Integrate Airtime Metric and Geocast over P2P-Based VoD Streaming Cache

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Abstract

Peer-to-peer based systems have been widely proposed to provide the Video-on-Demand (VoD) service on the Internet in recent years. With the development of mobile networks, we proposed a suitable VoD system for mobile networks, in which peers are classified into groups and the backbone networks are established so that peers in the same group can share and transmit the streaming videos through the backbone networks. Further, mobile nodes that are not located at the backbone networks can receive the streaming videos through the Wireless Mesh Networks (WMNs). Through our path selection mechanism, peers can route faster and the system will be load-balancing. By considering the influence of the locality to mobile nodes, we delimit the new range of WMNs. In addition, according to the Airtime metric proposed in IEEE 802.11s, the Airtime cost of every mesh loop is calculated and the optimal path thus can be figured out.

***Key Word*:** P2P-Based VoD, WMNs, Airtime Metric

1. Introduction

With the development of broadband technologies, the wide applications of P2P-based VoD systems have been greatly proposed [1–6]. The basic notion of P2P-based VoD system is to allow every node to simultaneously access and share the videos stored temporarily in the buffer. In this way, the network bandwidth can be fully utilized, the load of video servers can be reduced, and the cost to establish servers consequently can be decreased.

Usually, P2P-based VoD systems offer less access latency, which means that users can join in the system quickly to obtain the videos [1]. However, the problem that P2P-based VoD systems encounter is that the time for every user or node to access the video server is different, and the acquired video clips are also different. Therefore, some mechanisms are needed for users to manage the video clips efficiently and to share the clips with other nodes. Besides, in order to improve the VCR operations, P2P-based VoD systems often use cache management mechanisms to effectively manage and distribute the data stored in the buffer of each node.

On the other hand, VoD systems face more challenges in wireless networks. Since the location changes of mobile nodes (MNs) are not easy to predict, the transmission routes distributed in the original networks might change or become invalid due to the moves of mobile nodes.

The VoD system proposed in this paper is mainly based on the concept of P2P-based VoD systems, but the classification and management of groups are defined in different ways. We not only establish the backbone networks in the groups, but also investigate the possible situations in wireless environments. Thus, we consider the transmission range of MNs and the selection of the video transmission paths on the backbone networks. As for nodes out of the backbone networks, multi-hop method is adopted to transfer data via MNs. Therefore, we must choose the most suitable path to maintain the quality and steadiness of routing. To achieve such requests, the opti-

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mal transmission path is not determined based on the fewest hop number or the shortest path.

With the idea of Geocast, this mechanism defines the new transmission area, narrows down the range, and forms a new mesh network according to MNs within the area. Moreover, by using the Airtime cost proposed in IEEE 802.11s [7], we can figure out the optimal transmission path for MNs out of the VoD backbone networks to receive data. Our mechanism helps to reduce the load of the server, keep the system load-balancing, and improve the network QoS by transmitting the streaming videos through the chosen optimal path.

2. Related Works and Background

(1) Related Works

In [2], the author proposed a set of management strategies that introduce the idea of buffer map and manage the data in the buffer. [3] also brought up a cache mechanism with probability, which offers the VCR function and distributes the buffer of each node efficiently.

[4] proposed the DCMM model and introduced the VoD system composed of the ring network that manages and shares the data of every node. However, the scenario of this paper did not further investigate the nodes out of the ring network. The group notion is mentioned in [5], in which the video streaming is divided into direct delivery that offers videos by the streaming server directly, and relay delivery that transmits videos within groups. [8] proposed the interleaving architecture for H.264/SVC video transmission in order to improve bandwidth utilization through video data interleaving and less packet loss in wireless network.

(2) P2P-Based VoD System

Compared with traditional Client/Server structure that is hard to fulfill the increasing client nodes and thus limits the service ability, P2P-based VoD systems, which have many mechanisms to reduce the load of the Server, have been greatly discussed. P2P-based VoD systems allow all nodes that want to view the same video clip to share data efficiently, save the network bandwidth, promote the service quality and even reduce the cost to establish servers. Generally speaking, the architecture of P2P-based VoD systems is shown as Figure 1, in which data overlay and index overlay are composed of all nodes [3].

In P2P-based VoD systems, the streaming videos are usually divided into several equal segments as the minimum unit to play. Among the nodes, this unit is taken as the unit for request or cache, and data of this unit is used for sharing. Being normally composed of all nodes, index overlay offers and manages the information among the nodes, including the neighboring list, the clips broadcasted at present, the joining and leaving nodes, and the information about VCR function. The connections of data overlay take shape when the videos need to be exchanged by nodes with the same data. The proposed P2P-based VoD system will be realized in cross-layer networks, especially the WMNs. Further, how to find the optimal transmission path of the VoD system and how to keep the system load-balancing are also our purposes.

(3) Hybrid WMNs

Wireless Mesh networks (WMNs) are self-organized and self-configured. Every WMNs node can establish an Ad hoc network automatically and maintain the connections. Every mesh node in WMNs can be the mobile node or the router, which means that every mesh node can be a mesh router or a mesh client. Mesh routers are used to form the backbone networks and are able to connect to mesh clients and the gateways through the backbone. On the other hand, being self-organized, each mesh client can be an Ad hoc network to deliver or transfer the re-

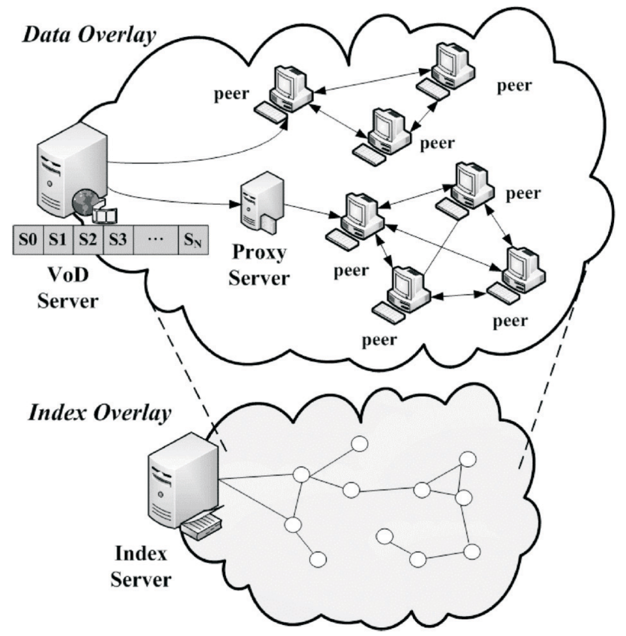

Figure 1. P2P-based VoD system.

quests to the backbone constructed by mesh routers. As a result, mesh clients connect to the Internet through the backbone and the gateways by wires.

Our proposed P2P-based VoD system can be used in Hybrid WMNs [9–11] and its architecture is classified into three layers. Layer 1 indicates that the gateways connect to the Internet by wires. Layer 2 consists of wireless mesh routers that connect to the gateways of Layer 1 and mesh clients of Layer 3. Through the wireless backbone, mesh routers allow mesh clients to connect to the Internet.

In WMNs, in order to select the optimal path among the terminal users, certain metrics are used for routing the paths between mesh routers and the gateways. Traditional metrics, like Hop Count metric, allow mesh routers to choose the gateway with the minimum hops, but this might lead to too heavy load of some gateways. Thus, in our proposed scheme, the Airtime metric mechanism is adopted to keep WMNs load-balancing.

(4) Airtime Metric

In order to select the best path, [12] suggests using radio metric as the path-selection protocol in mesh networks. By transferring test frames, the Airtime metric presents the channel resources wasted on one special path. Radio types, error rate of transferring frames and transfer rate of the present data are all what the metric takes into consideration. As defined in [7], Function (1) calculates the Airtime cost of every link.

$$C_a = \left[O_{ca} + O_p + \frac{B_t}{r}\right]\frac{1}{1-e_{pt}} \qquad (1)$$

O_{ca} denotes channel access overhead and O_p stands for protocol overhead. B_t symbolizes the size of test frames that its unit is bits. r refers to the transfer rate of data that its unit is Mb/s, and e_{pt}, which stands for the error rate of test frames. Some representative constants mentioned in [7] are shown in Table 1.

Table 1. Representative constants of the Airtime metric

	802.11a	802.11b/g	Description
O_{ca}	75 μs	335 μs	Channel access overhead
O_p	110 μs	364 μs	Protocol overhead
B_t	8192 bits	8224 bits	Bits in test frame

The Airtime cost can reveal the channel resources wasted on certain paths. Thus, through the transfer rate of data, radio types and the error rate of test frames, the Airtime metrics can obtain the Airtime cost of every path so that mesh nodes can choose the path with the minimum Airtime cost.

Expected Transmission Count (ETX) is adopted to estimate the frame error rate [13]. ETX metric periodically sends a message among the nodes and returns the message loss to the neighbors. According to the received data, the nodes figure out the new ETX number that results in the new metric. [14] defined ETX metric and the number of the expected transmission count is illustrated in Function (2).

$$ETX = \frac{1}{d_f \times d_r} \qquad (2)$$

Forward Delivery Ratio, d_f, denotes the ratio that the packets reach the destination without error in a time period. Reverse Delivery Ratio, d_r, represents the ratio of the successful ACK packets in a period. The reciprocal of the multiplication of d_f and d_r is the number to determine ETX.

The following Figure 2 is a path selection example based on the Airtime Metric. Supposing Node A is going to transfer data to Node B, according to the shortest hop count mechanism, there is only one hop for Node A to connect to Node B directly. However, based on the calculated the Airtime cost, the Airtime Metric path selection mechanism will choose for Node A to connect to

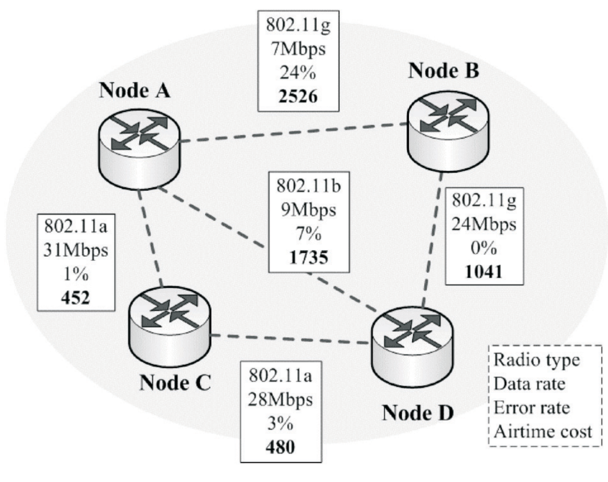

Figure 2. Path selection example based on the Airtime Metric.

Node B through Node C and Node D. Although there are more hops, the Airtime cost of this path is the minimum and the transmission quality is better.

3. Backbone-Based P2P-Based VoD System

Figure 3 shows our proposed P2P-based VoD system that divides a video clip in the video server into N equal segments: S0, S1……, S_N. The total length of this video is t, so the time of each part will be $\Delta t = t/(N + 1)$. Here, Δt is defined as the waiting time of the system, which means that when a node would like to view this video, the longest waiting time will not exceed Δt. The nodes that want to view this video in the same period are classified into the same group to establish their own backbone networks for data transmission.

From the angle of timeline, Node P_N refers to S_N that is received by the VoD Server at present. For example, as for streaming A in Figure 3, P5 means that this node is receiving the video of S5. Every node will click or access the videos it needs at different moments. After the classification of nodes, as for streaming A, Node P4 will inherit S5 temporarily saved in Node P5, and Node P5 will receive S6 from streaming A offered by the VoD Server. As a result, the videos received from streaming A can be continuously transferred to the newly-participating nodes. If the new nodes cannot connect with the data offered by the previous system, this system will offer another video streaming to satisfy the requests of other users. Data disconnection usually occurs when there is no node to directly connect with between two neighboring groups, or the time interval of the neighboring groups exceeds Δt. As far as streaming B is concerned, the time interval between group P22 and group P5 is too long, so that streaming B cannot share the video with group P5 and the new nodes.

When there are always some nodes that want to access to the same video, what all VoD Server needs to do is to send the video to Header of the first group. Through the group and the backbone connections, the rest nodes will inherit the video sequentially. As Figure 4 indicates, a Ring network is thus formed and each group establishes the backbone of its own group in the WMNs to transfer videos. Through the backbone, the videos can be transferred to other nodes of its own group efficiently.

4. Node Linking Methods in Different Regions

In the mobile network, as shown in Figure 5, the communication range of every mobile node is assumed to be r. Black nodes and white nodes watch the video at different moments, T1 and T2. Node a and b can communicate with each other and the distance between them is within the communication range r. In such a manner, the backbone formed by node a, b, c and d can be used to share the video streaming, but node e cannot connect to the backbone directly to receive the videos.

To solve this problem, multi-hop relay method can be adopted to transfer the videos to node e. As shown in Figure 6, through node b on the backbone, node e can receive the videos by multi-hop through node g. From the scenario in the figure, it is known that node e can obtain the videos by 4 paths that are extended from the backbone, path 1, 2, 3 and 4, which means that node f and node g will become the relay nodes for the multi-hop. Generally speaking, due to the mobility and variability

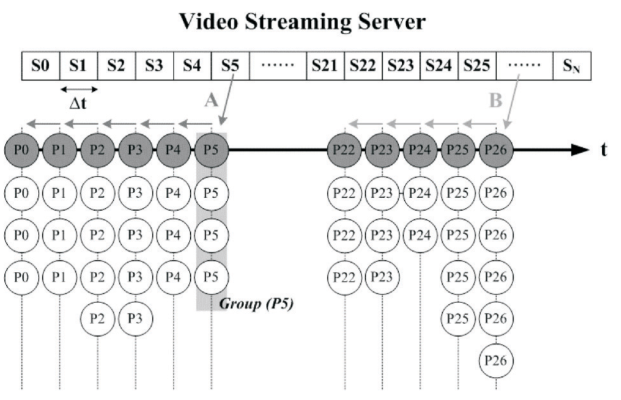

Figure 3. The proposed P2P-based VoD system.

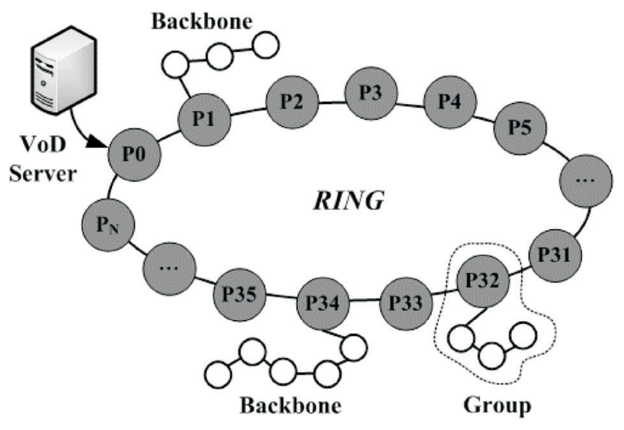

Figure 4. Backbone-based ring networks.

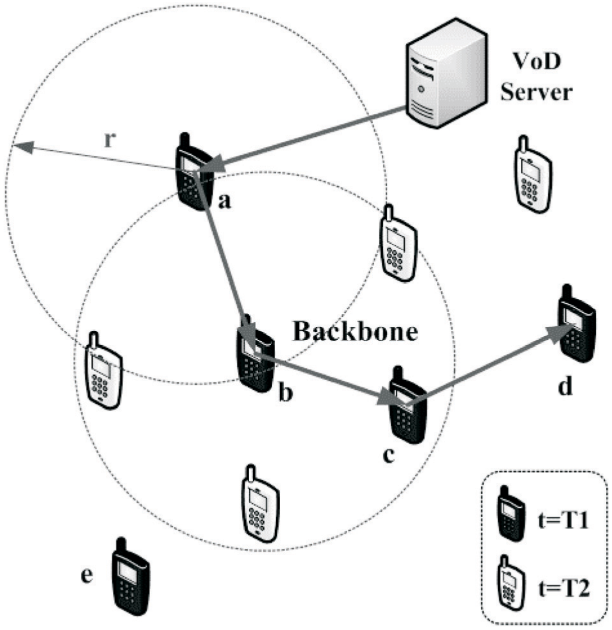

Figure 5. Backbone-based WMNs.

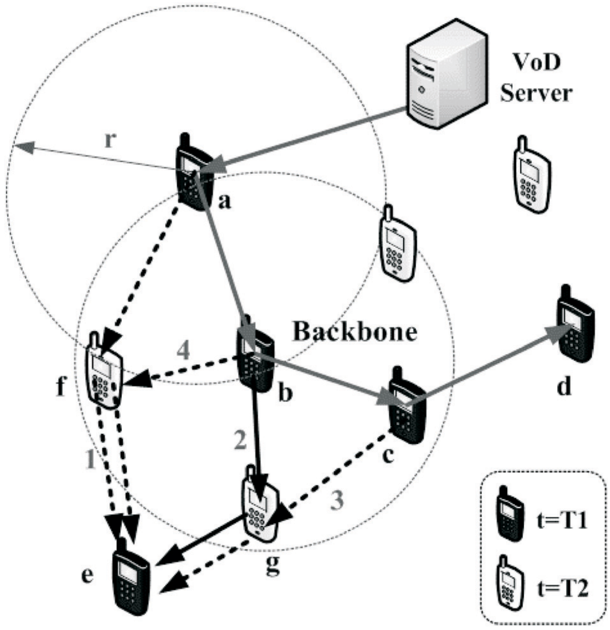

Figure 6. Backbone-based WMNs.

of mobile nodes, the locality must be considered while transferring data and the shortest path seems to be more reliable. As far as the four paths in Figure 6 are concerned, the number of relay nodes of each path is 1, which means that the hop number is 2. The transmission distance of path 2 is the shortest, so path 2 is the most possible one to be selected as the path for nodes out of the backbone to receive data. Nevertheless, in the mesh networks, the shortest path does not guarantee the best transmission quality and the fastest transmission speed.

Our proposed mechanism not only considers the idea of locality [15,16], but also estimates the Airtime cost of each circuit in the mesh networks for users to select the most suitable path as the optimal path for nodes out of the backbone to receive videos. We first use Geocast to choose the suitable direction, narrow down the range of the mesh network, and select the optimal transmission path by calculating the Airtime cost of each circuit.

As shown in Figure 7, mobile nodes with the same color belong to the same group. When the black nodes form a main backbone but one black node on the down left side cannot directly communicate with any node of the backbone, the neighboring nodes are needed to transfer the videos. This black node on the down left side is defined as the Destination peer. First, we find out the nearest node on the backbone to the Destination peer and define it as the Source peer. After determining the Source peer, from the Source peer, a θ angle is delimited on both sides of the line between the Destination peer and the Source peer. The range within the lines in Figure 7 is the transmission area.

As illustrated in Figure 8, we set up a new mesh network in the transmission area, calculate the Airtime cost of every path from the Source peer to the Destination peer, and select the path with the minimum Airtime cost as the optimal path.

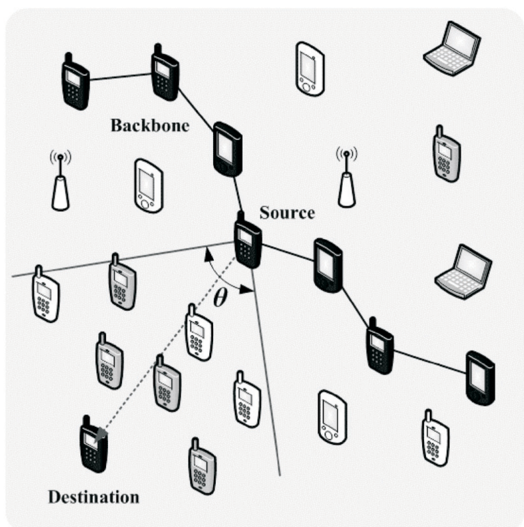

Figure 7. Range selection of the transmission area.

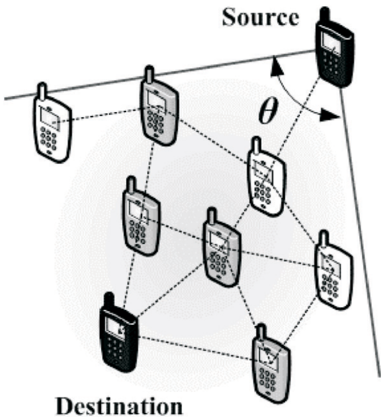

Figure 8. The newly-established WMNs.

5. Performance Analysis

ETX is taken as the error rate while calculating the Airtime cost in Function (1). However, ETX function can also be defined as the reciprocal of successful delivery rate or that of reliability, as shown in Function (3). Therefore, we place ETX into the function of the Airtime cost and its definition can be given by Function (4).

$$ETX = \frac{1}{d_f \times d_r} = \frac{1}{\text{successful delivery rate}} = \frac{1}{\text{reliability}} \quad (3)$$

$$ETX = \frac{1}{1 - e_{pt}} \quad (4)$$

By placing Function (4) into Function (1), we get Function (5) to calculate the Airtime cost of every mesh loop, in which channel access overhead and protocol overhead are combined into *O*.

$$C_a = \left[O + \frac{B_t}{r} \right] \times ETX \quad (5)$$

There might be n links between the source node and the destination node. The source node has to deal with and calculate the Airtime cost based on Function (6).

$$C_a = \sum_{r=1}^{n} C_{ar} = C_{a1} + C_{a2} + \cdots + C_{an} \quad (6)$$

Thus, in our proposed scheme, the mobility of mobile nodes is also taken into account. By Geocast, the transmission area is delimited to increase the reliability of the transmission path. Further, from the newly-established mesh network, the Airtime cost can be estimated to figure out the optimal transmission path to achieve load balance. In short, the transmission area framed by Geocast reduces the calculating volume while calculating the Airtime cost, accelerates the time to respond, enhances the network transmission efficiency, and improves QoS.

6. Simulation Results

NS-2 is used to establish a mobile network scenario, and generate a VoD streaming service with CBR/256 Kbps/300 seconds for the MNs. The other parameters are shown in Table 2. We will compare the server's workload to the peer arrival rate, and the other routing protocol in packet loss rate.

A video is divided into 300 segments, which means 1 segment/sec. Figure 9 that shows the peer arrival rate to server's workload reveals that by sharing the video th-

Table 2. Simulation parameters

Parameter	Value
Scenario	1000 m * 1000 m
Topology	Random/Grid
Number of nodes	25
Node velocity	0~5 m/sec
Transmission range	250 m
Streaming flow	CBR rate 256 Kbps, packet size 512-bytes
Simulation time	300 s
Transmission rate	802.11 b/g

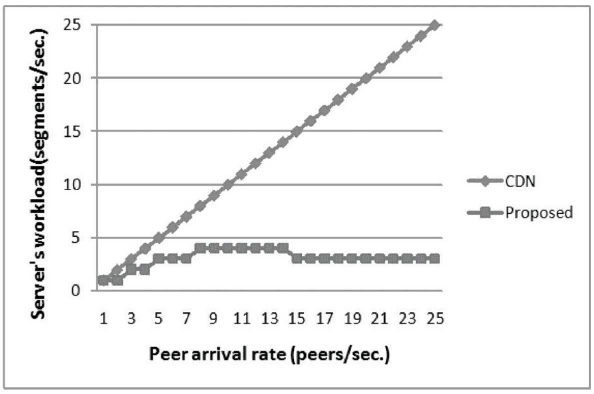

Figure 9. Peer arrival rate to server's workload.

rough the backbone network in the group, our mechanism reduces the server's workload. At the beginning, when the peer arrival rate ranges between 1 and 8, the server's workload increases because all the backbone networks are not established yet. During the steady state, since peers can share the video with each other, the server's workload is reduced to 3 segment/sec because the MNs in our scenario are separated into 3 parts with random distribution.

Comparing to the CDN (Content Delivery Network) architecture, CDN is a system of servers containing copies of data, placed at various points in a network so as to maximize bandwidth for access to the data from clients throughout the network. When the client requests the server for the service, CDN redirects new clients to a nearby cache server to avoid network congestion. Since the clients do not share data with one another, the peer arrival rate to the server's workload with CDN is linear. However, one disadvantage of the CDN is too costly to deploy many proxy or cache servers.

The relation of node velocity and packet loss rate is shown in Figure 10, in which AODV and DSDV routing protocols are compared. Based on DV (Distance-Vector routing), DSDV adds the record about destination sequence number. On the other hand, AODV checks the routing table fist. If there is no route to the destination, the source node will broadcast the RREQs (Route Requests) to find the new routing path. With the node's velocity variation, our proposed mechanism reduces the packet loss rate for around 10%~20% by considering the link error rate and resources. As shown in Figure 11, we find that the proposed mechanism performs better in the average delay time with different velocity.

In order to find out the relation between the parameter θ and the Airtime cost, we set up a grid topology, in which the distances between MNs are set to be 200 m. A backbone network is established in advance and the source node is selected to transmit data to the destination node. According to different angles of θ, the total Airtime cost calculated by Function (4) is shown in Figure 12. The increase of the angle increases not only the total Airtime cost but also the workload of the source node. Therefore, an appropriate angle selection mechanism can reduce the system load and improve the network performance.

7. Conclusion

This paper proposed a suitable P2P-based VoD system for WMNs, which takes the transmission and mobile features of mobile nodes into account. In the groups of classified nodes, the backbones of the groups are established to share the streaming videos so that the load of the server can be decreased and the network bandwidth can be utilized efficiently. Moreover, the nodes out of the backbone are also considered. With the proposed path selection mechanism, users can figure out the better

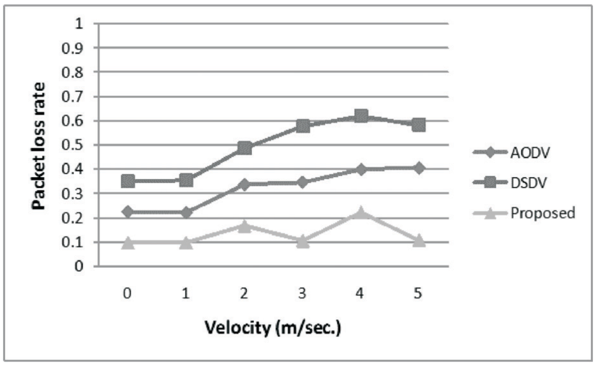

Figure 10. Velocity to packet loss rate.

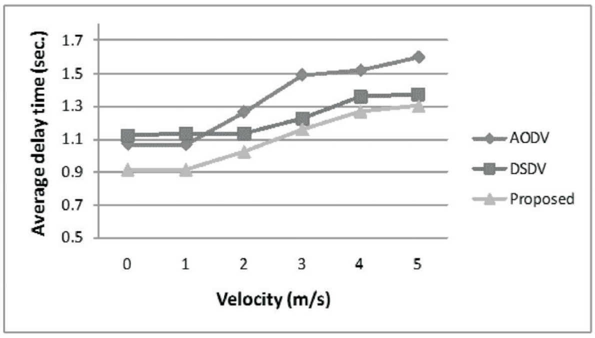

Figure 11. Velocity to average delay time.

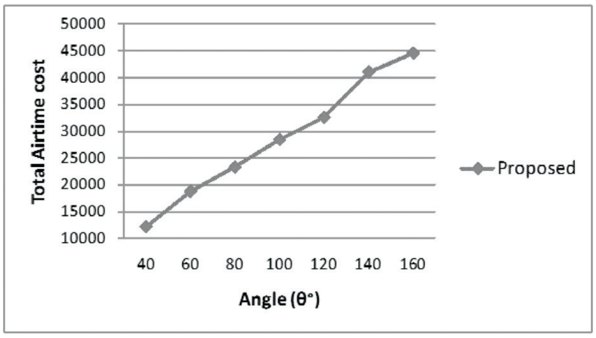

Figure 12. Angle to Total Airtime cost.

transmission path and keep the system load-balancing.

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