Multipath Routing for Video Streaming in Wireless Mesh Networks

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Received: July 19, 2009. Accepted: January 3, 2010

The performance of low-latency video streaming with multipath routing over wireless mesh networks is studied (WMN). This paper presents a novel multipath routing video delivery scheme (MRVD) in which video takes multipath to reach its destination, thereby increasing the aggregate throughput. Based on proposed multipath routing scheme, a video scheduling algorithm is proposed, which achieves high bandwidth with low delay. In MRVD, the video traffic is divided into multiple segments before transmitted according to the path available bandwidth and path delay. MRVD optimizes the video schedule scheme according to the path delay; therefore video can be delivered onto multipath with more high efficiency. The validity of the routing scheme and video load balancing algorithm are verified by network simulations performed with different network load, latency and encoding structures.

Keywords: multipath, wireless mesh networks, load-balancing, video streaming networks.

1 INTRODUCTION

Wireless mesh network (WMN) has emerged as an important technology for increased wireless network coverage, which are consisted of multiple radio nodes organized in a mesh topology [1–3]. The radio nodes in WMNs often consist of gateways, mesh clients, and mesh routers which are interconnected by wireless links. Actually, WMN can be seen as a special type of wireless
ad hoc network in which the mesh nodes are often constrained by resources. Compared with ad hoc networks, WMN has several appealing properties: (1) the static mesh routers form a backbone to provide connectivity, so, the links among mesh routers are relatively stabler than those in mobile ad hoc networks; (2) mesh routers have unlimited power supply and may be equipped with multiple network interfaces for enhancing performance [4].

WMN has three key characteristics: (1) self-organisation, self-management, and self-healing; (2) dynamic topology; (3) variation in scale [5]. WMN can tolerate node and link failures due to redundancy and self-organization in the network; therefore, WMN provides a reliable and robust wireless communication method and increases network resilience which is suitable in real-time emergency communications [6, 7]. It is very challenging to provide video communications in WMNs [8]. Although existing WMNs are mainly used for data transmission, the increase in both wireless channel bandwidth and the resource of mobile techniques makes video and audio streaming service feasible [4, 9–13].

A Related works
Recently, many research attentions are focused on real-time multimedia transport that has stringent quality of service requirements which is not supported by current mesh networks. Video streaming is very sensitive to packet loss, delay and jitter [1, 14]. The throughput in wireless network is limited by bandwidth, interference and fading on wireless links, so high rate video traffic challenges WMN for overload-free transmission [15]. Many works have been studying on video traffic over multihop wireless networks recently, and various server/client techniques, such as multiple description coding and path diversity from a single server to the receivers, were developed for transmitting videos over wireless networks [16–18]. Considering the requirements of real-time video traffic and the properties of wireless mesh networks, cross-layer approaches have been explored to improve the transport efficiency from a single server to clients [17]. Recently, there has been a growing interest in supporting video traffic delivery over multipath in wireless mesh networks, to improve the utilization of bandwidth and decrease the delay and jitter [14]. Indeed, there are a number of significant advantages in use of multipath for video traffic, such as load balancing, potentially higher video bit rate, and improved error resilience [10].

In traditional networks, routing primarily focuses on connectivity. Hop counts or delay are usually used to evaluate the route. Route is selected according to the objective of minimizing the hop counts or the delay of each path [14, 19, 20]. As mentioned above, the multipath routing protocols in WMN may save bandwidth, improve security and reliability. They can reduce frequent routing update, enhance data transmission and increase the bandwidth. Although a number of multipath protocols have been developed in WMN, multipath load balancing in wireless mesh networks is still very challenging
due to the following three reasons: First, the packets distributing scheme by the source nodes (video server) results in fairness and rate allocation problems. Since the resources in the WMN need to be fairly shared among all the flows [21].

Second, the broadcast nature of wireless radio propagation may cause the benefits of multipath load balancing in wireless mesh networks to be less obvious. Since the power consumption of nodes in WMN may increase the susceptibleness of mesh networks, the load on the multipath must be balanced adaptively according to the rate on disjoint paths. In most WMN, the topology of WMN is changeable. A good load balancing scheme can help improve the throughput of the networks. When the mesh networks scale up in size, effective network load distribution and adjustment approach should be of great concern. In multipath routing algorithm, the lifespan of the WMN will be longer. Load balancing is also useful for reducing the congestion when the path is under heavy traffic loading, which will cause long packet transmission delay.

Third, congestion control and rate adjustment in WMNs [21–25]. The congestion occurs when offered traffic load exceeds the available capacity, especially in large scale mesh networks. Congestion may decrease channel quality and cause the loss rates to rise, lead to packets drops and increase delays. Actually, the congestion also can cause the throughput to degrade and energy consumption rise. In multipath routing protocols, it is crucial to develop more effective congestion control and rate adjustment scheme [24–26].

In the area of WMN, many existing routing methods are multipath-capable, (e.g., AOMDV, TORA, and SMR). In addition, existing multipath routing protocols lack of a multipath evaluation metric with which the quality of multiple paths can be evaluated, which is critical for evaluating load balancing and congestion control scheme. In our previous work [5], we have developed a video communication system for wireless mesh networks. We found that using multipath concurrently for a video traffic is highly effective in combating fragile paths and frequent congestion.

B Contributions

In this paper, we present a new scheme for video streaming in WMN, named Multipath Routing for Video Delivery (MRVD), to facilitate video traffic on multipath. We make the following contributions. Firstly, we propose a multipath video streaming system for supporting concurrent video traffic service over a WMN, in which intermediate nodes can distribute video streaming. Secondly, we consider more realistic wireless network scenarios, where we model the packet loss, delay and delay jitter in WMN. Thirdly, we formulate the route discovery for the proposed streaming system using the rate/delay optimization framework and implement a genetic algorithm to solve it. Finally, we propose a new WMN video traffic control algorithm, the adaptive video load-balancing algorithm, which enhances the utilization of unused capacities in a WMN.
The proposed algorithm holds the following features:

Adaptive. We propose the congestion detection algorithm that detects a coming overload on multiple paths based on the flow input rate. Therefore, load-balancing can be implemented before congestion occurs which greatly decreases the possibility of unacceptable performance.

Load-balancing. Load are delivered by using the load-balancing algorithm. The algorithm enables the video streaming to be split into several trunks and transmitted over several multiple paths with suitable transmission rates.

Efficiency. In our method, we use the optimized number of paths and, therefore packet delays are decreased as short as possible.

Deployability. The proposed algorithm can cooperate with the current available routing protocols AOMDV and MAC protocols. Therefore, the algorithm is easily deployed using our Swanmesh wireless mesh networks.

II PROBLEM STATEMENTS

In this section, we formulate the multipath routing problem for wireless mesh networks and present support definitions. Before proceeding to the presentation of the multipath network model, we will give some necessary definitions.

A Network model

A WMN with \( N \) nodes can be modeled with a connected graph \( G(V, E) \), in which \( V \) is the set of \( N \) nodes and \( E \) is the set of links connecting the nodes in \( V \). Each mesh node \( v \in V \) has a circular transmission range \( R_t(v) \) and a carrier sensing range \( R_c(v) \). Let \( e_{ij} \) denote the link from node \( n_i \) to \( n_j \), where \( n_i, n_j \in V \), and \( 1 \leq i, j \leq N \). If node \( n_i \) is in the transmission range of \( n_j \) and at the same time \( n_j \) is in the transmission range of \( n_i \), the edge \( e_{ij} \in E \).

**Definition 1.** Load \( LL(e) \in \mathbb{R}^+ \) on link \( e = (u, v) \in E \). It denotes the traffic on a link \( L(u, v) \). It is the aggregate of traffic from different paths that traverse the links. For a link \( e \in E \) (\( e \) is the link between two neighboring nodes \( u \) and \( v \)), let \( f_m \) be the flow traversing through link \( e \) on path \( p_m \), if there are \( M \) paths through link \( e \), the the load on a link can be obtained by Eq.(1),

\[
LL(e) = \sum_{m=1}^{M} f_m
\]  

(1)

Similarly, the load on a path \( p_m \) can be calculated by Eq.(2),

\[
LL(p_m) = \sum_{e \in p_m} LL(e)
\]  

(2)
Definition 2. Delay on a link, \( d(e) \in \mathbb{R}^+ \). It consists of two components, the queuing delay and propagation delay. In general, it is independent between links.

Definition 3. Delay on a path \( d(p_m) \). For each path in multipath from the source node \( i \) to destination node \( j \), a path \( p_m \) is defined as a list of nodes \( n_i, n_{i+1}, \ldots, n_j \) such that \( \forall k, i \leq k \leq j, (n_k, n_{k+1}) \in E \) and no node appears more than once. It can be obtained by Eq.(3),

\[
d(p_m) = \sum_{e_{ij} \in p_m} d(e_{ij})
\]

in which \( d(e_{ij}) \) denotes the delay on a link from node \( n_k \) to node \( n_{k+1} \) on a path \( p_m \).

Definition 4. Available bandwidth \( b(p_m) \) on a path \( p_m \), which is defined as the lowest link bandwidth on the path, it can be obtained by Eq.(4).

\[
b(p_m) = \min\{b(n_k, n_{k+1})\}, i \leq k \leq j
\]

Definition 5. End-to-end loss rate. The packet loss on the links is independent, so the end-to-end loss probability for the path can be approximated as Eq.(5),

\[
dr_m^{ij} = 1 - \frac{1}{\Pi} (1 - dr(n_k, n_{k+1}))
\]

Further, the multipath from the source node to the destination node can be defined as \( P = \{p_1, p_2, \ldots, p_M\} \), in which \( M \) is the number of paths in the set of multipath. The aggregate bandwidth \( B \) of the \( M \) paths can be calculated with Eq.(6),

\[
B = \sum_{m=1}^{M} b(p_m)
\]

B Minimizing End-to-end delay

In [14], a traffic allocation scheme is proposed by using weighted round robin packet distribution to decrease the delay and improve throughput, in which the source node delivers load to the multipath according to the RTT(real-time traffic) of each path. Paths with small RTT are allocated more consecutive packets, and paths with large RTT are allocated small consecutive packets. The available bandwidth of each path is inversely proportional to the occupied bandwidth on it. In [27] a scheme is proposed in which the end-to-end delay for sending a segment from source node to destination node by using multipath routing and intelligent traffic allocation. In this method, data is routed along
multiple paths in sequential block. Since links on paths may be broken before all the data is transmitted, new paths must be discovered. The data are divided into chunks and uses a set of multiple paths to route each chunk [14, 27].

According to the definition above, for a multipath set with $M$ paths $P = p_1, p_2, \ldots, p_M$, the aggregate bandwidth $B$ of the $M$ paths is,

$$B(P) = \sum_{m=1}^{M} B(p_m)$$  \hspace{1cm} (7)

The video stream can be delivered onto the $M$ paths. The destination node then plays back the video after the data from the longest path arrives, the start-up delay can be modeled as $D(P)$,

$$D(P) = \max\{B(p_m)\}, m \in \{1, \ldots, M\}$$  \hspace{1cm} (8)

On the destination node, the data received before playback must be buffered and the corresponding buffer $R$ is,

$$R = \sum_{m=1}^{M} b_m(D - d(p_m))$$  \hspace{1cm} (9)

In our route scheme (to be discussed in Section III), videos are delivered onto multiple paths that fulfill bandwidth requirements. The aggregation bandwidth is essentially split into multiple sub-bandwidth. Each sub-path is responsible for one sub-bandwidth requirements. The local bandwidth information is available at each node.

C Overload detection

One of the key problems in video stream is to detect a coming overload to conduct effective traffic control according to the current flows. In [27] the authors presented an approach by sending probes to detect link status. Actually, sending probes is a re-active behavior, in which the overload can be generated only after it occurred, and it is not enough for effective traffic control.

For a multipath route scheme with $M$ paths, the source node $s$ needs to send/forward through the multipath. When a new video flow $f$ with a basic bit rate of $r_f$ enters in and wants to be output through multipath set $P$, $s$ checks whether $f$’s transmission will cause overload or not. Based on $s$’s detection result about the video flows’ incoming rates, the video stream can be delivered onto multipaths. The vacant ratio of each path can be obtained by Eq.(10),
Routing for Video Stream

\[ l = \int_{0}^{t} \sum_{j=0}^{M-1} r_j dt \]  

(10)

where \( r_m \) is the incoming rate on \( m \)-th path. If \( B(P) \geq r_f \), \( s \) thinks that the multipath \( P \) is able to carry \( f \); otherwise if \( B(P) < r_f \), \( s \) employs MRVD algorithms to release overload. Without introducing overhead, overload detection is in a distributed pro-active way. The calculation of available bandwidth is based on video flow’s incoming rate which shows that the active network status will take place in multipath.

A subsequent control therefore makes sense in avoiding channel overload. Furthermore, overload detection observes each path’s status instead of bottleneck in a multipath. It holds the advantage of fully utilization of each paths.

III Multipath Routing in WMN for Video Stream

In this section, we propose a novel multipath route discovery and maintenance for WMN and then give a load balancing algorithm with which the video traffic load can be balanced on multiple paths.

A Multipath Route Discovery

As described in Section 2, we model a wireless mesh network with \( N \) nodes as a graph \( G(V,E) \). Here, we use \( N(i) \) to denote the set of neighboring nodes of node \( i \), and \( S_{ij} \in N(i) \) denote the set of children nodes for reaching the destination node \( j \). Furthermore, let \( S_{ij}(k) \) denote the set of allowed next hops at node \( k \) for a set of traffic from node \( i \) to node \( j \).

In initial network setup phase, all nodes are allowed to find multiple paths to gateway (GW). At first, when the network is started, the GWs broadcast HELLO message to its neighbors. After receiving the HELLO message, the neighboring nodes in \( N(GW) \) will initiate the path discovery phase to find paths to all possible GWs in the order of their available bandwidth. These nodes further broadcast the HELLO message with links information. In these HELLO messages they announce all their routes to the GWs with their order of performance. After hearing these messages, a node then decides the different paths that are acceptable to it and adds this to its routing table. It then unicasts a PARENT message to the selected parent nodes from which it has received the HELLO messages. The PARENT message contains all the paths it has chosen from the HELLO message. Thus, through PARENT message, a child node notifies its parent node which paths are used for forwarding its traffic. For the parent node, it registers the children nodes in its routing table and updates the paths that should be used to forward the traffic from the children nodes.
Then, a parent node will unicast another notification message CHILD to all corresponding nodes. This message will inform all intermediate nodes along the path including the GW about a child node and the path that can be followed to reach this child node. On receiving the CHILD message, each parent node registers this child node and follows similar steps in registering the multiple paths to reach a child node in their respective routing tables. By this way, each intermediate node including the GW that is in the path from a child node to GW now has one or more paths to the responding child nodes.

In order to limit the paths that each node can access, each node can only send the best \( m \) paths to its descendants, and the \( m \) can be a system configurable parameter which provides a tradeoff between load balancing and complexity in route determination.

Fig. 1 illustrates the operation of the proposed protocol using a simple example. In the figure, there are two gateway nodes G1 and G2 connected to the Internet. The two GWs announce their presence by periodic broadcasting HELLO message, and n1, n2, n3 receive the HELLO message from G1, n3 and n4 receive the HELLO from G2. n3 receives two HELLO messages both from G1 and G2 (in fact each node can only belong to a GW), it thus prioritizes its paths to the GWs according to the link capacity and path performance.

Then, each node broadcasts the received HELLO message to its neighbors, and constructs the reverse paths. By this way, the paths can be established as shown in Fig. 1. n8 sends a PARENT message to n5 and n6, n5 then creates

FIGURE 1
Multipath routing illustration.
an entry in its routing table and notes the preferred paths to $n_5$. It then sends a
CHILD message to notify its parents $n_1$ and $n_2$ about the child $n_8$ along with
the selected routes. Similar to $n_5$ they also register the preferred next hops for
traffic from $n_8$, the notification goes until it reaches $G_1$. When $n_8$ received
HELLO message from $n_6$, with paths $G_1-n_2-n_6$, $G_1-n_3-n_6$ and $G_2-n_3-n_6$,
it would now try to select maximal disjoint paths. Thus, each intermediate
node maintains a set of routes that it can use to forward packets from an end
node.

B Route Maintenance
In WMN, when new nodes are added or some existing nodes are ‘dead’, the
protocol must maintain the paths. New node can be discovered by other nodes
and new paths from it to GWs will be found quickly. In our scheme, each node
continuously monitors the performance of each of these paths to the GW and
broadcasts this information to the neighbor nodes. Neighbor nodes examine
these changes by checking for the possibility of finding new routes to the GWs
and suspending the existing routes due to node failure or path degradation.

On finding new paths or new nodes, a node will update its routing table and
announces this information to its neighbor nodes. The affected nodes promptly
update their routing tables using this information and further broadcast the
changes. In our scheme, a node can be added to the WMN only after receiving
the admission by the GWs. Each new node will send an ADD message and
to find a route to the GWs. The GWs will reply it with an admission message
or veto message. When a node detects the failure of a particular next hop, it
immediately checks its routing table to identify the entire path passing through
the node, and then the source node that is affected in the routing table will
update the route, and multiple paths can be recovered quickly.

IV ADAPTIVE VIDEO LOAD BALANCING ALGORITHM

A Load Balancing
In the previous sections, each node can find and maintain multiple routes to
and from the GWs. Once we have these multiple paths established, next task
is to distribute the traffic among these routes to balance the load, enhance
the utilization of the wireless mesh networks. A round robin scheduling mech-
anism is used for load delivery. In order to avoid the degradation caused by
congestion, the route scheme should be congestion-aware.

B Framework
In WMN, the source maintains multiple paths to the destination and reserves
bandwidth along the paths such that the total bandwidth falls within an accept-
able range. Actually, the total number of paths depends on routing scheme.
It is equal to the number of streams. Therefore, a path may not carry packets
from different streams. Depending on the path conditions and video application requirements, the source delivers video to multipath. The source coder also must adjust the rate allocation to each stream depending on the available bandwidth.

As shown in Fig. 2, the system consists of five steps: step 1, the video encoder processes the input stream; step 2, in the video segment procedure the video stream is divided into multiple substreams, the number of substreams depends on the number of paths of the multipath and the application requirements; step 3, on each path, the corresponding substream is transmitted; step 4, on the destination, the received substreams with little delay are buffered until all segments are received; step 5, the video encoder can playback the video. In Fig. 2, the video encoder and video segment are on the source node, sub-segment is run on the relay nodes, and the destination node run buffering and video encoder.

1) Theoretical minimum achievable delay: In order to achieve the minimum delay, the server has to transmit the video stream in a specific scheme so that the video can be played back with the minimum delay while guaranteeing continuity. In this paper, the video stream (in our simulation we use video file to substitute the video stream) is split into multiple segments and these segments are delivered onto the multipath so that the end-host does not need to wait for all the substreams to arrive before playback.

For a set of multipath \( P = \{p_1, p_2, \ldots, p_M\} \), the responding available bandwidth on each path is \( b_1, b_2, \ldots, b_M \), respectively, and the delay of each path is \( d(p_1), d(p_2), \ldots, d(p_M) \), respectively. For the multipath \( P \), the aggregate bandwidth \( B = \sum_{i=1}^{M} b_i \). In [14], the authors proposed an approach in which an video can be divided into \( M \) substreams according to the available bandwidth of each path. However, for some link-disjoint multipath protocols, this scheme may cause congestion on some links and the performance may be degraded dramatically. In order to overcome the limitations due to the congestion, a new adaptive video delivery scheme has been developed, which is
based on its knowledge upon the load-aware analysis on multipath. In this paper, we will used the overload detection to improve robustness of video delivery onto multiple path. For a WMN with \( M \) pathes, at first we can find a set of multipath according to the multipath routing scheme described in Section III. Assume path \( p_k \) has the maximum \( d(p_k) \) in the multipath, so the destination nodes buffer all the data from the paths with shorter delay than \( p_k \) and hence, the buffer requirement on destination increases until the stream on path \( p_k \) with the longest delay. After that the video is played back, the start-up delay is equal to the delay of \( d(p_k) \). The required buffer at destination can be obtained as follows:

\[
R = \sum_{p_k \in P} b_m (d(p_k) - d(m)) = B \times d(p_k) - \sum_{p_k \in P} b_m d_m
\]  

(11)

Similar as the method in [2], the theoretical minimum delay that can guarantee playback continuity can be reduced by a time \( R_t/B \). Therefore, the theoretical minimum start-up delay \( D_t \) can be derived by

\[
D_t = d(p_k) - R_t/B = \frac{1}{B} \sum_{p_k \in P} b_m d_m
\]  

(12)

C Video scheduling algorithm to achieve the minimum delay

As shown in Fig. 4, a video sequence are divided into segments in time \( t_1, t_2, \ldots, t_K \); here, \( K \) is the number of paths with \( d(p_1) < \cdots < d(p_k) \). Each segment is transmitted along the paths, and data are transmitted in different paths in parallel. It can be seen that this scheme pushes the beginning segments of the video into the shorter paths, so that the video can be played back earlier. To guarantee continuity, \( t_i \)'s have to be chosen appropriately according to

\[
t_i = \frac{\sum_{j=1}^{i} b(p_j)(d(p_{j+1}) - d(p_j))}{B}
\]  

(13)
The video schedule algorithm on multipath (VSAM) can then be stated as follows:

**Algorithm 1** Video schedule algorithm on multipath (VSAM)

| **Input:** | A sending/forwarding nodes \( s \), and the basic bit rate \( r_f \), and a video flow \( f \), \( t_0 = 0 \). |
| **Output:** | \( s \) outputs \( f \) to multiple paths without causing overload |

**Step 1:** Find the multipath \( P = \{p_1, p_2, \ldots , p_M\} \);

**Step 2:** Segment the video from \( t_i \) according to Eq.(13);

**Step 3:** Overload detection.

\[
\text{foreach Path } p_m \in P \text{ do}
\]

- Calculate \( l \) according to Eq.(10);
- if \( l > 0 \) then
  - break;
- else
  - \| \( l \leq 0 \)
- end
- \( P = P - p_m; \)
- goto Step.2;
end

**Step 4**

if \( P \neq \emptyset \) then

- \( i \leftarrow i + 1 \)
- Segment the video from the beginning according to eq.(13);
- \( t_i \leftarrow t_i + t_M; \)
end
else

- Invoke Algorithm 2: Load adjust algorithms;
end

**D Achievable Delay Analysis**

Given \( M \) paths, \( P = \{p_1, p_2, \ldots , p_M\} \), the responding delays are \( \{d(p_1), d(p_2), \ldots , d(p_M)\} \) respectively. According the method introduced in [14], the
aggregate bandwidth $B$ is the sum of each path. In many existing works, the video stream are divided into multiple substreams in multipath support wireless ad hoc network according to the number of paths. Actually, how to divide the video is very critical for the performance of video stream mesh network. In [14], the authors proposed an uniformly method with which, the video is divided into multiple substream according to the delay and bandwidth of each path. However, this method may cause congestions when there are multiple video sources. In our scheme we take the available and consume bandwidth into consideration, it may overcome the congestion as shown in Fig. 3.

The received time of the last segment is,

$$t_M = D_t + b(p_1)d(p_k) - \sum_{m=1}^{M-1} b(p_m)d(p_{m-1})$$

(14)

In which the $D_t$ is the theoretical minimum start-up delay.

E Load-balanced Multipath Routing Scheme

Load-balancing is an effective alternative to congestion-optimized routing, in which traffic flows are distributed proportionally over a given set multipath. In order to avoid overload in a link, traffic is distributed proportionally to the bottleneck residual capacity. When each path in multipath is independent, load-balancing approaches the solution to congestion-optimized flow partitioning at high rates.
Algorithm 2 Load adjust algorithms

**Input:** $t, K, M$

**Output:** The load indicator $l$

```plaintext
foreach Time $t_i$ do
  foreach Path $p_m$ do
    Calculate $B_i = \text{pathload}(t_i, p_m)$;
    $l = \frac{B_i}{B}$ if $l \leq 1$ then
      return $l$;
    end
    else if $l \geq 0$ then
      Loadadjust();
    end
  end
end
```

It can be seen that when the load differs on different paths, the data of the same segment transmitted along different paths arrives at the destination at the same time. Therefore, the video can be played without intermittence.

V SIMULATION

In this section, we will give a set of simulations run in NS2 to evaluate the performance of proposed method. We will compare the results of simulation with and without our VSAM algorithms. At first, in order to evaluate the performance, we will introduce the metrics that we will going to measure in the simulations.

A Simulation metrics

1) Average packets delay:

2) PSNR (Peak to signal noise ratio is a common used image evaluation indicator): It also can be used in videos evaluation. The larger the PSNR is the better the quality of the image or video is, and can be obtained according to the Eq.(15).

\[
PSNR(n) = 20 \lg \left( \frac{V_{\text{peak}}}{\sqrt{\frac{1}{N_{\text{col}}N_{\text{row}}} \sum_{t=0}^{N_{\text{col}}} \sum_{j=0}^{N_{\text{row}}}[Y_s(n, i, j) - Y_D(n, i, j)]^2}} \right)
\]  

(15)
in which \( V_{\text{peak}} = 2^k - 1 \), \( k \) is the bits number of intensity image, more details can be found in [28].

3) Video delay jitter Jitter is very important in the video quality measurement. In this paper, we use average value of delay jitter as a metric to evaluate the performance of our routing scheme and video load adaptive balancing. At first, we define the jitter as: the delay variance between consecutive packets, for example, on path \( m \), the jitter between node \( i \) and \( j \) can be calculated by 

\[
J^m_{ij} = |D^m_{j,i+1} - D^m_{j,i}|
\]

where \( D^m_{j,i} \) and \( D^m_{j,i+1} \) are the delay of the \( i \)-th and \( i+1 \)-th packets at the \( j \) receiver on path \( m \). In this paper, we use the average delay of multipath. Denoting \( I_m \) the packet number received by \( r \) through path \( m \), then we have,

\[
J^m_r = \frac{I_m - 1}{\sum_{i=0}^{I_m-1} |D^m_{i+1} - D^m_i|}
\]  

in which \( D^m_{i+1} \), \( D^m_i \) are the delays of \( (i+1) \)-th and \( i \)-th packet at the receiver \( r \) on path \( p_m \), and \( J^m_r \) is the \( i \)-th delay jitter at the \( r \) receiver. So, the average delay jitter at \( r \) on multipath can be calculated as

\[
J_r = \frac{\sum_{m=0}^{M} J^m_r}{\sum_{m=0}^{M} I_m}
\]

Actually, it can be easily and without additional cost implemented in a wireless mesh network.

B Simulation scenarios
In this section, we show some illustrative numerical results and compare the results with other methods. At first, we generate nodes on a 1000m × 1000m plane. The delay and bandwidth definition of a link are defined in section II.

Fig. 5 shows the network topology. The wireless mesh network includes 6 nodes, including a source node \( s \) and a destination node \( r \). \( s \) is the video sender and \( r \) is the video receiver. WMN adopts IEEE 802.11 protocol, and the channel bandwidth is set as 2Mbps. Video transmission rate is set as 128kbps. In the simulation, we import distributive traffic to generate network load. In simulation, we use the MyEvalVid framework proposed by Ke [28,29], which is based on Jirka klaues work, EvalVid - A Framework for Video Transmission and Quality Evaluation. In NS2 we can easily experiment with MPEG video transmission.

Fig. 6 gives the average packet delay curves, in which each point is an average value of 50 runs of the simulation. It can be seen from Fig. 6 that our protocol reduces packet transmission delay greatly when network traffic
load becomes larger than 600kbps. Our VSAM improves performance when network traffic becomes heavy.

Fig. 7 illustrates the average delay jitter performance in this simulation. It can be seen from the figure that when we use our VSMA algorithm, the jitter is reduced. This simulation clearly demonstrates that VSMA algorithm can reduce the delay jitter. Comparing to the existing AOMDV, delay jitter is generally reduced by 5% to 9%. Therefore, for multimedia stream transmission, the method to use load balancing to implement video streaming in WMN appears more suitable.
Fig. 8 compares original image and recovered image extracted from video for a *forman* on a multipath of WMN shows in Fig. 3. In Fig. 8, the left image is the original image extracted from original video, and the right image is the recovered image extracted from the received video. Here we just extract the same frame to compare. It can be seen from the figure that left image has better quality than that of right, it is because some packets were lost on transmission on WMN. Actually, the WMN has a packet loss rate, therefore the received video is recovered based on packets with a loss rate. These packet loss causes the recovered image quality decreased. In fact, in order to clearly evaluate at the quality of image, a metric PSNR is proposed to evaluate the quality of the video. In our simulation, we use avgpsnr.exe [28] to calculate the PSNR value of the received value.

In Fig. 9, we report the packet loss rate as a function of network traffic load. It can be seen that as the network traffic load increases, the packet loss rate is increased gradually. For VSAM, when the network traffic load increases to 600 kbps, the packet loss increased by 3.4%, actually it is very low and also can be acceptable for streaming application. We note that the packet loss rate of AOMDV without VSAM is much greater than that of VSAM when the network traffic load is high, it is due to the fact that VSAM can adaptively schedule streaming to multipath.

### FIGURE 8
Original image (left) and recovery image (right).

<table>
<thead>
<tr>
<th></th>
<th>2hops</th>
<th>3hops</th>
<th>4hops</th>
<th>5hops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only video stream</td>
<td>33.60902</td>
<td>33.059581</td>
<td>30.140721</td>
<td>27.049580</td>
</tr>
<tr>
<td>Video+Load(without VSAM)</td>
<td>30.145727</td>
<td>28.451186</td>
<td>26.721488</td>
<td>20.377835</td>
</tr>
<tr>
<td>Video+Load(with VSAM)</td>
<td>31.334745</td>
<td>29.781692</td>
<td>28.367433</td>
<td>24.279145</td>
</tr>
</tbody>
</table>

**TABLE I**

PSNR of video with different hop counts in WMN
VI CONCLUSION

We propose a video multipath routing scheme based on AOMDV with which a video delivery algorithm onto multipath in wireless mesh networks. The routing scheme incorporate contributions from both encoder distortion and packet loss due to networks load balancing.

Further work is needed for the optimal of multipath so that the optimal video rate can be obtained on-the-fly by actively probing the network conditions. Experiments with multiple sender/receiver pairs are in progress to investigate how the video streams influence each other. Future research is also planned to extend current work to other types of wireless networks and to consider the effect of mobility for the proposed multipath routing algorithm.

REFERENCES


