Dynamic Node Join Algorithm with Rate-Distortion for P2P Live Multipath Networks

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Abstract: - The delivery of multimedia that efficiently maximizes its quality in changing network conditions is one of the most challenging tasks in the design of live streaming systems. This study attempts to improve current P2P (peer-to-peer) live streaming systems by allowing users to enjoy high-quality service under the limitations of network resources. The proposed improvement method involves summing up and analyzing the consideration factors and restriction factors involving live stream quality during system operations. The proposed R-D (Rate-Distortion) optimized dynamic nodes join algorithm is based on multipath streaming concept and receiver-driven approach. This distributed algorithm enables the system to evaluate the current network status, in order to optimize the end-to-end distortion of P2P networks. Results of this study demonstrate the effectiveness of the proposed approach.

Key-Words: - P2P live streaming, Rate-Distortion, multipath streaming, receiver-driven, end-to-end distortion

1 Introduction

The use of live streaming systems is growing dramatically, especially for sharing real-time multimedia programs. The structures of multimedia streaming systems are classified as CDN (Content Deliver Network) systems and P2P live streaming systems. A CDN system has a client-server architecture (e.g., Akamai, Limelight Networks) [1][2]. One advantage of CDN systems are that users can efficiently obtain high-quality streaming service from adjacent proxy servers. Their drawbacks are high server costs and bandwidth rental fees for ICP (Internet Content Provider). P2P live streaming systems integrate the dispersed resources, distribute system loading and have low ICP operation cost. Achieving high streaming quality in end-to-end streaming transmission and broadcasting poses a major challenge for systems with various equipment and bandwidth [3]. The following issues need to be addressed : (1) Related Scalability Analysis: the selection of the best nodes for future end-to-end connections by a network probe or receiver-driven approach[4][5]; (2) Related R-D Optimization Method: how optimized R-D algorithm improve packet scheduling or flow transmission quality[6][7]; (3) Related Meshed-Multipath approach: increasing the quality of system service through Meshed-Multipath architectures [3][8].

While media scheduling processes and system architectures have been extensively studied, the limitations of P2P live media transmission in enhancing streaming quality have seldom been addressed [9][10]. However, users of P2P live streaming systems usually do not use them for very long periods. Since the stream paths change frequently, the making too many adjustments to optimize the transmissions for clients affects the viewing stability for users. Therefore, this paper presents a novel approach that is optimized for P2P live transmission, based on previous approaches, that achieves viewing stability.

The rest of this paper is organized as follows. Section 2 summarizes the issues influencing media streaming quality, and explains the improved method in these issues. Section 3 then discusses receiver-driven approach with rate-distortion theory, and applies it to the relevant proposed approach. Section 4 describes the simulation test performed with different algorithms to measure the efficiency of the proposed algorithm. Conclusions are finally drawn in Section 5.

2 Improvement for Live Stream Quality of P2P Network

Without loss of generality, this chapter discusses the issues influencing the quality of P2P live streaming. An appropriate network structure and operational process are then presented to achieve our research objective.

2.1 Quality Issues of P2P Live Stream Network

Individuals access the Internet frequently. In particular, P2P live streaming systems are increasingly popular due to advances in computer equipment, application functions and operating environments[11][12].

Streaming services have a high bandwidth requirement, as well as require both serve and play streamed content simultaneously. This operation pattern not only makes a heavy load on the network interface, but also increases the utilization of CPU and Memory, making its operation unreliable. Various studies have indicated that the stream flow quality of the clients' networks is affected by end-to-end distortion (including the end-to-end streaming rate and distortion rate)[13][14], Additionally, limitations in computer resources and bandwidth influence the network capability of a node when the user client transmits media streaming to others (reference Table 1)[15]. We can thus infer that the following factors influence the stream quality of the P2P live streaming system:

Table 1 Optimal $degree_{out}$ number of a P2P client under different bandwidths

Downlink Bandwidth	Uplink Bandwidth	$Degree_{out}$
512 kbps	256 kbps	0
3 Mbps	384 kbps	1
1.5 Mbps	896 kbps	3
20 Mbps	2 Mbps	6
20 Mbps	5 Mbps	17
※The test streaming rate in the experiments is 220 kbps		

[Issue 1: Maximum Connections Capacity] The number of uplink (degreeout) and downlink (degreein) connections in a node should be restricted according to computer performance and the network environment.

[Issue 2: End-to-end Delay Limitation] To ensure that the P2P live stream network is operating in real time, the end-to-end delay must be no larger than a reasonable limit value (δ).

[Issue 3: End-to-end Distortion Effect] Although the stream quality of the P2P live stream network is affected by the end-to-end distortion, the value of the end-to-end distortion contains the end-to-end streaming rate and the distortion rate.

Based on these three factors, the live stream quality of P2P network is assessed according to the end-to-end delay, streaming rate and distortion rate.

2.2 P2P Network Structure

The first issue [Issue 1] is a fundamental restriction. Therefore, based on the other two issues, this study chooses an appropriate network structure and handling mechanism, then develops an algorithm to improve the live streaming quality of P2P network. The network structure in this work is based on Mesh-Overlay, and has the following characteristics. First, every front-end may have parent nodes and child nodes (as found in other Mesh-Overlay P2P systems such as CoopNet and Split Stream) [16][17][18]. Second, any network inner-node can independently obtain the required resources from adjacent nodes via a pull method [19]. This approach improves transmission performance, since the Mesh-Overlay structure sufficiently makes good use of the uplink bandwidth of each node. However, this approach is unsuitable for the live streaming service, because the characteristics of the Mesh-Overlay structure are loosely controlling and inconsistent unidirectional transferring [20]. To eliminate overcome this shortcoming, two mechanisms are added, namely multipath streaming concept and a receiver-driven approach. First, the multipath streaming concept is added to the Mesh-Overlay structure so that each node can maintain the consistent stream flow direction [21]. The resulting network is called a P2P multipath network. In receiver-driven networking, the receiver node controls the download schedule during media transmission based on the estimation of the current network status. One control method is the "Parent selection" [20]; Therefore, parent selection is addressed in order to improve the end-to-end delay, the streaming rate and distortion rate of live streaming in the P2P multipath network.

2.3 Operation Scenario and Processes

Without loss of generality, the operation scenario of the proposed system has three aspects (Fig.1). First, the issues relating to the P2P multipath network structure are considered. Second, the proposed system adopts RTP streaming strategies with neither feedback nor packet retransmission. Third, since the streaming rate does not affect the distortion rate, the proposed approach does not consider the influence of channel coding such as FEC (forward error correction) protection [22].

This work focuses on two types of affiliated nodes: Node A as the new node. Node B as the node loses its parents and looks for new parents. Under such conditions, Note A selects the suitable parents to establish connections using optimized distortion method, through the receiver-driven approach when it adds itself to a network. The process flow and related algorithm of an appraisal process are described below (Table 2).

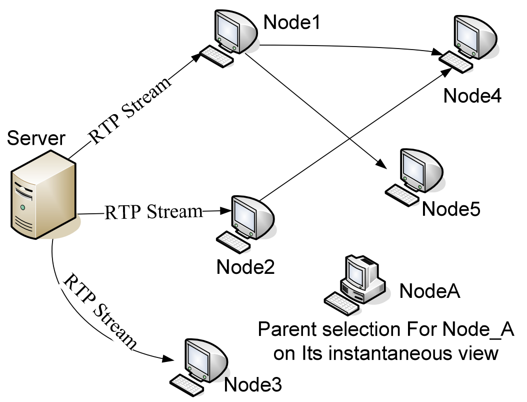


Fig.1 Operation Scenario of P2P Multipath Network

The algorithm can be broken down into four parts. First, if Node A wishes to join the system, it transmits the request "appoint parent" to the server, and obtains Candidate_list_1 from the server. After that, to begin with through Algorithm_1 filtering out those candidate nodes, Node A obtains the end-to-end delay information of all candidate nodes from Candidate_list_1 through ICMP. Based on the principle of [Issue 2], Node A eliminates the nodes with RTT>δ, and generates Candidate_list_2. Second, Node A tests each connection on Candidate_list_2 one by one using Algorithm_2 (from the server passing through the candidate nodes to Node A), then gets ASR (the average streaming rate) and ADR (average distortion rate) which are generated during streaming transmission between all candidate nodes and Node_A in a period of times. Third, Algorithm_3 is responsible for streaming test in a unit period time and provides information needed by Algorithm_2. It computes RTP distortion rate with following information: the accumulative RTP packet lost from candidate node, and extended highest sequence number of the current RTP packet. Finally, Algorithm_Opt proceeds the most important work－selects the best parent nodes. During the selecting process, Node A transmits these end-to-end streaming and distortion rates to Algorithm_Opt to calculate the most appropriate candidate nodes, and establishes the network connections. The following section describes the mathematical model and details of the proposed method.

Unlike Node A, Node B must transmit its degree to its original grandfather node after being disconnected from its parent. Node B selects other candidate nodes according to the above procedure once the $degree_{out}$ values of all grandfather nodes have been distributed. Since this process involves multi-stage distributed handling, it can be applied to large scale networks, and therefore is consistent with the main aim of this study.

Table2. Parent Selection Algorithm

Algorithm_1
Input Candidate_list_1 1.For each candidate_nodes in Candidate_list_1 [1] Node_A gets the RTT value from candidate nodes through ICMP protocol. 2.End for 3.Filter in [1] the candidate nodes with RTT value> δ away, and the remaining nodes will output as Candidate_list_2 4.Output(Candidate_list_2)
Algorithm_2
Input Candidate_list_2 1. Use all available downlink connection of Node_A, proceed: 2.For each candidate_nodes in Candidate_list_2 [1] Call Algorithm-3 to calculate ASR and ADR of connection provided by these nodes [2]Save the information which Algorithm-3 sends back into candidate_list_3 [3] If the distortion rate of this connection is the lowest on Node_A, keep this connection, otherwise Node_A stops accepting that stream flow connection※1. 3.End for 4.Output(Candidate_list_3) ※1:if available downlink connection of Node_A is only one, directly test next candidate node.
Algorithm_3
Input candidate node 1. Require that candidate_node sends the stream coming from the server to Node_A, establish connection 2. Record the following information from *RR* packet※1: A.cumulative_number_of_packet lost(*CPL*) ： accumulative RTP packet lost from candidate node. B.extended_highest_sequence_number_received (*EHS*)(32bit) ：low 16 bits record the maximal sequence number of the current RTP packet, and High 16 bits are sequence cycles. 3. Compute RTP distortion rate (*DR*): $DR=\frac{(RR_2[CPL]-RR_1[CPL])}{(RR_2[EHS]-RR_1[EHS])}$

base on two consecutive *RR* packets (RR_1 and RR_2) and the traveling time from RR_1 to RR_2.
4. Compute statistics for average streaming rate (*SR*).
5. Output (*SR*, *DR*).

※1: *RR*(Receive Report) is conveyed in existing RTCP packets.

Algorithm_Opt※1

Input Candidate_list_3
1.For i=1 to m※2
 [1] Get ith path information form server,(include N_i, $P_{s,i}$, $p_{s,i}$, min(b_k) in $P_{s,i}$)
 [2] Compute the streaming bitrate r_i and distortion rate p_i of ith path※3.
2 End for.
3.Initial $J_m(\pi)=[J(\pi_1),J(\pi_2),.., J(\pi_m)]$, $\pi_1=[P_1]$, $\pi_2=[P_1, P_2]$,..,$\pi_m=[P_1,..,P_m]$, arrange the network paths is ascending order of their p_i
4.For i = 1 to m do
 [1] If [First Terminated Condition] is hold then break;
 [2] Compute $D(\pi_i)$,$R(\pi_i)$
 [3] If [Second Terminated Condition] is hold then break;
 [4] Compute $J(\pi_i)$
5.End for
6.Comput $J^*(\pi)$= arg $\min_\pi J_m(\pi)$
7.Output the optimized parent node set：$J^*(\pi)$

※1: the time complexity of Algorithm_Opt is O(N)
※2: m equal to the number of Candidate_list_3
※3: ith path is the disjoint path from server to Node_A through candidate node N_i

3 Optimized Parents Selection with R-D Algorithm

An optimized parent selection algorithm is described to ensure that Node A selects the most appropriate candidate nodes (such that stream paths have minimal end-to-end distortion scenarios based on a receiver-driven P2P multipath network. The related mathematical model and method of the algorithm is described below.

Step 1: Identify the method of quantizing end-to-end distortion, in terms of [Issue 3].

Step 2: Establish the basic flow model for P2P multipath networking in order to analyze the relevant flow constraints.

Step 3: Achieve the multipath streaming characteristics based on the stream features (streaming rate and distortion rate) and the analysis results in Step 2.

Step 4: Link the information provided by Step 3 with the quantization process of Step 1, and build the optimized parent selection algorithm.

3.1 Distortion Model and Related Constraints

First, the end-to-end distortion of stream flow in the system is measured using this well-known formula [23]: $J=J_R+J_D$……………….. (1).

Here, J denotes the end-to-end distortion, and comprises the expected rate J_R and expected distortion J_D. The J_R depends on the average streaming rate R (also called encoding rate), and J_D is driven by $p(\text{RTT} > \tau)$ (where RTT is roundtrip time, and $p(\text{RTT} > \tau)$ denotes the average distortion rate that a packet transmitted at sender time T_s is not received at receiver by $T_s+\tau$, whether lost or simply delayed, and $\tau < \delta$).

A simple P2P multipath network M(N,L) is used to explain the required relevant parameter (see Fig. 2). N_i denotes a peer node, and $N_i \in N$. L_k is the network link between two adjacent nodes N_i and N_j, and $L_k \in L$. p_k represents the distortion rate of the stream flow F_k passing through L_k, and $p_k \in [0,1)$. $b'_{i(o)}$ indicates the uplink bandwidth of N_i ; $b'_{i(i)}$ is the downlink bandwidth of N_i. $P_{i,j}$ denotes the stream path from N_i to N_j (such as $P_{1,5}$). Finally, $r_{i,j}$ represents the streaming rate of $P_{i,j}$.

The relevant constraints in the P2P multipath network are described below.

[Constraint 1: End-to-End Flow Constraints] The streaming rate $r_{i,j}$ of direct connection between two adjacent nodes N_i and N_j is not greater then the minimum value between the uplink bandwidth of N_i and the downlink bandwidth of N_j , such that $r_{i,j} \le \min(b'_{i(o)}, b'_{j(i)})$.

[Constraint 2: Downlink Flow Constraints] If node N_i has many flow resources with stream paths between N_i and the resources, then the sum of the streaming rate passing through all the paths is no larger than the downlink bandwidth of the node N_i, such that $\forall P_{j,i} \in M, \sum_j r_{j,i} \le b'_{i(i)}$.

[Constraint 3: Uplink Flow Constraints] If a node N_i has many flow receivers with stream paths, then the sum of the streaming rate passing through all the paths is no greater than the uplink bandwidth of N_i, such that $\forall P_{i,j} \in M, \sum_j r_{i,j} \le b'_{i(o)}$.

[Constraint 4: Flow Conservation Constraints] If flow F_k passes through node N_i, then the streaming rate $r^k_{i(i)}$ of F_k into N_i is equal to the streaming rate $r^k_{i(o)}$ of F_k leaving N_i: $r^k_{i(i)} = r^k_{i(o)}$, and $\sum_{F_k} r^k_{i(i)} = \sum_{F_k} r^k_{i(o)}$.

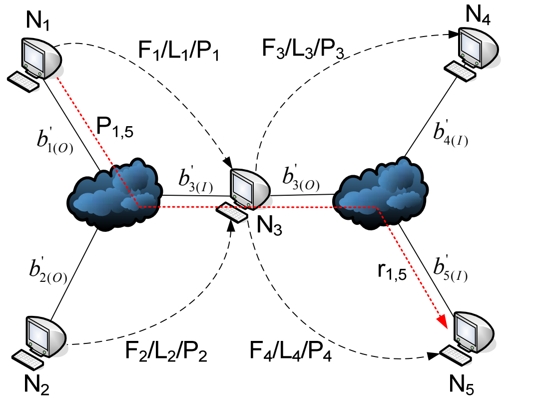
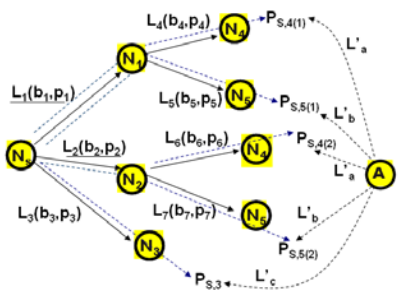


Fig.2 Diagram of a Basic P2P Multipath Network

3.2 Optimized Method and Related Lemmas

The system adopts the parameters of end-to-end distortion in P2P multipath network derived in the third step for candidate selection [13][14]. Thus, if the system can calculate the J_R and J_D of stream flows from the server that pass through candidate nodes to Note A, then it can evaluate the total end-to-end distortion J through formula(1). Every the Scenario of Fig. 1 can be transformed into the P2P multipath network diagram of Fig. 3, the notation of Fig. 3 is explained as follows.



Node ID	In (degree)	Out (degree)
N_s	-	3
N_1	2	2
N_2	2	2
N_3	2	1
N_4	2	2
N_5	2	2
A	2	2

Fig.3 Operation Scenario of a P2P Multipath Network

1. N_s denotes the server, and A denotes Node A.
2. The degree table on the right hand side of Fig. 3, based on [Constraint 3], shows the restrictions of the uplink and the downlink numbers of all user nodes.
3. The b_k of L_k between adjacent nodes N_i and N_j replaces $\min(b'_{i(o)}, b'_{j(i)})$. Define $P_{s,i}$ as the stream path from N_s to N_i , and define $p_{s,i}$ as the distortion rate of $P_{s,i}$. Define $r_{s,i}$ as the streaming rate of $P_{s,i}$ (note that if more than one disjoint stream path is found from N_s to N_i , these disjoint paths are indicated as $P_{s,i(k)}$, by analogy with $p_{s,i(k)}$ and $r_{s,i(k)}$)
4. All stream paths on the P2P multipath network are marked. Link L_1 is shared by paths $P_{S,4(1)}$ and $P_{S,5(1)}$, and L_2 is shared by $P_{S,4(2)}$ and $P_{S,5(2)}$, These shared links on different paths are called bottleneck links. The candidate nodes (N_3, N_4, N_5) for Node A are also marked, and the possible links are given by $\{L'_a, L'_b, L'_c\}$ (These links are adopted to estimate the end-to-end distortion J).

The quantization procedures for the end-to-end distortion are followed to obtain all $r_{s,i}$ and $p_{s,i}$, and thus obtain the following deduction based on the multipath characteristic and the above constraints.

[Lemma 1: Server Flow Budget] The total streaming bandwidths of direct-link from N_s to adjacent nodes N_i is no larger than the uplink bandwidths of N_s such that $b'_{s(o)} \ge \sum_i r_{s,i}$.

[Proof] Since the server is regarded as a specific node with no downlink bandwidth, ICP can estimate the uplink bandwidth of N_s in the network center by [Constraint 3]. This bandwidth is no less than the streaming rate obtained by clients linked directly to servers.

[Lemma 2: Server-to-end Flow Rate] In a P2P Multipath network, each streaming rate of the disjoint path from N_s to N_i is no greater than the minimal network bandwidth of all links in the path, such that: $r_{s,i} \le \min_{L_k \in P_{s,i}} \{b_k\}$.

[Proof] According to [Constraint 1] and [Constraint 4], any flow F_k passes through adjacent nodes N_i and N_j with $r^k_{i,j} = r^k_{i(i)} = r^k_{j(o)} \le \min(b'_{i(o)}, b'_{j(i)})$. Since $P_{s,i}$ is consists of the links connecting continuous adjacent nodes from N_s to N_i, the minimal b_k of all links can be obtained by multiple comparison. The streaming rate $r_{s,i}$ is computed from this minimal b_k.

[Lemma 3: Server-to-End Distortion Rate] The distortion rate $p_{s,i}$ of path $P_{s,i}$ in a P2P multipath network is written as $p_{s,i} = 1 - \prod_{L_k \in P_{s,i}} (1 - p_k)$.

[Proof] The distortion rate in the previous operation scenario is not affected by the streaming rate, and is derived independently for each link. Therefore, p_k of each L_k is not influenced by other links. Hence, get the total distortion rate $p_{s,i}$ is calculated by deriving the value (1- p_k) of each link session.

The computation formula of $r_{s,i}$ and $p_{s,i}$ can be confirmed by applying [Lemma 2] and [Lemma 3] [22][24][25]. The Langrangian formulation and policy π is adopted to quantize (1), as:

$J_m(\pi)$=($J(\pi_1)$, $J(\pi_2)$,…, $J(\pi_m)$)………….(2), and
$J(\pi_i)=\lambda_1[R(\pi_i)]^{\eta}+ D(\pi_i)$…………………(3)

Amog $R(\pi_i) = \sum_{j=1}^{i} r_{s,j}$, $D(\pi_i)= \lambda_2 \cdot \sum_{j=1}^{i} \frac{p_{s,j} \cdot r_{s,j}}{r_{s,j}}$ … (4)

In this work, policy π consists of a set of vectors $\{\pi_1,.., \pi_m\}$ as $\pi_1=\{P_{s,1}\},\ldots,\pi_m=\{P_{s,1},.., P_{s,m}\}$, and m is the number of all nodes in candidate_list_2. π_i is the paths set from N_s to Node A through the candidate nodes. Thus, λ_1 and λ_2 are positive Langrangian multipliers and $\eta \in [-1,0]$. The system generates the distortion metric $J_m(\pi)$ based on two factors, namely the restrictions imposed by the operation scenario, and the most suitable policy π^*. The system generates the distortion metric $J_m(\pi)$ by running Algorithm_Opt to calculate nodes in Candidate_list_2 (according to formula(2)). The close-to-optimal distortion J^* is thus obtained from the minimum argument of $J_m(\pi)$:

$$J^* = \arg\min_{\pi} J_m(\pi) = \arg\min_{\pi} (J(\pi_1),\ldots, J(\pi_m)) \ldots\ldots(5)$$

Formulae (3) and (4) reveal that the ordering approach of policy π influences the result of formula (5). Therefore, experiments were performed to find an ordering method of policy π^* that yields J^*.

Experiment A: A node was connected to two parent nodes (denoted as N_3, N_1 and N_2 of Fig 2), where N_1 and N_2 separately transmit stream flows F_1 and F_2 to N_3, p_1 and p_2 are fixed and $p_1 < p_2$.

Based on [Constraint 2], $b'_3 = 1M$ and $r_{1,3} + r_{2,3} = b'_3$ were set so that $r_{2,3} = b'_3 - r_{1,3}$. The value of $r_{1,3}$ was raised gradually from 0 bps to 1 Mbps to observe the distortion MSE (mean-square-error) of N_3. Figure 4 shows the experimental results. The transmission distortion gradually decreased as $r_{1,3}$ increased (and $r_{2,3}$ decreased), and was lowest when $r_{1,3} = b'_3, r_{2,3} = 0$. Thus, if a node has more than one source nodes, then it has minimal distortion when all of its downlink bandwidths are assigned to the receiver node with the lowest distortion rate.

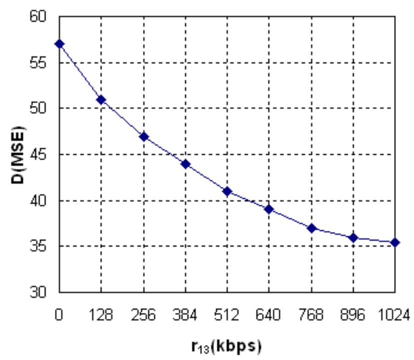


Fig. 4 Experiment for Measuring End-to-End Distortion

Experiment B: A node was connected to two child nodes (see N_3, N_4 and N_5 of Figure. 2; N_4 and N_5 are child nodes of N_3); N_3 transmitted stream flows F_3 and F_4 to N_4 and N_5; p_3 and p_4 were fixed, and $p_3 < p_4$. According to [Constraint 3], $b'_4 = 1M$ and $b'_4 = r_{3,4} + r_{3,5}$ were set such that $r_{3,5} = b'_4 - r_{3,4}$. The experimental results produced the same conclusion as those of experiment A. Thus, if a node has more than one receiving nodes, then its distortion is optimal when it assigns its uplink bandwidths to the receiver node with the lowest distortion rate.

The path arrangement order for policy π can be determined from these experimental results as ascending order for the distortion rate of all paths. Still, three issues need to be solved to obtain the optimal J^* in the proposed algorithm.

1. Given that the sequence of $P_{s,i}$ in policy π is in ascending order of the distortion rate, then the streaming rates of $P_{s,i}$ forming solution J^* need to be determined.
2. The streaming rate of the bottleneck link to all paths $P_{s,i}$ allocated by the system needs to be considered.
3. The termination conditions of the algorithm must be identified.

The first issue is deduced in terms of the influence of $J(\pi_i)$ on the variance of $r_{s,i}$. Thus, formula (4) is transformed into (3). The partial differential form of $J(\pi_i)$ is then taken, resulting in the following Formula (6):

$$\frac{\partial J(\pi_i)}{\partial r_{s,i}} = \lambda_1 \eta \left(\sum_i r_{s,i}\right)^{\eta-1} + \lambda_2 \frac{\sum_j r_{s,j}(p_{s,i} - p_{s,j})}{\left(\sum_i r_{s,i}\right)^2} \ldots.(6)$$

According to this formula, $J(\pi_i)$ decreases when the value of formula (6) is negative, while $J(\pi_i)$ is increased when the value of the formula (6) is positive. Additionally, the parametric properties of formulae (3) and (4) demonstrate that formula (6) is always negative if i=1. Thus, disregarding the streaming rate $r_{s,1} \in (0, \min_{L_k \in P_{s,1}} \{b_k\})$ based on [Lemma 2], the path $P_{s,1}$ with the minimal distortion rate is always part of J^* (which is why Algorithm_2[3] must keep a stream path with the minimal distortion rate). To obtain the value of the streaming rate for other paths that may form part of J^*, formula (6) = 0 is set in order to obtain the extreme $r^*_{s,i}$ of $r_{s,i}$:

$$r^*_{s,i} = \left[\frac{\lambda_2}{\lambda_1 \eta}(p_{s,i} - p_{s,j})\sum_j r_{s,j}\right]^{\frac{1}{1+\eta}} - \sum_j r_{s,j} \ldots\ldots\ldots(7)$$

According to formula (7), streaming rate $r_{s,i} = 0$ for $P_{s,i}(2 \le i \le m)_i$. The distortion of $J(\pi_i)$ increases when $r_{s,i} < r^*_{s,i}$, and decreases when $r_{s,i} > r^*_{s,i}$. Therefore, a possible component of J^* is

$r_{s,i} = \min_{L_k \in P_{s,i}} \{b_k\}$ when $r^*_{s,i} < \min_{L_k \in P_{s,i}} \{b_k\}$. Consequently, for all $J(\pi_i)$ $(2 \le i \le m)$, the solution of J^* may include $r_{s,i} = 0$ and $r_{s,i} = \min_{L_k \in P_{s,i}} \{b_k\}$.

Figure 2 illustrates the second problem. A "bottleneck link" can be defined as a link where the end nodes of the path have more than one resource node or receiving node. Hence, based on [Constraint 2], [Constraint 3] and [Constraint 4], the paths sharing the same bottleneck link are separated into fully independent paths. The bandwidth of the bottleneck link is allocated to these disjoint paths, according to the conclusion of the first problem. Therefore, the distributed principle can be inferred as follows:

[Lemma 4: Bottleneck-link Bandwidth Sharing] In a P2P multipath network, if one bottleneck link is shared by many stream paths, then it allocates its bandwidth in a greedy way, beginning with the path $P_{s,i}$ with the lowest distortion rate, and sets the streaming rate according to $\min_{L_k \in P_{s,i}} \{b_k\}$ (the last one $P_{s,j}$, the allocated streaming rate may be less than $\min_{L_k \in P_{s,j}} \{b_k\}$).

The termination condition of the algorithm is now considered. First, according to [Issue 1] and [Lemma 4], Node A can choose from numbers $n=min(m,degree_{in}(1))$ in candidate_list_3, indicating the First Termination Condition (Judgment reference for Algorithm_Opt 4[1]). The distortion resulting from N_i affiliating with a new end-to-end stream path may rise if $r_{s,i} < r^*_{s,i}$, according to formula (4) and answers from the first and second problems. In summary, not all candidate nodes necessarily be chosen, and the first termination condition is as follows (combining Eqs. (5) and (6)):

$$\begin{cases} \dfrac{\partial J_m(\pi)}{\partial r_{s,i}} \ge 0, & r_{s,i-1} = \min\limits_{L_k \in P_{s,i-1}} \{b_k\}, r_{s,i} = \min\limits_{L_k \in P_{s,i}} \{b_k\} \\ \dfrac{\partial J_m(\pi)}{\partial r_{s,i}} \le 0, & r_{s,i-1} = \min\limits_{L_k \in P_{s,i-1}} \{b_k\}, r_{s,i} = 0 \end{cases}$$

Therefore, the second terminated condition is as follows (Judgment reference for Algorithm_Opt 4[3]):

(Condition-2A): $D(\pi_i) \le \dfrac{\lambda_1 \eta}{\lambda_2} \cdot [R(\pi_i)]^\eta + p_{s,i}$,

$$r_{s,i-1} = \min_{L_k \in P_{s,i-1}} \{b_k\}, r_{s,i} = \min_{L_k \in P_{s,i}} \{b_k\}$$

(Condition-2B): $D(\pi_i) \ge \dfrac{\lambda_1 \eta}{\lambda_2} \cdot [R(\pi_i)]^\eta + p_{s,i}$,

$$r_{s,i-1} = \min_{L_k \in P_{s,i-1}} \{b_k\}, r_{s,i} = 0$$

Thus, in a P2P live stream network, the calculation of the end-to-end distortion for $J_m(\pi)$ terminates the computation when either the First Termination Condition or the Second Termination Condition occurs.

In summary, Algorithm_Opt based on the lemmas in this chapter is shown after suspending the calculation of the end-to-end distortion. The optimized solution set J^* is derived by computing the optimal answer of $J_m(\pi)$.

4 Simulation Results

This chapter describes the simulation results obtained with the described operation scenario and algorithms. The P2P stream network was constructed on NS2 and MyEvalvid (relevant parameters in Table 3) [26][27]. The network comprised 20 nodes (with the first node labeled N_s). Node information was recorded in a 20×20×4 matrix M as $M(\text{degree}_{in}(N_i), \text{degree}_{out}(N_i), p_{i,j}, b_{i,j})$ containing the degree$_{in}$, degree$_{out}$ of N_i, and $b_{i,j}$, $p_{i,j}$ of the direct-link value with N_j. The following three network scenarios were simulated.

Scenario-1) Wired network pattern: links between nodes have high bandwidth and low distortion rate.

Scenario-2) Wireless network pattern: links between nodes have low bandwidth and high distortion rate.

Scenario-3) Hybrid network pattern: a hybrid of above two patterns, where N_s is connected to a wired network, and clients can access streams via a wired or wireless link.

Table 3: Parameters for Simulation Scenarios

	p_i-max	p_i-min	b_i-max	b_i-min
Simulation-1	0.03	0.01	2M bps	1 Mbps
Simulation-2	0.08	0.06	512 kbps	128 kpbs
Simulation-3	0.08	0.01	2M bps	128 kpbs
degree$_{in/out}$=[1,4], δ=200ms,τ=100ms,θ=[2.00,4.00]sec				
η=-0.87,λ_1=1.8x10^5,λ_2=1624,				

The distortion simulations were performed according to these three patterns (total 18 simulation networks). With the $b_{i,j}$, $p_{i,j}$ values of each of the twenty nodes in M assigned from parameter's range in Table 3 according to the following algorithms. The values of N_i of matrix M gradually affiliate system in time interval θ (with α_i as the path parameter, and S=min(3,degree$_{in}$(N_i))).

1.A_{DR} : a single-path selection algorithm with distortion rate given by $\alpha_i[1-\Pi_i(1-p_i)]$.

2.A_{DR3}: an S-path selection algorithm with distortion rate measured as $\alpha_i[1-\Pi_i(1-p_i)]$, using the maximum available value of S.
3.A_{GP}: a single-best-path selection algorithm with good-put value given by $\alpha_i b_i p_i$.
4.A_{GP3}: an S-path selection algorithm with good-put value measured as $\alpha_i b_i p_i$.
5.A_{MP}: a maximum-paths algorithm, using the maximum available degree$_{in}$ number of N_i .

In the NS2 network simulation scenario, the network maximum transmission unit (MTU) was set to 1000 bytes worth of video data. The foreman_cif sequence was joined with itself to form 2700-frame video stream encoded at 30 frames per second. Each GOP (Group of Pictures) consisted of 9 frames (pictures). Each newly affiliated node passes through the paths chosen by those six algorithms, and gains the packets from N_s following an FCFS scheduling.

The three network scenarios were each simulated 100 times. The PSNR (Peak Signal-to-Noise Ratio) between the original and decoded sequences was calculated, and the average total end-to-end distortion was then computed. Figures 5, 6 and 7 present the experimental results. The proposed algorithm had the highest average efficiency among the six algorithms tested. The experimental results are summarized as follows:

1. In the Scenario-1 simulation, calculated distortion of A_{MF} was closest to A_{OPT}. Clearly, a new node in an environment with a lower distortion rate and higher streaming rate can obtain a better stream quality by using more alternative paths to transmit stream flows, thus reducing the end-to-end distortion.
2. In the Scenario-2 simulation, the distortion calculation result of A_{DR} compared to others is closer to A_{OPT}, in contrast to Scenario-1. A new node in an environment with a higher distortion rate and lower streaming rate it cannot decrease the distortion effect by using many transmission paths. In this case, the closest to optimal streaming quality is obtained by streaming media only through the path with the lowest distortion rate.
3. The simulation Scenario-3, which combines properties of both Scenario-1 and Scenario-2, confirmed the simulation results of both those scenarios. Algorithm A_{DR} achieved less total distortion than A_{GP} algorithm in choosing candidate nodes.

To compare simulation results with actual execution, experiments were performed with A_{OPT}, A_{MF} and A_{DR} (simulation 1, Node A pattern). Figure 8 shows the experimental result. The result sequences of the simulated and actual distortion for each algorithm were similar.

Next, 18 simulation networks were constructed by six algorithms randomly removes 5 nodes excluding N_s. The child nodes were required to look for other parent and generate connected paths under each of the six algorithms. Each simulation was performed 50 times, and the average distortion value was obtained. Figures 9, 10 and 11 illustrate the experimental results. The results of these simulations were similar to those of the original simulations.

These simulation results demonstrate that the user node can reduce overall network distortion by selecting paths with high streaming rates and low distortion rates for media transmission under various P2P multipath network scenarios.

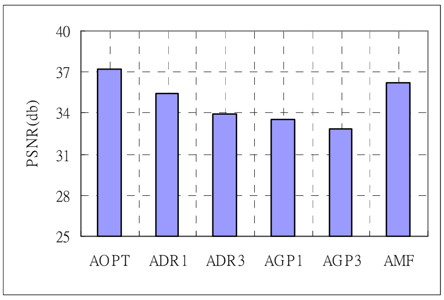


Fig.5 Distortion Comparison for Scenario-1 (Type: NodeA)

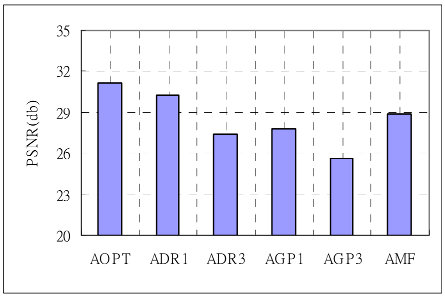


Fig.6 Distortion Comparison for Scenario-2 (Type: NodeA)

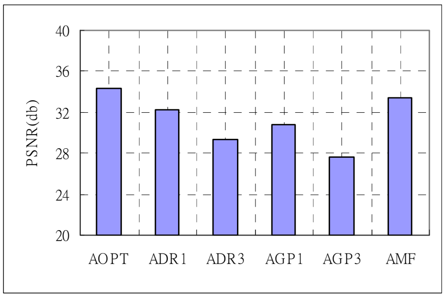


Fig.7 Distortion Comparison for Scenario-3(Type: NodeA)

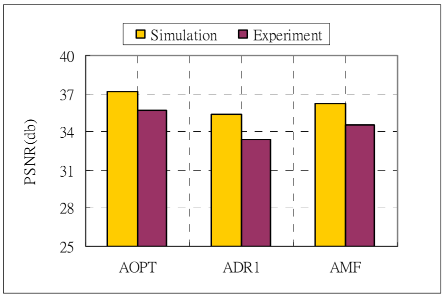


Fig8. Distortion Comparison for Simulation with Experiment.

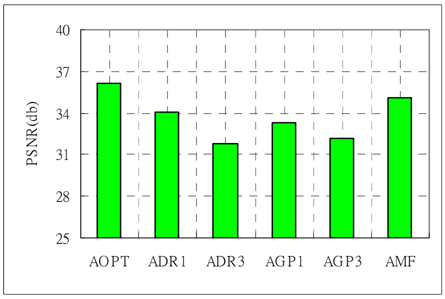


Fig.9 Distortion Comparison for Scenario-1 (Type: Node B)

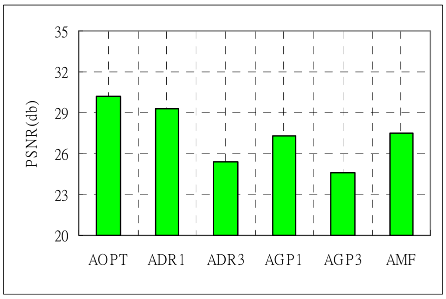


Fig.10 Distortion Comparison for Scenario-2 (Type: Node B)

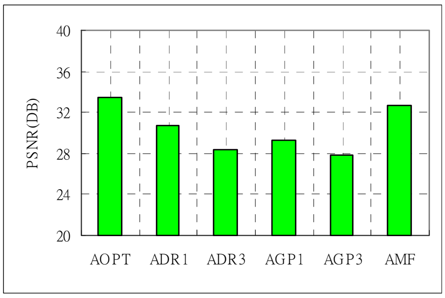


Fig.11 Distortion Comparison for Scenario-3 (Type: Node B)

5 Conclusion

Owing to the shared stream flows between front ends, P2P live streaming is affected by bandwidth limitation and the client computer environment. In addition to summarizing stream quality-related issues and analyzing in depth the end-to-end distortion constraints in the operation scenario, this work proposes a receiver-driven dynamic node join algorithm for a P2P multipath network. Simulation results indicate that the proposed algorithm performs better than others under various network circumstances. The proposed distributed structure and algorithm can decrease the computational loading of servers and improve the overall streaming quality.

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