UNIVERSITY OF VAASA

FACULTY OF TECHNOLOGY

COMMUNICATIONS AND SYSTEMS ENGINEERING

Nwosu Chinedu Benjamin

SATELLITE GAME SERVER: OVERVIEW AND ANALYSIS

Master’s thesis for the degree of Master of Science in Technology submitted for assessment, Vaasa ,29 May, 2018.

Thesis Instructor: Ahmed Elgrgouri

Thesis Supervisor: Professor Mohammed Elmusrati

ACKNOWLEDGMENT

The journey of a thousand miles they say starts with just a step and for every beginning, there must be an ending. All glory be to the Almighty God for His mercy, guidance and knowledge.

I show my appreciation to Finland for giving me an opportunity to have this wonderful education in systems and communications engineering. I extend my profound gratitude to all the teachers and the staff members of University of Vaasa for their support throughout the course of my studies.

I would like to acknowledge Mr. Ahmed Elgrgouri and Professor Mohammed Elmusrati for their generosity and academic guidance towards me right from the start till this very moment, thank you so much and God bless you. I appreciate my friends who have shown me love, affection and emotional support in this cold and sometimes acrimonious environment.

Finally, to my lovely family, words can't express how grateful I am to you all. From the start you have served as a reliable source of motivation, encouraging me to push myself from zero to apex to succeed. Your prayers, emotional support and love have made this possible and I therefore dedicate this thesis to you all. I reserve special thanks to my father Mr. Edwin Nwosu, your struggles made these wonderful experiences a reality and I am sincerely grateful for your efforts, I hope and believe they are not in vain. I love and appreciate you all.

Nwosu Chinedu Benjamin

Vaasa Finland

15 May 2018

TABLE OF CONTENTS

SYMBOLS

E_{min}	minimum elevation angle
e	electricity
a	semi-major axis
b	semi-minor axis
M	mass of the sun
m	mass of the planet.
G	gravitational constant.
T	orbital period
M_e	mass of the earth
H	altitude
ሐ	area of the size of coverage by the satellite
E_b	energy per information bit
G_T	antenna transmit gain
G/T	figure of merit of receiving equipment
N_0	noise power spectral density
Ps	signal power
Pn	noise power
B	bandwidth
f_b	bit rate
P_T	power fed to transmitting antenna
d_{max}	maximum distance
h	the satellites height
ϑ	the elevation angle for the ground station antenna
P_n	thermal noise
k	Boltzmann’s constant
T_n	the physical temperature of the object
B_n	noise bandwidth.
R_b	Information bit rate

$\boldsymbol{R_c}$	channel bit rate
$\boldsymbol{\eta}$	channel Efficiency
$\boldsymbol{C}$	the power of the received carrier
$\left(\frac{\mathrm{C}}{\mathrm{N_0}}\right)_T$	overall link carrier power to total noise power spectral density ratio

ABBREVIATIONS

ACK	Acknowledgement
AIS	Automatic Identification System
ATM	Asynchronous transfer mode
BER	Bit Error Rate
CDN	Content Delivery Network
CPU	Central Processing Unit
CUBESAT	U-Class Spacecraft
DVB	Digital Video Broadcasting
EIRP	Effective Isotropic Radiated Power
ES	Earth Station
ESOA	European Satellite Operators' Association
FSPL	Free-Space Path Loss
FSS	Fixed Satellite Service
GA	Genetic Algorithm
GENSO	Global Educational Network for Satellite Operation
GEO	Geostationary Earth Orbit
GPS	Global Positioning System
GS	Ground Station
GSO	Geostationary Satellite Orbit
GVF	Global VSAT Forum
HDD	Hard Disk Drive
HPA	High Power Amplifier
HVAC	Heating, Ventilation, and Air Conditioning
IoT	Internet of Things
IP	Internet Protocol
ISL	Inter-Satellite Link
ITU	International Telecommunication Union
LAN	Local Area Network
LEO	Low Earth Orbit
MCS	Master Control Station
NGSO	Non-Geostationary Satellite Orbit
P2P	Peer 2 Peer

QoS	Quality of Service
RAM	Random Access Memory
SNR	Signal to Noise Ratio
TCP	Transport Control Protocol
TT&C	Telemetry, Tracking, and Command
TV	TeleVision
UDP	User Datagram Protocol
UHF	Ultra High Frequency
VHF	Very High Frequency
VSAT	Very Small Aperture Terminal
WAN	Wide Area Network

LIST OF FIGURES

LIST OF TABLES

UNIVERSITY OF VAASA
Faculty of Technology

Author:	Nwosu Chinedu Benjamin
Topic of the Thesis:	Satellite Game Server: Overview and Analysis
Supervisor:	Professor Mohammed Salem Elmusrati
Instructor:	Ahmed Elgrgouri
Degree:	Master of Science in Technology
Major:	Communication and Systems Engineering
Year of Entering the University:	2014
Year of Completing the Thesis:	2018 Pages: 64

Keywords: Game Server, Satellite Networks and Communications, Online Gaming, Link Budget Analysis, Low Earth Orbit

ABSTRACT

Online gaming has in recent years grown as an entertainment service for many users. As the number of users who play games continues to increase, it requires a massive amount of computing resources to ensure the desired gaming experience for the users. This master's thesis presents the trends, issues and possibilities of a satellite game server. A server is designed to handle traffic and provide a place for all the events that are going on, in a game, to be wrapped up in a single package that is constantly sent over a communication network. Game development started with big companies with huge budget releasing high quality games. They employed the use of a dedicated server, this is a machine running in a building somewhere for a specific purpose, for the users playing games to connect to and it handles all the host services. This thesis revolves around the possibilities of having a game server launched in space and will focus on the basic guidelines and issues. The main aim and objective of this thesis is to provide the reader the general overview of the idea of a satellite-based game server, its advantages over existing types of game servers, what constitutes in the technology, market trends, future growth of technologies and possibly how it can be implemented.

The thesis is motivated by the tremendous growth in game development in recent years and the numerous advantages of satellite communications. The satellite internet (VSAT) has already been employed as an alternative internet access for online gamers, especially for its advantage of having a global coverage to reach gamers where the IP connection is impossible. To meet an increasing demand for online game services and connectivity across the world, satellite server will play an indispensable role in the reach of online gamers globally, therefore increasing the market of online games.

The thesis investigates and concludes that the construction of a working satellite game server solution is possible to achieve on a high budget and several issues yet to be resolved but will be cost effective at the long term.

1 Introduction

1.1 Topic of Research

Technological advancements have allowed companies to produce light and wireless host devices that allows a growing number of internet users to access electronic media applications easier. The increasing availability of broadband wired and wireless connections and powerful thin clients, such as cell phones, game consoles, and PDAs, allows us to consider offering online services to large numbers of non-expert users (Leavitt 2003). One of the application that has been attracting attention in the entertainment industry is online game. This class of applications has grown tremendously, because game developers have been able to provide customizable entertainment and the possibility for real players to be able to compete and interact with each other. This feature has made it possible for most recent game services to include an online multiplayer option. Online games have made it possible for thousands of players to play simultaneously, from different areas of the globe. There are popular games that enable game player to stay in the game over longer time of period mostly from 6 months to the next release of latest version of the game. During this time, the game players develops their game styles and get more involved with the game. Therefore, it is required that the servers will still be online and functional over this period of time.

A scalable server is required to support this feature and other services required of online games. Online games are enabled by a server. The game users connect to this server as a client and the server is required to handle traffic, actions, events, request and maintain consistency over a network. There are a number of game types that can be played online. According to Vaddadi et al (2008) online games can be divided into four different categories; single player games, pseudo multiplayer games, turn-based multiplayer games and real-time multiplayer game. These different game types require different role and demands as they are designed and the ability to support the number of game users is determined by a cost-effective game server. The game server is required to wait for an incoming request of connection from client(s). Once a connection is established, the server proceeds by serving the client(s). The structure and functionality of a server and a client are very much different as the game types varies.

An online game can be seen as a content delivery network, which is also known as content distribution network which is a geographically distribute network of specialized servers that accelerate the delivery of the media contents to the internet-connected devices. Each server is strategically and graphically placed to feed the game user effectively. The major drawback of this this system is cost. The cost of maintaining this system is very high because as game services get popular, more servers need to be deployed to reach the game users effectively. The cost of maintaining the CPU, storage space etc. (Sun et al 2005).

Online games are one of the application that have been able to emerge because of exponential growth of the Internet. It is therefore required that game users should have internet access, so that they can play games. The satellite internet (VSAT) has already been employed as an alternative internet access for online gamers, a satellite link is typically the same as a terrestrial link, in that it will give you internet access. A satellite link could give access where there is no terrestrial connection. A satellite game server will include the certain advantages that satellite networks offers which includes: Wide geographic coverage, presently countries in Africa and other remote areas cannot play most online games. Broadband and mobile internet access is quite poor in this region, thus making this an ideal solution to open the market reach for online games. A satellite game server would serve as an alternative to fibre-optic networks for disaster recovery options, some dedicated servers have been down due to natural disaster. There is also a possibility of having them in the downtime of dedicated servers and an alternative for load sharing. From the environmental point of view, it will save energy. The housing of most game servers consume energy, the energy for cooling can be eliminated if installed in satellite where the weather does not require energy for cooling.

There are several design constraints concerning the implementation of a satellite game server that are being discussed in this thesis project, some of which can be beyond the scope of this thesis. For instance, the design constraints for the game server equipment to withstand the issues of launch and space. Networking aspects regarding online games is addressed where main areas as the client/server operations, communication protocols, data rate, speed and latency. It is also important to note that the implementation of a game server comes with a very high cost, thus there is no simulation or practical implementation of this technology in this thesis. I intend rather to create a handbook to elaborate the trend, issues and possibilities of a satellite game server, as there is currently no papers or research on this topic.

1.2 Motivation

The evolution of game development has been growing and innovating. There is a huge market for development in the game industry. In the past, only big companies were dominant in the game industry releasing games with million-dollar budget, this have changed in recent years with addition of small group of game developers coming together to create online games with a good market share and less funding. The highest taxed income earners in Finland for the year 2016 is stated to come from game industry, which is a group of new developers (YLE 2017). Therefore, it is a good strong point that motivated the topic of thesis, that the technology can be further researched on and can be one of the numerous solutions to the game industry.

1.3 Thesis Structure

The thesis is structured in six chapters

Chapter 1: This chapter explains the introduction of the topic, topic of research, purpose and motivation.

Chapter 2: Background, basic concepts and a literature review of game server. This chapter briefly explains about the existing studies on game server. It also provides a high-level understanding of different types of gamer severs, their operations, the networking aspects of game server, communication protocols and the telecommunication metrics required in exiting game server.

Chapter 3: In Chapter 3, the general overview of the satellite networks and communications is discussed. The topic of the thesis resolves having an equipment in space(satellite), therefore the basic concepts of the topic and its connection to satellite communication is elaborated in this chapter.

Chapter 4: A proposed satellite game server architecture and the practical implementationn is presented. The issues, link budget analysis and possible solutions of the prototype design is identified, and the correspondent options are discussed. In concluding the chapter, the advantages that this technology will bring to online gaming is highlighted.

Chapter 5: The main contribution of this thesis is in this chapter which includes: summary, conclusion and recommendations. The last chapter concludes the research by showing the possibility of having a working satellite game server and the recommended areas to continue the research work.

2 Game Server

Game server may be a local or remote server used by game users to play multi-player games. Today, most online games connect to the game server. Game servers transmit adequate information about the internal state of the server to get permission for access to the connected clients. Game server get and process every user request. A game server can be customizable in a way that it can still allow for modified client to connect to the server. Such customizations include; configuration for built-in games setting, content which is downloadable by a client after joining the game, plus brand code that modifies the behaviour of the server. Although customizing server is mostly done by the server administrator and player, it might not be appealing to the developers of the game and different players as it might change the game experience. It might aggravate a player as well through having a varying game service. In the preceding sub sections, we will outline the different types of game server that has been employed in the game industry.

2.1 Types of Game Server

Game servers are responsible for delivering a game experience to the users. To offer quality services, game servers are required to process the game request under timing constraints and support interactive control operations such as authentication, the physics that involves all the movements of game events and other necessary parameters.

2.1.1 Dedicated server

A dedicated server is a single computer in a network reserved for serving the network requirements (Beal, 2018). Dedicated servers have been used in online games, especially in the administration of the games. Game users can connect to the servers, if one logs on from client programs. Dedicated servers are hosted in reliable data centres. The reliable data centres improve the server consistency and effectiveness. Dedicated servers are commonly used to run a game hosting environment. The server resources are usually not shared thus one receives full access to the resource of the single server. The security and performance of a dedicated server are significantly improved when compared to shared servers. Online games with low or medium traffic can significantly improve their uptime and loading speed when moved to dedicated servers, therefore it offers more reliability and stability. Dedicated servers allow improved security as no sharing space with other service users who might have infected files. It is important to note that dedicated server allows client flexibility as the server can be customized to suit the client needs. Server resources such as CPU, RAM, and disk space and application software can be adjusted to client needs (Srivastava, 2018).

Dedicated servers have high cost and energy consumption to run compared to other types of game severs which is much cheaper. Game companies with huge budget for online games have been employed to use dedicated server in the release of their online games which commands a big market share in the game industry. However, in whichever case, emerging game companies rely on the third parties offering this type of servers for connection, which as a result makes a lot of online games that adopt a dedicated server to offer listen server support as well. The **Figure 1** portraits what a typical dedicated server looks like.

Figure 1: Dedicated Server

2.1.2 Listen server

A listen server runs at the same processing time as the game users request. They run similarly to a dedicated server, however, a listen server includes host as a local player. Listen server runs on client hardware rather than on the fully supported server. In a listen server the host joins the game at the same time as the players. When the host leaves, all players are subsequently disconnected. When compared to a dedicated server, the system is cheaper as it only requires a less number of softwares to support. This means only limited data is used on game computing apart from requests from the game server. A listen server communication does not have an entire knowledge loaded to HDD as the case with a dedicated server. However, its knowledge is loaded to game computing which act as its form of understanding.

The host of the system handles all information, unlike peer-to-peer system where information is handled by the peers. These systems rely on the host to perform their necessary functions and if the host leaves, all players are disconnected (Maurina 2006). The server requires huge bandwidth. Listen servers possess the benefit of being basically unrestricted and without needing any specialized equipment for setting them up, this fact makes listen servers popular at Local Area Network (LAN) parties whereby latencies and bandwidth problems is not a limited. Listen servers have been employed mainly in console game which has an online feature.

2.1.3 Peer-to-Peer Server

Peer to Peer server consist of a game device connected for sharing information. The unique characteristics that a peer to peer server exhibits is the ability of each device in the network to serve as both a client and a server. P2P severs are distributed servers consisting of interconnected nodes able to self-organise into network topologies with purpose of sharing resources such as content, CPU cycles, storage and bandwidth, capable of adapting to failures and accommodating transient population nodes while maintaining acceptable connectivity and performance, without requiring the intermediation or support of a global centralized server. (Spinellis et al, 2004). In "peer-to-peer" servers there aren't involved servers: every "peer" as an alternative and gets the raw inputs stream of every other individual plays and controls the outcomes itself. It is usually thought-out that a P2P server as out-dated for actions type of games, however, it is still popular in the real-time strategy type because of its appropriateness for games with huge number of token and less count of participants. Nevertheless, peer-to-peer has a lot of benefits:

- It’s very hard keeping every peer synchronised. Minutes difference among peers might intensify as it goes on to games-breaking absurdities.
- It is so hard supporting fresh peers connecting in the course of playing the game.
- Every peer is supposed to establish communication with every other peer, restraining the count of players in connection.
- Every peer is supposed to wait for a message from other peers before the simulation of the consequent "network frames", leading to every player going through the similar inactivity as the players with the poorest connections.

2.2 Client-Server architecture model

The term Client-Server refers to a relationship between two game programs in which the client makes a service request from another program and the server fulfills the request. The idea of client-server can be used by programs within one single game network. In a network, the client-server model gives an easy way to interconnect game programs that are distributed efficiently across different area. There is several online games or application using the client-server model. For instance, for a game user to enter his own personal game account(mode), a client program in your game device sends request to a server program at certain location, that program can in turn send the request to its own client program that forwards a request to a database server at another game server facility, to retrieve the game account details. The details are returned back to the game data client, which in turn serves it back to your game device, which displays the information for you.

The client-server model has become the main idea of network computing in game development. **Figure 2** shows how a simple network computing between a client and server. Most game application that is written today use client-server model and the Internet’s main program, TCP/IP as well uses the client and server model

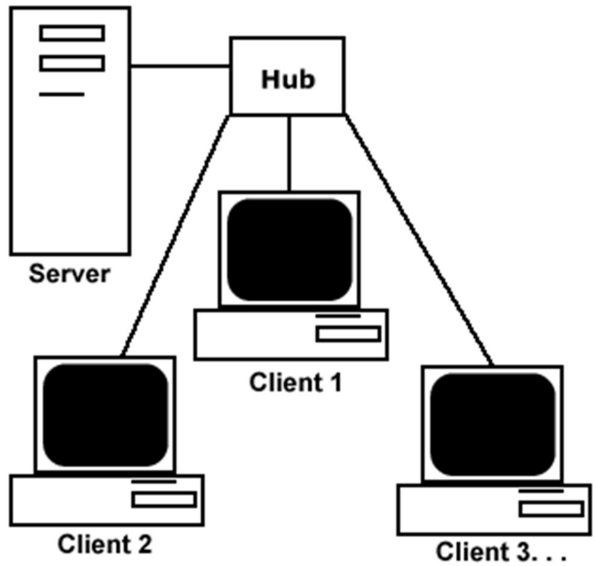

Figure 2: Client-Server Model

Game devices or console have interfaces for allowing the game users to ask for a service from the servers and show the outcomes the servers return. A server waits for enquiries to come from a client and consequently reply to them. Preferably, servers provide uniform clear interfaces to a client, so that the client do not need to have knowledge of the particulars of a system (that is, software and hardware) which is offering the services. A client is mostly located at a game devices or consoles, whereas a server is suited somewhere else at the network, typically on extra powerful computers. These game models are particularly successful when a client and servers both have separate tasks in which they regularly do. A client-server network involves multiple clients connecting to a single central game server. The client-server model was developed in a way to allow more users to share access to database applications. Public data and applications are installed on the server. The client game devices communicate over the network to use the resources. Servers often have private user directories as well as multiple public directories.

2.2.1 Game server structure

Most game server are structured on the client-server model. The client-server network tends to be faster in terms of access because of the large number of clients (game users) they are designed to support. The clients are allowed to function as workstations without sharing any resources. It is easier to upgrades software application and files because they are held on one single game server. Security is enhanced on a client and server networks because the security is handled by the game server.

2.2.2 Game Server regionalization

This is the process of distribution of game servers in different areas known as regions. Regionalization is used by game developers as management tools and a method of making sure that requirements exclusive to certain areas are achieved. Server regionalization divides the game virtual world with an aim of modelling the interactions of the player to offer some manageable consistency. The regionalization can be behavioural or geographical. Behavioural regionalization subdivides the server virtual world to create player interactions while geographical subdivides the virtual world into regions when the game is initialized (Lu et al 2006). The geographical approach is used when virtual world presents clear spatial borders. In such situations, the players can't play outside the allocated space. Behavioural approach is independent of spatial constraints. However, it is influenced by the ability of the players to express their interest (Alecu 2012).

2.2.3 Game Server overload

Game server overload is whereby the game server does not have the ability of handling the received requests to its processing server (Beal 2017). When a game server has an overload, the users or players using the server get slow response in running of the game. This is the reason why sometimes, some games load or play slowly. The player does not actually possess any control over game server overloads, because they are normally under shared servers with other users, in shared servers, the host game server is under management by the game host organization and don't allow for any access of controlling or managing the loading of the game server. In cases where you have dedicated servers or VPS servers, here, you get to have complete control of the servers and you have the capability of finding out the root origin of the server overload and some actions by the game administrators is required to fix the issue.

2.3 Networking aspects of a Game server

2.3.1 Introduction to Networking

The satellite game server will provide a connection between one game user to another. Usually baseband signals produced by most terminals are digital but, in some cases, analogue signals are produced too. For successful communication between two terminals, the satellite game server network performs the following functions;

- Connection: it provides for a connection between a source and a destination terminal.
- Routing: it routes the signal between the source and destination terminal since other signals might be present in the physical connection established. It is also possible that there might be routing between several game server network.
- Reliable delivery of information: connection established should be reliable in that, data transmitted from one end should arrive at the other end in the same order and the same count (with no duplication or loss of packets).

2.3.2 TCP and UDP

TCP (Transmissions Control Protocol)

TCP is a connection-oriented protocol that provides flow of data between two computers. Network functions are separated into different layers, and each layer performs a specific task and is transparent to its neighbouring layers in the TCP/IP model. For the network protocol and the hardware to work together, network models are used to conceptualize how networks should work. **Figure 3** shows the network connections.

TCP/IP Model Visualised

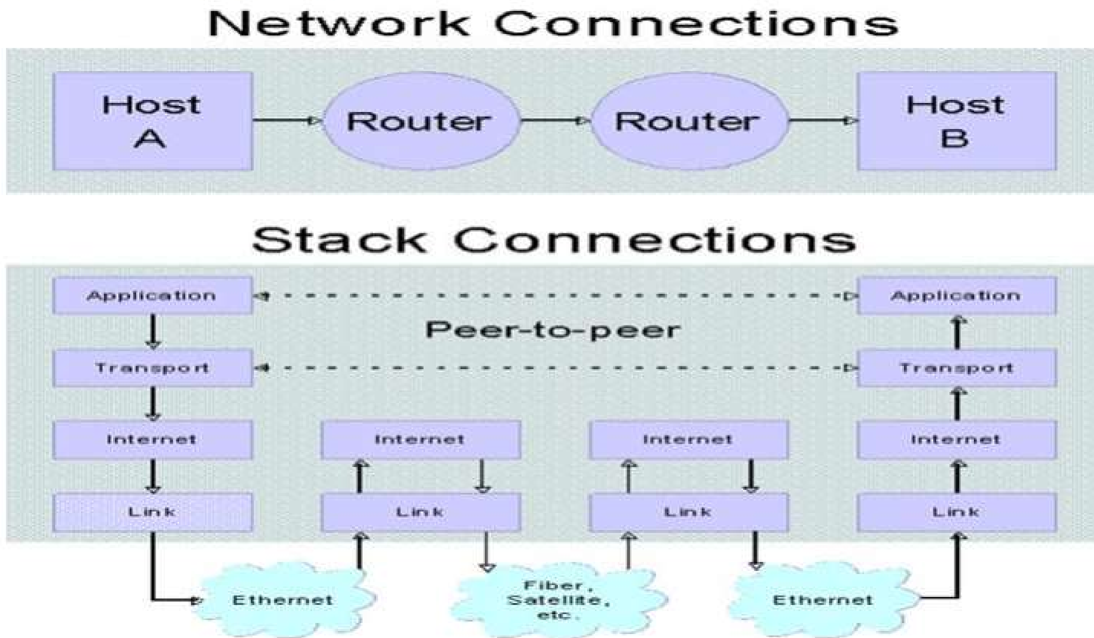

Figure 3: TCP/IP Model

UDP (User Datagram Protocol)

UDP is based on the IP (Internet Protocol) for the client/server network application and is a simple transport layer protocol. It was introduced in 1980 (Fairhurst, 2008) making it one of the oldest network protocols in existence today. Although it is an alternative to TCP, it provides an unreliable service as it gives no assurance for delivery nor protection from duplication of files. Duplication may be caused by errors in software within an IS (Intermediate System).

Unlike other protocols, UDP does not establish end to end connections between systems that are in communication. Its characteristics offer a very efficient communication transport to some applications, although it lacks congestion control or reliability. UDP sends data at the line rate of the link interface. Applications using UDP need to be well designed to reduce congestion along a path since The line rates of these link interfaces is usually much more than the path capacity available.

The UDP protocol packets are sent with no retries and to increase performance datagrams and may be received in any order different from how they were sent. Re-ordering of UDP packers may be caused by intermittent connectivity or mobility. Datagram ordering is done in applications that require datagrams to be of the right order as they were sent. Thus, it is used in applications designed for video conferencing as it happens in real time and in some computer games.

2.3.3 Client/Server System

As the name implies, this system consists of clients and servers. There exist dedicated workstations that house data content and function to serve these data content to clients. The clients are able to set up connection with the game content source(server) and are then able to receive requested contents from this server. In more advanced setups, multiple servers also called proxies are deployed to increase total system capacity. In this setup, game content is replicated on these proxies and clients receive data from the proxies closest to them (Tu et al 2005). This system is usually referred to as Content Delivery Networks (CDN).
A CDN typically consists of a set of servers that deliver game content to game users, a request routing infrastructure which directs clients request to the server closest to them, a distribution infrastructure and the accounting infrastructure maintains logs of client accesses and records the usage of the CDN servers. A CDN improves network performance by maximizing bandwidth, improving accessibility and maintaining correctness through content replication (Buyya et al, 2006). The most obvious disadvantage of CDN is its cost. The cost of maintaining a CDN is high considering massive CPU power, storage space and bandwidth needed (Sun et al, 2005). Another major challenge is scalability, as the number of clients increase, the number of bandwidth must proportionally increase.

2.3.4 Hub Station

The hub station which is located at the earth station will have a dedicated large hub. At the central site of a network operator, a direct connection between a host computer and a dedicated large hub offers a full control of the network. This large hub with an antenna size, has a capacity of a full single network that can easily support thousands of the satellite game server connections, the remote terminals are then connected to a hub. A dedicated hub is advantageous in that it accommodates making changes to the network easier (changes include, expanding a network or fixing problems in the network). However, a dedicated hub is very expensive, and this option only makes economic sense if its cost can be spread over many satellite game servers in the network. Thus, to cut back on the large initial capital investment, network operators lease hub services taking advantage of the functionality that allows for many separate satellite game servers networks to share a hub. Sharing a hub result to some disadvantages but it is the most appropriate option for small networks.

2.4 Game Server Operations

2.4.1 Communications Protocol

In a communication network, there is a certain rule which governs every system in the network. These sets of rules are called protocol. A communication protocol is a system of digital message formats and rules for exchanging those messages in between computing. A communication protocol includes signalling, data rate, bandwidth, error detection and correction capabilities. It is important that the satellite and the ground station use the same communication protocol to enable communication between both segments. The proposed satellite game server will orbit in a Low Earth Orbit (LEO), which makes the distance between these two stations reduced and limits the time that the satellite can communicate with the ground station. In our prototype design, it is suggested by The Global Educational Network for Satellite Operation (GENSO) to use AX25 as packet protocol. The AX25 is designed for radio amateur usage and is often used in the amateur radio packet networks. These communication protocol have been successfully used in several student satellite projects.

2.4.2 Data Link

A data link is a two-way communication channel; Uplink and Downlink. The uplink is the communication from the ground station to the satellite and the downlink is the communication from the satellite to the ground station. The downlink is used to transmit telemetry, typically measured data from the game events i.e. hit points, whether a goal is scored or not and so forth. The uplink is used to send request to the satellite game server.

3 Satellite Communications

3.1 Introduction

Satellite communication plays a crucial role in a global telecommunications system. There around 2000 human-made satellite orbiting around the globe to convey analogue and digital signals that carry videos, data and voice from one location to another.

Satellite communication consists of the ground segment component and the ancillary equipment. A typical link for satellite networks, is that it transmits from stations on earth to satellite. The satellite receives the signal from the station and then amplify it before re-transmitting it back to earth. On reaching earth stations and terminals, it is re-amplified. The receivers on the earth stations involve the equipment that offer direct-to-home capability as well as reception for aircraft, mobiles and telephones using satellite signals and small hand size devices. Satellite communication have distinct characteristics because of its high altitude, its transmission can cover a very large area, as an overhead wireless repeater station that provides a microwave communication link. It is also having long transmission delays, large channel bandwidth and the cost of transmission is quite high and independent of the distance of the ground segment.

3.2 Basic Concepts of Satellite Networks

Satellites networks have been effectively used for communication purposes and this section 3.2 will cover the basic geometry of the area that a satellite network can cover, that is the area of the coverage area, orbit period and the transmission delay. According to Werner et al (1997), the geometry is shown in **Figure 4**.

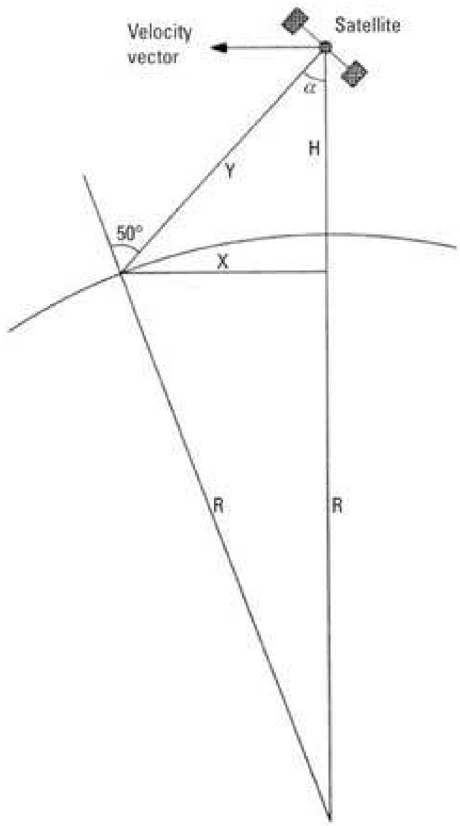

Figure 4: The geometry of a satellite's footprint.

The altitude H and the minimum elevation angle E_{min} (in **Figure 4** it is given as 50^0) are used to determine the coverage area of the satellite, which is sometimes referred to as the footprint of the satellite system. The angle E_{min} is the minimum angle from the tangent to the earth's surface at a covered point and the satellite. The smaller the angle, the larger the attenuation of the signal between the satellite and the covered point due to the earth's atmosphere. It is ideal to use a large E_{min}, so that the power requirement of the satellite system is minimized. However, using a large E_{min} will limit the size of the coverage area. The size of the satellite coverage area is defined as a region of the earth where the satellite is seen at a minimum predefined elevation angle. The satellite's coverage area on the earth depends on orbital parameters.There are several factors that affect the range of minimum elevation angle selected by the network operator. Structural objects like buildings, trees, and other terrestrial objects that would block the line of sight. When there is a block in the line of sight of propagated signal, there is attenuation of the signal by absorption or in distortions due to multipath reflection.

The effectiveness of satellite application is attained through building of satellite links. A satellite can work as a microwave repeater for earth terminal within the area covered by the satellite. The path used by a satellite is defined by satellite attitude and antenna design. The satellites revolve around the earth in elliptical orbits. Today the number of earth stations that want to transfer data over satellite has increased significantly. Satellite communications can also offer internet services which make it easy for satellite communication from the satellite equipment to the ground station. The length of the path taken by a satellite introduce propagation delays since the radio signals travel at the speed of light. The increased propagation delay of MEO and GEO orbits may cause throughput or quality degradation of service offered by the satellites. The earth stations maintain the satellite as they govern the subsystem. The sub-stations obtain their power from the sun through energy harnessing from solar panels which is connected to them.

Maintaining satellite in its specific orbit require a lot of efforts, as position is not static and changes due to some external forces that act upon the equipment. Satellites today have a wide range of application like navigation, military, monitoring, atmospheric conditions, radio, crop monitoring, internet services, television broadcasting e.t.c. This makes satellites networks an integral part of our daily life. This is not only due to their vast application but also due to their flexibility and the wide geographical coverage its offers more than terrestrial networks.

Satellite move around another body in a mathematically predicable path and thus, it has been successfully employed in the transmission of telecommunication, radio, internet and television signals.

The repeater circuit increases the signal strength that is received before re-transmitting it. The receiver functions as a transponder which changes the transmitted frequency band. **Figure 5** shows the signal is sent to space with uplink frequency while then its send back by the transponder with the downlink frequency.

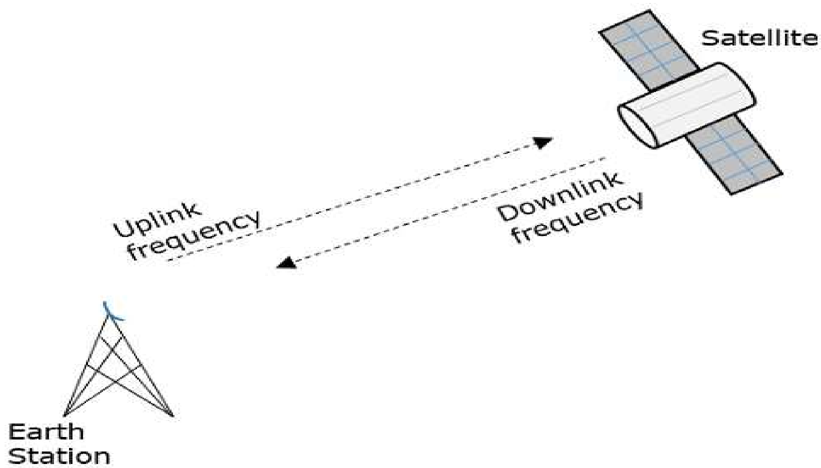

Figure 5: Downlink and Uplink Frequencies

The orientation of the satellite is explained by Kepler's 1st, 2nd and 3rd laws (Pelton et al, 2013). The first Kepler principle says that "every planet revolves around the sun in an elliptical orbit with the sun as its foci". This is shown in **Figure 6** and mathematically represented as:

$$e = \frac{\sqrt{a^2 - b^2}}{a}$$

Where ***e*** (electricity) represents the difference in ellipse shape rather that circle shape.

a (semi-major axis) represent two foci diameter joining with the longest diameter.

b (semi-minor axis) representing the shortest diameter drawn through the center.

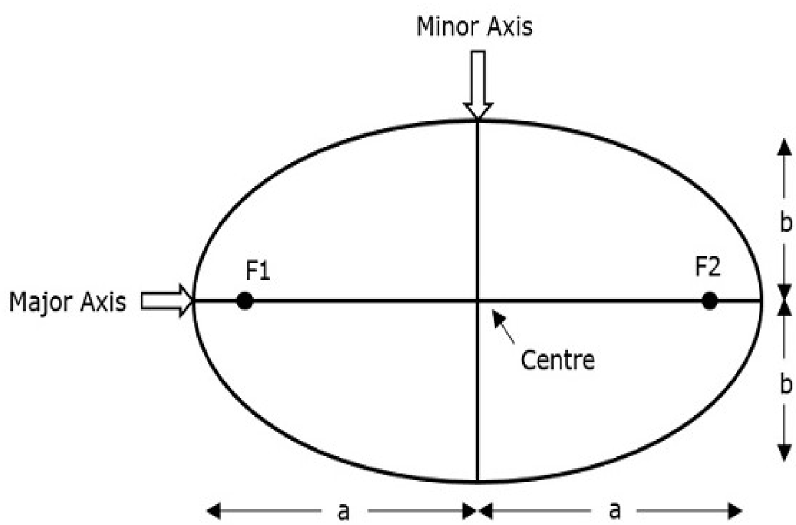

Figure 6: Kepler first law

From the above elliptical path, the eccentricity should line between 0 and 1 ($0<e<1$).

This is true because if **e** is 0 then the path is in a non-elliptical shape.

The second principle states that "each equal intervals of time, the covered area by satellite is equal with respect to earth centre". This is as demonstrated in the **figure 7** below:

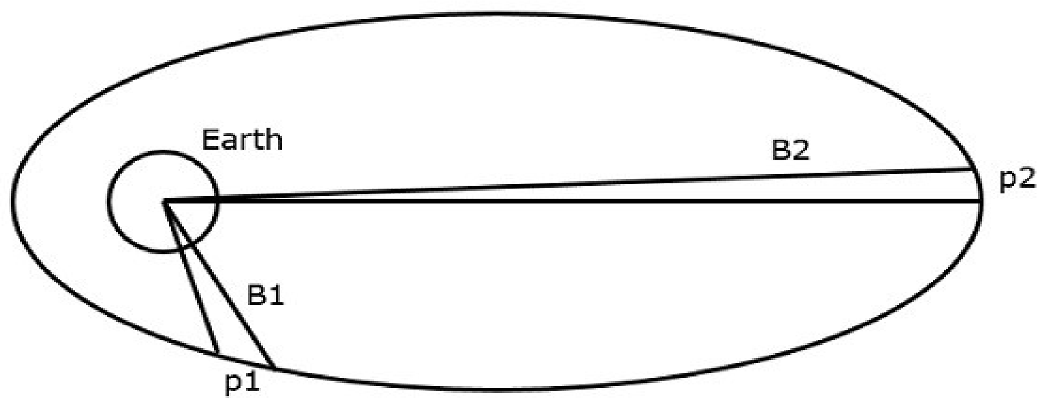

Figure 7: Second Kepler Law

If the satellite covers a distance P_1 and P_2 in time interval t, then their areas covered are equal. These areas are B_1 and B_2

The third Kepler principles states that "the square of the periodic time of the orbit is proportional to the cube of the mean distance between two bodies"

This is expressed mathematically as

$$T^2 \ \alpha \ a^3$$

This implies:

$$T^2 = \frac{4\pi^2}{GM}a^3$$

Where:

M is the addition of the mass of the sun and the mass of the planet.

G is the gravitational constant.

T is the orbital period

a is the elliptical semi-major axis.

3.3 Satellite Frequency Allocations

There are various frequency ranges used in satellite communications like the C band, X band, Ku band, Ka band and EHG band and V-band. To avoid multiple site transmission interference on the same frequency, the standard organizations and government agencies attempt to keep usage of the frequencies organized. These controls are done through government regulations. For instance, The United States Federal Communication commission holds regular frequency spectrum auctions. The government has placed some frequency regulations to control the use of the frequency allocations. Any unauthorized use of frequencies is considered an offense and can lead to a fine or jail time.

The earth stations frequencies are not regulated within their infrastructure. The stations require frequency bands to process and transmit data signals with no interference with other radio communication within their locality. These frequencies used by earth stations are usually in the same range as TV and radio broadcast which cause interferences. The interferences can be prevented by heavily shielding the radio shacks and the devices.

EARTHSTATION FREQUENCIES		
BAND	**FREQUENCY**	
IF	70 - 150 Mhz	
L	800 - 2150 MHz	
SATELLITE FREQUENCIES (Ghz)		
BAND	**DOWNLINK**	**UPLINK**
C	3.700 - 4.200	5.925 - 6.425
X (Military)	7.250 - 7.745	7.900 - 8.395
Ku (Europe)	FSS: 10.700 - 11.700 DBS: 11.700 - 12.500 Telecom: 12.500 - 12.750	FSS & Telecom: 14.000 - 14.800 DBS: 17.300 - 18.100
Ku (America)	FSS: 11.700 - 12.200 DBS: 12.200 - 12.700	FSS: 14.000 - 14.500 DBS: 17.300 - 17.800
Ka	~18 - ~31 GHz	
EHF	30 - 300	
V	36 - 51.4	

DBS = Direct Broadcast Satellite (Consumer direct-to-home Satellite TV)
FSS = Fixed Satellite Service (Geostationary Comms Satellites for TV/Radio stations and networks)

(Hz = Hertz, Mhz = Megahertz, Gh z= Gigahertz)

Table 1 : Frequencies Allocation Standards (Source: InetDaemon.Com, 2012)

The higher frequency bands give access to wider bandwidth. However, higher frequencies have vulnerable to degradation of signal which is caused by radio signal absorption by atmospheric snow, rain and sometimes ice, depending to the atmospheric conditions of the regions or the footprints of the satellite.

There have been increased satellite use which has led to congestion of lower frequency band. As a result, higher frequency bands are being studied to see how they can be used to reduce congestion.

3.4 Broadband Satellite Systems

Broadband satellite systems primary purpose if to offer a wide range of communication services to the society. Today, the society expect ubiquitous access to broad band telecommunication services. The growth of broadband satellite systems has been influenced by the need for fast internet and multi-media services.

The availability of broadband satellite services depends on orbital resources and radio spectrum availability. As a result, the geostationary orbit slots have C-band and Ku-band satellites. Satellite networks have superior remote access which offer broadband services to diverse groups in diverse locations. The higher remote access of the satellites means, they can support a wide range of broadband services and thus there is likelihood that earth stations will be able to enjoy terrestrial multi-media stations.

Some of new satellites architectures have incorporated ATM, TCP/IP and DVB protocols so as to support broadband satellite communication. The access to broadband services is influenced by the orbit of the satellite systems (Kırtay, 2002). When broadband services use satellites system as access and as main transport system there are various technical features that are made available. For instance, satellite give higher bands which broadband services requires to function. Broadband services operate in higher bands such as Ka and V. The services use unique solutions which must be compatible with the existing systems (Bem et al, 2000).

Provision of broadband service depends on availability of radio spectrum and orbital resources. The Geostationary orbits comprise of the C-band (4 - 6 GHz) while the Ku-band comprise of (12-14 GHz) satellite systems. Another high capacity Ka-band (20-30 GHz) has been introduced. The high capacity Ka-band system application that involves hundreds of GSO and NGSO satellites for International Telecommunication Union (ITU)

Deregulation of telecommunication services as well as the development of GSO satellite has led to changes in satellite communication structure, spectral and orbital resource congestion. This drives the exploitation of orbital configuration and new frequency band.There are various NGSO systems proposed for Ku-band and Ka-band frequencies. These include Sky Bridge, Ku-band Teledesic, Ka-band constellation of 80 satellites and low earth orbit constellation that consists 80 satellites.

3.5 Space Segment

This is one of the satellite three major component. The other component includes the ground and the user segment. Space segment has various satellite constellations. The space segment introduces the satellite fundamental governing laws that explain the earth's artificial satellite motion.

The GPS space segments consists of satellite constellation which transmit radio signals to users. The space segment satellites have a circular orbit with an average height of 1469 km and a 53 degrees inclination. The main functions of the space segments are transmission of the radio-navigation signals. The segment also stores and retransmits the segment. The signal stored and retransmitted is usually from the control segment. The satellite orbits types are compared, classified and presented from the MSC system perspective which describe how their performances are linked and covered.

The segment has satellite constellation as well as uplink and downlink satellite links which give it a 99.9% availability. The higher inclination angle means there is a lower blockage by various structures and terrain. Reduced blockage reduces the microwave interference. Also, the rain attenuation effects and multi-path reflection are minimised.

In a multicast packet switched network, the constellation satellites serve as nodes. The constellation has a satellite to satellite communication linking to ISL with RF ISLs dedicated for backup solutions. The inter-satellite communication joins other satellite and adjacent orbit plans as shown in **Figure 8** below:

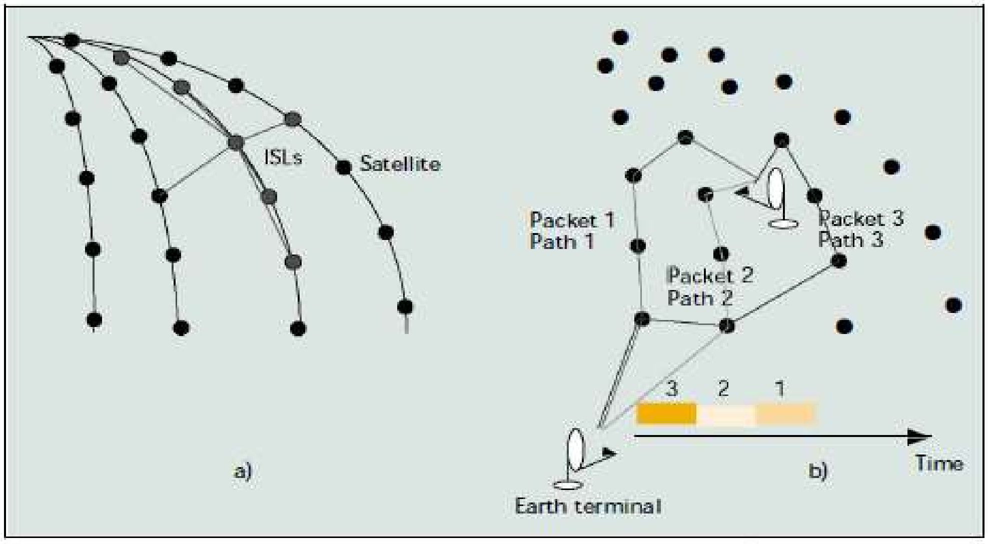

Figure 8: Teledesic concept of inter-satellite connection and adaptive routing

The space segment configuration includes the inter-satellite configuration to form network mesh that can resist faults, congestion and overlapping coverage. The inter-satellite configuration improves the reliability of the system. The system uses an on-board switch that acts as access and the core network. Geostationary satellite has almost the same technical configuration and appearance. However, there exist a few differences between the satellites. The satellite capacity and satellite operation services may differ. The uplink beams for fixed earth mapping allow direction of traffic to any satellite beam. The satellite beams provide geographic coverage to respective earth terminals. Satellite downlink beam is directed to particular points on the earth, based on satellite traffic needs from a satellite in charge for area coverage. The communication links among satellites is defined and disconnected as the satellite orbits, move in and out of communication range. Teledesic satellites use a propriety autonomous orbit definition system to offer specific constellation satellite positioning.

The propagation delay has helped in the research of having more satellite systems in different orbits closer to the earth stations. The information on propagation delay help control and manage beam between earth stations.

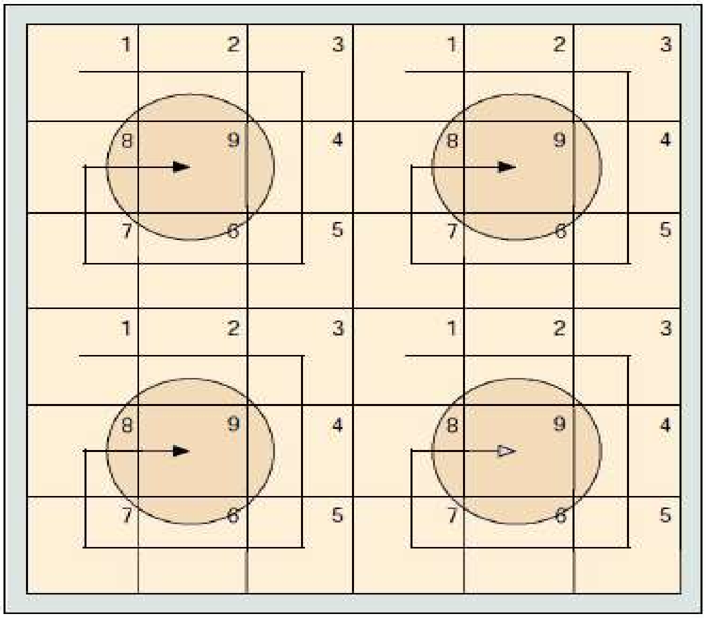

Figure 9: Space division between cell scan pattern and supercells

From **Figure 9**, it's clear that each supercell for a square has arranged in parallel bands to the equator. The link between satellite orbit positions and supercell geographical coordinates allow us to determine which satellite has the primary coverage to service the earth station.

3.6 Ground Segment

The ground segment is a network of user terminals and earth stations. The network offers various services and application to the end users. The ground segment requires a central point to facilitate the management and control of the network as well as connect remote internet content users to their sources.

The network of user terminals and earth stations are connected through a network of WAN data transmission gateways. This is a network of gates, user terminals and control systems (Bem et al, 2000). The network stations and gateways can be connected by the sky bridge system. The Sky bridge system ensure that there no differences between user terminals and gateways so as to allow smooth connection to required networks. Smooth connection minimize interference. This usually occur when the elevation angle is greater than the minimum elevation value. The swift connections of the terminals enhance the satellite throughput.

The base station controls the ground network traffic through the appropriate interfaces. The gateways sometimes serve as many cells and can be connected to terrestrial telecommunication infrastructure through another gateway. Connection to terrestrial infrastructure expand the system coverage to regions of low population density and poor terrestrial telecommunication infrastructure through one gateway. Ground segment terminals act as are interconnected gateways, that connects via existing networks, service provider networks and standards interfaces. The gateways form a Teledesic network boundaries between the satellite network and terrestrial end-users. Teledesic application system is independent, which make the interfaces more user friendly. The gateways do translate between the internal and standard protocols. The ATM, VSAT, and television indoor and outdoor units are some examples of the devices that exist in the ground segment.

3.7 Control Segment

The control segment comprises of the master control station (MCS), dedicated monitors, ground antennas and alternative master control station. The above components form a network of earth stations to monitor the velocity and shape of satellite orbits.

Control segment is responsible for proper functioning of the GPS system, activation of satellites, resolution of satellite problems, satellite passive monitoring as well as selective availability control and anti-spoofing. The control segment is an important segment in improving the quality of service. Control segment do all monitoring and uploading of distributed facilities around the globe. These facilities monitor the L-band signals, updating of the signal navigation messages, monitoring of the satellite health as well as satellite manoeuvre tracking.

The MCS process the MS measurements to approximate satellite orbits, clock errors, produce navigation messages and other measurement parameters. The MCS approximations and navigation messages are uploaded via GA.

3.8 Types of Orbit

There are four types of satellite orbits. They include Low-Earth Orbits (LEO), Geosynchronous Orbits (GEO), Medium Earth Orbits (MEO) and Sun-synchronous Orbits. The type of orbit chosen by a satellite system depends upon its application. The geostationary orbit has been employed in the direct broadcast of television services. The actual orbit chosen by a satellite system is influenced by the satellite orbit function and the the area it covers.

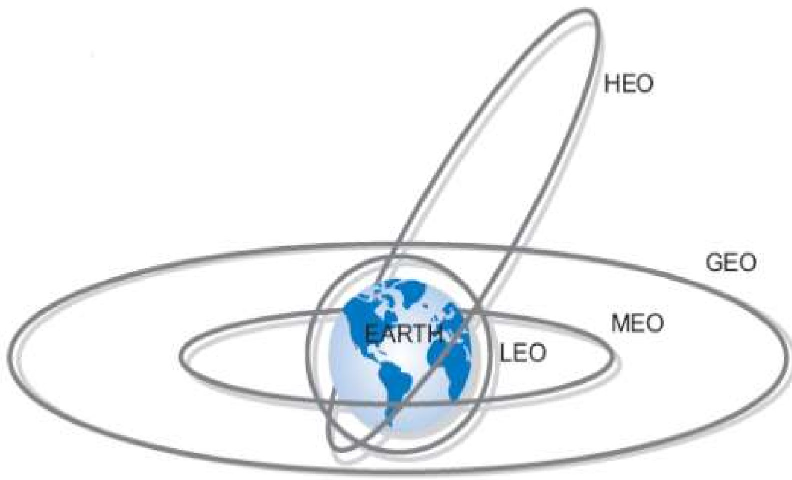

Figure 10: Types of Satellite Orbits (Source: New RAND report 2015)

3.8.1 GEO

GEO satellites orbit the earth at a height of 36000 km. The orbital period of GEO satellite is 24 hrs just like the rotational period of the earth. Geostationary satellites remain in the orbit above a fixed spot above the earth. However, not all geosynchronous satellites are geostationary. Some satellites have elliptical orbits. They drift to the west of east over a fixed point on the surface during a full orbit. Some other orbits are not even aligned to earth's equator and have orbital paths with inclinations. Geostationary satellites fly above earth's equator to remain at a specific spot above the Earth. Geostationary orbits are used by hundreds of televisions, communication and weather satellites.

3.8.2 LEO

Low Earth Orbits satellites occupy a space region of approximate 180 km to 2,000 km above the earth. LEO satellites move closer to earth surface and makes it easy and possible to make an observation for weather data collection and military purposes. Most of LEO satellites are for military reconnaissance satellites. They observe tanks from a height of 160 km from the earth. LEO satellites orbit faster and can complete one orbit in 90 minutes. However, when compared to GEO satellites, they usually have short lifecycles that last for weeks while GEO last for decades. The satellites are launched with small launch vehicles which place them into the orbit. A particular interest lies in this LEO orbit,as it is the orbit in which the proposed satellite game server will be the area of concentration. In **section 3.2**, we have seen the impact of minimum elevation angle to determine the area covered by one satellite. The area of the satellite coverage, orbit period *T,* and propagation delays are functions of the altitude *H.* The relationship is represented in **Table 2**, but first we show the mathematics between the functions. The angle between the most distant covered point and the satellite as seen from the centre of the earth, which is equivalent to the area of the size of coverage by the satellite is denoted as ⫛ . The relationship between the minimum elevation angle and ⫛ is given by

$$⫛ = \arccos(\frac{R}{R+H} cos\, E_{min}\ ) - \ E_{min}$$

Where;

R is the radius of the earth.

The orbit period and propagation delay depend on the satellite's altitude as well. The relationship between the orbit period *T* and the attitude *H* is given by:

$$T = 2\pi\sqrt{\frac{(R+H)^3}{\mu}}$$

where μ = 398, 600.5 km^3/s^2 is a constant equal to the product of the gravitational constant *G* and earth's mass M_e.

The gravitational constant *G* is given in the Newton's law of gravitation (universal gravitational constant). It is given as:

$$F = \frac{GMn}{r^2}$$

The value $G \approx 6.672 \times 10^{-11}\ Nm^2\ Kg^{-2}$

r is the distance between two points

The value for the earth mass $M_e = 5.9722 \times 10^{24}$ kg

The **Table 2** shows the different calculated results for their respective parameters.

H	**ɱ**(degrees)						**T**
Km	$E_{min(}$ degress)						*Min*
	0	10	20	30	40	50	
0	0	0	0	0	0	0	84
250	16	9	5	4	3	2	90
500	22	14	9	7	5	3	95
750	27	18	13	9	7	5	100
1000	30	22	16	12	9	6	105
1250	33	25	18	14	10	7	111
1500	36	27	20	15	12	9	116

Table 2: Table which shows that the footprint size. orbit period ***T,*** and propagation delays as a function of the altitude ***H.***

3.8.3 MEO

MEO satellites systems park between low and high flyers from about 2,000 km to 36,000 km. The Common use of MEO satellites is constellation such as GPS at an altitude of 20,200 km, Glonass at 19,100 km attitude and Galileo at 23,222 km attitude. Navigation satellites have various applications such as in Car GPS. The satellite communication also covers the north and south poles. The period of MEO orbit is 2-12 hrs (Rouse, 2007).

Some of MEO satellites orbit in perfect circles and therefore the satellites have constant altitude and travel speed. The satellites revolve in an elongated orbit where the orbital speed in lowest attitude (perigee) is higher than that of greatest attitude (Apogee).

Type	LEO	MEO	GEO
Description	Low Earth Orbit	Medium Earth Orbit	Geostationary Orbit
Height (Km)	300 - 1500	5000 - 12000	> 35000
Propagation Loss	Least	High	Highest
Advantages	Low launch cost Shorter round trip delay Small path loss Number of handover is the highest	Moderate launch cost Small roundtrip delays	Large coverage area covers about 42.2% of the earth surface Doppler effect is not a problem.
Disadvantages	Short satellite life Gateway cost can be expensive	Round Trips delay Greater path loss	Larger round-trip delays High cost

Table 2: The differences between LEO, MEO and GEO orbits.

3.8.4 Sun Synchronous Orbit

Meteorological satellites are placed in an helio-synchronous orbit. The satellites are in polar orbits which are designed in a way that the orientation of the satellite equipment is fixed in relation to the sun. This allows accurate weather forecasts by the meteorological stations. Various meteorological satellites orbit the Earth at 15 to 16 times a day.

The sun-synchronous satellites position is fixed. This is in relation to the sun. The satellites always have the same sun angle due to its fixed position in relation to sun. The sun rays land at the same area as result, thus allowing the reflection and radiation of the sun from the earth surface.

Sun-synchronous orbits facilitate convenient communication and data collection. The dawn to dusk sun-synchronous orbit trail the shadow of the earth as shown in **Figure 11**. When the sun shines on one side of the earth (daytime), the other side casts a shadow which is the night.

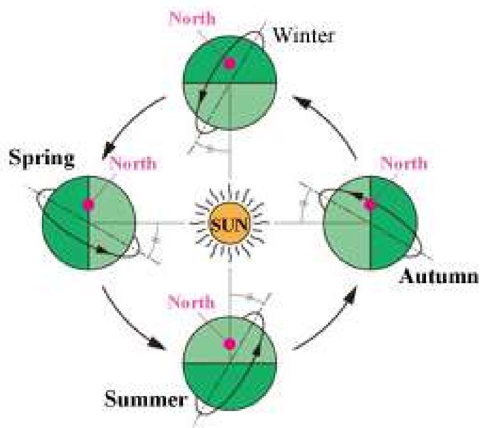

Figure 11: Sun-synchronous Orbit

3.9 Existing Satellite Systems

There is various existing satellite system that provides coverage or serves some specific functions in the entire universe. GEO and some LEO system do not offer coverage to arctic regions. However, some other satellites have been launched to allow communications to and from the Arctic. Different existing satellites system have different properties and commercial opportunities for public users.

Below is a list of messaging, tele and data communication satellite systems. Satellite systems for messaging is for only one-way communication and mostly used for tracking objects. Messaging systems are tailor-made and support only one type of service.

Gonets

This is a Russian messenger composed of 12 satellites system in 1400 orbit at an 82.5-degree inclination (Birkeland, 2014). The satellite data rate is 2.4 kbps to 64 kbps range. The satellites offer to track and monitoring services of remote equipment as well as telemetry sensor data. The *Gonets* constellation has 18 satellites of two different kinds.

Iridium

Iridium is an open planet-wide communication system that facilitates voice and data transmission services in the Arctic area. Through Iridium one can transmit one-way sensor monitoring data through short data burst service and two-way data rates of 2.4 kbps to 132 kbps (Manikiam et al, 2009).

Iridium Communication LC plan to launch a new range of satellites from 2015. The new range of satellite referred to as *Iridium NEXT* will be in operation by 2017.

OrbComm

OrbComm offers a machine to machine communications. It has a constellation of 29 LEO satellites at a height of 775 km. These offers to monitor of moving equipment. The satellites are usually small with a 50 kg weight. The constellation has no continuous coverage with a latency of up to 20 minutes. OrbComm system uses VHF and UHF frequencies. This is a type of messaging satellite system.

Argos

This is a monitoring and messaging system mainly for wildlife monitoring. The system facilitates one-way transmission for small messages from bits of around 32 to 256 bits. The received load is flown on meteorological satellites and data downloaded at various locations around the globe. Argos system uses UHF frequency.

Satellite-based AIS

Automated Identification systems receivers have been placed in orbit such as the Norwegian AISSat-1 mission that facilitates global AIS coverage. Some companies such as ExcatEarth, a Canadian Company operate the Satellite based AIS.

3.10 Benefit and Applications of Satellite systems

Satellite communications allow extension of business operations to the geographical remote environment. The satellites offer an essential means for tracking of remote facilities and real asset management in unguarded sites and platforms.

The companies that explore minerals and deal with energy use satellite-based sensor networks to facilitate the exploration of offshore projects. The transport sector has also benefited greatly as a result of satellite system as the cargo vehicles and trains use satellite communication for innovative mobile services (Roberts, 2018).

City administrators have turned to satellite communication to address the need for efficient energy requirements. Satellite system allows developing more sustainable cities. This as a result of satellite enhancement of smart grids which are extended to Remote Areas

Satellite communication serves as the backbone of communication. It helps keep the wireless ATMs and mobile point of sales across a broad geographical span.

Maintenance of high communication level of service reliability is important for the increased communication traffic. The career integrated providers, as well as satellite, provide need to work together for a reliable network.

There has been rapid emergence of innovative IoT which have been attributed to satellite enhancement of intelligent connection of devices. The satellite communication is expected to encompass billions of devices all the world with the scale for the demand of IoT ubiquitous between operators and carried integrated services.

Terrestrial is expensive to deploy in some remote regions. Satellite service is cheaper and more affordable.

4 Design Concepts

4.1 A prototype design

The design of the satellite game server is described, I assumed that the prototype to be a student satellite project. The system was designed by studying existing and future satellite communication concepts as discussed in **chapter 3** and the networking concepts in **chapter 2**. The satellite game server system will have three main functions, (1) To transmit a tracking signal, (2) send and download processed request to the ground station and (3) to receive request from a ground station.

Game users meet their specific game services needs through single dedicated server. The ideology as seen so far in this thesis will offer a dedicated game server type solution launched in the satellite. Customization of server specifications is in accordance with the clients' requirements. This type of game server solution has some benefits such as flexibility, increased speed, and control from the earth station. There is possibility to create additional space for future and the economic cost associated with the management of the server build facility is eliminated. These functions make it a typical satellite communication system. The basic configurations of the satellite game server are that it is connected by a radio frequency channel to the satellite game server equipment launched in space, with an uplink from the earth station to the satellite and a downlink from the satellite to the earth station. A radio frequency link is a modulated carrier conveying information. Basically, the satellite receives the uplinked carriers from the transmitting earth stations within the field of view of its receiving antenna, amplifies those carriers, translates their frequency to a lower band in order to avoid possible output/input interference, and transmits the amplified carriers to the stations located within the field of view of its transmitting antenna. It is important to note that to reduce the propagation delay of these transmitted data to and from the satellite, I propose that the satellite game server will be launched in the LEO orbit. I will discuss about the important system requirements in this section.Figure 12 below shows they proposed a prototype design, where a dedicated game server is mounted on the satellite equipment.

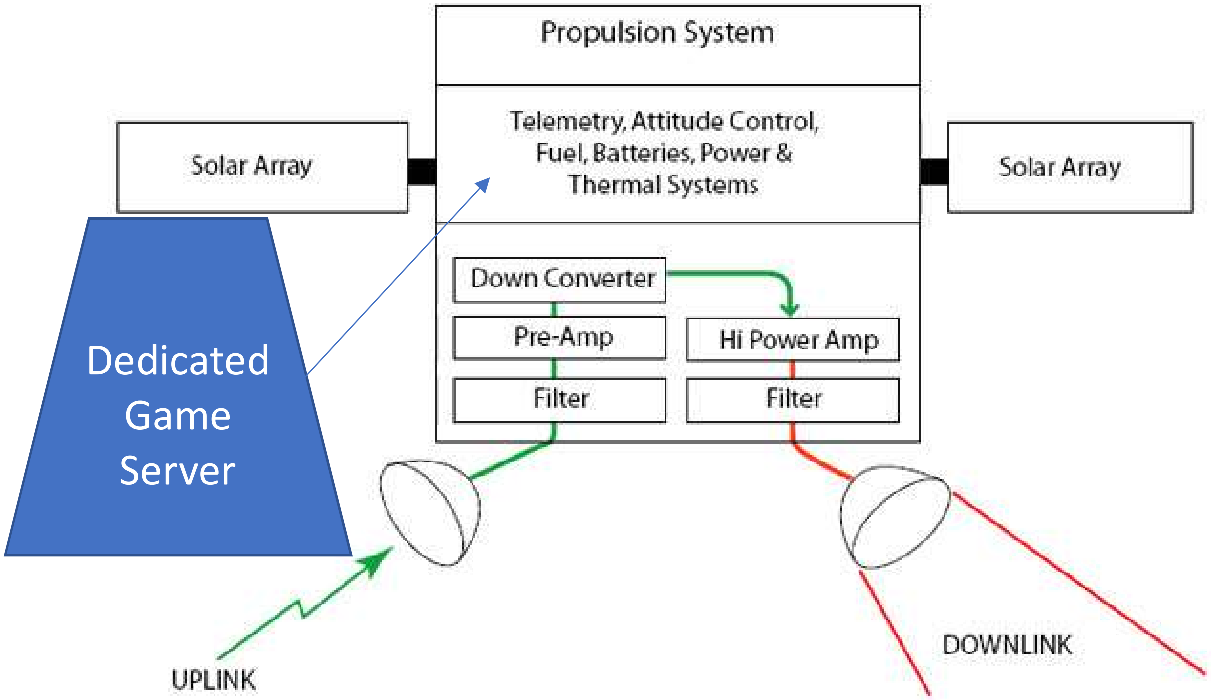

Figure 12: Proposed Prototype Design of the Satellite Game Server

Beacon

A *beacon* can be defined as a tracking signal that makes it possible for an operator at the ground station to locate and find the position of a satellite equipment moving in space. The tracking signal is normally transmitted periodically and automated to the ground station, this transmitted signal helps the operator at the ground station to be able to know the position of the satellite game server in space and maintain optimal positioning of the equipment (Ghazvinian et al, 2000). It also carries vital information on the status of the equipment to the ground station operator such as internal temperatures, battery conditions etc.

Frequency Band

The satellite game server will operate in the Ku band and C band frequencies. According to the frequencies regulations in place, the C- band which has an advantage for having lesser issues from rain attenuation, can be used to cover the game server regions in Asia, Africa and Latin America. It is important to note that the C-band also requires large antennas to operate effectively. The Ku-band will be used to cover game server regions in Europe and North America. Rain fade is a drawback in the use of this frequency band, but it uses smaller antenna. Interactive antenna sizes range from 75 cm to 1.8 m for Ku-band and C-band from 1.8m to 2.4 m.

4.2 Issues

4.2.1 Link Budget Analysis

In this chapter, an overview of applicable parameter in the communication link. The analysis of these key applicable parameters is used in a link budget calculation to determine the quality of the information content delivered. The link budget calculates the gain and loss of a RF signal from the modulation in the transmitter to the demodulation in the receiver. From the calculations, result can be represented in several parameters, as a measure of the quality of service. In this satellite game server network, it will be typically expressed as bit error rate (BER) of 10^{-7}. This guarantees an acceptable quality for digital voice and video communications.

E_b/N_0

E_b/N_0 is the ratio of energy per bit and noise per hertz. One of the necessary parameter to check for a link budget analysis is to determine the required E_b/N_0 at the receiver input. E_b (J) is the energy per information bit and N_0 (WHz^{-1}) is the noise power spectral density. The required E_b/N_0 can be identified using graphs found in communication textbooks where:

$$f = E_b/N_0$$

$$f(BER, modulation\ scheme)$$

The E_b/N_0 is a normalized value of the SNR and it is common to use this value to compare digital communication links.

SNR

SNR is the ratio between signal power and noise power (*Ps/Pn*) at the receiver input. This measure is preferred when calculating link budget analysis for wireless communication systems to the E_b/N_0 value because the system uses power waves with infinite duration.

SNR is determined by two calculations, the received signal effect (*Ps*) and the received noise effect *Pn.*

From the SNR, one can determine the E_b/N_0 in the actual system using equation expressed below and thus determine if the required E_b/N_0 is met and subsequently if the communication link can meet the specified Bit Error Rate (BER) value.

$$\frac{S}{N} = \frac{P_s}{P_n} = \frac{E_b}{N_o}\frac{f_b}{B}$$

Where:

f_b = bit rate

B = bandwidth

If the calculated E_b/N_0 is equal to or greater than the required E_b/N_0 it is said that the link closes.

Bit Error Rate

BER is a measure of the quality of a communication link. The value indicates the statistical probability for a bit transmitted through the communication link to be received with the wrong value. E.g. a BER value = 10^{-8} indicates that only one in a billion bits transferred through the communication link will be received with wrong value. The BER value is dependent on the E_b/N_0 value at the input of the receiver.

EIRP (Effective Isotropic Radiated Power)

EIRP is the signal power level emitted from the transceiver. The EIRP is the sum of the effect supplied to the antenna and the gain in the antenna. The EIRP of the transmitting equipment is a factor to determine the merit of figure for the receiving equipment, which can help the designer to determine the type of the topology to be implemented in communications between different game servers. With references to the VSAT networks, designers can choose either a star-shaped network or a meshed network topology. The EIRP depends on the antenna gain, therefore the size of the antenna and the frequency are important parameters to deduce the EIRP at both the uplink or downlink. The values can be different in different frequency band.

It can be calculated as follows:

$$\text{EIRP} = P_T G_T$$

Where:

P_T is the power fed to the antenna

G_T is the antenna gain by the satellite equipment.

Transmitted Power

This is an important parameter in the link budget analysis, as the transmission of data from the satellite game server equipment which is in the satellite to the earth station will required some consumed power. In this thesis, we did not carry out any simulation or design, therefore it will be extremely difficult to estimate the transmitted power required for the system. It is ideal to compare similar satellite projects which has similar TT&C functions in published papers. There are two perspectives to the transmitted power which will be given: Firstly, the transmitted power where the satellite game server is a student pilot project(CUBESAT) and secondly as a commercial satellite communication system.

Klofas (2008) lists different communication systems used on various CUBESAT satellites used until 2008. The paper shows that except for one commercial CUBESAT all CUBESAT transmitted 1000mW or less. Taking into account some signal attenuation between the output of the High-Power Amplifier (HPA) and the antenna, we can state that the transmitted power from my first perspective (when the game server equipment is launched to space as a CUBESAT satellite) can be set at 1000mW or 30dB. For a commercial satellite system ,it can be estimated the the transmitter output power at uplink saturation is given as 33 dBW (Harris 1978)

Path Loss

Path loss is the total loss of signal power. Path loss is determined by;

- Free space path loss.
- Atmospheric attenuation.

Free Space Path Loss

This is caused by the reduction of flux density due to the distance the signal must travel and the ability of the receiving antennas to absorb the emitted energy.

Free space path loss is determined by

1. The maximum distance.
2. The frequency of the radio signal.

The maximum distance (d_{max}) sometimes referred to as the Slant range between the satellite and the ground station is determined by

1. The height of the satellite above the Earth's surface.
2. The minimum elevation angle on the ground station antenna.

As stated above, an important factor to reduce the free space path loss is to reduce the distance in which the signal has to travel from the satellite to the earth station. The maximum distance (d_{max}) can be calculated using equation :

$$d_{max} = \sqrt{(R + h)^2 - R^2 \cos^2 \vartheta} - R \sin \vartheta$$

Where
R = is the Earth's radius (R = 6378km)
h = the satellites height above the Earth's surface
ϑ = the elevation angle for the ground station antenna

From the above equation, we know that h = 35 786 km if the satellite game server is launched in the GEO orbit and h = 300 - 1000 km if the satellite game server is launched in the LEO orbit. This significant differences in the satellite height h, will impact on the reduction of the free space path loss and thus enhance information delivery to game users.

There is an assumption that the eccentricity of the orbit is close to zero. Due to terrestrial obstructions and thermal noise, the minimum elevation angle has a practical limitation between 5^o−10^o (Gordon et al, 1993). It is important to make sure the ground station antenna do not pick up interference within its location

Atmospheric Loss

Atmospheric losses include different phenomena that can lead to loss of a radio signal. These are:

1. Polarization mismatch loss.
2. Rain attenuation
3. Refraction

They should all be taken into consideration when making a communication link in a satellite network. However, atmospheric losses are much smaller than Free-Space Path Loss (FSPL) and should be considered in the analysis of the uplink/downlink path loss. For satellite communication using frequencies from UHF and above reduces this effect on the signal.

Noise

Thermal noise introduces noise power to a communication link. Thermal noise which is also known as *white noise* is calculated using the below equation:

$$P_n = kT_nB_n$$

where
k = Boltzmann's constant = 1.39×10^{-23}J/K
T_n[K] = the physical temperature of the object in Kelvin
B_n[Hz] = Noise bandwidth.

The noise figure of the components between the antenna and the receiver must be added to the noise power $\boldsymbol{P_n}$ at the receiver input to find the actual S/N ratio at the receiver input. There are several sources of electric noise sources that should be presented, since the equipment will compose of several CPU units (severs). Noise sources electrically connected to the satellite system might influence the transceiver circuit (like e.g. a switched power supply) and may reduce the S/N ratio. The effect of these kind of noise sources and other several noise sources should be analysed to reduce its contamination of the received carriers.

Delay

The response time would be measured as a difference between the time gaps when the first bit of the transmitted data message leaves the sender terminal to the instant the last bit of the message is received at the destination terminal for a data transfer service.

The response time of the satellite game server network would be measured as a difference between when the 'enter' key is pressed at the remote terminal and the first character of the response appears on the screen, for an interactive data, game event or an enquiry/response service. The propagation delay value can be determined from the relative position of the satellite with respect to the satellite game server at a given instant and the network topology used. It good to note that there will be several types of delay in the whole transmission of data. The satellite sever networks will cause a routeing delay (where routing between different game servers is used, since the d_{max} is smaller, the coverage is also reduced) which includes the propagation delay and processing delays as a result of the overhead to the signal by the communication protocols and the computing resources from the earth station. Overall, it is important to note that since the satellite game server will be a LEO system, the propagation delay can be assumed to be estimated like the Fiber-like propagation delay (Redding, 1999).

Bit Rate

The number of bits transmitted (usually in seconds) over a specified time is the bit rate of that link. With the calculations of the bit rate, we can see how effective the modulation is used in the system and further used estimate the traffics on the system, when active and vice versa. Data link transmitting at a high bit rate are more demanding for bandwidth and power than smaller data links with smaller bit rate.

It is of importance to differentiate between

1. Information bit rate R_b:

The speed at which bits of information are transmitted to the end users from the data source.

2. Channel bit rate R_c:

This is the actual bit rate on an active link, when the connection is said to active. The channel bit rate is more than the information bit rate because of the addition of error correction bits and signalling bits are that are carried along the link. This additional overhead to the data link, consume some bandwidth and there a good coded modulation type must be implemented. They can be represented as s*ymbols*, a group of bits or bit.

3. Average bit rate R:

Connections are used intermittently, thus not all links are active all the time. Having this in mind, on average when the link is active, the bit rate observed is greater than the bit rate when a data is being transmitted. Averaging may apply either to the information bit rate or to the channel bit rate.

THRU (Throughput)

THRU is the average rate at which a receiver receives information bits form a connection in the network. The throughput is a function of the information bit rate R_b and expressed in bits per second as shown in equation below:

$$THRU = R_b \qquad (bs^{-1})$$

The throughput cannot be more than the information bit rate (R_b) at which the source transmits bits of information into a network. When the information is passed to the data link, there is a flow of control (overheads, message loss, source blocking time) on the signal. The maximum throughput can be used to estimate the network load. As the game users continue to make request and an increase in the information sent over the network, the actual throughput will increase accordingly, however, after reaching a certain limit it will remain constant or may deteriorate (Ferrari, 1990).

Channel Efficiency

This is used to calculate the efficiency of the connection by comparing its throughput to the rate (R_b) at which information bits are transmitted from the source. It denoted by and calculated as shown below in equation:

$$\eta = \frac{(\mathrm{R_b})}{R_b}$$

Link quality and capacity

This is a summary of the necessary calculations for a data link. The link in consideration in this case is the kind that lies in between the transmission station, the satellite game server and the receiver earth station. Such a link is being made up of a single hop link with an uplink and a downlink. The quality of a signal should be taken into consideration in the case of link quality. The two types of signals in this case that at first the modulated carrier at the input to the receiver, with its uplink and downlink components, ends the link from the transmission station. Secondly the baseband signals is delivered (after carrier demodulation they are transmitted to user terminal). The user terminal has an earth station interface that ends all user –to- user links from the source device to the input device.

The $\left(\frac{\mathrm{C}}{\mathrm{N_0}}\right)_T$ ratio, measures the link quality of the radio frequency input of the receiver station.

- ***C*** represents the power of the received carrier
- ***N_0*** represents the power spectral density of noise.

The bit error rate (BER) measures the baseband link quality. BER is a function of the value of the (E_b/N_0) at the input of the receiver.

- ***E_b*** (*J*) is the energy for every information bit
- ***N_0*** (WHz^{-1}) represents the noise power spectral density

The value of E_b/N_0 of the measured link is related to the overall quality of the radio frequency link $\left(\frac{\mathrm{C}}{\mathrm{N_0}}\right)_T$ and the capacity of the link, measured by its BER

4.2.2 Economical Cost

The satellite game server will have to be economical viable, so that it can face the competition in the game industry where terrestrial, web or cloud servers are already in use. These other types of game servers will be strong contenders for the satellite game server provided that desired server reliability, response time, quality of service and throughput are achieved, we can compare both based on the cost per month. Every £1 of public/private funding invested in satellite communication technology generates downstream returns of £47 (ESOA). According to Maral (2003) in his book *VSAT Networks*, he showed with an elaborated cost budget, where he showed that over a five-year period the VSAT cost per month and concluded that the VSAT network is a cost-effective solution.

We have seen the success behind the VSAT business and how they have been a cost-effective solution in providing internet access in the telecommunication industry, I then will assume that the satellite game server also will be a cost-effective solution for the game industry. The VSAT networks is launched in the GEO orbit, while this satellite game server is proposed to be launched in LEO orbit, this difference is an advantage in the economical aspect, because it is easier and cheaper to launch an equipment in the LEO orbit. There are currently small launch systems in the LEO orbit currently in development with the budget cost for as low as $500,000 (Crisp et al, 2014). Considering the growth on the number of game users across different regions and the challenges with eco-friendly solutions, the proposed satellite game server is supposed to be cost effective at the long run, assuming the satellite game server cost and initial investment will be dependent on the number of game users it will server over a large distance.

However, there are some economic constraints that adds to the technology which includes the regulatory aspects: licensing, access to the space segment and permission for installation (local regulations).

4.2.3 Bandwidth Limits

An online game should have the ability to have a good bandwidth measurement per player. This will enable the player to still be on the game even at very low speed internet quality. There are several factors that should be in place on the satellite game server, so as to ensure a desired quality of game services. The refresh frequency, data storage for each player, handling events and the prediction of movements (in case of action required games) are some factors that takes a toll on the bandwidth limit of the server machine. All these factors if not handled properly by the machine can cause overloading of the server machine.

4.2.4 Overloading

Overloading – sometimes referred to as crowding – is the most challenging problem to solve when it comes to a client-server architecture. A high number of requests happening at the same time on a server may be more than its processing capabilities. Overloading can lead to loss of packages, increase in latency or may cause the server to crash.

A grid setup of the servers, which allows each server to communicate with its neighbours, offers one solution to this problem (Duong et al, 2007). The way this works is, by allowing a server that is close to its maximum load to transfer data to one of its neighbours that has a lower load. This transfer continues if the neighbouring server also nears its maximum load on and on until the system is stable. The downside to this method of propagation is that each server uses up part of its processing power to monitor the state of its neighbours. Instead of using all the processing power available to handle clients, some is used to be in continuous communication with its neighbours making each server a miniature master over them. Measured per machine basis, this loss of processing power is not that significant but when viewed over the entire system the loss is quite significant. Furthermore, latency to client layer will also be affected due to increased bandwidth usage of each server communicating with its neighbours.

Having a single master server over others that act as slaves is another alternative to this problem (Malarvannan et al, 2010). The way this system works is by having the master have a single role of overseeing the state of other machines and only handle data transfers from one machine to another. The slaves and not the master handle any incoming requests from clients. This method has an upper hand compared to the previous one in that all slave servers are equally connected. A single data transfer, in the case of overload in one of the servers, from one machine to another is sufficient to solve the problem with no propagation through others. Using this method, loss of processing power over the system remains static as a single machine takes care of that. On smaller scales, the first method may give better results in terms of processing power loss but on a larger scale, this approach is superior. However, this approach has a downside of its own, since the master is the only managing entity over the system; it acts as a bottleneck. Having this in mind, a good backup system should be in place since the master server may experience crashes or other fatal scenarios.

Having discussed the main layers of the proposed client-server architecture this presentation will now move a step further to offer a solution to deal with overloading scenarios, which will be present. From the options presented above, for a system that mostly focusses on player interaction, the most effective solution is the use of an overall master server. It falls under the notion of having a *closeness graph* (This graph is used by the master server in order to determine the most efficient way of transferring data between servers) that is frequently updated thus monitoring interactions between players. In an architecture where each system shares responsibility of the overall system (shared-responsibility system), this would not be possible. However, this approach has a drawback as discussed earlier, because of very high demands from the slaves or if an error occurs in the master, the whole system will be disrupted as the master acts as a bottleneck for the whole system. Load balancing, database layer division, classification of game users request, data distribution choice, fuzzy logics and Artificial Intelligence are several methods that can be implanted on the server network to reduce the effects of overloading.

4.3 Benefits

Flexibility

The satellite game server like most satellite networks have a huge advantage in that, the network can be expanded, new terminals can be added and in addition, new services can be accommodated without affecting the operation of the rest of the network. As a result, the performance satellite game server network is sensitive to the amount of traffic as this has a significant effect to the quality of the service delivered to a user. Allowing for more share capacity than initially planned in the hub and space segment is of critical importance. Putting into perspective today's business world of daily corporate restructuring and acquisitions, network growth beyond expected initial capacity must be orderly and modular. This ensures that a customer's potential growth in telecommunications is not constrained.

Distance-insensitive cost

Distance is not a factor in determining cost in satellite game server connection. To ensure services to a wide geographical distribution of game users, the game network operator is expected to have different sites housing dedicated servers. Therefore, cost savings are expected if the network displaces a large number of sites and a high geographical dispersion.

Low bit error rate

We can see that in today satellite networks, a BER rate of about 10^{-7} has been well achieved in satellite communications, even though that most of this satellite networks have existed in the geostationary orbit. At this bit error rate of less than 10^{-7}, there is a guarantee of an acceptable quality for digital voice and video communications. The proposed satellite game server will have a low error bit rate. A low bit error rate is a benefit because of it improves the quality of game experience.

Independence to earth events

The satellites are not influenced by events on earth, such as natural or man-made disasters and social or political events. The game satellite server can therefore be used as a backup sever to already terrestrial game servers, since it will continue to provide game services without been influenced by the activities of the local policy and the service can be supplied in difficult environments (e.g., mountain areas) and therefore has a speed advantage when it comes to rapid deployment of critical communications services

Environmental Friendly

This issue about world climate is becoming a big factor to consider in the engineering world. The main source of energy for the satellite game server will be solar energy, it obtains its operating power from the sun, through solar panels that are installed on the equipment. This is renewable source of energy for the technology. Most existing dedicated game server, that provide the same level of service over a territory, would require construction works that would increase the environmental pollution and electrical energy is mostly the source of energy to power this server and HVAC demands. All these consumes quite a large sum of electrical energy which are mostly generated by from power station with a perceived negative impact on the environment.

5 Summary and recommendation

5.1 Introduction

The role of satellites has changed from the traditional telephony and TV broadcast services to user-oriented data services. This trend is expected to continue in the future and therefore ongoing innovations will use smart satellites systems that will incorporate functions such as switching, buffering and beam switching in addition to signal reproduction. Satellite data services on existing GEO satellite systems, like VSAT, will continue to compete with the terrestrial options such as Telephone line and optical fibre links. Small and large LEO constellations are expected to become a candidate in the media market and in this orbit, we expect that the propagation delay which is a major problem for the satellite communications in the existing GEO satellite systems is solved. Latency eases voice and IP applications which is one of the advantages of the LEO satellite system, therefore raising a conclusion for the research, since the latency has been shown to decrease as stated above, then it is ideal to have a dedicated satellite game server as one of the functional satellite systems.

5.2 Future Works

The thesis topics requires a practical demonstration of ideas, probably as pilot project of launching a game server machine as a CUBESAT to space. From this pilot project, there can be a practical link budget analysis done to ascertain the feasibility of this technology. Interreferences is a major important topic in satellite communications, as the small size of antenna on the earth station causes interference in the radio frequency signal, a deeper research will be required on this subject.

The energy of the satellite game server aspect, as the main energy source of satellite systems is the solar energy this energy is in sufficient supply in the sun. The orbital period of the LEO orbits-based satellite systems will pass through Earth’s shadow almost in each orbit and will remain in Earth’s shadow for almost half of its period each time. Therefore, the use of batteries is necessary to provide power to the satellite system during the earth shadow, where the supply from the sun is near zero.

The ability to practically build and design a satellite game server which would withstand the physics of space manufacturing process and can be launched with the few existing launch vehicles needs to be studied and outlined. To analyse the performance degradation of the system in the space atmosphere conditions.

Finally, the economic, cost accounting of the whole technology would be analysed.

5.3 Conclusion

The background study and the overview of a satellite game sever was given in this thesis and their advantages and disadvantages. The basic parameters in the link budget analysis and mechanism which are like most satellite communications were discussed as well.

To conclude the thesis, I would highlight the benefits of the satellite communications which makes it desirable and feasible to have a satellite game server. The area of coverage is a good advantage in satellite base communication which far exceeds that of terrestrial system. The satellite communications are already providing game services to users and the speed to deliver new game services,as most online gaming are mostly released in several and subsequent version to the market is a benefit of satellite communication over that of terrestrial systems.We assumed and showed that is also possible to have a satellite - to - satellite communication ,therefore routeing links can be designed with great precision because the conditions between communicating satellites are more time invariant than those between two terrestrial wireless antennas. The cost of ttransmission is independent of distance, within the satellite’s area of coverage unlike the existing dedicated game server which requires constructing buildings in several regions and more cost will be incurred to cover as much area as satellite does. · Broadcast, multicast and point to point applications are already employed in satellite communication systems and will be improved with the future LEO satellite systems which will continue to offer a vvery high bandwidths or data rates · The environmental advantages and insensitive to man-made activities.

The thesis work has taken in consideration, of these advantages and the drawbacks and would predict that have a working satellite game server is feasible and a possible solution in the game industry.

6 References

Alecu V. (2012). *Developing a client-server architecture and minimizing data transfer for a massively multiplayer online game*. Utrecht, The Netherlands.

Beal V. (2017). *What is Client Server Architecture?* [Online]. Available: www.webopedia.com/TERM/C/client_server_architecture.html [Accessed: 13-March-2018]

Bem, D., Wieckowski, T., & Zielinski, R. (2000). *Broadband Satellite Systems*. Wroclaw University Of Technology.

Birkeland R. (2014). *An Overview Of Existing And Future Satellite Systems For Arctic Communication* . ESA Small Satellites Systems And Services Symposium.

Buyya R., Pathan A., Broberg J., and Tari Z. (2006). *A case for peering of content delivery networks* IEEE Computer Society, Vol 7 (10), pp 3

Crisp N., Katharine S., and Peter H. (2014). *Small Satellite Launch to LEO: A Review of Current and Future Launch Systems*. University of Manchester.

Ferrari, D. (1990). *Client requirements for real time communications services. IEEE Communications Magazine*, Vol 11, pp 65–72.

Ghazvinian F., Sturza M. A., Hinedi S. M., Sarrafan S. S., and B. N.Shah. (2000). *Low-earth orbit satellite acquisition and synchronization system using a beacon signal.* U.S. Patent 6 127 967.

Gordon, G. D., & Morgan, W. L. (1993). *Principles of Communications Satellites*. p.150

Harris R.A. (1978*). Transmission analysis and design for the ELS systems.* Proceedings of the

4th International Conference on Digital Satellite Communications, INTELSAT, Montreal.

Kırtay, S. (2002). *Broadband Satellite System Technologies For Effective Use Of The 12–30Ghz Radio Spectrum*. Electronics & Communication Engineering Journal.

Leavitt N. (2003). *Will wireless gaming be a winner?* IEEE Computer,Vol 36(1) pp 24–27.

Lu, F., Parkin, S., & Morgan, G. (2006). *Load balancing for massively multiplayer online games.* Proceedings Of 5th ACM SIGCOMM Workshop On Network And System Support For Games - Netgames '06.

Mani Malarvannan, and Ramaswany S. (2010*). Rapid Scalability of Complex and Dynamic Web Based Systems: Challenges and Recent Approaches to Mitigation*, IEEE International Conference on System Engineering.

Manikiam, B., Jayaraman, V., & Chandrasekhar, M. (2009). *Existing And Future Satellite Sytems For Marine Applications And Their Capabilities In The Indian Ocean Region*. Conference Proceedings On Engineering In The Ocean Environment.

Maral G. (2003). *VSAT Networks.* Second Edition John Wiley & Sons Inc.,

Maurina, E. (2006). *The Game Programmer's Guide to Torque: Under the Hood of the Torque Game Engine*. CRC Press, 2006.

Redding C. (1999). *Overview of LEO Satellite Systems.* International Symposium on Advanced Radio Technologies

Roberts R. (2018).*10 Benefits Satellite Communications Brings to the Iot*. [Online]. Available: Https://Blog.Bosch-Si.Com/Internetofthings/10-Benefits-Satellite-Communications-Brings-To-The-Iot/ [Accessed: 06-February-2018]

Roddy D. (2006). *Satellite Communications.* 4th ed. McGraw-Hill Professional. Chapter. 10.6.

Rouse, M. (2017). *What is monolithic architecture?* [Online]. Available: www.whatis.techtarget.com/definition/monolithic-architecture [Accessed:10-February-2018]

Rouse, M. (2007). *What Is Meo Satellite (Medium Earth Orbit Satellite)?* [Online]. Available: Http://Searchmobilecomputing.Techtarget.Com/Definition/Meo-Satellite [Accessed:10-February-2018]

Shkelzen Cakaj, Bexhet Kamo, Algenti Lala and Alban Rakipi. (2014). *The Coverage Analysis for Low Earth Orbiting Satellites at Low Elevation*. International Journal of Advanced Computer Science and Applications (IJACSA), Vol 5(6).

Spinellis D., and Androutsellis-Theotokis S. (2004). *A survey of Content Distribution Technologies.* ACM Computing Surveys, vol 36 pp 4

Srivastava, P. (2018). *What are the advantages of dedicated server hosting?* [Online]. Available: https://www.quora.com/What-are-the-advantages-of-dedicated-server-hosting [Accessed:18-February-2018]

Sun J., Hefeeda M., and Tu Y. (2015). *An Analytical study of peer to peer media streaming systems*. ACM Transactions on Multimedia Computing, Communications and Applications. Vol 1(4), pp 354-376

Ta Nguyen Bihn Duong and Suiping Zhou. (2007). *A Dynamic Load Sharing Algorithm for Massively Multiplayer Online Games.* School of Computer Engineering Nanyang Technological University, Singapore

Vaddadi P. Chandu, Karandeep Singh, and Magued Iskander.(2008). *Innovative techniques in instruction technology, e-learning, e-assessment, and education*. Pp 241–248. Springer Netherlands.

Werner M. (1997). *A dynamic routing concept for ATM-based satellite personal communication networks*. IEEE Journal on Selected Areas in Communications, Vol 15(8): pp 1636-1648.

YLE News (2017). [Online]. Available: https://yle.fi/uutiset/osasto/news/finlands_top_3_earners_in_2016_from_game_firm_supercell/9910878 [Accessed: 18-January-2018]