Real-time Information Querying over Peer-to-Peer Networks using Timestamps

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Abstract: Most P2P networks are used for file-sharing applications. These forms of applications mainly rely on keyword searching to locate file resources on the peers. Whilst this querying is suitable for many data-intensive applications, it is not suitable for applications where data changes over short periods of time, also known as time-critical applications. We investigate the use of timestamps on a peer's knowledge about an application to create queries so that other peers may reply with more up-to-date information to keep the peer's knowledge up-to-date. We propose means to synchronise peers to provide them with a shared, independent clock so that they utilize timestamps. To show that a peer's knowledge about a time-critical application affects the performance of other peers, we carried out experiments to show information propagation over a P2P network and use various metrics to evaluate our approach.

1 INTRODUCTION

Information propagation is the distribution of information between peers and is one of the major challenges in (pure) peer-to-peer (P2P) networks because there are no servers to direct messages among the peers. Therefore protocols have been developed to help facilitate this. Most of these protocols are suitable for data-intensive applications because of their ability to locate resources through the use of *keywords*. These protocols include *flooded request* and *document routing* (Taylor and Harrison, 2008) which have been used in commercial applications, such as Gnutella (Taylor and Harrison, 2008). While keyword-searching allows peers to retrieve resources themselves, the disadvantage of this is the peers are acting "selfishly"—they will not voluntarily contribute resources to assist other peers. Wu (2009) looks into how faster peers share their bandwidth with slower peers so that all peers complete the download of resources at the same time.

This research focus on *real-time applications* where it is important that each peer has a shared view of the global information. Instead of peers sharing files with each other, they will share information about a common, but independent, application with each other to keep each peer's perception of the application up-to-date. To evaluate the performance of the application over P2P networks, the applications themselves must reflect the performance of each peer in terms of how their knowledge of the application will affect other peers. Therefore, we will use *computer games* as the domain. Computer games have different types of data-intensive and time-critical properties and the performance of a game is dependent on the abilities of each player (peer) within the game. However this does not mean our proposed solution is limited to one domain. The games will be encoded as *rules*—when certain conditions are met, then an action takes place. The purpose of this is two-fold: the information requirements of the rule can be checked to make sure the rule is legal to fire, if not then the peer will have to perform other actions (most likely query other peers) to make the rule legal and most domains can be encoded as a set of rules. Our proposed solution is thus impartial to any rule-based domain.

Although we mainly mention *peers*, this is a synonym for *agents*. Generally speaking, a peer is only responsible for handling messages to and from others whereas agents can make decision for themselves within their environment as well as communicate with other agents. Although our primary focus is on P2P research, when dealing with applications, agents are required to evaluate the current situation of the application as well as neighbouring peers to make decisions on how to continue executing the application. This is especially important when running automated tasks like our experiment in Section 4. Therefore,

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when we mention *peer*, we don't necessarily mean just the messaging handled by a generic peer, but the inclusive body of the application, agent and peer working together to handle application execution, decision making and message handling.

To further explain the proposed research, this document has been laid out in the following sections; Section 2 covers related work in sharing knowledge over P2P networks; Section 3 looks into our proposed solution in how peers join a network and contribute information to other peers; Section 4 describes our experiment to show how knowledge accuracy affects the performance of peers; Section 5 looks into how we evaluated our experiment and its results and Section 6 concludes the document with how our current evaluation turned out with regards to our proposed solution and what we aim to accomplish in the future.

2 RELATED WORK

Since our chosen domain is computer games, we will cover existing work regarding games on P2P networks and how it differs from our work. Neumann (2007) provides a survey regarding the issues related to gaming and P2P, namely *game-state management*. Most games use the client/server architecture because the server acts as the manager for all events and states within a game. Without this manager, players would not be able to know the current status of the game environment. Current frameworks tackle this with the use of *interest management* (Bharambe et al., 2008; Fan et al., 2007) which works by making players be only interested in other players depending on their virtual distance. For example, if two players are interacting in the game, then they are both interested in sharing data with each other since they will see the results of the other player's actions. Other techniques similar to interest management; for example, *zoning* (partitioning a game world for close players to communicate within) has also been looked at with the use of frameworks (Glinka et al., 2007). The biggest issue with these kinds of frameworks is they are only useful for computer games and not for other domains. Although we are using games as our domain, they will only be used for testing our solutions and the solutions themselves will be adaptable to any domain.

For our research, we need up-to-date results so that each peer will have accurate knowledge for optimal contribution to the network. One of the common themes between interest management work and our research is the use of *database-related queries* (Castano et al., 2003; Nejdl et al., 2002) to retrieve data between peers. Whilst this is useful for updating a peer's own knowledge, there is no time limit on sending and receiving knowledge, just as long as the knowledge will eventually contribute to the community of peers. This is not suitable for us because time-critical application require information as soon as possible in order to be useful. Liu (2011) uses polymorphic queries to attempt to retrieve attributes from other peers if the queried peer does not contain all of the requested attributes. However, because this uses an algorithm to forward queries to other peers depending on its "quality", the queries will only be approximately answered and we need accurate answers.

Ensuring that each peer is synchronised with each other requires a form of *distributed timekeeping*. It is unreasonable to assume all distributed systems will run at the same speed and have the exact same time as each other so a relative approach is required. *Lamport logical clocks* (Lamport, 1978) allows events among distributed systems to be ordered between themselves. This is especially important for distributed information systems because the order of received messages will have an effect on the output – rearranging the order of events will typically produce different outcomes. Lamport clocks uses timestamps from sent and received messages to resynchronise its clock so that future messages from other sources will not arrive out-of-order. Another way to keep distributed systems synchronised is to use a common clock so that all systems will have the same time as each other, leading to accurate global timestamps. The *Network Time Protocol* (NTP) (Mills, 2003) uses servers with accurate clocks to provide systems with the current time. However, there are disadvantages in using NTP for synchronization: depending on the server the time may not be fully accurate and the time it takes for the time message to arrive at the requestor will affect the real time; this is even more so for distant requestors to the same server.

3 PROPOSED SOLUTION

In our solution, two major algorithms are used during a peer's lifetime in an application: *bootstrapping* and *query generation and sending*. This document only provides an overview of the algorithms used in our solution, but detailed explanations can be found in Gibson et al. (2012).

Bootstrapping only occurs once in a peer's lifetime to join a network, but query generation and sending occurs at every application (game) cycle. Other parts of a peer's lifetime have been omitted as these occur during the application cycle.

One main disadvantage of P2P networks is the

Algorithm 1: Bootstrap.

Input : $S = \langle address, port \rangle$, $speed$
Output: $P = \{p_1, p_2, ..., p_n\}$, $N' = \{n_0, n_1, ..., n_m\}$, $speed'$

```
1  connect(S)
2  send(S, speed)
3  receive*(S, ⟨speed', remainingTime, P, N⟩)
4  for n ∈ N do
5  |  send(n, PING)        // Gnutella PING-PONG
6  end
7  while remainingTime > 0 do
8  |  receive(A, msg)
9  |  let msg be of the form ⟨type, info⟩
10 |  if type = PONG then
11 |  |  N' ← N' ∪ {A}    // Gnutella PING-PONG
12 |  else if type = SPEED then
13 |  |  speed' ← info
14 |  end
15 end
16 if |N'| > 0 then
17 |  startGame(P, speed', N')
18 end
```

lack of an entry point for new peers to join an existing network. Most existing P2P applications tackle this using an entry-point node, typically called a "bootstrapping node" so that new peers can either directly join the bootstrapping node and form neighbourhoods from it, or download a list of peer addresses to directly connect to. The latter method is commonly used in BitTorrent with the use of a tracker and in Gnutella with the use of web caches (Taylor and Harrison, 2008). Because of the ease of using a bootstrapping node and a list of available peers, we have used these methods in our solution. This allows new peers to directly join a bootstrapping node which sends the peer a list of available peers to directly connect to.

Algorithm 1 (A1) explains the bootstrapping procedure; how a peer joins a network. The inputs are the bootstrapping node's address and port, S, and the peer's game playing speed, $speed$. The outputs are the peer's player attributes, P, the peer's list of connected neighbours (as well as their player details), N', and the game speed to play at, $speed'$. P allows others to identify this peer's player within the game and allowing this peer to update its own player attributes.

To generate queries to update a peer's (B) knowledge about the application, the knowledge has to be explicit. So a reasoner is able to infer what needs to be retrieved for B to continue participating. How the knowledge is explicitly stored and managed depends on the application domain. This applies to the reasoner as well; how it creates queries to update B's knowledge depends on how the knowledge is handled. For example, let's say the domain was a car racing game. Apart from knowing important information

Algorithm 2: Query Generation and Send.

Input : $N = \{n_1, n_2, ..., n_m\}$, $Q = \{q_0, q_1, ..., q_n\}$, $R = \{r_1, r_2, ..., r_p\}$, $S = \{s_1, s_2, ..., s_q\}$, $Threshold$
Output: $Q = \{q_0, q_1, ..., q_r\}$, $S' = \{s_0, s_1, ..., s_t\}$

```
1  Q' ← ∅
2  S' ← S
3  for s ∈ S do
4  |  let s be of the form ⟨v, t⟩
5  |  if v ∉ Q and v ∉ Q' and t ≥ Threshold then
6  |  |  Q' ← Q' ∪ {v}
7  |  |  S' ← S' \ {s}
8  |  end
9  end
10 for v ∈ Q' do
11 |  send(bestNeighbour(v, N), request(v))
12 end
13 Q ← Q ∪ Q'
```

about each players' location and position, knowing *when* this information was taken affects how each player plays the game. Therefore, being able to show the age of each piece of information allows the reasoner to generate update queries depending on how old the information is, hence the use of *timestamps*.

Algorithm 2 (A2) explains how queries are created based on the age of game variables. The inputs are B's set of connected neighbours (created from A1), N, a set of previously queried variables, Q, the variables used to control each player in the game, S, and a time limit to represent when a piece of information becomes out of date, $Threshold$. The outputs are an updated set of queries to ask each player, Q, in order to update B's information about the queried player(s) and an updated list of player variables to be used with the game rules in the current game cycle, S'.

4 EXPERIMENT

To evaluate our proposed research, we have devised an experiment to show how the accuracy of knowledge affects the performance of a peer which will have an affect on neighbouring peers. The test application is a simple racing game where players have to complete a certain number of laps around a circular track to win. To encourage competition, the players are able to use the shortest lane to complete a lap sooner, travel at various speeds and are allowed to overtake slower players. There are also penalties to consider as well; each player has a limited amount of fuel and is consumed quicker if the player is travelling fast. A pit stop is available for refuelling, but it is only available at one point along the track and requires time to fully refuel a player. If the player runs

out of fuel before the pit stop, the player loses. Players can overtake or independently move to outside lanes providing they do not crash into others. Whilst outside lanes are useful for overtaking, they have a longer length than inside lanes so it is not advantageous to remain on the outside for long periods of time. By forcing players to pick the best route whilst being conservative with fuel, the game will be competitive, strategic and fun. Figure 1 shows player A playing the racing game with seven opponents.

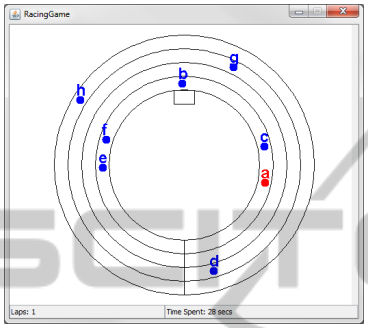


Figure 1: The racing game application running.

For our experiment, we have eight peers which will run their own copy of the game and be able to communicate with each other. Each peer will be able to play the game as a player with the capacity to win and play by the rules. The peers are based on the Rete algorithm with rules to control where the peer may move to depending on its condition and the locations of the opponents. They also perform random moves, such as change lanes and speed to simulate a human player and to encourage the peers to perform more update queries so that their knowledge base of opponents is kept up-to-date. For a simple racing game like this, more than eight players may be too much for an "enjoyable" experience, but the results will help us refine our proposed mechanism for larger-scale and more data-intensive applications.

In each configuration, each peer's perception of the game will have to be compared with the other peers' perceptions. This will allow us to use a convergence metric to see how close an opponent's perception of a player state is in relation to the player's actual state. For the racing game, the most important attributes to keep up-to-date are the player's location (in terms of lane and how far around the track) and speed since these determine how an opponent will react. There are also other attributes which are not as important, but will affect how the game is played as well; for example, the player's fuel to see if they require a pit stop and the number of laps to see if they have won. By seeing if an opponent's perception of a player's attributes is accurate over time, as well as vice versa, should lead to accurate gameplay by both parties. However, since queries are only directed to the closest virtual player, distant players may not have constant accurate perceptions of each other. This should not be a problem though because it is unlikely they will interact with each other due to the distance between themselves–this is related to interest management. Since this will have an effect during the comparison of perceptions, *weights* will have to be allocated to show that the difference of player states between distant players is not as important as the difference of player states between close or neighbouring players. As a game continues and players overtake others, the importance of perceptions between players will constantly change but should lead to accurate gameplay among each player's closest opponent.

5 EVALUATION

For our evaluation we ran four experiments to show how the "hops" of a message affects each peer's perception of its opponents. A hop refers to how many peers a message will be sent to before the message is classed as expired and therefore not to be forwarded any more. A hop is commonly referred to as the *time-to-live* (TTL) of a message. Since we are using eight peers in a ring topology, each experiment sets each message to hop one, two, three and four times respectively. This ensure that at least one experiment (four hops) will enable all peers to communicate with each other with no dropped messages. Since a message can travel in either direction from a peer, the furthest distance to travel to reach all peers is four hops because of three intermittent peers in each direction, ensuring that a message with four hops will reach any peer within the 8-peer ring topology.

To enable fine control over our experiments, we have created our own in-house P2P simulator called *P2P Tool*[1] which allows us to create peers with certain rule sets and custom topologies around structured or unstructured presets. It also allows us to manage how messages are directed among peers and how peers should deal with certain types of messages.

In order to show how affective our mechanism is, we use the metric of *divergence* to show how different a peer's perceived knowledge of another peer differs from the other peer's actual knowledge. Figure 2 shows how much a peer (in this case, D) diverges from opposing peers over game time. Whilst we only show peer D's perceptions of peers A, B, C, E, F, G and H, every peer will produce similar looking graphs

[1] https://github.com/msgibson/P2PTool

due to each peer being equal with each other in terms of relative neighbours and functionalities. In this document, only the experiments with one and three hops will be discussed; discussions on hops two and four as well as how our mechanism differs from a pure exhaustive search are available in (Gibson et al., 2012).

To calculate the divergence of a peer, we calculate the difference between the peer's knowledge of each opponent with the opponent's actual knowledge at each game tick. For each graph, the higher the divergence, the more different the perceived and actual values are, leading to inaccurate gameplay.

In Figure 2(a), each message only lasts one hop, meaning only the immediate neighbours of D (peers C and E) will receive messages. The graph shows that peers C and E mostly have a low divergence, meaning the perceived knowledge peer D has of C and E are close to C and E's actual knowledge respectively. However for the remaining peers (A, B, F, G and H) divergence is high because D is never able to communicate with them. Peers A, B, G and H appear to flatline around the 5000 game tick point because in all instances (peer D's perception and the actual peers controlling the players), the players seem to have "lost" (ran out of fuel) at the same time. The divergence is still high because the perceived and actual player positions will be at different locations around the track.

Figure 2(b) shows that since messages can arrive at more distant peers, the divergence among these peers will be smaller. For three hops, peers A and G can be reached. Since peer H is never in reach, it always has a high divergence. There are some spikes in divergence in the reachable peers. We believe this is caused when peer D tries to overtake the reachable peers in its copy of the game, but failing to complete the overtake. This may affect the peer's closest opponents, leading to fluctuating thresholds for the opponents and affecting queries being sent.

By looking at Figures 2(a) and 2(b), total divergence among the peers decreases as the number of hops increases. This should be obvious because as messages are able to reach more peers, information retrieved will be more accurate and hence lower divergence. To show how much hop count improves information accuracy, Figure 3 shows how peer D's convergence with all peers combined improves over time with increasing hop count and how all peers benefit from increased hop count for their convergences.

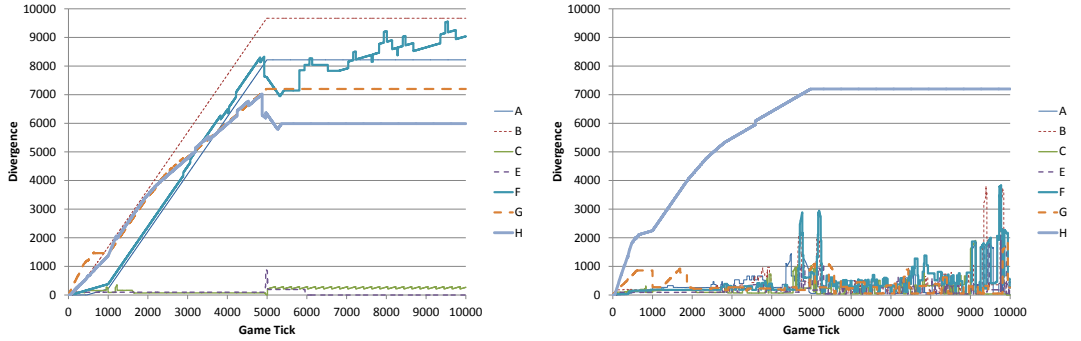
In Figure 3(a), the graph shows that as the number of hops increases per message, the divergence is generally lower at each point in game time. Each line represents the average of each opponent perceptions from each experiment. For hops one and two though, hop two's divergence spikes over hop one's divergence at some points. This is also present in hops three and four where hop three's divergence spikes over hop four's divergence at some points. These spikes are likely caused by the spikes seen in Figures 2(a) and 2(b), resulting in some errors being carried over. To smooth out the errors, we averaged each peer's total divergences (each peer's version of the graph in Figure 3(a)) and applied weighting to the closest players of each peer at each game tick to highlight divergences in the closest opponents are more important than divergences in distant players since closer opponents are in the player's interest set. This combination of peer divergences and weightings led to Figure 3(b) which clearly shows that as hop count increases for messages, all peers improve because of lower divergence, leading to more accurate application performance and gameplay.

6 CONCLUSIONS, DISCUSSION AND FUTURE WORK

In this paper, we have discussed an alternative approach to exchanging information over P2P networks through the use of timestamps. We have also showed how we approach this using rule-based applications (specifically, but not limited to, computer games) by evaluating the age of its knowledge base and generating queries to a peer who will be able to update the information. Finally, we showed and explained our experiment results to show how our approach performs in varying configurations. Using the experiment results will allow us to further refine our proposed approach for other types of applications, specifically data-intensive applications.

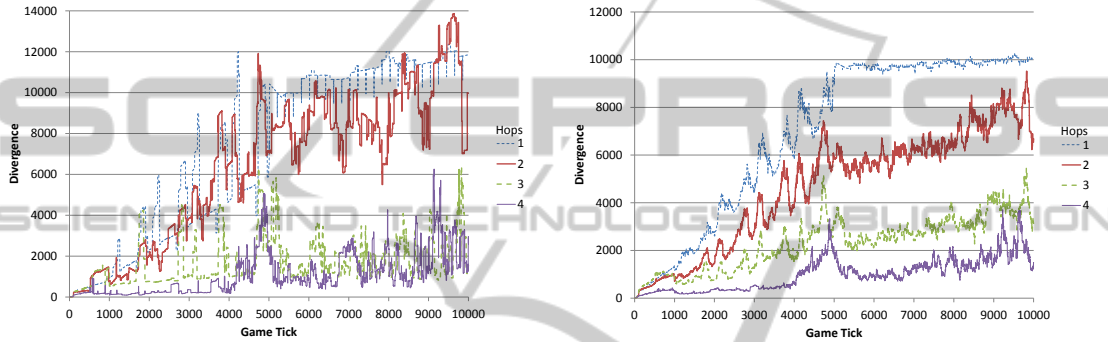
Although the results may be obvious in showing that as message hops increases, a peer's perception of other peers improves, it confirms that our mechanism of reducing queries based on certain times throughout an application's life leads to similar results compared with an exhaustive querying to all peers.

We will use the results to develop our research to focus on data-intensive applications as well as improve our simulator's performance to minimise divergence spikes. This will mean looking at other means of creating queries depending on the state of the player instead of just time. One area that will be focussed on more in the future is security. Whilst running our experiment, we assume that all peers are trustworthy and have no devious intentions. This is not a reasonable approach for real-world applications though. One area that should be focussed on is rogue messages. Peers may be able to "lie" by sending wrong information about itself or even other peers so



(a) 1 hop (b) 3 hops

Figure 2: Peer D's divergence with other peers over game time.



(a) Peer D's divergences over hops (b) All peers' divergences over hops

Figure 3: Comparison of divergences over hops.

that it can gain an advantage in a game. This can be prevented by comparing the new received information with a peer's own information to see if there is a significant difference between them. If there is a large difference, then it is likely the new information is false so it should be discarded. The new information could also be compared with neighbouring peers to see if they think the information is false.

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