC a better option than the conventional coding scheme. Interested readers are refer to [9] for a complete explanation of MDC scheme. Unfortunately, the strength of MDC scheme is associated with one major drawback. During the encoding process, the main video stream is divided into several sub-streams; therefore, the difference between neighboring frames within the sub-stream is larger. Consequently, the inter-frame coding has smaller compression and thus, higher bandwidth is needed to host the encoded video as compared to single description video. A comprehensive analysis shows that every additional description generated adds 10-20% overhead to the encoded video depending on the content of the video [10].

Studies have shown that using 2 descriptions of video can maintain the compression efficiency and at the same time increase the error resilience [11]. Further increment in the number of description has lesser impact. Therefore, our design in this paper is based on two points and two descriptions.

The algorithm of our mechanism is as follows:

i. Receiver sends out request for video.
ii. Nodes with the required video reply to the receiver. (we assume more than one node contains the required video)
iii. Receiver selects the first two nodes, whose reply arrives at the receiver first, as video senders, and a reply is sent to these nodes.
iv. Video senders activate the route discovery mechanism to find a valid route to the receiver. In our proposed method, the receiver is responsible in ensuring the routes replied to each sender are optimally disjoint.
v. Video senders start the video transmission when a valid route to receiver is available.

We make an assumption that the same MDC codec is installed in every node to generate only two descriptions of video. Therefore, the receiver must also inform the sender node which description to be sent. The focus of time paper is on the discovery of disjoint paths for the senders. The initial video sources searching step is not included in this paper.

B. Extended Dynamic Source Routing for Multipoint-to-Point Transmission (M2PDSR)

The Dynamic Source Routing (DSR) protocol is used in our approach because it has been proven to outperform many other routing protocols and it is suitable for use in finding disjoint paths [12, 13]. DSR is an on-demand routing protocol for multi-hop wireless ad hoc networks in which the end-to-end route is carried by the packet header. The flow state extension is disabled in our proposed mechanism. The DSR protocol is extended to accommodate multipoint-to-point video streaming, we called it Extended DSR Protocol for Multipoint-to-Point Transmission (M2PDSR). The main objectives are twofold: first, to distribute the video workload evenly within the network and second, to ensure the route traveled by each description is optimally disjoint. It is important to note that the extension is applied to video applications only. Besides, some additional steps are also added to provide better protection for video traffic.

During the route discovery, the route request (RREQ) packets are replied by the destination (receiver) only. This step allows the receiver to compare the routes used by both senders and ensure that only disjoint paths are replied. Besides, the intermediate nodes can send duplicate copies of

RREQ with the same sequence number if the routes traveled by these RREQs are different. As compared to the original DSR protocol that forwards only the first RREQ arrived, this forwarding method provides more choices for the receiver to obtain disjoint paths [14]. Obviously, this method creates more control overhead and causes congestion. With this in mind, we limit this mechanism by checking the shared-node ratio (I) between the route carried by the current RREQ and those previously forwarded using equation (1). The RREQ is forwarded only if the ratio is smaller than certain threshold value. This value is set to 0.2 for simulation in the next section considering the tradeoff between overhead and efficiency.

$$I = \frac{\text{number of shared nodes}}{\text{lenght of the shorter route}} \quad (1)$$

At the destination, DSR allows all RREQs received to be replied; but in M2PDSR, the route is compared with routes previously replied to the same sender. The RREQ is replied only if the shared-node ratio is smaller than certain value. This value should not be too small because it will make the route discovery mechanism inefficient; it is set to 0.8 for simulation in next section. Another important extension here is to provide 'priority' to the route carried by each RREQ. The route carried by the current RREQ is compared with high priority routes previously replied to the other sender. If the average shared-node ratio is smaller than certain threshold value (0.2 for simulation in section III), it is given high priority to indicate its high disjointedness. Otherwise, it is set to low priority. The priority is carried by the Route Reply (RREP) packets back to the video sender. More than one high priority route can be assigned and the senders always choose the shortest one to be used. The destination is given the task to find disjoint paths because it is the common node for both senders. This also explains why the RREQ packets are replied by the receiver node only.

A major strength of DSR protocol is salvaging, a mechanism used by intermediate node to rescue a packet when the next node stated in the source route is unreachable. During salvaging, the intermediate node tries to find another valid route to the destination from its route cache. If it is found, the packet is salvaged using the new route. Otherwise, the packet is discarded. In M2PDSR, we allow the intermediate node to initiate a non-propagating route discovery for the video packet. In order to avoid excessive control overhead, the route discovery is carried out only once.

Another mechanism utilizing the salvaging mechanism explained above is introduced to avoid buffer overflow at the senders, it is called gambling load distribution. This mechanism is activated only if both the following conditions are fulfilled: there is no valid route to the destination, and the buffer queue has reached a critical threshold. When the above conditions are fulfilled, the sender checks its route cache for the longest high-priority route which was previously valid. Then, it sends a portion of the packets stored in its buffer using this route and leaves it to the last valid node to salvage these packets. This approach is rather irresponsible, but it has its logic behind. It can be imagined that the end node of a broken link is usually closer to the destination; therefore, the successful rate for this node to salvage these packets is usually high.

III. PERFORMANCE EVALUATION

Simulation study has been carried out using NS-2 [15] with CMU wireless extension [16] to compare the following 3 cases: (C1) Single-point-to-point Transmission, (C2) Multipoint-to-point Transmission using DSR, and (C3) Multipoint-to-point Transmission using M2PDSR. The simulator contains the IEEE802.11 protocol in the MAC layer working in the Distributed Coordination Function (DCF) mode, a form of Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). Its physical layer features are not modeled. The channel bandwidth is 11Mbps and the transmission range is 250 meters. The simulation topology contains 50 nodes within an area of 1500 meters by 800 meters. A rectangular shape area is used to create more connection breaks during simulation as mentioned in [14]. The node mobility is modeled using the enhanced Random Waypoint Model [17]. The minimum traveling speed is set to 0.1 m/s and the maximum speed is varied from 2.5 m/s to 15 m/s to represent different levels of mobility. For each maximum speed, 30 scenarios are generated to observe the average performance. In each scenario, every node is assigned randomly with an initial location, a destination and a traveling speed, which is uniformly distributed between the minimum and maximum speeds. These nodes travel from their initial location to the destination at the assigned speed. After they reach the destination, a new destination and traveling speed are assigned. This is repeated until the simulation ends. Also, we consider continuous movement with zero pause time. Five cross traffics of 18kbps each are introduced in the networks to represent background traffic.

We model video application at 20 frames per second (fps). In this simulation, we consider only two descriptions of video for multipoint-to-point transmission, with 10fps each. The frame size for single description is 820 bytes and 1000 byes for double descriptions (500 bytes for each description). The larger frame size is introduced to simulate the extra overhead generated during MDC coding as explained in section 2. The playback deadline for each frame is 1 second after it is generated. A total of 10,000 frames are sent and each simulation runs for 1000 seconds, which is more than enough for the video transmission to complete. The arrival of each frame at the receiver is traced according to its sequence number. For evaluation purpose, we assume each frame is divided into two descriptions. If both descriptions are received within their playback deadline, it is called a good frame; if only one description is received within the deadline, the frame is marked as acceptable frame; otherwise, a bad frame is inserted. For single description video, the frame is either good or bad [8].

The evaluation carried out in this section is quantitative analysis on the successfully received frames. Two aspects are observed:

i. *Video Quality Index (VQI)* as given by equation (2). This index is a direct measurement on the overall video quality based on the quality of each frame; the quality index for a good frame is one, a bad frame is zero, and an acceptable frame is given 0.5 because we are using only two descriptions in this paper. This parameter does not take into account the influence of neighboring frames.

$$\mathrm{VQI} = \frac{1.0 \times N_{\mathrm{good}} + 0.5 \times N_{\mathrm{acceptable}} + 0.0 \times N_{\mathrm{Bad}}}{N} \qquad (2)$$

where N_{good} = number of good frames;
$N_{\mathrm{acceptable}}$ = number of acceptable frames;
N_{bad} = number of bad frames;
N = total number of frames.

ii. *Number of Bad Periods and Total Length of Bad Periods*: an interruption on video streaming is observed when one or more consecutive bad frames are received, it is called a bad period. The severeness of an interruption depends on how long the bad period is, and the video quality depends on how frequent the bad period occurs. These parameters are good measurement on the video quality from the perspective of viewers because every interruption is taken into consideration.

IV. RESULTS AND DISCUSSION

The results of the simulation study are shown in Fig. 2, 3 and 4. Fig. 2 shows the Video Quality Index versus mobility. At low mobility (< 5m/s), the difference between P2P and M2P is very small. The main reason is that link breakage occurs less frequently in this situation. Therefore, a single node is enough to provide good video quality. As mobility increases, C2 and C3 outperform C1 at greater scale because using two senders can significantly reduce the probability of losing connection to both senders at the same time due to link breakage. However, we can still observe that C1 performs better than C2 at 15m/s. This clearly demonstrates the need of using disjoint paths for each sender because by using M2PDSR in C3, the performance is better than C1. Moreover, it is obvious that C3 outperforms C2, contributed by the salvaging process and the load distribution mechanism explained in the previous that give better protection to video packets. Another interesting observation is that the performance does not follow a linear function with increasing mobility. Fig. 2 shows that bad performance is observed at 10 and 15 m/s. An explanation on this phenomenon is given in [7]. As mobility increases, connection breaks easily but the topology reformation is slow because the node movement is slow; this leads to a drop in network performance. However, new topology is formed more easily and the downtime becomes shorter when the nodes are moving faster, and this gives better performance. When the mobility is too high, the link breakage becomes too frequent and the network performance degrades drastically because it is overloaded with control packets. The parameters of the routing protocol can be fine-tuned to improve the performance but this is not done here to maintain the fairness of the comparison.

Fig. 3 shows the number of bad periods and the total length of bad periods. Smaller value of the first parameter indicates less number of interruptions occurs during the video streaming. Meanwhile, shorter total length of bad periods means the interruptions last for shorter period. Obviously, M2P (C2 and C3) has smaller value for both parameters as compared to P2P (C1) especially at high mobility, the improvement is more than 50% in C3 as compared to C1 in all cases. When C3 is compared with C2, the improvement is more obvious at high mobility (>7.5m/s), which gives about 10-40% reduction in both parameters. It is fair mentioning that the superior performance of M2PDSR is caused by the use of disjoint paths for each sender. This ensures a single node or route failure does not affect both descriptions. Consequently, the probability of losing both descriptions together is smaller and this leads to lesser bad periods. Fig. 4 is presented in order to observe the percentage of each type of frames. As expected, P2P has higher percentage of good frames as compared to M2P. Our objective here is to compare between DSR and M2PDSR. At low mobility, C2 has slightly higher percentage of good frames but as mobility increases, M2PDSR outperforms DSR. Generally, better improvement is achieved at high mobility.

Lastly, table 1 below show the normalized routing workload, which is a ratio of total number of control packets propagated within the network to the total number of data packet received at the destination [14]. As expected, the proposed M2PDSR has the higher overhead due to the modified RREQ forwarding method and salvaging.

Table 1. Normalized Routing Workload

Max. Speed (m/s)	C1	C2	C3
2.5	0.09	0.10	0.18
5.0	0.10	0.12	0.17
7.5	0.14	0.15	0.22
10.0	0.20	0.23	0.34
12.5	0.24	0.25	0.38
15.0	0.45	0.46	0.68

In summary, the video quality index given in fig. 2 cannot clearly show the improvements brought by the proposed mechanism. However, fig. 3 shows that the proposed method gives smoother video streaming in terms of less number of interruptions and shorter duration of interruptions. These aspects are more important for the users than the average quality because human visual system is more sensitive to every interruption that occurs as compared to the overall performance.

V. CONCLUSIONS AND FUTURE WORK

In this paper, we have adopted the concept of multipoint-to-point transmission together with Multiple Description Coding scheme to enhance video streaming over mobile ad hoc networks. The DSR protocol has been extended to support multipoint-to-point transmission. The contributions are twofold. First, the use of multipoint-to-point transmission provides fault-tolerant for the video applications. Second, better load balancing is achieved within the network by sending these descriptions of video using disjoint routes.

Future work includes analysis on the fairness and stability of our approach. It is desired to minimize the influence of our proposed approach on non-video applications. Besides, the routing overhead is quite high in our proposed mechanism; we are working to reduce the routing overhead due to the mechanism introduced to find disjoint paths for each sender by introducing more efficient route discovery mechanism.

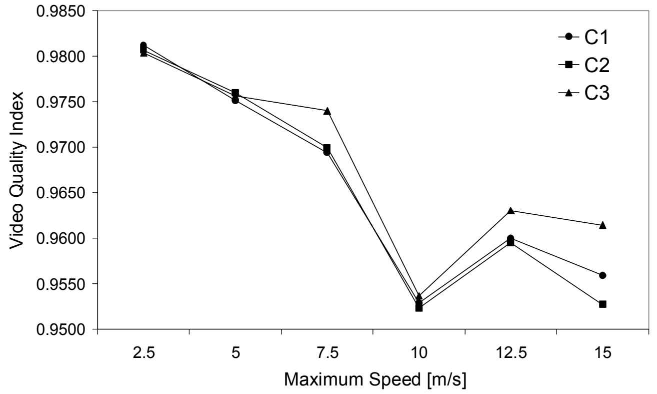

Fig. 2 Video Quality Index at different levels of mobility.

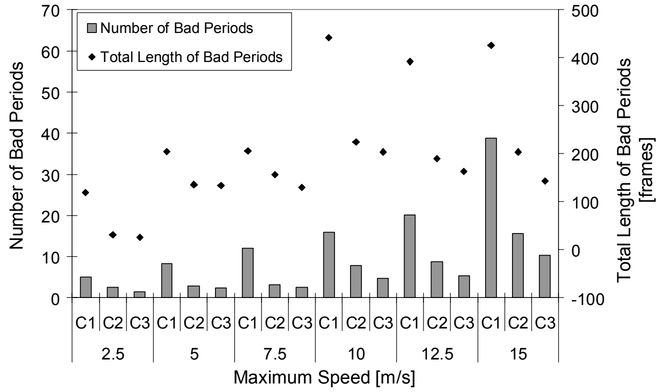

Fig. 3 Number of bad periods and total length of bad periods at different levels of mobility.

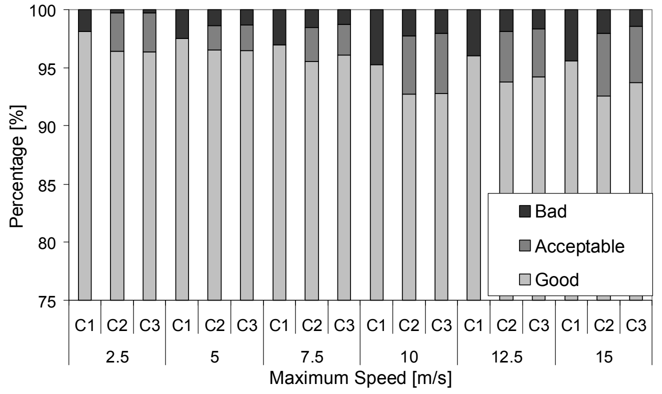

Fig. 4 Percentage of each type of frames at different levels of mobility.

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