Maintaining Consistency in Distributed Network Games

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Abstract— There are basically two approaches, conservative and optimistic, to maintain consistency in distributed network games. In the former, players may experience network latency, depending on packet transfer delay, caused by the send-and-wait frame and acknowledgement packets. In the latter approaches, the processes do not wait for other players' packets and advance to their own frames, hence no network latency. However, when inconsistency happens the processes must roll back. These can cause irritation and confusion to players. Overall, the optimistic approaches may not be suitable for networked games. To overcome the network latency problem in the conservative approaches, this paper introduces a network system which can reduce network latency and bandwidth by utilizing packet-relay and shortest path algorithms. Furthermore, game efficiency comparison between lock-step and bucket-synchronization algorithms on the proposed network system is presented in this paper.

Keywords— consistency maintenance, distributed games, low-latency, peer-to-peer network.

I. INTRODUCTION

Multiplayer Online Games (MOG) prefer Client/Server (C/S) network architecture to Peer-to-Peer (P2P) because of its advantages such as simplicity of consistency maintenance, better security, authentication, and easy billing system. However, C/S architecture can cause network latency and server(s) can become network bottleneck [1]. To solve the bottleneck problem, server clustering methods can be used, however these may not be cost effective.

Other types of games use P2P network architecture but the total number of players in one game session is limited because of network bandwidth problems. In addition, consistency maintenance problems must be solved in P2P architecture.

In C/S structure, clients send packets which consist of object states or user commands to the server. Subsequently the server determines the validity of the packets and sends back the result to the client. The states of all objects in the game are kept in the server side, so there is no or less inconsistency problem compared with the P2P structure. On the other hand, each node manages its own object states in the P2P structure so, inconsistency can occur in case of network delay.

As mentioned above, C/S structure can cause network latency because of the two-way packet transfer which is from Client to Server and then from Server to Client again. So, if T is the network latency between Server and Client then $2T$ is required for communication. However, only $1T$ is necessary in P2P structure because movement validations are made in each peer.

If P2P uses unicast and unstructured overlay then each node sends the same packets to all other peers and this will cause network bandwidth problems. This paper examines tree-based P2P network system which helps to resolve the P2P network latency and bandwidth problems.

In the next section, related work in consistency maintenance area is briefly reviewed. In section 3, basic architecture of Tree-Based P2P system is introduced. Experiment related facts and result are shown in section 4. Finally, conclusions and future work are presented in section 5.

II. RELATED WORK

The Lock-Step algorithm [2] is one of the simplest solutions for consistency maintenance in the P2P structure. Each peer waits for other peers' packets of current frame, makes its next move, sends packets and waits again. The drawback of this approach is that it can cause slowdown for game play if network latency is slower than the frame rate. For example, if the game's FPS (Frame per Second) is 25 then each frame takes about 40ms

to load. In case the network latency is longer than 40ms then players will have to wait until they get other players' packets.

Frequent State Regeneration [8] approach eliminates the slowdown-time of the lock-step algorithm by frequently transmitting the status of objects in game sessions. Generally, an unreliable protocol such as UDP is used with this approach to alleviate the overhead of using a reliable protocol such as TCP. However, sending the status of objects frequently to all players requires high bandwidth and this requirement limits the maximum number of players for network games.

Bucket Synchronization algorithm [5] and Local Lag [3] introduce artificial delay so as to synchronize its own frame with other nodes' frame by utilizing imperfect human visual perception ability. This approach is the analogous to the buffering method of streaming audio. Even though the lock-step time is extended, it still requires inconsistency resolution algorithms because network latency is longer than the extended lock-step time. The approaches used in [3] and [5] also require high bandwidth due to frequent state transmission they had adopted in their solutions.

Dead Reckoning [4] algorithms interpolate and/or extrapolate missing and/or incoming information to reduce bandwidth requirement and latency. Local Perception Filter [9] approach also utilizes the limitation of human eye perception by altering the speed of objects in networking games for hiding network latency. Time Warp [6] algorithm has been introduced to solve inconsistency and/or network latency problems by adapting optimistic approaches. However, the overhead of rollover process is unavoidable.

III. TREE-BASED P2P NETWORK SYSTEM

To maintain fair games for all players in a game session, the game speed is synchronized with the slowest process and network latency node. There are two variables: process speed and network latency. The first variable, process speed, is easy to test before game sessions start and it is not changed dramatically during game sessions. Therefore, process speed problem can be solved by a pre-test to ascertain whether players' computers can process adequate frame rate during game sessions.

However, network latency is hard to be predicted correctly and it is also not consistent during game sessions. Therefore, a tree-based P2P system is proposed and explained in the following sections.

A. Graph to tree conversion

Existing P2P games use a graph structure to format network topology in which each node connects to every other nodes. As explained before, this can cause bandwidth problem if unicast is used. Also, all nodes are synchronized with the slowest node, so this structure cannot take advantage of fast connections between other nodes.

On the other hand, if network topology is structured by tree-based architecture then nodes will be hierarchical and fast connection nodes will be grouped together. Figure 1 shows the graph structure and network latency values between nodes.

Fig. 1. Graph structure for network topology and network latency values between nodes.

Figure 2 displays the final result after removing high network latency links from the graph structure. As shown in figure 3, node A creates its own tree structure from the graph structure.

Fig. 2. Finding alternative paths for high network latency nodes.

Fig. 3. Conversion from graph structure to tree structure for node A.

As it can be seen in figure 1, the longest path from node A to other nodes is the link between A and D which takes 20 ms. Therefore, we create the A – C – E path because the total time from node A to E is 10 ms, which is shorter than 20 ms (A to D).

Furthermore, the new path reduces network latency by 20 ms since the latency from A to E is 30 ms if direct link is used.

The most important aspect is that this conversion can increase the overall game speed by reducing the network latency of the slowest link in the network topology. Again, as it can be seen from figure 1, the B-D connection is the slowest link and the B-A-D link can reduce network latency by 50ms. For graph to tree conversion, one of the most well known shortest path finding algorithm, Dijkstra algorithm [7], is used.

B. Relay Method

Nodes in this tree-based P2P system may need to relay packets to its child nodes because the sender nodes may not have direct connection to destination nodes. To create the relay process, the sender node becomes a root node and transmits packets to its own child nodes which are one level below nodes only. The sender node includes the identification numbers of destination nodes in its packet header and when its child nodes receive the packet they remove their id from the packet header and relay this packet to their own child nodes.

Fig. 4. Tree Structures for each node (Node A, B, and C only)

Figure 4 shows the tree structures for three nodes. When node A sends a packet to other nodes, it includes the ids of destination nodes. To send a packet from A to E, the destination node list will be [C, E]. Because node B and D do not have child nodes, their destination node lists will be [B] and [D] respectively. When node C receives the packet from node A, it removes itself from the destination node list and relays the packet to node E only (because node A is not in the destination node list). The following pseudo codes show the relay algorithm in detail.

C. Retransmission

Retransmission is unavoidable when packet drop or corruption happens, especially when frequent packet regeneration scheme [8] is not used. The decision for retransmissions is based on ACK timeout and ACK numbers from opponent nodes. The retransmission procedure is exactly the same as sending packets at the first time except the retransmission will occur at the parent node of the node that requests the missing packets.

D. Acknowledgement

This tree based P2P system can prevent ACK implosion problems because, each node manages its own child/ children. When a packet is sent, the destination node sends ACK to its origin node immediately. The sender retransmits the packet if $(ACK_timeout_of_destination_node < Current_Waiting_Time_For_ACK)$ is true. The ACK timeout is based on ping time between the two nodes.

```

/*
Pre-condition:
    nodeNum: A
    origin node list: originNodeList
    destination node list: destNodeList
Post-condition:
    packets are relayed to immediate child nodes
*/

// Frame Packet Relay Algorithm
relayFramePacket ()
    tempDestNodeList = [ ];
    add A into originNodeList;
    delete A from destinationNodeList;
    for each node in destinationNodeList C
        recursively visit each node in
        destinationNodeList
            if each node is in destinationNodeList
                add the node into tempDestNodeList
            end if
        send a packet with tempDestNodeList and
        originNodeList to C;
    end for
end relayFramePacket;

```

E. Simulator Architecture

The tree-based P2P network simulator is implemented in C++ with STL and consists of three main classes, namely, Player, Simulator and Statistics. The player class utilizes three data structure types, Queue for an input buffer, Priority Queue for a re-sending buffer, and Circular Array for a game buffer to store other players' packets, to re-send dropped packets, and to gather frame data respectively. Figure 5 shows the basic architecture of the simulator.

Fig. 5. Tree-based P2P Network Simulator Architecture

IV. PRELIMINARY EVALUATION

The tree-based and graph-based P2P networks are evaluated and their performances are compared in this section. An Intel Pentium 4 CPU 1.60GHz equipped computer with Microsoft windows XP operating system and 512MB RAM was used for experiments.

A. Experimental Data Set

The simulator initially generated a data set for eight players with randomly generated network latency between 5 ms and 100 ms.

TABLE 1
LATENCY VALUES (ms) BETWEEN PLAYERS

	0	1	2	3	4	5	6	7
0	0	26	58	76	10	46	11	60
1	26	0	64	52	37	58	36	28
2	58	64	0	15	48	77	35	54
3	76	52	15	0	18	15	21	24
4	10	37	8	18	0	27	77	25
5	46	58	77	15	27	0	76	9
6	11	36	35	21	77	76	0	70
7	60	28	54	24	25	9	70	0
Sum:	287	301	311	221	242	308	326	270
Avg.:	41	43	44.43	31.57	34.57	44	46.57	38.57

B. Comparison between graph-based and tree-based structure

Frame rate and average latency were recorded on four different occasions, which were created using two consistency maintenance algorithms (bucket synchronization and lockstep) and two network types namely, graph-based, and tree-based.

Figure 6 and Table 2 show the changes of frame rate according to drop rate in the four occasions. The frame rate dropped to 24.78 and 23.9 from 25 when drop rate was 5% and 10% respectively for a bucket and tree combination. However, for bucket and graph combination Table 2 shows that the frame rates became 20.3 and 18.13 with 5% and 10% drop rate respectively.

TABLE 2
FRAME RATE (FPS) vs. DROP RATE(%)

Drop Rate	Bucket + Tree	Bucket + Graph	Lockstep + Tree	Lockstep + Graph
0	25	25	12.52	12.51
1	25	23.62	12.08	9.32
2	25	22.37	11.57	8.38
5	24.78	20.3	10.77	7.07
10	23.9	18.13	9.42	5.95

Fig. 6. Frame Rate vs. Drop Rate

The graphs of the average packet propagation time on packet drop rate of the four combinations are shown in figure 7. As it can be seen in figure 7, the latency of the two graph-based approaches is similar and so is the latency of the two tree-based approaches. According to the table 3, the graph to tree conversion improved the network delay from 39.74 to 26.93 when the packet drop rate was 0% and the change rate was linear.

TABLE 3
LATENCY (ms) vs. DROP RATE (%)

Drop Rate	Bucket + Tree	Bucket + Graph	Lockstep + Tree	Lockstep + Graph
0	26.93	39.74	26.93	39.74
1	27.46	40.49	27.45	40.58
2	27.99	41.33	28.07	41.39
5	29.59	43.85	29.44	43.63
10	32.51	48.35	32.54	47.86

Fig. 7. Latency vs. Drop Rate

Figure 8, Table 4, and Table 5 show the maximum frame latency in each frame on two cases: graph-based and tree-based P2P networks. For both cases, the bucket synchronization algorithm is used. The average delayed frame rates for graph-based and tree-based approaches are 14.58% and 1.58% respectively.

Fig. 8. Max latency of each frame in the two approaches (5% drop rate, 120 ms playout delay and 40 ms frame interval).

TABLE 4
FREQUENCY OF DELAYED FRAME (GRAPH-BASED)

Player	No. Frames	Delayed Frames	Delay Rate %
0	1215	235	19.34
1	1217	174	14.3
2	1215	224	18.44
3	1215	124	10.21
4	1215	64	5.27
5	1214	232	19.11
6	1214	178	14.66
7	1214	186	15.32

Consistency algorithm: Bucket-synchronization

Network type: Graph

Frame interval: 40 ms

Average delay rate: 14.58 %

Packet drop rate: 5%

Playout delay: 120 ms

TABLE 5
FREQUENCY OF DELAYED FRAME (TREE-BASED)

Player	No. Frames	Delayed Frames	Delay Rate %
0	1485	0	0
1	1482	99	6.68
2	1483	4	0.27
3	1482	76	5.13
4	1483	2	0.13
5	1484	3	0.2
6	1485	2	0.13
7	1483	1	0.07

Consistency algorithm: Bucket-synchronization

Network type: Tree

Frame interval: 40 ms

Average delay rate: 1.58 %

Packet drop rate: 5%

Playout delay: 120 ms

V. CONCLUSION

Network latency and bandwidth are important factors to the playability of network games. Packet drop rate is the most important factor which can cause network latency. In this paper, we investigated the effects of packet drop rate on two P2P approaches. We have evaluated the efficiency of the tree-based P2P approach by comparing its performances with that of the graph-based P2P approach. Two consistency maintenance algorithms, lockstep and bucket synchronization, were implemented to analyze the efficiency of the tree-based approach. Our experimental results showed that the tree-based approach with the bucket synchronization algorithm performed close to optimal frame rate, even with a 10% packet drop rate.

Therefore, the tree-based peer-to-peer network system with bucket synchronization algorithm is more appropriate for the Internet games, which suffer mainly from unpredictable network latency and packet drops. For further performance enhancements, the effect of the tree-based approach on network bandwidth under dynamic drop rate conditions will be investigated in future.

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