Minimising Lag in Game Networking Models Without a Central Server

Implementation and Analysis of Client-Hosted and Peer-to-Peer
Networking Models in the Context of Games.

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Declaration

"I declare that this dissertation represents my own work except, where otherwise stated."

Acknowledgements

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Abstract

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Chapter 1: Introduction

Throughout this project, I will be exploring the different methods of providing a synchronised, multiplayer gaming experience on two or more computers on a network. I will be covering the networking basics of how two game clients running on seperate machines can communicate with each other as well as exploring the relevant details of how and why the networking systems in games are designed the way they are.

I will explore the existing methods of writing an online multiplayer game from scratch and aim to provide an implementation of a networking library for online games to communicate without a central server. I also aim to provide analysis of efficieny of different methods of achieving this goal.

1.1   Project Goals

When developing a multiplayer game the most important aspect of the codebase is likely to be the networking functionality and speed. In most games designed for two or more players interacting with each other or the environment, the whole experience can be ruined by slow or inefficient networking implementation. The most common way for games publishers/developers to address this, is to rent out servers space optimised for fast network speeds and a large amount of processing power. This allows each player to connect to a central known entity that can be trusted to be fast enough to handle the load of processing each simulation step and broadcasting information quickly. This solution provides many benefits in terms of security, cheating prevention and fairness, however it is an expensive investment and risk for games developed on a smaller budget.

I will be investigating other options that exist for the smaller budget projects and how to make the gameplay as seamless as possible with the limitations of consumer hardware and network connections. While some aspects of this, such as high ping between clients due to a bad network connection or suboptimal routing are out of control of the implementation, there are many ways that the game netcode can be implemented to minimise latency and provide a synchronised experience for all clients.

Implementation goals:

- Implement a system that allows one client to act as a server for all others. Throughout this document, I will be refering to this as the **Client-Hosted** model.

- Implement a system for each client to send their updates to each other client directly. Throughout this document, I will be refering to this as the **Peer-to-Peer** model.

Data gathering goals:

- TODO

1.2   Basic concepts and terminolory

First of all, I will define some basic concepts and terminolory that will be used throughout this document.

Client: Within the context of this document, a client can be defined as a piece of software responsible to running the game (i.e. game client). A client can also be defined as a computer interacting with a server, however it is possible to run two different instances of a game client on a single machine.

Online Multiplayer Game: A video game can be defined as a simulation of a certain scenario that can be manipulated by the player of the game. When talking about online multiplayer games, it can be thought of as a simulation that runs on several clients connected by a network (e.g. LAN or the Internet) that is to be synchronised. When one player performs an action that effects the state of the simulation, this action should also be seen by all participants of this perticular simulation instance and therefore the simulation should remain in the same state across all participating clients.

Ping: In network connections, the ping between different clients refers to the shortest amount of time that is needed for one client to send information to another and receive a response from this client. One client sends a "ICMP echo request" to another networked client (e.g. a game server). The receiving client, then responds with an "ICMP echo reply" back to the original device. The time between sending the request and receiving the reply, is the ping between the two clients.

Lag: The grater the ping between two connected clients, the bigger the difference in the state of each clients' simulation once an action to be synchronised is performed. When a change is made by one client, this change should be seen by other clients participating in the same simulation and lag occurs when this change does not appear instentaneous to the user.

Jitter: The difference in frequency that the messages are sent from a sender and received by the receiver. If a sending client sends packets at a constant rate, they would ideally arrive at the receiver's client at the same rate. This is not always the case however and could lead to some unwanted results in certain applications such as VOIP.

1.3   Networking principles in games

TODO: talk a bit about UDP, TCP/IP and routing...

1.3.1   Communitaction Issues

In the dissertation *A Network Software Architecture for Large Scale Virtual Environments.*(Macedonia), the author has identified and grouped the most prevelent issues that occur in internet communications. In real time applications such as online games, these issues can be very impactful on the experience of the players.

Data Distribution

Broadcast to each client

Latency

Lag and Jitter

Reliability

UPD can lose packets........ The article "The Internet sucks: Or, what I learned coding X-Wing vs. TIE Fighter"(Lincroft) documents the issues that the developement team encountered when developing the netcode for the 1997 game "X-Wing vs. TIE fighter". The author has experimented with TCP connections in game data transmission and found that "TCP refuses to deliver any of the other packets in the stream while it waits for the next "in order" packet. This is why we would see latencies in the 5-second range." and "if a packet is having a tough time getting to its destination, TCP will actually stop resending it! The theory is that if packets are being dropped that it's due to congestion.". The features that have been implemented into TCP to make it reliable, end up negatively effecting real-time application data traffic and due to the volume of data to be transmitted, should not be used for time sensitive data.

Bandwidth

Consumer hardware and networking slow (esp upload)

1.3.2   The Centralised Server Model

Most AAA online multiplayer games that are played today, make use of the "centralised server model" for synchronising the simulation state between several clients participating in the same simulation. This means that in an example of a First Person Shooter (FPS), if one player presses the "jump" key, their character will jump and this information is would also be sent over to the game server. The server would then send the information that this player has jumped, to all other clients. There is a potential problem here however. Given that the ping between the server and client A is α and between the server and client B is β, the time between client A pressing an input and client B being notified of this input can not be less than $\alpha + \beta$ and due to the limitations of physics $\alpha > 0$ and $\beta > 0$. This means that at any given time the lag experienced between clients A and B will be more than $\alpha + \beta$ when processing times are factored in too. This leads to a problem of a poor experience for a client with a high ping to the server, as they will receive the updates from the server later than every other player and therefore be at a disadvantage if the

game requires real time reactions. Unfortunately under some implementations, this also results in a poor experience for every other player, who despite having resonable ping to the server, can be shot from behind cover by a laggy player who fired a shot before the cover was reached.

There are many different possible reasons for the lag to the server to vary widely from player to player. Firstly, it is possible that there are not enough servers throughout the world or that they are not spread out evenly enough across all regions. Players who live in geographically more remote locations, are likely to experience higher ping to servers compared to those that live in more densly populated cities due to where the servers are likely to be located. Secondly, there is no way of guaranteeing if the clients are going to be using a wired or a wireless connection to connect to the server. Wireless connections can be much slower and are more likely to introduce other potential problems such as packet loss.

Possible solutions to the variable ping problem

Netcode developers of the most popular games, have tried many different solutions to fix or at least mitigate the issue of widely differing ping to the game server between players. One example of a solution here could be "region locking". This is the idea that only players with equally low ping, can connect to the same game instance on a server. This could be done by providing game servers spread out across as many geographical regions as possible and only allow players to connect to their local one. This presents two main issues however. Firstly, this prevents players in different geographical regions from playing together and therefore serperates the community. Also, the issue of players in remote areas playing together and having a suboptimal experience due to the server lag, has not been addressed. The developers of Battlefield 1 have implemented an interesting solution to this problem and I will talk about this further on.

Chapter 2:   Research

TODO:

2.1   Existing networking implementations

TODO:

2.1.1   Variable ping system in Battelfield 1

An interesting approach to the issue of variable ping in a game has been implemented by DICE in the game Battelfield 1. Given 2 players; player A with a low ping to the server and player B with a ping of <150ms to the server.

When player B fires at a moving player A, player B's client will perform the check concluding that player A has been hit and this information is sent to the server. The server will then perform it's own checks and if the server agrees that this hit is possible, then it sends the hit confirmation to player B and damage information to player A. This approach is called Clientside-Server Authoritative as while the hit registration is calculated on clientside, the server must still confirm that this is valid.

Concidering another scenario, suppose that player A still has a low ping to the server but player B, now has the ping of >150ms. An icon will appear on player B's UI showing an "aim-lead" indicator. Now when the shot is fired in the same scenario, the hit will not register anymore as the hit registration has switched from Clientside-Server Authoritative to Fully-Server Authoritative, meaning that the check is performed only once the shot information is received by the server.

Whilest this implementation makes the game feel less responsive for players with high ping, it provides a lot more fairness for everyone else and allow for players with different pings play in a more fair way.

2.1.2   Networking in Apex Legends

Apex Legends is a "Battle Royale" game by Respawn Entertainment. Due to the genre of this game, the implementation of networking has been implemented in an interesting way. The premise of the game consists of a starting amount of 60 players, all competing to be the last one alive at the end. An interesting aspect of this, is that while at the start of a match, the server might have to work quite hard to effectively synchronise the simulation for 60 different clients, as more and more players die off and less are left, less information needs to be sent to each clients, freeing up some server performance.

Since transferring all the information about 60 different players would most likely exceed the average MTU of a UDP packet, with each update, the server sends 1 smaller packet per each player to each player. This means that when 60 players are in the game, 60 packets are sent to 60 different clients from the same server. This is shown in the Netcode analysis in *Apex Legends Netcode Needs A Lot Of Work*(Battle(non)sense).

An interesting outcome of this, is quite noticible network lag that slowly goes away, as less and less players remain in the game. It is also likely due to this, that Respawn felt the need to implement a "Client Authoritative" aiming model. Meaning that the server will favor what the client sees over it's own view of the simulation (i.e. If the client

claims that a shot has hit an enemy, the server is likely to agree). The choise for this implementation could have been made to fix two potential issues; reducing the load on the server by reducing the need to perform extencive checks for each shot (this could be significant if a lot of players are playing), making the game feel more responsive on slower client hardware that may need more time to process up to 60 packets that arrive from the server at each update tick.

2.2 Security

TODO:

Chapter 3:   Design

3.1   Code Architecture

Test for inline: `test Hello;`

3.2   Protocols

During any connection that can be deployed between several processes on a machine or even different physical hardware in seperate geographical locaitons, many different protocols come into play.

3.2.1   Protocols in Network Communications

Firstly, in the network layer, most commonly the IP[1] is employed however other options such as X.25 are also available but have more niche uses. These protocols are responsible for "packaging" the data to be sent between two different computers identified by their IP address. The packet from the sending machine, will travel through a network of routers that will eventually lead it to the machine with the IP address of the recieving machine.

Next comes the transport layer where either UDP[2] or TCP[3] can be chosen, both have different properties, advantages, disadvantages, useses and both are used in game networking. The UPD protocol is a simple, connectionless protocol which will simply send a packet from one IP address to another. Since each packet sent with UDP, can take a different route through the router network, there is no guarantee that the packets will be received in the same order as they were sent in. Due to many different reasons, packet loss can occur, meaning that it also cannot be guaranteed that every packet sent with UDP will arrive at the destination at all. Despite these dissadvantages and due to the simplicity of how this protocol was designed with it's connectionless nature, it inately has a major advantage in the speed that the packets can just be sent out and forgotten about. The TCP protocol, is built upon UDP to add some important features for reliable data sharing at a cost of speen and use in real-time applications. The most important property of TCP includes the assurance that if a packet is not received by a recipient, it is requested to be resent to guarantee that every pacet that is sent, is also recieved. This also means that the packets are aranged in the same order that they were sent meaning that we can be sure that not only data will arrive at the destination, but it will arrive just as we sent it. This implementation has many obvious benefits and in most scenarios, the delay of possibly re-sending a packet if it was not received is neglegible. In real-time applications however, this is likely to be an unnecessary waste of time and resources as even id a packet is dropped and and resent, by that time, new updated information is available so resending the dropped packet is useless when a packet with new information could be sent at that time instead. Simply, old information is quickly outdated and it's more important to send new information then old, non-useful information.

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[1]IP: Internet Protocol
[2]UDP: User Datagram Protocol
[3]TCP: Transfer Control Protocol

The next layer of protocols is the Operating System Iterface or library, that is called by applications needing to share data using the above protocols. With Windows, a library called "WinSock" is often used, however other options are also available such as enet, asio, RakNet... This is where a programmer would be able to configure which protocols to use (Like TCP or UDP, IP or X.25 amongst many other configurable options).

3.2.2   Connecting the clients together

TODO: Tried UDP for connection. Big problems if packet is not delivered

3.2.3   Message Structure Startegies

Data Representation

There are many different ways that the same data can be represented and each one is carefully designed to be the most appropriate for it's use. Consider the two figures below of common ways of goruping complex data in an "easily readable" format; XML in Figure 3.1 and JSON in Figure 3.2. These example have been adapted from the article *Reading and Writing Packets*(Fiedler).

```xml
<world_update world_time="0.0">
  <object id="1" class="player">
    <property name="position" value="(0,0,0)"></property>
    <property name="orientation" value="(1,0,0,0)"></property>
    <property name="velocity" value="(10,0,0)"></property>
    <property name="health" value="100"></property>
    <property name="weapon" value="110"></property>
    ... 100s more properties per-object ...
 </object>
 <object id="110" class="weapon">
   <property type="semi-automatic"></property>
   <property ammo_in_clip="8"></property>
   <property round_in_chamber="true"></property>
 </object>
 ... 1000s more objects ...
</world_update>
```

Figure 3.1: An example of a representation of world data in the XML format

```json
{
  "world_time": 0.0,
  "objects": {
    1: {
      "class": "player",
      "position": "(0,0,0)",
      "orientation": "(1,0,0,0)",
      "velocity": "(10,0,0)",
      "health": 100,
      "weapon": 110
    }
    110: {
      "class": "weapon",
      "type": "semi-automatic"
      "ammo_in_clip": 8,
      "round_in_chamber": 1
    }
    // etc...
  }
}
```

Figure 3.2: An example of a representation of world data in the JSON format

Checking for Packet Loss in connection

The packet information could contain a certain amount of bits that would be incremented with each simulation step[4]. This counter value could loop round when a maximum value is reached as long as several simulation steps in a row have unique values. The receiver could evaluate this value when received, checking if a packet has been dropped since the last received update. Knowledge about the quality of the connection could be important information when determining how much of the simulation has to be estimated between the received updates and could also be vital information to the player when in a game demanding split-second reaction time allowing them to change their strategy with the knowledge that they may be at a dissadvantage against other players.

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[4]A simulation step refers to a state of values that represent the current state of a simulation. Each time the values are updated, is a new simulation step. This is often done and broadcasted several times a second in central server models.
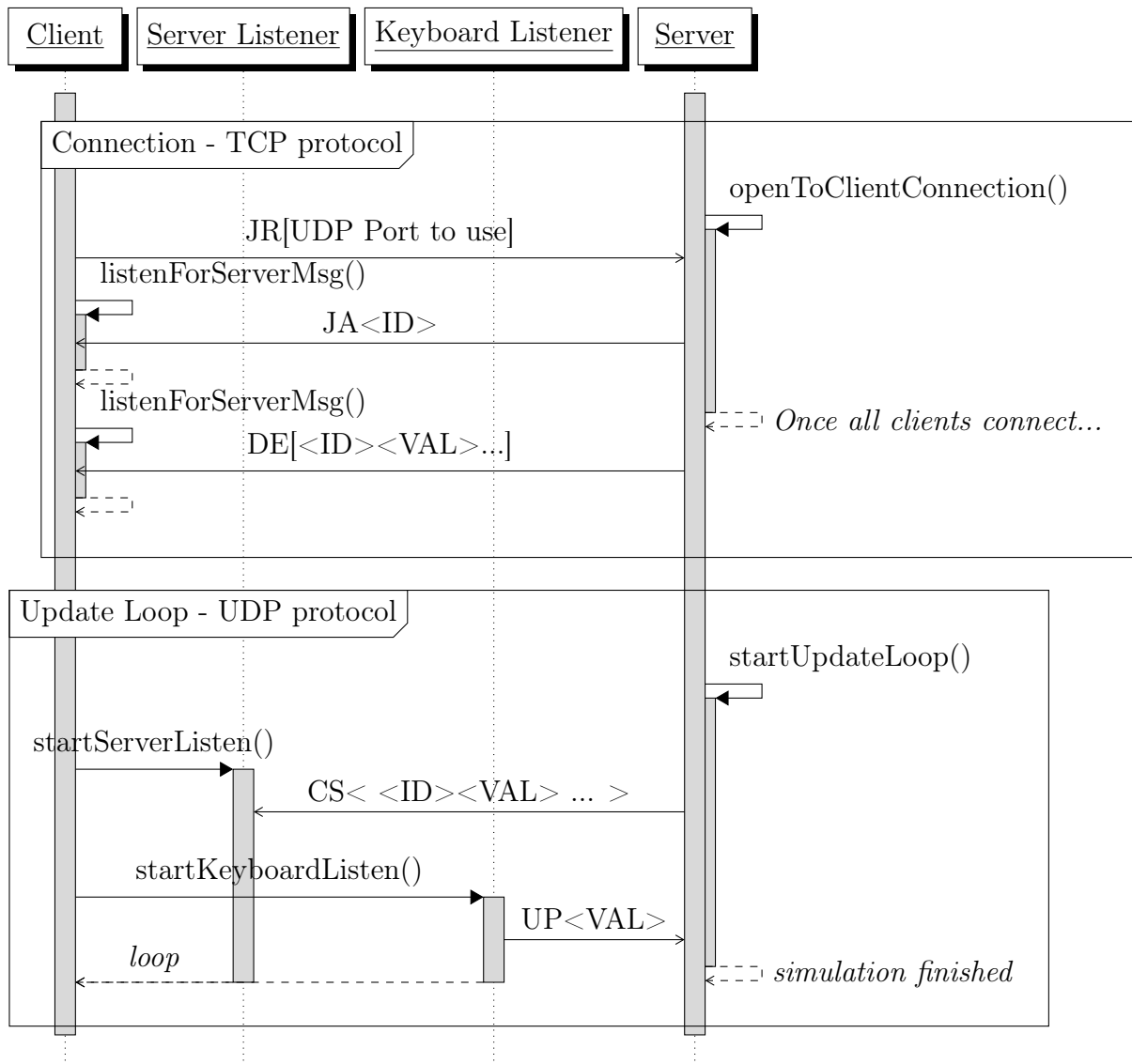
Figure 3.3: Graph showing the protocol of joining a session hosted on the server as well as sending and receiving updates.

3.2.4 Potential issues with the Client Hosted protocol

The protocol for establishing a connection and transfering of data can be found in Figure 3.3. There are many potential flaws with this approach.

Packet Loss

Time outs in place in case response lost... resend.... Resend request if no response....

Security

anyone could send update by spoofing ip

3.3   Message Codes

Message Type	Message Code	Description	Example Payload
Join Request	JR	Allows a client to send a join request to the server.	JR
Join Acknowledgement	JA	Allows the server to confirm that the client's information has been saved. Is followed by 1 byte indicating the client's ID	JA1
Ping Request	PQ	Message instructing the recipiant to reply with PS. Can be used to time the delay in this connection.	PQ
Ping Response	RS	This should be sent whenever a PQ message is received.	RS
Update	UP	Used by a client to update it's value on the server. Is followed by 1 byte representing the new value.	UP9
Define	DF	Used by the server to define the initial values for each of the clients connected to this instance. It is followed by a non-zero, even amount of bytes representing the client ID and it's value pair.	DF1020304050
Current State	CS	Used by the server to broadcast it's real state to all clients. When this is received, clients are expected to update their local state to this. It is followed by a non-zero, even amount of bytes representing the client ID and it's value pair.	CS1927344157

Table 3.1: Table showing the message codes for distinguishing messages from each other and how each one is to be used

Appendix A: Appendix Title

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