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Engineering

Implementation of NTRIP and Management System in NIGNET Network

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Dedication

I dedicate this thesis to "ABBA YAHWEH" my Elohim, who is Sovereign over all his creation, and has been orchestrating the course of my life. May all praises, honour and power be ascribed unto his "kadosh" Name, through the Power of HIS Truth in "YEHOSHUAH HA-MASHIACH" the Lamb of Israel. HalleluYAH!

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Abstract

Nowadays, several applications require knowledge of their position in real time in order to achieve its intended design result. Global Navigation Satellite System (GNSS) has proved to be the most effective and efficient way of positioning in a global scale, using a GNSS receiver, to determine ones position with an accuracy of few millimetres. However, for centimetre-level accuracy such as Precise Point Positioning (PPP) one must use differential mode (directly or indirectly). In case of differential position, in Post-Processing (PP) or Real Time Kinematic (RTK) observation, one uses the GNSS observations from nearby Base stations, of which the position is well known, to determine ones relative position. Whichever way, the observations need to be corrected either by PP or in real time correction method in order to achieve higher positioning accuracy. These corrections, in the case of RTK mode, are mostly GNSS pseudoranges (distance measurements), positional (ephemeris) data and models, like ionosphere. These are simultaneously measured to all satellites in view, and using the known position of the receiver's antenna from each satellite, the errors in the pseudoranges and models are calculated at both the Base and the Rover GNSS receiver stations. These errors are converted to correction data at the Base station and broadcasted to Rover GNSS receivers in real time. As several applications are emerging to solve many positioning problems, the need to improve positioning solutions in real time is increasing. However, issues of transmitting these real time correction data has been a matter of concern. This is because, the use of several methods of transmitting real time correction data like Frequency Modulation Radio (FMR) has proved ineffective in terms of cost, efficiency and coverage. The current advancements in Internet and telecommunication systems have attracted the interest of researchers in using Internet as a Communication channel for the distribution of GNSS correction data in real time. Networked Transport of RTCM via Internet Protocol (NTRIP), which is a protocol that supports the streaming of GNSS correction data via the Internet for real time positioning, appears to be one of the best solutions for GNSS real time correction data distribution, because of the improved availability and coverage of Internet.

This thesis focuses on the implementation of NTRIP protocol in NIGNET Network, which is a network of GNSS permanent stations in Nigeria, West Africa. It deals with the development of a management system for real time positioning services. A test bed approach, which was setup in Space and Earth Geometric Analysis Laboratory (SEGAL) was used during the implementation process. The BKG Standard NTRIP Caster, which runs on Linux Operating System was used in the implementation, and the management system was developed using the PHPStorm, Mysql, and NTC applications. The NTC application was developed in order to integrate the NTRIP system with the website which serves as a management system. The management system offers the administrator the flexibility to manage the NTRIP system, GNSS source generating data and users activities in a friendly web interface. In addition, a billing/payment mechanism integrated with PayPal online payment platform was incorporated in the management system. Furthermore, its viability was tested by carrying out test observations in RTK mode using Trimble R8 GNSS receiver and smart mobile phone. This was done by activating the Internet connectivity of the GNSS receiver using the smart mobile phone and configuring it to the mountpoint CLBR, which is a NIGNET station's mountpoint maintained by the NTRIP and Management System. Using the services of the NTRIP and Management System, real time correction data from CLBR station was able to be streamed to the GNSS receiver in RTK mode via the Internet.

So far the results of the preliminary test are not yet satisfactory in terms of accuracy, due to the distance, but logistic constraints did not allow us to do the planned tests within at most 40-50km from CLBR. Nevertheless, the NTRIP and Management System was able to perform its designed purposes and can be used operationally for observations nearer the Reference Stations.

Keywords

NTRIP, RTCM, NIGNET Network, GNSS, RTK, NTC, Real Time Correction, Management System

Extended Abstract

Hoje em dia, várias aplicações exigem o conhecimento da sua posição em tempo real, a fim de atingir o resultado pretendido de criação. Global Navigation Satellite System (GNSS) provou ser a forma mais eficaz e eficiente de posicionamento em uma escala global, usando um receptor GNSS, para determinar as posições com uma precisão de poucos milímetros. No entanto, para precisão de centímetros, como Precise Positioning Ponto (PPP) deve-se usar o modo diferencial (direta ou indiretamente). Em caso de posição diferencial, no pós-processamento (PP) ou observação Cinemática em Tempo Real (RTK), um usa as observações GNSS das estações de base próximas, de que a posição é bem conhecida, para determinar as posições relativas. Seja como for, as observações precisam ser corrigidas, quer por PP ou no método de correção em tempo real a fim de alcançar a precisão de posicionamento superior. Estas correcções, no caso do modo RTK, são na sua maioria pseudo GNSS (medições à distância), os dados de posição (efemérides) e modelos, como a ionosfera. Estes são medidos simultaneamente para todos os satélites em vista, e usando a posição conhecida de antena do receptor de cada satélite, os erros nas pseudo divisões e modelos são calculados, tanto a base e as estações de recepção Rover GNSS. Esses erros são convertidos para dados de correção na estação de Base e transmitido para os receptores GNSS Rover em tempo real. Como vários aplicativos estão surgindo para resolver muitos problemas de posicionamento, a necessidade de melhorar soluções de posicionamento em tempo real está aumentando. No entanto, as questões de transmitir estes dados de correção em tempo real tem sido um motivo de preocupação. Isto é porque, a utilização de vários métodos de transmissão de dados de correcção de tempo real como de frequência de modulação de rádio (FMR) demonstrou ser ineficaz em termos de custo, eficácia e cobertura. Os avanços atuais em sistemas de Internet e de telecomunicações têm atraído o interesse de pesquisadores no uso de Internet como um canal de comunicação para a distribuição de dados de correção GNSS em tempo real. Networked Transport of RTCM via Internet Protocol (NTRIP), que é um protocolo que suporta o streaming de dados de correção GNSS através da Internet para o posicionamento em tempo real, parece ser uma das melhores soluções para GNSS em tempo real a distribuição de dados de correção, por causa da melhoria da disponibilidade e cobertura de Internet.

Esta tese centra-se na implementação do protocolo NTRIP em NIGNET Network, que é uma rede de estações permanentes GNSS na Nigéria, na África Ocidental. Trata-se do desenvolvimento de um sistema de gestão para serviços de posicionamento em tempo real. Uma abordagem de ensaio, que foi instalado em espaço e Laboratório de Análise Geométrica Terra (SEGAL) foi utilizado durante o processo de implementação. A BKG Padrão NTRIP Caster, que roda em sistema operacional Linux foi usado na implementação, eo sistema de gestão foi desenvolvido utilizando o PHPStorm, MySQL e aplicações NTC. A aplicação NTC foi desenvolvido a fim de integrar o sistema NTRIP com o site que serve como um sistema de gestão. O sistema de gerenciamento oferece ao administrador a flexibilidade para gerenciar o sistema NTRIP, fonte de geração de dados GNSS e as atividades dos usuários em uma interface web amigável. Além disso, um mecanismo de cobrança / pagamento integrado com a plataforma de pagamento online PayPal foi incorporada no sistema de gestão. Além disso, a sua viabilidade foi testada através da realização de observações de teste no modo RTK usando receptor Trimble R8 GNSS e telefone celular inteligente. Isso foi feito através da activação da conectividade com a Internet do receptor GNSS usando o telefone móvel inteligente e configurá-lo para o CLBR ponto de montagem, que é ponto de montagem de uma estação NIGNET mantido pelo NTRIP e Sistema de Gestão. Usando os serviços

do Sistema NTRIP e Gestão, dados de correção em tempo real da estação CLBR foi capaz de ser transmitido para o receptor GNSS RTK no modo via Internet. Newpage Até agora, os resultados do teste preliminar não são ainda satisfatórios em termos de precisão, devido à distância, mas as restrições logísticas não nos permitem fazer os testes planejados no prazo máximo de 40-50km de CLBR. No entanto, o Sistema de Gestão de NTRIP e era capaz de realizar seus objetivos projetados e pode ser usado operacionalmente para observações mais próximas as Estações de Referência.

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List of Acronyms

AFREF	African Geodetic Reference Frame
AGMNIS	Annual General Meeting of the Nigerian Institution of Surveyors
APN	Access Point Name
ARIMA	Autoregressive Integrated Moving Average
BKG	Bundesamt für Kartographie und Geodäsie
BNC	BKG NTRIP Client
CDMA	Code-Division Multiple Access
CMR	Compact Measurement Record
CODIST	Committee on Development and Information Science and Technology
CORS	Continuously Operating Reference Station
CPF	Central Processing Facility
CPU	Central Processing Unit
DGNSS	Differential Global Navigation Satellite Systems
DGPS	Differential Global Positioning System
EDGE	Enhanced Data rates for GSM Evolution
EPN	European Permanent Network
EUPOS	European Position Determination System
EUREF	European Geodetic Reference Frame
FM	Frequency Modulation
FMR	Frequency Modulation Radio
GALILEO	Europe’s European Satellite Navigation System
GIS	Geographic Information System
GLONASS	GLObal NAvigation Satellite System
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Services
GPS	Global Positioning System
GSM	Global System for Mobile communication
HTTP	Hypertext Transfer Protocol
I/O	Input/Output
IGS	International GNSS Service
INS	Inertial Navigation System
IP	Internet Protocol
IRI	International Reference Ionosphere
IRNSS	India’s Regional Navigation Satellite System
ITRF	International Terrestrial Reference Frame
LAMBDA	Least-squares AMBiguity Decorrelation Adjustment
LBS	Location Based Service
MAC	Master Auxiliary Concept
MGN	Monitoring GNSS Network
MSM	Multiple Signal Messages

NCC	Network Control Centres
NIGNET	NIGerian GNSS Reference NETwork
NMEA	National Marine Electronics Association
NRTK	Network Real Time Kinematic
NTC	NTrip Connection
NTRIP	Networked Transport of RTCM via Internet Protocol
OS	Operating System
OSGoF	Office of the Surveyor General of the Federation
OSI	Open Systems Interconnection
PC	Personal Computer
PHP	PHP: Hypertext Preprocessor
PP	Post-Processing
PPP	Precise Point Positioning
RTCM	Radio Technical Commission for Maritime Services
RTK	Real Time Kinematic
RTSP	Real Time Streaming Protocol
SEGAL	Space and Earth Geometric Laboratory Analysis
SPP	Serial Port Profile
SV	Space Vehicle
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
UMTS	Universal Mobile Telecommunications System
UNECA	United Nation Economic Commission of Africa
VPN	Virtual Private Network
VRS	Virtual Reference Station
VSAT	Very Small Aperture Terminal

Chapter 1

Introduction

Global Navigation Satellite System (GNSS) is widely used to determine ones position with an accuracy of few millimeters . However, for centimetre-level accuracy such as Precise Point Positioning (PPP) one must use differential mode (directly or indirectly). In case of differential position, in Post-Processing (PP) or Real Time Kinematic (RTK) observation, one uses the GNSS observations from nearby Base stations, of which the position is well known, to determine ones relative position. Whichever way, the observations need to be corrected either by PP or in real time correction method in order to achieve higher positioning accuracy, because several distortions in the GNSS signals caused by the atmospheric effects and other error sources are mitigated, when the difference between the GNSS signals are computed and corrected. These corrections are mostly GNSS pseudoranges (distance measurements), positional (ephemeris) data and models, like ionosphere. These are simultaneously measured to all satellites in view, and using the known position of the receiver's antenna from each satellite, the errors in the pseudoranges and models are calculated at both the Base and the Rover GNSS receiver stations. These errors are converted to correction data at the Base station and transmitted to Rover GNSS receivers in real time, in the case of RTK observation. Therefore, this creates a new problem that the GNSS correction data at the nearby stations need to be sent to the GNSS Rover user's.

The current scenery of telecommunications, characterized by several technologies that are offering many ways to make connection between users and/or application servers over the Internet [SX90],[DM92], have attracted the interest of researchers in using Internet as a communication channel for the distribution of GNSS-data in real-time. This is to help improve the accuracy of GNSS positioning solutions in real time. Networked Transport of RTCM via Internet Protocol (NTRIP) is an application-level protocol, developed by "Bundesamt für Kartographie und Geodäsie" (BKG) Germany, which supports the streaming of GNSS correction data via the Internet. NTRIP became the world standard GNSS correction data streaming protocol in year 2004 [RTC04a],[Thi08], and currently the most widely used protocol in terms of distribution of GNSS correction data for RTK purposes. These correction data are aimed at improving the GNSS positioning accuracy in real time. NTRIP is a generic, stateless protocol (i.e. it does not require the server to retain session information or status about each communications partner for the duration of multiple requests) based on the Hypertext Transfer Protocol (HTTP/1.1), whose objects are extended to GNSS data streams [RBL99]. It enables the streaming of Differential Global Positioning System (DGPS) or RTK data correction formats for the stationary and mobile GNSS users via the Internet. This could be made possible by using GPRS or other Internet communication technologies to enable the Internet connectivity of the GNSS equipment. It also permits simultaneous PC, Laptop or receiver connections to a broadcasting host [RFC05].

Since NTRIP became the world standard protocol for GNSS data streaming in year 2004 [Thi08], [Rui14], several investigations all over the world, especially in Germany, indicate that the protocol is reliable, efficient and cost effective for real time GNSS-data distribution through the Internet, provided that, there is good Internet and mobile coverage [Hje02].

It is on this backdrop that it becomes obvious that this protocol could be implemented in NIGNET Network.

NIGNET, which refers to Nigerian Permanent GNSS Network, is a network of GNSS permanent reference stations, installed and managed by the Office of the Surveyor General of the Federation (OSGoF) Abuja, Nigeria West Africa, in collaboration with Space and Earth Geometric Analysis Laboratory (SEGAL), Portugal. Nigeria is a country in West Africa with latitudinal and longitudinal extent of 4° to 14°N and 2° to 15°E respectively. It covers a total area of about 923,768 sq.km. It shares land borders with the Republic of Benin in the West, Cameroon in the East and Niger Republic in the North. In addition, its coast lies on the Gulf of Guinea in the South and it borders Chad to the North-East [Wik15],[Map14].

NIGNET Network provides a continental reference system that is consistent and homogeneous with the International Terrestrial Reference Frame (ITRF), as a basis for the national reference network [BJG10]. The initial motivation for the implementation of NIGNET was to contribute to the African Geodetic Reference Frame (AFREF) project, in line with the United Nation Economic Commission of Africa (UNECA) recommendations, through its committee on Development, Information Science and Technology (CODIST) [BJG10],[Hus11]. As at 2015, NIGNET Network consist of 15 Continuously Operating Reference Station (CORS) also referred to as Reference Stations in this work [SEG15]. Although, there are 4 additional stations installed by various stakeholders which are undergoing evaluation by OSGoF before incorporating them to the Network. The geographical location of Nigeria and these CORS are shown in Figure 1.1.

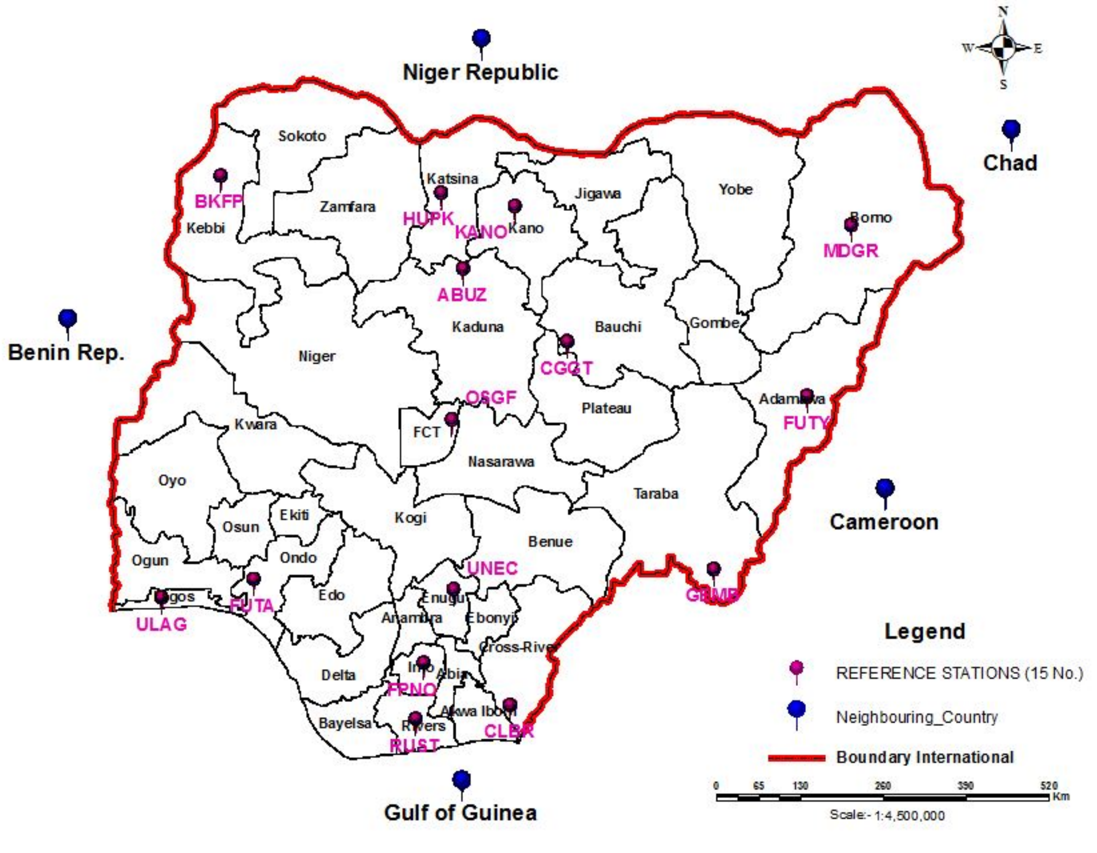


Figure 1.1: Geographic Location of Nigeria and NIGNET Stations

NIGNET provides GNSS data used for high accuracy positioning and navigation, for surveying and mapping, environmental management, geodynamics, scientific researches and other practical uses. There are several modes data from NIGNET suppose to be made available to the end-users, for optimal utilization of the network, such as PP and RTK modes. However, only data for PP is currently being made available to the users via the NIGNET website. This have seriously contributed to the underutilization of the resources invested in the installation and management of the network, and consequently undermined the development of the country in geospatially related research and application areas. Although, GNSS-data could be distributed to the end-users via Frequency Modulation (FM) radio [RFC05],[Hje02], but the coverage, availability, reliability, cost of implementation and management of the infrastructures that support this, are of major concern.

This thesis "Implementation of NTRIP and Management System in NIGNET Network" uses NTRIP protocol for streaming and distribution of GNSS data through the Internet in real time, for correction of RTK positioning. It also provides a website, which was integrated into the NTRIP system to form a management system, that improves the administrative management of the system. In addition, it offers a billing/payment mechanism which was integrated with PayPal online payment platform.

1.1 Motivation

The current challenges in the infrastructural development, environmental management, security issues and geospatial research works in the world, especially in Nigeria, have necessitated high demand for reliable and accurate positioning solutions in real time, for effective and efficient resource management.
Although, the Federal Government of Nigeria has made a reasonable effort through OSGoF by implementing NIGNET, which is a GNSS network of CORS [BJG10],[Won05], to address several geospatially related application issues in the country, and to contribute to the AFREF project. However, data streaming and distribution to the numerous end-users have been a serious issue to manage, therefore, only data for PP are being currently made available. This has undermined the progress of several sectors of the economy such as surveying and mapping, GIS, construction projects, commercial Agriculture, Mining and Location-Base Services (LBS), that usually require real time GNSS corrections to improve their positioning accuracy.
The increase demand for the GNSS-data to be made available in real time, was evident at the 2012 Survey Co-ordination Art Conference and 2013 Annual General Meeting of the Nigerian Institution of Surveyors (AGMNIS) held in Nigeria, which comprises of Surveyors, Engineers, Researchers, private sectors and the Military.

In trying to address this issue, several real time GNSS data distribution techniques have been studied, such as Frequency Modulation Radio (FMR) and repeaters in a network-based DGPS using a number of interconnected DGPS reference stations [DR03]. In general, they all operate at different coverage-ranges and are either not efficient or not cost-effective in their implementations [FK06],[RFK10]. With the current wider coverage of Internet services, development and adoption of a protocol that handles GNSS-data streaming and distribution via the Internet in real time, and advancement in mobile communications, study of the possibilities of using NTRIP protocol to stream and distribute NIGNET GNSS data corrections through the Internet in real time, to improve the RTK positioning solutions, happens to be of great interest.

1.2 Research Aims and Objectives

The main aim of this thesis is to implement the NTRIP system that streams and distributes through the Internet, GNSS data corrections in real time from the NIGNET Network to RTK GNSS users, to improve their positioning accuracy.
Secondly, to integrate the NTRIP system to a web interface, in order to provide a management system for the users and the administrator, that would enhance the effective and efficient service delivery.
In addition, to try and provide some necessary steps and background knowledge to anybody wishing to implement the NTRIP services on their own, even with little or no understanding about the protocol.
To achieve these aims, the under listed objectives were performed:

1. An extensive literature review was carried out in order to investigate NTRIP system architecture and components, along with positioning technology and their techniques, in particular GPS/GNSS (see chapter three).

2. Examines several NTRIP software and implementation of NTRIP services in some countries, in order to adopt a functional prototype of real time GNSS-data distribution techniques.

3. Investigates the existing network and services currently in NIGNET visa-vices the hardware and software requirements for the implementation of NTRIP system in the network.

4. Develop a website and integrate it into the NTRIP system, for the users and administrative management of the system.

5. Provide a billing and payment system in case of future commercialisation of the services.

6. Carry out field experiment in Nigeria, using the implemented system to test and confirm its viability.

1.3 Research Methodology

Having studied the conceptual bases of the NTRIP system and various scenarios this system has been used, such as TrigNet in South Africa [C.M07] and SIRGAS in South America [MN09]. A test-bed and field experimental approach was adopted in the implementation method. This is to ensure that every implementation issues were identified and corrected before actually deploying the NTRIP and Management System into use.

The test-bed was setup in SEGAL, and the Standard NTRIP Caster was installed and configured with the mountpoints of three selected NIGNET CORS stations (CLBR, FUTY and HUKP) that have been consistently online during this research work.

A website was developed and integrated into the NTRIP system, to provide a management system, in order to improve the management process.

NTRIP Client was installed and configured in a Laptop PC. In addition, Trimble GNSS-R8 inbuilt NTRIP Client was equally configured for RTK survey during the field experiment. These were used to check the streaming of Radio Technical Commission for Maritime Services (RTCM) message format, which is a GNSS data correction formats, via the Internet for RTK positioning correction. RTCM refers to an international standard organisation consisting of several Special Committees, each charged with the responsibility of addressing a particular navigational issues. For example, Special Committee (SC) 104 on Differential Global Navigation Satellite Systems (DGNSS) is responsible for providing standards that are often used in DGPS and RTK operations [RTC13a],[RTC97].

The system was tested during the field experiment, by enabling the GNSS receiver's Internet connectivity using Bluetooth from smart phone that supports Serial Port Profile (SPP) and/or Tethering and Portable Hotspot. These are functionalities in telecommunication devices that allow one to share its Internet data connection in a wireless form with other devices that are nearby and also support this services.

The obtained data was analysed to ascertain the viability of the implemented system. Having certified the performance of the NTRIP and Management System test-bed setup, the system was put into operational use.

1.4 Contribution to Knowledge

First and foremost, this research work have tried to proffer solution, with respect to NIGNET Network and real time correction data streaming and distribution issues. This would help to improve the accuracy of GNSS positioning in real time, for several surveying and mapping activities, and other sectors of the Country's economy that require real time positioning solutions.

The implemented system could help to improve several sectors in Nigeria, most especially, in commercial Agriculture, in the area of research works in the education sector and in the industrial sector, such as mining and construction work. Furthermore, other contributions of this research work could be summarized as follows:

i. The NTRIP and Management System would enhance the BKG Standard NTRIP Caster's management interface, by providing an integrated web interface that has statistical analysis among other functions, which seems more user friendly. In addition, the integration of a payment mechanism would help the billing/payment management by the administrator, when the system is deployed into commercial use.

ii. This thesis might be of help, in providing basic background knowledge and a guide for a novice wishing to implement the NTRIP system for their own use.

1.5 Thesis Structure

This thesis consists of six chapters, the first chapter was an introduction, which contains the problem statement, the aims and objectives, the motivating factors and the contribution to knowledge. The remaining chapters are described as follows:

Chapter 2 presents the state of the art with respect to this research study. It examines several contemporary work carried out in this field aimed at acquiring both technical and theoretical background knowledge.

Chapter 3 presents the concept of NTRIP protocol and its use for streaming and distributing GNSS correction data in real time via the Internet. It also examines the basic component units that make up a functional NTRIP Caster system, and few implementation scenarios of the system.

Chapter 4 highlights the hardware and software required for the implementation of the research work and further describes the steps taken for the actualisation of the NTRIP and Management System implementation.

In chapter 5, the field experiment test exercise and the result analysis aimed at confirming the viability of the implemented system is presented.

Finally, in chapter 6 the conclusions and recommendations are presented.

Chapter 2

NTRIP, GNSS, GNSS Errors and NIGNET

2.1 Introduction

Over the years, Networked Transport of RTCM via Internet Protocol (NTRIP) has been considered as one of the fundamental techniques for the streaming, management and dissemination of real time GNSS-data correction through the Internet. This is aimed at improving the accuracy of Global Navigation Satellite System (GNSS) positioning in Real Time Kinematic (RTK) mode. The concept of NTRIP is used to indicate services, where GNSS data streaming and distribution through the Internet are important parameters, mostly in real time positioning.

Looking at it from the technical perspective, the implementation of this protocol in a network could be seen as "NTRIP services", which makes it to be a compounded system, consisting of several component systems for it to function. These component systems are: technology for position determination (Satellites), Internet communication technology and application (Internet and NTRIP), and the GNSS-data providers and Clients, such as GNSS Reference and Rover GNSS receiver stations respectively.

Based on this, NTRIP implementation could been refer to as "NTRIP System". Therefore, in most cases in this work, the term is mostly used. Figure 2.1 illustrates the inter-relationship of the component systems of an NTRIP system.

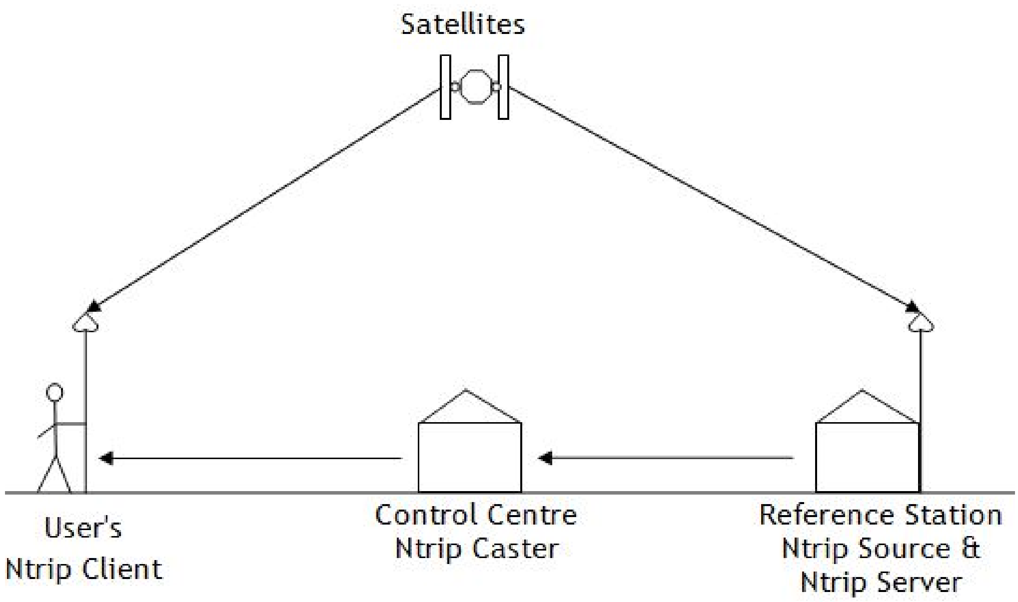


Figure 2.1: Schematic Inter-relationship of NTRIP Component Systems

In Figure 2.1, the Satellites in the space transmit GNSS positioning messages to both the GNSS permanent Reference station and the users with GNSS Rover equipment. The Reference station acts as the NTRIP Source and NTRIP Server, or as the NTRIP Source only, depending on the Reference station GNSS equipment manufacturer's support and the design of the network operation. Where it acts as NTRIP Source only, it requires an NTRIP Server running on a Personal Computer (PC), configured and connected to the Reference station receiver via serial or Universal Serial Bus (USB) connection. Only if you want to have a local server. Whichever way, the Reference station NTRIP Server can be configured to send real time GNSS correction messages for RTK/DGPS through the Internet to a mountpoint in the NTRIP Caster at the control centre which corresponds to the mountpoint at the Reference station NTRIP Server.

On request, the NTRIP Client at the User's Rover GNSS receiver station connects through the mountpoint and receives real time corrections from the NTRIP Caster through the Internet. The NTRIP Caster is the NTRIP component that receives GNSS correction data from the Reference receivers and distributes it to Rover GNSS receiver users, in real time. This is aimed at improving the accuracy of their RTK and DGPS observations in real time. This Internet connection is established either via Bluetooth from a smart phone or through a serial connection to the Rover GNSS receiver from a PC that is Internet enabled, and running NTRIP Client. These data exchange between the Reference station NTRIP Server, Rover GNSS station's NTRIP Client and the Control Centre's NTRIP Caster make use of the popular Client-Server mode of communication approach, where both the NTRIP Server and the NTRIP Client are acting as the Client side (service requesters), while the NTRIP Caster is acting as the Server side (resource or service provider).

The idea of NTRIP GNSS data correction method is based on the assumption that, both the Reference receiver(s) and the Rover GNSS receiver are within the same vicinity and must have suffered similar GNSS errors during observations, and since the reference stations already know their position, therefore, its GNSS correction data are used to improve the positioning of the Rover GNSS receiver relatively. This is done by sending GNSS correction data from nearby reference station(s) to the Rover GNSS receiver in real time via Frequency Modulation (FM) radio or through the Internet using NTRIP. These corrections which are mostly GNSS pseudoranges (distance measurements), positional (ephemeris) data and error models, such as ionosphere, that are simultaneously measured to all satellites in view, and using the known position of the receiver's antenna from each satellite, pseudoranges errors are computed at both the Base and the Rover GNSS stations. These errors are converted to corrections at the Base station and subsequently transmitted to Rover GNSS receivers using the NTRIP system at the central processing center as illustrated in Figure 2.2 below.

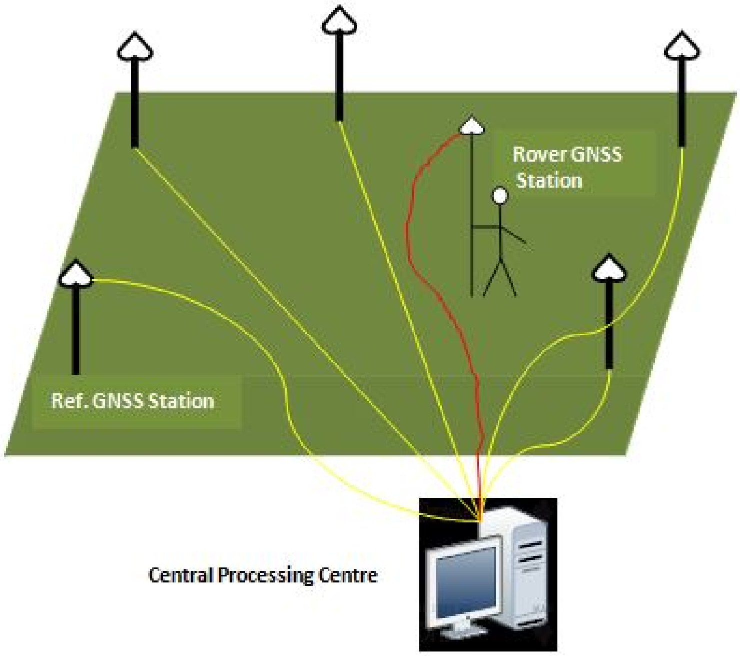


Figure 2.2: Concept of NTRIP system

2.2 NTRIP Component Systems Overview

NTRIP, which stands for "Networked Transport of RTCM via Internet Protocol" is a protocol designed to handle the receiving and distribution of GNSS correction data from the Reference stations to the stationary or mobile GNSS receivers over the Internet, in real time [RTC97]. This is aimed at improving the positioning accuracy of DGPS and RTK applications. As observed in section 2.1, a functional NTRIP services is viewed as a combination of multiple independent component systems brought together via the Internet and satellite signals.

This NTRIP system consists of NTRIP Sources which generates data streams at a specific location and NTRIP Servers which transfer the data streams from a source to an NTRIP Caster which is the major system component. Finally, NTRIP Clients access data streams of desired NTRIP Sources from the NTRIP Caster [Duv06],[L.L11a]. It is important to note that, when streaming GNSS correction data using NTRIP Client running on a PC, although you may be receiving data streams from many mountpoints, but the NTRIP Client can only output correction data of only one mountpoint of an NTRIP Source to the Rover GNSS receiver. In the same vain, the inbuilt NTRIP Client in the Rover GNSS receiver also allows you to select only one mountpoint at a time. This data streaming component relationship is illustrated in Figure 2.3 below.

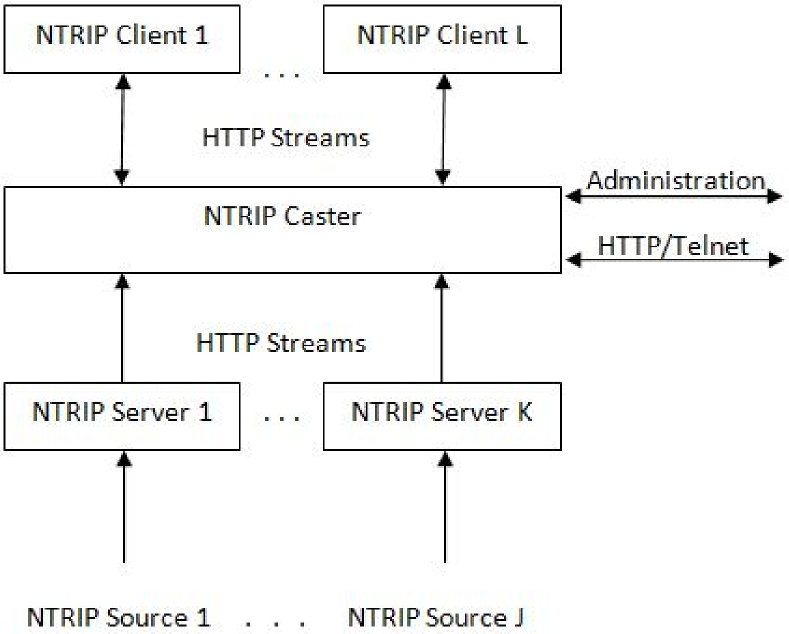


Figure 2.3: NTRIP Streaming Systems

Consequently, in order to implement the system, it is essential to examine the operation of each NTRIP component systems.

Therefore, this section presents the underlying technology in each component systems, by observing the mode of operation and how they interact with each other.

2.2.1 TCP/IP, NTRIP and HTTP

The concept of distributing GNSS real time correction data for RTK is addressed in this subsection, by looking at the principle of Internet network and communications which is one of the underlying bases of NTRIP system.

NTRIP, which is an application layer protocol derived from ICECAST Internet Radio technology, happens to be a redesign of Hypertext Transfer Protocol (HTTP) version 1.1 [Geo03b],[Har03a]. The HTTP is an application-level protocol, which is the underlying protocol used by world wide web. It is also used for streaming multi-media contents. HTTP, is a generic, stateless, protocol, which can be used for many tasks beyond its use for hypertext. These include tasks such as, name servers and distributed object management systems. This is made possible through the extension of its request methods, error codes and headers [L.M98].

However, this protocol runs on top of Transmission Control Protocol/Internet Protocol (TCP/IP) layers and is located in the application layer [FW13],[T.C05]. TCP is a protocol designed to provide a connection oriented reliable byte stream on top of the Internet Protocol (IP) [U.B94]. This is to provide reliable data transmission with flow control.

The Open System Interconnection (OSI) model in Figure 2.4, shows the layers which each of these protocols operates [Six12], and they are in a hierarchical order.

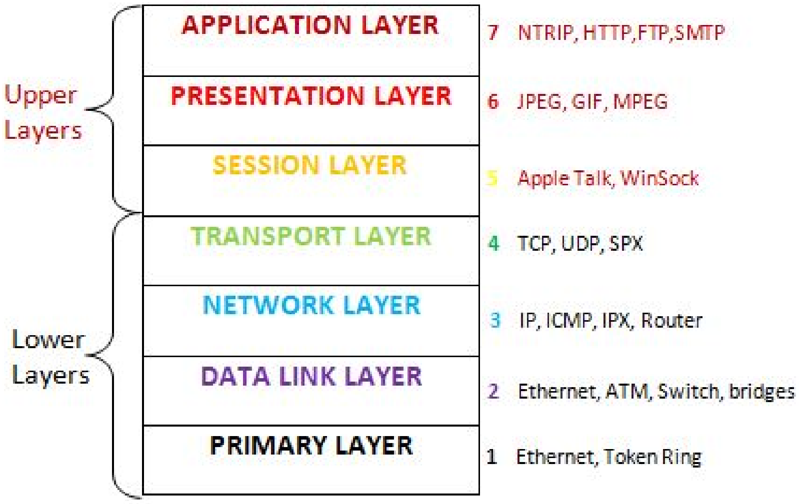


Figure 2.4: Open Systems Interconnection (OSI) Model

2.2.2 RTCM and Message Types

RTCM stands for "Radio Technical Commission for Maritime Services", which is an independent international non-profit organization, whose mandate is to develop standards for radio communications and related applications. However, it does not enforce or control the use of these standards by manufacturers, service providers and users [RTC04b].

The RTCM message is an encrypted signal incorporating GNSS information, used to improve the accuracy of DGPS or RTK positioning solutions. They have been several RTCM versions and changes since its development with aim of improving the RTK positioning issues [RTC13a]. These changes as applied to each version is illustrated in Table 2.1.

Table 2.1: RTCM Trend

RTCM version	The year of application	Changes applied
RTCM 1.0	1985	Temporary recommendation for DGPS (PRC and RRC)
RTCM 2.0	1990	DGPS corrections and additional information Messages 1-17, 59
RTCM 2.1	1994	Extension for RTK Messages- 18/19 and 20/21
RTCM 2.2	1998	Extension for DGLONASS Messages 31-37
RTCM 2.3	2001	Additional information for RTK Messages 23,24
RTCM 3.0	2004	New solution for RTK
RTCM 3.1	2006	Solution for transformation

Each of these versions were made to address specific issues, in order to improve the real time GNSS data distribution [RTC90],[RKB11] and also the accuracy of positioning solutions in real time.

There are also various RTCM message types in these evolving versions, and each is meant to improve GNSS data streaming from either a single source or central source to the Rover GNSS users. These messages primarily comprise of compressed observation data from a GNSS CORS network which are transmitted to the Rover GNSS receiver through the Internet to improve its position correctness [RTC06], [Den13]. The current RTCM version is version 3.x, which was design to overcome the limitations of RTCM version 2.x, however, they are not compatible. Table 2.2 presents RTCM version 3.0 message types and their accompany content.

Table 2.2: RTCM v3.0 Message Types (GPS and GLONASS Observations)

GPS	
Message type	**Content**
1001	L1 only GPS RTK observables
1002	Extended L1 only GPS RTK observables including satellite signal-to-noise (CNR), full milliseconds for code observations
1003	L1 and L2 GPS RTK observables
1004	Extended L1 and L2 GPS RTK observables including satellite signal-to-noise (CNR), full milliseconds for code observations
GLONASS	
1009	L1-only GLONASS RTK observables
1010	L1 only GLONASS RTK observables including satellite signal-to-noise (CNR), full milliseconds for code observations
1011	GLONASS L1+L2 observations
1012	Extended L1 and L2 GLONASS RTK observables including satellite signal-to noise (CNR), full milliseconds for code observations

Furthermore, RTCM SC104 Standard Version 3.1 introduced the use of the network-RTK technique in place of single-base RTK which increases not only inter receiver distance but also reliability. Although, RTCM network-RTK improved broadcast solution, the required bandwidth for the RTCM network messages need to be considered.

In order to achieve comparable performance, the RTCM network solution generally requires a 1Hz update rate for the master and network correction, which actually require less bandwidth. Also the geometric corrections can be transmitted at a lower update rate. As a result, use of GPRS is desirable over GSM, due to limitation on Baud Rate [YHR09], which makes it more viable in distributing GNSS correction data through the Internet. These message types of version 3.1 and their contents are shown in Table 2.3 below.

Table 2.3: Network messages (RTCM v3.1)

Message type	Content
1014	Network Auxiliary Station Data coordinate difference between one auxiliary station and the master station
1015	GPS Ionospheric Correction Differences for all satellites between the master station and one auxiliary station
1016	GPS Geometric Correction Differences for all satellites between the master station and one auxiliary station
1017	GPS Combined Geometric and Ionospheric Correction Differences for all satellites between the master station and one auxiliary station
1018	Reserved for alternative Ionospheric Correction Difference Message
1019	GPS ephemeris
1020	GLONASS ephemeris

2.2.3 NTRIP Caster

The NTRIP Caster is one of the major components in the implementation of NTRIP system. It is the component that is deployed at the control centre, which receives GNSS correction data from various NTRIP Sources through NTRIP Servers, and disseminates them via the Internet to Rover GNSS users on request by an NTRIP Client.

In principle, the NTRIP system consist of NTRIP Caster, NTRIP Server, NTRIP Source and NTRIP Client, but practically both the NTRIP Server, NTRIP Source and NTRIP Client function as a TCP/IP clients on the GNSS Reference station side and the Rover GNSS receiver side respectively [Sys05],[Lei06]. Whereas the NTRIP Caster functions as a TCP/IP server, acting as a device that listens for connections and forward data from several NTRIP Servers to many NTRIP Clients [Den06].

The Servers initiate a connection to the NTRIP Caster asking to upload data from a certain stream through a mountpoint. In the same vain, the Clients initiate a connection to the NTRIP Caster asking for data from a certain stream through a chosen mountpoint. The Caster maintains a Source description parameters called Sourcetable. The Sourcetable contains vital information about all the Streams, Networks and Casters mountpoints maintained by the NTRIP Caster [Wik12],[Lei05]. In addition, access to the NTRIP Caster is made possible through the IP address, port number, username and password authentications.

2.2.4 NTRIP Source

Basically, the NTRIP Source is the GNSS Reference station that is generating the RTCM message corrections for real time kinematic. Every single NTRIP Source needs a unique mountpoint on an NTRIP Caster which is maintained by the administrator operating the NTRIP services.
Currently, most GNSS manufactures have integrated NTRIP functionalities in their equipment which enhances the implementation process [Tri11].

2.2.5 NTRIP Server

NTRIP Server is the component part of the NTRIP system that is responsible for transferring GNSS data corrections of an NTRIP Source to the NTRIP Caster, using the TCP/IP connection protocol. It is basically, a computer program running on a PC that streams corrections data from the

NTRIP Source to the NTRIP Caster. However, as earlier on observed, most GNSS manufactures are currently integrating it into the NTRIP Source GNSS equipment.

During the setup, the administrator of the NTRIP Caster has to define and made available the IP address of the Caster, the listening port number, the Caster encode password, the username and mountpoints, for the various administrators of the participating NTRIP Servers [Tri11].

2.2.6 NTRIP Client

NTRIP Client is the NTRIP system component that is deployed at the Rover GNSS receiver side. It is responsible for sending a request message to the NTRIP Caster and receiving GNSS data corrections from it via the Internet, for real time correction purposes.
This is possible only if the NTRIP Client sends a correct request message. The correct request message consists of correct NTRIP Caster's IP, listening port, username and password for authentication purposes. In response, the Caster sends the updated Sourcetable text file to the NTRIP Client. This contains list of Streams, Networks and Casters mountpoints and their descriptions, which is maintained by the NTRIP Caster. Subsequently, it transmits corrections data to the Client when connection has been established through a chosen mountpoint.

2.3 Implementation Scenario

Implementation scenario refers to the mode of deployment of the NTRIP system, for the dissemination of GNSS data corrections through the Internet, for RTK purposes. The location of the NTRIP Caster and the way data from the NTRIP Sources interact with the Caster are the fundamental factors in determining the implementation scenario being adopted. They are several implementation scenarios in the deployment of NTRIP system [L.L11b]. The two prominent situations identified are namely: Centralised and Decentralised mode of implementations.

2.3.1 Centralised NTRIP Caster Approach

The centralised NTRIP Caster approach refers to a situation where the Caster and the Server are at separate locations. This is the fundamental principle of Network RTK, therefore, are usually applied in a network of GNSS CORS. In this case, the reference stations which are the GNSS correction data generators (i.e. NTRIP Source and the NTRIP Server are integrated together in the GNSS equipment or connected through serial connection) are in a remote locations.
The NTRIP Servers encapsulates the GNSS correction data into TCP/IP packets and send them via the Internet to a centralised unit, which may be refer to as a Central Processing Facility (CPF) - NTRIP Caster, which is managed by the Administrator in another location. Probably in the data centre office.
The NTRIP Caster, which acts as a Server, in turn, distributes these GNSS RTK corrections data to NTRIP Clients on request after passing the authentication processes.
Figure 2.5 below, illustrates the centralised NTRIP Caster approach.

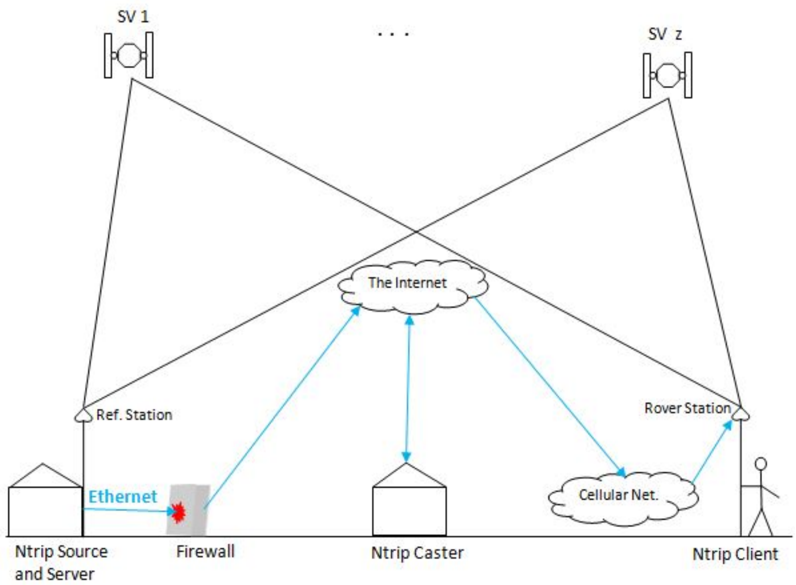


Figure 2.5: Centralised NTRIP Caster Approach

2.3.2 Decentralised NTRIP Caster Approach

The decentralised NTRIP Caster approach refers to a situation where the Caster and the Server are the same device, and is deployed to render NTRIP services independently, in a single or network stations. Where this approach is adopted in a network, each reference station acts as an independent node of the network. The Rover GNSS receives information from surrounding reference GNSS stations and decides which mountpoint to use.

However, the decentralised NTRIP Caster approach is often utilized in a situation where you only have one reference GNSS receiver station for the implementation of the NTRIP services. In this case, the reference GNSS receiver which is the data streaming generator is basically installed at a desired location.

It is then connected to a computer running the NTRIP Caster through a serial port or USB connection, where the GNSS equipment does not support NTRIP Caster. On request to the Caster, the NTRIP Client at the Rover GNSS receiver side receives real time GNSS corrections data through the Internet. This scenario is illustrated in Figure 2.6 below.

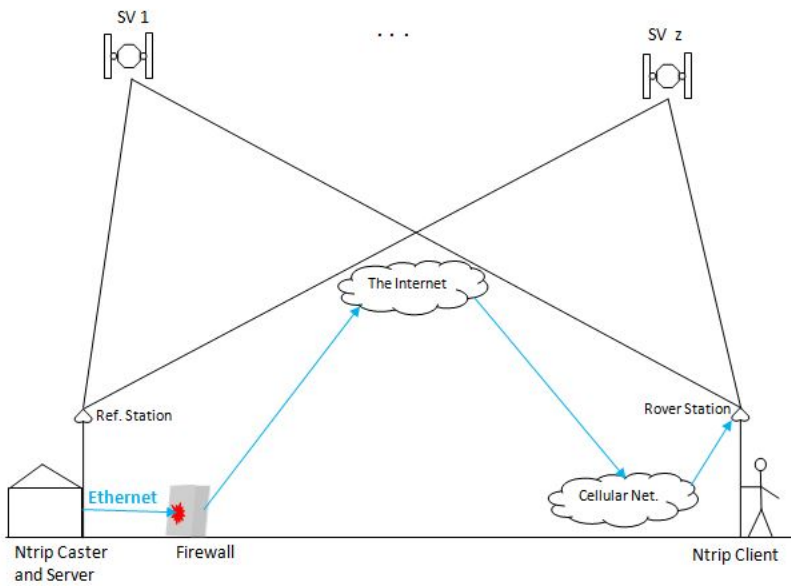


Figure 2.6: Decentralised NTRIP Caster Approach

2.4 GNSS and GNSS Errors

The implementation of NTRIP services will not be complete and functional without the positioning systems and the GNSS reference station(s) which are the NTRIP Sources. This section briefly presents the fundamental concept of GNSS in determining position, the GNSS errors and NIGNET Network. This is aimed at highlighting the GNSS positioning errors that need to be corrected at the Rover GNSS receiver side (i.e NTRIP Client) by the transmitted correction messages from the NTRIP Caster, for a better positioning accuracy. In addition, to examine the current status of NIGNET Network.

2.4.1 GNSS

The term GNSS refers to Global Navigation Satellite System, which is a generic name for all space positioning satellite techniques with worldwide coverage [BJ96],[And01]. Currently, GNSS include two fully operational global systems, namely the US, Global Positioning System (GPS) and the Russian Federation's GLObal NAvigation Satellite System (GLONASS). In addition, there are several GNSS implementation projects, aimed at developing global and regional systems, namely Europe's European Satellite Navigation System (GALILEO), China's COMPASS/BeiDou, India's Regional Navigation Satellite System (IRNSS) and so on.

GNSS includes constellations of Earth-orbiting satellites that broadcast their locations in space and time, and of GNSS receivers that calculate ground positions by trilateration method[HWBE08], [HWW03], as illustrate in Figure 2.7. The GNSS receiver at an unknown location uses trilateration method to determine its position on the surface of the earth by timing signals from a minimum of four satellites in the space. Its space segment, which is a network of space vehicles (SV's) that orbit the earth, and send a signal to GNSS receivers, provides precise details of the receiver's location, the time of day and the speed the device is moving in relation to the four satellites. Each SV in the GNSS constellation sends out periodic signals along with a time signal.

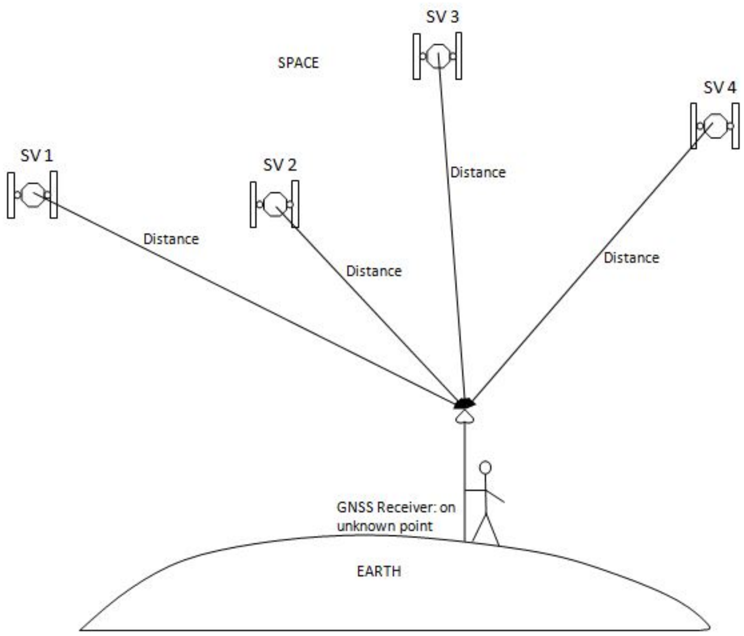


Figure 2.7: Concept of GNSS Positioning by Trilateration

These are received by GNSS devices which then calculate the distance between the device and each satellite based on the delay between the time the signal was sent and the time when it was received. Once a GNSS device has distances for at least four satellites it can perform the trilateration calculations, and therefore determine its location.

2.4.2 GNSS Errors

The idea behind the transmission of GNSS correction data using the NTRIP for RTK positioning is based on the fact that, all GNSS receivers in the same vicinity would simultaneously experience common errors. In this case, since the GNSS reference station knows its solution, therefore, can calculate the errors in the observation, which is then transmitted in the form of RTCM encrypted messages as corrections to the Rover GNSS receiver station in real time, to improve it's positioning accuracy [GP02],[JL98].
The following factors are responsible for the GNSS positioning errors [EC06] during observations:

1. Satellite and Receiver Clock Errors: This refer to the slight discrepancies in the satellite's atomic clocks and the GNSS receiver clock, which may cause slight position errors in the GNSS receiver. However, this errors are monitored and corrected by the Master Control Station.

2. Satellite Orbit Errors : This concerns the variations of the altitude, position and speed of the satellite, which is as a result of the gravitational pull and solar pressure fluctuations. Orbit errors are equally monitored and corrected by the Master Control Station.

3. Atmospheric Interference : This refers to the Ionospheric and Tropospheric errors which tends to slow or speed up the signal from the satellite, therefore, introducing errors on the receiving signal by the GNSS receiver.

4. Multipath : This refers to the error introduce by reflected signals from surfaces near the receiver, that can either interfere with or be mistaken for the signal that follows the

straight line path from the satellite. This type of error is difficult to detect and sometime hard to avoid, although with the use of choke ring antenna, this error can be mitigated. However, the error due to multipath cannot be corrected by the DGPS and RTK corrections.

2.5 NIGNET Network

NIGNET refers to Nigerian Permanent GNSS Network. It evolves in pursuant of the African Geodetic Reference Frame (AFREF) project by Nigerian Government through OSGoF [Won12],[RH11] and [AFR15]. NIGNET is a network of Continuously Operating Reference Stations (CORS), consists of state of the art GNSS equipment as at 2015 [BJG10]. These CORS are geometrically distributed within the country and constitute what could be termed permanent GNSS reference stations (see Figure 1.1).

All the remote GNSS reference stations within the network are configured to stream their GNSS data to a cloud based data storage, through File Transfer Protocol (FTP) push over the popular TCP/IP protocols. This is made possible by providing Internet support via Virtual Private Network (VPN) to the remote stations, with an exception of one station (GEMB) that makes use of Very Small Aperture Terminal (VSAT). The data from the cloud based storage are them transmitted to the OSGoF control centre as a backup.

In addition, a web interface was made available, which gives users access to the GNSS data in hatanaka format, which is a special compression format developed for rinex files [UNA15]. Furthermore, the web interface offers a remote monitoring capability of all the stations within the network by an administrator. This is very vital, in order to ensure that the stations status are operating properly and to report any malfunctioning to the appropriate quarter for further action. This is done by the integration of MGN-NIGNET v1.2 lite software in the network, which is a GNSS remote monitoring suit [P.M12] that enhances remote access to the stations.
Figure 2.8 below, describes the NIGNET data dissemination architecture.

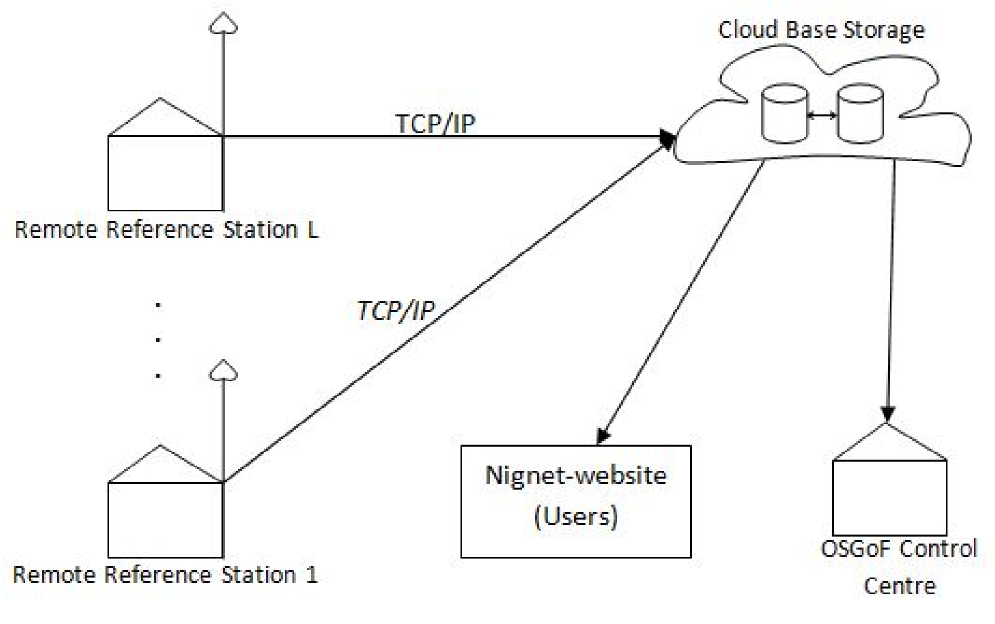


Figure 2.8: NIGNET Data Dissemination Architecture

2.6 Summary

The concept of NTRIP, GNSS, GNSS errors and NIGNET Network have been examined and presented in this chapter. These were addressed by investigating the inter-relationship of NTRIP component systems, system overview and the implementation scenarios of NTRIP system. Furthermore, the fundamental principles of GNSS positioning was highlighted and some of the factors that causes errors in the GNSS observations. This is to ensure basic theoretical knowledge of each system for successful implementation of the research work. In addition, the current status, geographical locations, monitoring mechanism and data streaming architecture of NIGNET Network were presented.

These fundamental knowledge of all the various components that make up a functional NTRIP system, highlighted in this chapter, obviously reveals the possibility to use NTRIP system in NIGNET Network, for the distribution of GNSS data corrections to various RTK users in real time via the Internet.

Chapter 3

State of the Art

3.1 Introduction

This chapter presents several contemporary research works being carried out, in order to reveal the state of the art of Networked Transport of RTCM via Internet Protocol (NTRIP) and Nigerian Permanent GNSS Network (NIGNET). The evolution, trends and various applications of NTRIP protocol, as well as current status of NIGNET are examined in this chapter. This is to gain more knowledge about the application. In addition, it would guide in the choice of hardware and software applications, for proper implementation of the project.

3.2 NTRIP Evolution

The evolution of NTRIP system, and its deployment for the dissemination of Global Positioning System / Global Navigation Satellite System (GPS/GNSS) data, for real-time corrections and current improvements, are presented in this section. This is aimed at revealing the origin of the NTRIP protocol.

The evolution of NTRIP protocol was attributed to the result of a feasibility study on real-time streaming of differential GPS corrections, as described in [GK02]. The paper reveals that, the NTRIP project was initiated by the German Federal Agency for Cartography and Geodesy (Bundesamt für Kartographie und Geodäsie, BKG). The work also observes that, because dissemination of RTCM SC-104 messages is the principal application, therefore, the whole system presents a transport protocol that is referred to as NTRIP Protocol.

The underlying application-level protocol for the design of NTRIP was observed to be developed and standardized by Radio Technical Commission for Maritime Services (RTCM) [RTC90],[RTC92], which is an international standard organisation with several Special Committees. Each committee is responsible for providing standard for a particular navigational problem. The Special Committee (SC) 104, for instance, is charged with the responsibility of providing standards for DGPS and RTK applications.

RTCM consist of over 130 member organizations and fifteen Special Committees as of 2014, each having a special task to accomplish [RTC14b]. The Special Committee-SC-104 on Differential Global Navigation Satellite Systems (DGNSS) is charged with the responsibilities of providing standards that are used in Differential GPS and Real Time Kinematic operations [Wik14], [RTC01]. This is to enable the transmission of GNSS data correction in real time through the Internet. The RTCM message is an encrypted signal incorporating GNSS information used to improve the accuracy of DGPS or RTK position solutions. They have been several RTCM versions and changes since its development with aim of improving the RTK positioning.

There have been several versions of RTCM since its inception, each aimed at standardizing and/or improving the NTRIP protocol performance. These were presented in [RTC13a], and the descriptions of the standard and additional supports of each developed versions. The current RTCM was observed to be RTCM 1040-3.2 and Differential GNSS Services - Version 3.1. These papers [RTC13a],[RTC13b] and [RTC14a] agreed unanimously that, it is more efficient alternative to RTCM version 2.3.

In [RTC97], the documents that describes system design and protocol details are presented. It aimed at defining a standard for a HTTP based protocol, for the dissemination of Differential Global Navigation Satellite System (DGNSS) data (or other kinds of GNSS streaming data) to stationary or mobile receivers over the Internet. In addition, It also report on some implementation examples, therefore contributing to software availability.

The "Usefulness of Internet-based NTRIP Real Time Kinematic (RTK) for navigation and intelligent transportation systems" was investigated in [Mar01]. The research work focuses on evaluating the performance of NTRIP/RTK solutions for accurate and precise car navigation. The approach was based on field experiments, and the analysis of both the accuracy and availability of RTK data using mobile wireless transmissions prove to be satisfactory. The paper also investigates the advantages and disadvantages of each component in the navigation system, by deploying car experiments on test routes under different driving conditions, which also reveals a better positioning solutions using NTRIP.

Test results from the NovAtel RT2 real-time-kinematic carrier phase positioning program was presented in [JBNM96]. The research presents test results from the new RT2 real-time carrier phase positioning system developed by NovAtel. The work tries to expand the single frequency carrier phase positioning technology introduced in 1994 as RT20, by taking advantage of the dual frequency capability recently introduced in GNSS equipment. The result shows typical integer resolution times of about 1 minute on short baselines and typical low latency horizontal position accuracies of 1 to 3 cm, with a direct RS232 data link, Baud Rate of 1200 to 2400 (about twice the message bit rate).

NTRIP, as an application-level protocol for streaming GNSS data over the Internet was examined in [Geo03a],[Har03a] and [Har03b]. They papers reveal that, it is a generic, stateless protocol based on the Hypertext Transfer Protocol HTTP/1.1., whose HTTP objects are enhanced to real time GNSS data streaming.

The completion and release of a new standard, designated as version 1.0 and titled “Networked Transport of RTCM via Internet Protocol" (NTRIP), by RTCM Special Committee 104 in 2004, was discussed in [RTC04a],[RTC04b]. The papers reveal that, this new standard was named for the widely used RTCM data format, and defines a protocol for streaming differential correction data or other kinds of GNSS data for RTK corrections to stationary or mobile GNSS users over the Internet.

The theoretical and technical basics of NTRIP was addressed in [Len04],[Duv06] and the survey controller software from Trimble Navigation Ltd was used to illustrate the practical application of the NTRIP technique. The papers reveal that, NTRIP protocol is capable of providing the most cost effective, secure and fastest means of obtaining centimetre level GNSS positioning solutions. In their separate investigations and conclusions, the research works mutually agreed that the NTRIP is a technique for now and in the future, in terms of GNSS correction data streaming and distribution.

The EUREF-IP pilot project presents "NTRIP Example Implementation", which consist of a detailed documentation of NTRIP system [Den06]. The paper outlines the architecture and the techniques involved in the successful implementation of NTRIP protocol, in any real time GPS/GNSS data dissemination network. Furthermore, It itemises the developed programs and operating system each programs are compatible with.

In [GWG06], the descriptions of the http-based technique for streaming GNSS data to mobile users, such as RTK and DGPS applications in the construction and mining work, that are connected to the Internet via Mobile IP-Networks like GSM, GPRS was presented. The paper concludes that , NTRIP technique remains GNSS data streaming protocol for now and also in the future.

3.3 NTRIP Applications and CORS GNSS

Analysis of networked transport of RTCM via Internet protocol and real-time IGS (RT-IGS) was carried out in [Tho11].The work investigates, various design aspects of both protocols from the computer network perspective, covering factors such as data latency, integrity, firewall or proxy server compatibility and scalability. The paper observes that, the differences in these characteristics between the two protocols come from their selection of the transport layer protocol. It reveals that, NTRIP uses TCP while RT-IGS uses UDP. The work further reveals that, version 1.0 of NTRIP is currently the most widely-used protocol for distributing real-time GNSS data over the Internet. In addition, data latency and integrity using NTRIP over the Internet were examined, in order to identify their impacts on user's applications in terms of quality of real-time kinematic positioning. The test data obtained from the SydNET GNSS reference station network in Sydney, Australia, were evaluated using both wired and wireless data networks. The research work concludes that, the performance of the real-time GNSS data distribution system satisfy the requirement of the end-user applications. The observed latency was less than two seconds during most of the test period and within this range, there was little variation in the positioning quality.

Various GNSS data protocols such as Transmission Control Protocol (TCP), File Transfer Protocol (FTP) and NTRIP, used for dissemination of Continuously Operating Reference Station (CORS) data was reviewed in [IGN06]. The paper re-evaluates several choices available to both CORS network operators and end users, by presenting a comprehensive analysis of the similarities and differences between these methods. Furthermore, the advantages and disadvantages of each of the GNSS data distribution methods were described, with respect to their implementation in Australian setting. The research work concludes by observing that, changes in how CORS network operates have resulted in new GNSS data transfer protocols, which evidently changed the way GNSS data are accessed and applied in our day to day GNSS applications.

The NTRIP system was observed to be technique for now and for the future, as opined by [GWG06]. This was evident in [MY08], which pointed out the drawbacks in other methods of position fixing that has to do with long baseline. It was observed that, for differential correction data, it is important to be streaming from a nearby source. According to the paper, the best results was obtained when the source is less than 40-50km.

Performance test exercise in TrigNet was presented in [C.M07]. The paper discussed the NTRIP resources available in TrigNet, which is a network of active GPS/GNSS base stations in South Africa. It highlights the strengths and weaknesses of the system. The research work analyses and presents various accuracies achievable, with respect to the distance from a base station. It pointed out that, for RTK, accuracy use to decrease with distance in the following manner: 3cm at 2km, 8cm at 113km, and 18cm at 1,315km. It further observed that, no difficulty was experienced in resolving integers at a range of 113km, although only a floating point solution could be obtained at the 1315km range. In addition, the work suggests that, for any functional NTRIP system to guarantee reliability, there should be data integrity monitoring from the provider, and good internet network for both the client and the server sides.

Investigation of RTK and Real-Time DGPS corrected observations based on NTRIP protocol was carried out by [Thi08]. The work deployed three different GPS receivers; high, medium and low accurate GPS, which was classified according to the receiver accuracy performance and cost. The research work observes that, NTRIP is a cost effective, secure and reliable alternative to replace traditionally accepted methods of RTK and real-time DGPS correction streaming techniques such as the use of Very High Frequency (VHF) radio signal and Wide Area Augmentation Systems (WAAS) for transmission of GNSS correction data.

NTRIP corrections via CORS network for TeeJet Technologies RX-600RTK was researched in [Tee08]. The paper describes, the steps that can be taken to evaluate whether or not NTRIP type RTK corrections delivered via cellular modem from a CORS network are available in any given US location. However, the paper observed that, due to the inherent in-accurate nature of defining cellular coverage areas, the results obtained following this evaluation should be considered indicative, therefore, does not constitute a guarantee of successful operation of the system. The work further pointed out that, accessing NTRIP data via cell modem is possible almost anywhere you have cell phone coverage, but better RTK level accuracy will only be achieved if the unit is within the network being referenced.

The European position determination system technical standards was presented in [EUP08], which is a standard for the implementation of NTRIP services. The work extensively outlines the general guidelines necessary for NTRIP implementation in EUPOS. The paper concludes by stating that, the "EUPOS Steering Committee decides that the EUPOS Technical Standards are to be used by all members and partners of EUPOS as obligatory EUPOS standards". In addition, the paper made it clear that, changes of the standard definitions need an EUPOS Steering Committee resolution.

The "International standard GNSS real-time data formats and protocols" were examined by [YHR09]. It describes the mechanisms for real-time delivery of GNSS data in terms of transmission protocol, data format, communication link issues, message structure and data types. In addition, content between the various versions of RTCM SC-104 formats, including recent amendments were addressed. RTCM SC-104 is the Special Committee charged with the responsibilities of defining protocol for the streaming and distribution of GNSS correction data in real time. Format specification and structure of both RTCM SC104 version 2 and version 3 were equally examined. Also, comparisons were made in terms of throughput, bandwidth and flexibility. The drawbacks of RTCM SC104 version 2 were equally highlighted in [RTC97],[YHR09], and the improvements that were made in RTCM SC104 version 3 were then presented.

A tool (GNMobile/GNMobileTM) that was said to aid GNSS data distribution via mobile connection was developed and presented in [Geo09]. The paper demonstrated that, GNMobile/GNMobileTM is capable of establishing connections with available and supported hardware interfaces of a terminal such as: Mobile phones (GNMobile), Terminal modems (GNMobileTM) and other Micro controller. In addition, the following interfaces of the terminals could be supported: Modems (GSM/GPRS), Serial Ports (RS232), Infrared and Bluetooth. Supplementary features supported by the tool were equally presented by the research work, which ranges from different protocols which could be applied on the several hardware interfaces. They are the Low-Level-Protocols, TCP/UDP, HTTP and NTRIP. The work further illustrates the overall main principle of the applications, which is based on the fact that, several hardware interfaces and the protocols that can be used on it can equally be used in all possible combinations. This is possible for creating a connection between two interfaces. These are for example: a serial interface, the access to a mountpoint on NTRIP Caster in Internet, a Bluetooth-access to a GPS receiver and so on.

In order to demonstrate the wide spread of mixed-receiver systems, these research works [Mar01],[Geo09], use both NovAtel and Trimble mobile receivers and connect them via a CDMA network to an NTRIP broadcaster, hosted by a Trimble NetR5 reference station receiver. Additional tests were performed using a 2/9 NTRIP stream, delivered by a free-standing mountpoint obtaining data from the same reference receiver acting as an NTRIP server. The research works observe that, the performance of the systems are appropriate to be put into practical use for controlling vehicle motion. They further present that, while using a fast wireless Internet connection, latency of the reference data did not have a significant impact on the RTK results. In addition, the combination of GPS and GLONASS constellations were very precise, even in the urban environment.

Low-cost RTK-GPS receiver with an open source program package called RTKLIB was developed in [TY09]. The research work presents that, RTKLIB is an open source program package for RTK-GPS application, which is a compact and portable program library written in C to provide a standard platform for RTK-GPS applications. The library in the tool, implements fundamental navigation functions and carrier-based relative positioning algorithms, for RTK-GPS, with integer ambiguity resolution using LAMBDA, which is an algorithm developed to solve these values. It is an essential condition to have centimetre-level accuracy. The RTKLIB application proved to be capable of supporting data communication via serial I/O, TCP/IP connection and NTRIP. Also, various data formats including RTCM 2.3, RTCM 3.1 and proprietary raw messages for some GPS receivers were supported, according to the paper. The work further introduces the functions, the application programs and the algorithms for RTKLIB. It equally describes the detailed design of the low-cost RTK-GPS receiver with RTKLIB. Furthermore, the research work adopts a field test approach to demonstrate and verify the performance of the developed low-cost RTK-GPS receiver. The following evaluation tests were carried out: CPU/memory usage, accuracy of solutions and fixing ratio. From the test results, the paper concludes that, even with such a low-cost RTK-GPS receiver, a satisfactory performance was able to be achieved in company with RTKLIB.

Investigations of de-correlation effects on the performance of DGNSS systems in the Baltic Sea was carried out in [SA10]. The work uses a reference station and integrity monitoring station by streaming the gained corrections and integrity information in the RTCM format via a medium frequency antenna. This corrections were observed to be received by users in the surroundings of almost 300 kilometres. The paper presents a preliminary results of DGPS measurement activities. The results show relatively weak DGPS de-correlation effects in time and space over a maximal distance of 214km.

In [MUJ10], "Towards precise car navigation: detection of relative vehicle position on highway for collision avoidance" was examined. The paper presents an Internet-based RTK system evaluation using NTRIP protocol and real time relative car positioning for providing accurate centimetre-level positions. The research work observes that, where buildings and tree canopies were very harmful to navigation solution, and the frequent blocking of the signals of low elevation satellites, the combination of high accuracy positioning information obtained from NTRIP/RTK with high-precision Inertial Navigation System (INS) or other sensors was able to solve the problem. The research result demonstrates that, the performance of the system is suitable for controlling vehicle motion for driver assistance.

The paper [JPCR11], presents an accuracy test using L1 and L1/L2 GPS receivers. It examined the effects of using different reference stations, the variation in accuracy over distance, the use of single frequency receiver and dual frequency receiver in RTK and DGPS techniques, in terms of accuracy stated in their user manual. The analysis of the accuracy test of the GPS equipment with various frequencies using NTRIP services reveals that, the accuracy attained in each case of the investigation strongly depends on the GNSS receivers and on the ionospheric effect. The paper concludes that, this was so because, each receiver or manufacturer implements different programs and strategies to solve ambiguity, modelling the ionospheric effect and to calculate the coordinates.

The research work [DC11], presents the CORS requirements for high vertical accuracy for single epoch applications such as civil machine guidance systems. The paper investigates the nature of some actual errors that are seen during the course of a normal day's use of CORS RTK and compare some of the preferred CORS RTK techniques such as: Master Auxiliary Concept (MAC) [Ahm12], Single Base RTK using NTRIP at 10km, Single Base RTK using NTRIP at 35km. The research demonstrates that, over data sets of 24 hours or more, approximately 86 percent of resulting elevations happens to fall within the ±35mm tolerance during normal working hours. It further proposed that, to achieve accuracies consistently in the order of ±10mm, it is necessary to augment the system with, for example, an integrated laser based levelling techniques.

The concept of increasing the accuracy of mobile phones positioning by using Internet data link to the pseudo-range correction data provider was investigated in [W.R11]. The paper addresses the issue of DGPS application in mobile phones. In its approach, the software was separated into three parts: NMEA decoder part, NTRIP Client software and DGPS solution. NMEA decoder part transfers the measurements (pseudo-ranges residuals, almanac and coordinates) to the required form/file, while NTRIP Client connects to the port on NTRIP Caster to download pseudo-range corrections data and also ephemeris to speed up the fix time. The paper observes that, this approach was able to enhance the accuracy of phones positioning solution.

NTRIP system software application program that operate on windows operating system was developed in [L.L11b]. It is an open source application that consist of the basic component requirements, for the implementation of NTRIP system services in stand alone station, and/or networked stations. The work presents that, the application is capable of handling infinite number of sources and clients connections simultaneously. Despite this capability, the paper advises that, the hardware component and the bandwidth of Internet communication are major constraints for the optimal operation.

In [ABZ12], investigation of the RTCM Multiple Signal Messages (MSM) was carried out. MSM which is currently a concept in GNSS correction data dissemination that bridged the gap between various GNSS vendors by presenting all GNSS observation data corrections in a generic form. This is aimed at standardizing all GNSS observables. The paper described the principles of MSM organization and presents their view on applications where MSM can be efficiently utilized. The work concludes that, MSM messaging is a main step in standardization of GNSS observables and is currently being implemented in handling GNSS correction message formats for DGPS and RTK from various manufacturers.

The research work [Ahm12], presents "Precise real-time positioning using Network RTK". The paper discussed the principles of Network RTK (NRTK), and the advantages of this method over RTK observations from single GNSS reference station. The work observed that, RTK measurement from a single reference station is often limited to a baseline distance of about 10-20km, because of the tropospheric and orbital errors which are distance-dependent errors. In addition, malfunctioning of the GNSS receiver station could cause delay in service delivery. The work suggested that, these problems could be solved by a GNSS observation method known as NRTK, which is a GNSS technique where reference stations are networked within a range, usually less than 100km from each other. These network stations constantly sent GNSS correction data to a central processing facility, which in turn, broadcast it to the RTK users within the vicinity of the network, in real time. The work concludes that, since the RTK users now have several stations to choose within the network, these issues in the case of single GNSS station are mitigated.

3.4 Trends in NTRIP Development and Software Application

In June 2009, RTCM Special Committee 104 (SC104) completed version 2.0 of its NTRIP standard, which is compatible with version 1.0 as observed in [GDC14]. Several changes were made, and the major changes compared to Version 1.0 was to clear and fix the design problems such as, HTTP protocol violations, replacement of non standard directives, addition of chunked transfer encoding, improvement of header records, provision for source-table filtering and the provision for Real Time Streaming Protocol (RTSP) communication.

The evolution of NTRIP system evolves from 2002 to 2007 and was brought to public use through the EUREF-IP Pilot Project, which finally stimulates and develops the necessary tools for European Permanent Network (EPN) stations, to make available their data in real-time [EPN14c].

The EUREF resolutions from 1993 to 2006 were presented in [EPN14b], and at the recommendation of IAG Sub-commission for Europe (EUREF) in 2002, the EUREF Technical Working Group was set up to maintain a differential GNSS infra-structure through the Internet, based on selected

EPN stations. Also, the member countries were requested to support the new activity by the necessary upgrade of the respective EPN stations. The project was aimed at achieving real time GNSS data distribution [EPN14a], which was based on GNSS data dissemination standard called NTRIP. This pilot project, which started with 112 EPN stations [GDC14] was aimed at evaluating and stimulating the use of the NTRIP technology in distributing GNSS data in real-time.

The standard NTRIP Caster (the component of the NTRIP system that streams and distributes GNSS correction data from the CORS to the rover GNSS receivers) software, developed within the framework of the EUREF-IP project that runs on Linux operating system was presented in [Get14]. It was derived from the ICECAST Internet Radio as written for Linux platforms under GNU General Public License (GPL), therefore, is an open source software. The paper reveals that, the standard NTRIP Caster software has been tested so far on various Suse, Debian, Gentoo and Redhat (up to Enterprise 5) Linux distributions. Furthermore, the version 0.1.5 of the standard NTRIP Caster was proved to supports a maximum of 50 NTRIP Sources and 100 NTRIP Clients on a given mountpoint simultaneously. The software application download and the configuration steps were also presented in [Get14],[BKG14b].

Comprehensive overview of BKG NTRIP Client (as discussed in chapter two) (BNC) was investigated in [BKG14a]. The work presents the purpose, handling, settings and limitations of BNC. It was revealed that, the BNC happens to support so many GNSS applications services. Although, BNC was designed mainly for real-time tool to be operated online, the paper reveals that, it could also be run offline for post processing and to simulate real-time observations situations, for debugging purposes.

A tool for GNSS service providers to verify the supplied correction data called "InspectRTCM" was developed by [Alb14]. The paper presents that, the following features are supported and/or inspected using the tool: real-time visualisation of original RTCM data, support of RTCM versions 2 (2.0, 2.1, 2.3) and 3 (3.0, 3.1), support of CMR, CMR+ data(SISNeT and NovAtel formats), automatic identification of RTCM data formats, display of recorded/logged data for analysis, control of system time delay, support of TCP data streams, NTRIP support, support of NTRIP VRS via NMEA and supporting Linix or Microsoft Windows operating system. The work suggests that, the tool is an excellent means for GNSS service providers to verify the supplied correction data, due to its interdependency from the data generating source. It also recommends that, providers of NTRIP services can use InspectRTCM for analysis of the quality of GNSS correction data being streamed from the GNSS reference stations to the NTRIP Caster.

3.5 NIGNET Network

The NIGerian GNSS Reference NETwork (NIGNET) establishment was presented by [BJG10]. The paper reveals that, NIGNET which was initiated in 2008, is formed by state-of-the-art GNSS equipment. It was installed to provide Continuously Operating Reference Station (CORS) services. This is intended for the implementation of the new fiducial geodetic network for Nigeria. The research work summarizes by describing the motivations, preparation, implementation and current operations of the network as at 2010. It further presents the difficulties and benefits faced with the implementation of this modern network, which according to the work, will undoubtedly contribute for the development of Nigeria in particular and Africa in general if properly managed.

The Role of CORS GNSS data for climate monitoring using NIGNET Network as a case study, was investigated and presented in [Aba13]. The work observes that, NIGNET Network can be used to detect variations of precipitation through the different periods of the year. Furthermore, that data from NIGNET Network can be integrated in forecasting numerical models as it is already being done in other parts of the world. The paper argued that, with sufficient data, it would also be able to compare more significantly the differences between different years.

3.6 NTRIP Application Analysis and Choice of Software

Having examined several literatures presented by several researchers, we present some prominent NTRIP Caster application software and their features, with the view of looking at them and taking a decision on choice of implementation software. The summary of few of these software and their examined features are presented in Table 3.1 below.

Table 3.1: Summary of NTRIP Applications Analysis

Name of Software	**License**	**OS**	**Interface**	**No. of Server con.**	**No. of Client con. per source**	**Listening Port**	**Type of Source table**	**Cost**
BKG Prof. NTRIP Caster	Proprie-tary	Linux	Command lines with web interface	>10,000	>10,000	User defined: 80,2101	Dyna.	$1000
BKG Standard NTRIP Caster	Open source	Linux	Command lines	≤ 50	≤ 100	User defined: 80,2101	Static	N/A
Lefebure NTRIP Caster	Open source	Windows	Windows based	∞	∞	Static: 5000	Static	N/A

After some considerations like the source of the initial concepts, design and development of NTRIP protocol, the mandate of each developer, human and financial resources for updates, the number of prototype usage of the applications and cost of implementation, we decided to adopt BKG Standard NTRIP Caster which runs on Linux OS for the implementation of this research project.

However, this application only provides a command prompt interface for monitoring its current activities and a log file, which is a text file maintained by the NTRIP system, containing the overall activities of the system. This makes it less attractive and little bit difficult to get the information being presented by the system. In addition, in the event of commercializing the services of the NTRIP System, management of billing and payment processes would be an issue.

To address these problems, we proposed a website which would be integrated with the BKG Standard NTRIP Caster, this is aimed at providing a management system that offers users and the administrator more friendly user interfaces. Furthermore, the billing/payment issue was handled by integrating the website with PayPal online payment platform. PayPal refers to a transaction processing platform that offers services that enables you to pay, send money and accept payments online without revealing your financial details [Pay15].

3.7 Summary

In this chapter, the state of the art of NTRIP protocol and status of NIGNET Network have been examined in a chronological manner. It reveals several contemporary developments and implementations of this protocol, for GNSS data distribution and correction in real-time, via the Internet, for various GNSS RTK purposes.

Several conclusions were equally drawn from the literature review, in order to justify the need for the research solutions being presented in this work. These are summarized as follows:

• That the NTRIP protocol was meant to be an open source software, however it was observed that, several proprietary NTRIP software have been developed.

• In spite of the aforementioned scenario, that the BKG Standard NTRIP and Lefebure open source NTRIP software [L.L11b],[BKG14b] and [BKG14a] seems to be outstanding in handling almost all the services needed to be delivered by the NTRIP services.

• That the NTRIP protocol has been implemented and tested in various countries, and the results were satisfactory.

• That modern GNSS equipment have deployed inbuilt NTRIP system, which makes it more convenience to implement.

• That the current status of NIGNET Network is capable of being adapted to NTRIP protocol with little adjustment/improvement.

• NTRIP communication protocol seems to be an efficient and cost effective method of broadcasting real time GNSS data corrections for RTK applications, where there is good Internet services.

• That several implementation prototypes of this protocol seems to show that, the BKG Standard NTRIP application software could be a better choice for the implementation of the NTRIP and Management System in NIGNET Network.

• That the command prompt monitoring interface of the BKG standard NTRIP Caster, necessitated the need to provide an integrated management system capable of improving the administrative management of the NTRIP system in a user friendly web interface. In addition, the provision of a payment mechanism would be necessary for future commercialization of the NTRIP services to aid management of the billing and payment of the services.

Chapter 4

NTRIP Implementation

4.1 Introduction

As earlier on stated in section 1.3, a prototype NTRIP system was setup in SEGAL, which served as a test-bed, with the aim of hosting the system in the cloud after its certification, since the location of the NTRIP and the Management System does not matter. In view of this, the hardware component requirements being described in this chapter are that of the test-bed in SEGAL. In addition, it is worthy to point out that, although the hardware infrastructures were domiciled in SEGAL, it was configured with some of the NIGNET stations in Nigeria.

This chapter presents all the basic requirements and steps taken in the "Implementation of the NTRIP and Management System in NIGNET Network". It describes the geographic location of the research work, software and hardware requirements, configuration details and the architecture of the NTRIP and management system. Furthermore, it presents the website, which follows a conventional Users and Administrator web interface presentations. This is aimed at providing a platform that will enhance the users access to the system and administrative management of the system.

4.2 Implementation Requirements

The implementation requirements for the realization of the NTRIP and Management System in NIGNET Network are categorized into hardware and software components.
The hardware component is as follow:

1. 1 No. of Desktop Computer (model name: Intel(R) Pentium(R) 4, CPU 2.80GHz)

On the other hand, the software applications used are as follows:

1. Centos 6.5 OS application software (Linux Operating System)
2. Standard BKG NTRIP Caster version 0.1.5 (see [Den06],[Git08])
3. Mysql Database Software
4. PHPStorm (editor for PHP scripting language)
5. NTrip Connection (NTC) (An application developed in order to integrate the NTRIP system with the developed website)

4.3 NTRIP Installation and Configurations

This section describes the installations and configurations of the server and the NTRIP system. It highlights the locations of the files to be configured and the parameters to configure in those files.

4.3.1 NTRIP Installation

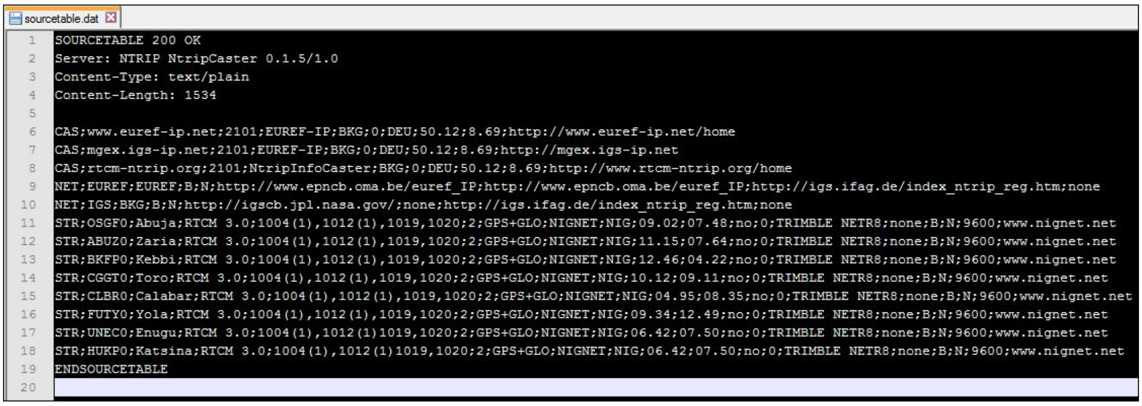
The Centos 6.5 server software, which is a Linux OS, was installed in the test-bed PC and configured. For detailed installation guide visit [Tec15]. After the successful installation of the Centos server, the Standard BKG NTRIP Caster version 0.1.5, which runs on Linux operating system, was installed. At default, the following file paths were created: "/usr/local/ntripcaster/bin", "/usr/local/ntripcaster/conf" and "/usr/local/ntripcaster/logs". These contain the binary file, the ntripcaster.conf and sourcetable.dat files, and ntripcaster.logs file respectively. For detailed step by step guide on the installation and configuration see [Den06],[Git08].

4.3.2 NTRIP and GNSS Reference Station Configurations

The configuration of the NTRIP and the source (GNSS Reference station), which generates the RTK correction data are presented in this section. The NTRIP files required to be configured and their configuration parameters were highlighted.

The ntripcaster.conf, which is one of the NTRIP configuration files was configured. It contains the NTRIP authentication details, network information, mountpoint and Client authentication information. These information was configured with respect to the NIGNET Network. It is worthy to point out that, the CORS identification codes was added (zero) at the end, to conform to the conventional standard of naming, for example CLBR0 for the station in Calabar. A typical configured ntripcaster.conf file is shown in Appendix A.1.
In addition, the sourcetable.dat file was also configured. The sourcetable refers to a file maintained by the NTRIP Caster which contains all the relevant information about the GNSS data generating sources such as the mountpoint, stream location and RTCM format type. These information are sent to Client as sourcetable, whenever they make connection to the ntripcaster to enable them make a choice of the data source mountpoint. The GNSS generating sources are categorized in the sourcetable as Streams, Casters and Networks.

The configuration of the sourcetable requires the administrator's knowledge of the GNSS reference stations that form part of the NTRIP data correction sources. The major information expected to be configured in the sourcetable as shown in Figure 4.1 below, include the mountpoint, stream location, RTCM format type, RTCM format-details, GNSS carrier, generator, country. All these information were made available in the sourcetable configuration file.



```
SOURCETABLE 200 OK
Server: NTRIP NtripCaster 0.1.5/1.0
Content-Type: text/plain
Content-Length: 1534

CAS;www.euref-ip.net;2101;EUREF-IP;BKG;0;DEU;50.12;8.69;http://www.euref-ip.net/home
CAS;mgex.igs-ip.net;2101;EUREF-IP;BKG;0;DEU;50.12;8.69;http://mgex.igs-ip.net
CAS;rtcm-ntrip.org;2101;NtripInfoCaster;BKG;0;DEU;50.12;8.69;http://www.rtcm-ntrip.org/home
NET;EUREF;EUREF;B;N;http://www.epncb.oma.be/euref_IP;http://www.epncb.oma.be/euref_IP;http://igs.ifag.de/index_ntrip_reg.htm;none
NET;IGS;BKG;B;N;http://igscb.jpl.nasa.gov/;none;http://igs.ifag.de/index_ntrip_reg.htm;none
STR;OSGF0;Abuja;RTCM 3.0;1004(1),1012(1),1019,1020;2;GPS+GLO;NIGNET;NIG;09.02;07.48;no;0;TRIMBLE NETR8;none;B;N;9600;www.nignet.net
STR;ABUZ0;Zaria;RTCM 3.0;1004(1),1012(1),1019,1020;2;GPS+GLO;NIGNET;NIG;11.15;07.64;no;0;TRIMBLE NETR8;none;B;N;9600;www.nignet.net
STR;BKFP0;Kebbi;RTCM 3.0;1004(1),1012(1),1019,1020;2;GPS+GLO;NIGNET;NIG;12.46;04.22;no;0;TRIMBLE NETR8;none;B;N;9600;www.nignet.net
STR;CGGT0;Toro;RTCM 3.0;1004(1),1012(1),1019,1020;2;GPS+GLO;NIGNET;NIG;10.12;09.11;no;0;TRIMBLE NETR8;none;B;N;9600;www.nignet.net
STR;CLBR0;Calabar;RTCM 3.0;1004(1),1012(1),1019,1020;2;GPS+GLO;NIGNET;NIG;04.95;08.35;no;0;TRIMBLE NETR8;none;B;N;9600;www.nignet.net
STR;FUTY0;Yola;RTCM 3.0;1004(1),1012(1),1019,1020;2;GPS+GLO;NIGNET;NIG;09.34;12.49;no;0;TRIMBLE NETR8;none;B;N;9600;www.nignet.net
STR;UNEC0;Enugu;RTCM 3.0;1004(1),1012(1)1019,1020;2;GPS+GLO;NIGNET;NIG;06.42;07.50;no;0;TRIMBLE NETR8;none;B;N;9600;www.nignet.net
STR;HUKP0;Katsina;RTCM 3.0;1004(1),1012(1)1019,1020;2;GPS+GLO;NIGNET;NIG;06.42;07.50;no;0;TRIMBLE NETR8;none;B;N;9600;www.nignet.net
ENDSOURCETABLE
```

Figure 4.1: A Typical configured Sourcetable

The configuration of the RTK corrections generating sources was done remotely, with the help of the MGN-nignet v1.2 lite developed by SEGAL, since the stations are remotely located and also the research work was in Portugal. The Input/Output (I/O) of the GNSS equipment offers the location of the NTRIP configuration options. The NTRIP Server was selected and the NTRIP Caster's access authentication information were configured, such as the NTRIP version, IP address, port number, mount point, username, password, identifier, network and country. In addition, the RTCM was enabled and the RTCM version 3.0 selected. In addition, Compact Measurement Record (CMR+) which is a real-time message format developed by Trimble for broadcasting corrections to other Trimble receivers was enabled. Furthermore, the RTCM correction types were equally set. Figure 4.2 shows a typical configured NTRIP Server in Trimble NetR8 GNSS receiver, which is acting as data generating source. From Figure 4.2, CLBR refers to the NIGNET CORS in Calabar, Cross River State (see Figure 1.1)

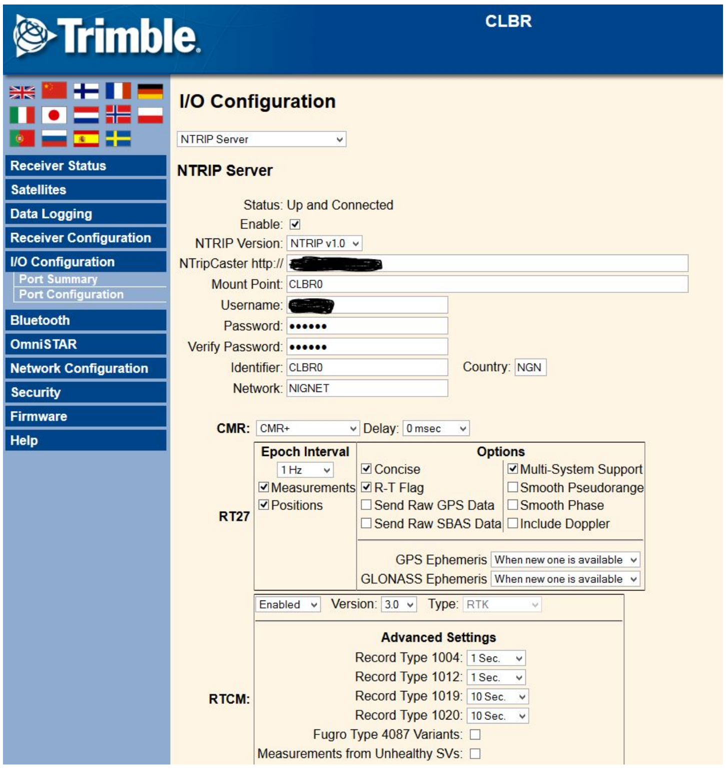


Figure 4.2: A Typical Configured NTRIP Server in Trimble NetR8 GNSS Receiver

4.3.3 NTRIP and Management System

This section presents the NTRIP and Management System, which refers to the product of integrating the NTRIP system and the developed web interface, in order to improve the management of the NTRIP services. Having setup the NTRIP system up and running, it displays its current activities on a command prompt interface, and keeps a log file which contains the overall activities of the NTRIP system. This necessitated the development and integration of a web interface that improves the management of users access to the system, payment/billing mechanism and the activities of the NTRIP system by the administrator. In addition, it enables the administrator to carry out statistical analysis base on the information generated by the NTRIP system.

This integration was carried out by developing an application called NTC, which greps the ntricaster.log file generated by the NTRIP Caster, and creates six statistical text files namely: StatisticalUserMount.txt, StatisticalSources.txt, StatisticalAccepted.txt, Accepted.txt, Kicking.txt and Parameter.txt files. Each contains vital information that helps monitoring the activities of the NTRIP system. These text files are used directly for the website integration because of its simplicity in using it to generate the statistical charts at the NTRIP and Management System. These text files and their information are presented are as follows:

1. StatisticalUserMount.txt :- This text file contains KickingClient(date), ClConn1, AcceptedClient(date), ClConn2, User, Mountpoint, Time(sec) and Bytes which refer to the time a client/user attempts to connect, number of client/user connected, the time the client/user was given access, the total number of client/user connected, The username of the client/user, the source/mountpoint connected, the duration and the size of correction data being transferred by the NTRIP Caster, respectively. This is illustrated in Figure 4.3.

```
KickingClient(date) ClConn AcceptedClient(date) ClConn User Mountpoint Time(sec) Bytes
11/Feb/2015:19:10:37 0 11/Feb/2015:19:09:59 1 guest1 BKFP0 38 12255
02/Mar/2015:17:36:18 0 02/Mar/2015:17:31:41 1 Abuja1 CLBR0 277 91506
02/Mar/2015:17:41:52 0 02/Mar/2015:17:41:32 1 Abuja2 CLBR0 20 6035
02/Mar/2015:17:47:48 0 02/Mar/2015:17:42:26 1 Abuja2 FUTY0 322 105613
03/Mar/2015:11:21:32 0 03/Mar/2015:11:21:27 1 Abuja1 FUTY0 5 0
03/Mar/2015:11:29:21 1 03/Mar/2015:11:21:42 1 Abuja1 CLBR0 459 160422
03/Mar/2015:11:32:38 0 03/Mar/2015:11:26:19 2 Abuja1 CLBR0 379 132963
03/Mar/2015:12:38:25 0 03/Mar/2015:11:36:04 1 Abuja1 CLBR0 3741 1264687
03/Mar/2015:14:29:27 1 03/Mar/2015:13:28:23 1 Abuja2 CLBR0 3664 1328602
03/Mar/2015:14:34:31 0 03/Mar/2015:14:25:09 2 Abuja1 CLBR0 562 207863
05/Mar/2015:16:47:10 0 05/Mar/2015:16:42:47 1 Abuja1 CLBR0 263 90429
05/Mar/2015:17:01:26 3 05/Mar/2015:17:01:21 4 Abuja1 FUTY0 5 601
```

Figure 4.3: A Typical StatisticalUserMount Text File

2. StatisticalSources.txt :- This file maintains information about all the KickingSource(date), all the sources/mountpoints and the total number of connected sources within the KickingSource(date). The KickingSource(date) refers to the time the NTRIP Source made connection to the Caster. Figure 4.4 shows the information on StatisticalSources.txt text file.

26/Feb/2015:10:56:25	FUTY0	1
26/Feb/2015:11:01:29	FUTY0	3
26/Feb/2015:11:12:55	FUTY0	1
27/Feb/2015:03:12:12	FUTY0	1
27/Feb/2015:04:05:57	CLBR0	1
27/Feb/2015:04:08:18	CLBR0	1
27/Feb/2015:04:10:34	CLBR0	1
27/Feb/2015:04:11:37	CLBR0	1
27/Mar/2015:05:07:27	CLBR0	1
27/Mar/2015:07:21:03	CLBR0	2

Figure 4.4: A Typical StatisticalSources Text File

3. StatisticalAccepted.txt :- This file has the KickingClient(date), ClConn2, User and Mountpoint. It contains information about all connections accepted from clients/user and sources /moutpoint within the KickingClient(date). In addition, information about the frequency of connection to a particular mountpoint is equally maintained as shown in Figure 4.5.

AcceptedClient(date)	ClConn	User	Mountpoint
26/Mar/2015:10:57:35	1	JIDE	CLBR0
26/Mar/2015:10:58:53	1	WILLIAMS	CLBR0
26/Mar/2015:11:02:00	1	WILLIAMS	CLBR0
26/Mar/2015:11:03:35	2	JIDE	CLBR0
26/Mar/2015:11:10:39	1	JIDE	CLBR0

Figure 4.5: A Typical StatisticalAccepted Text File

4. Accepted.txt :- The information about the active client/user and the source/mountpoint connected at a given time are maintained in this file. If it is empty, it means that there is no user that have connected at the time of the analysis.

5. Kicking.txt :- This file keeps the information about the time, the client/user and the mountpoint disconnected from by the Client. If it is empty, it means that no user have disconnected at the time of the analysis.

6. Parameter.txt :- This file only contains the last line number in the ntripcaser.log file. This is to give the administrator information that the log file is still being updated by the NTRIP Caster.

The web interface developed and integrated with the NTRIP system using the NTC application, to form the NTRIP and Management System, sits on Mysql Database. It was developed using PHPStorm, which is an editor for PHP scripting language. The NTRIP and Management System website was called "NIGNET NTRIP Services".

The web contents are stored in the database, and the PHPStorm uses the GET/POST request functions to work on the web contents and that of the statistical files, and present them to the user web interface or the administrative web interface. This depends on the type of information required and the visibility set by the administrator. The information visibility refers to those web contents which the administrator wants the public users to see at the user web interface. The NTRIP and Management System gives the administrator the choice to set what he/she wants the public users to see in a dynamic way. Figure 4.6 shows the NTRIP and Management System architecture.

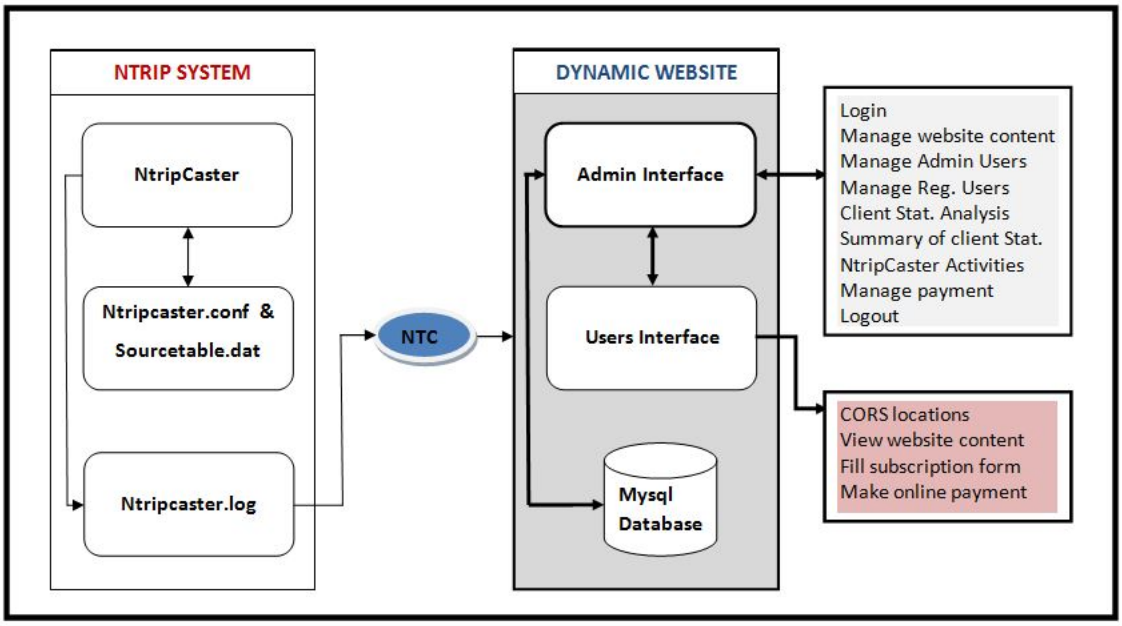


Figure 4.6: NTRIP and Management System Architecture

Furthermore, information generated from the users subscription form at the users web interface are used to configure the NTRIP and Management System, in order to grant those users access to the system, and for billing management. There are three types of management web interfaces implemented in the system namely: management of registered users, statistical analysis and payment/billing web interfaces.

4.3.3.1 Management of Registered Users Web Interface

Since these management interfaces were implemented at the administrator's web interface, there is a need to present them, because after hosting the system nobody sees these functionalities again except the administrator of the system. In view of this, this subsection describes the management of registered users web interface. It is also worthy to point out that, at the users web interface, there is a subscription page where clients fill some details as shown in Figure 4.7.

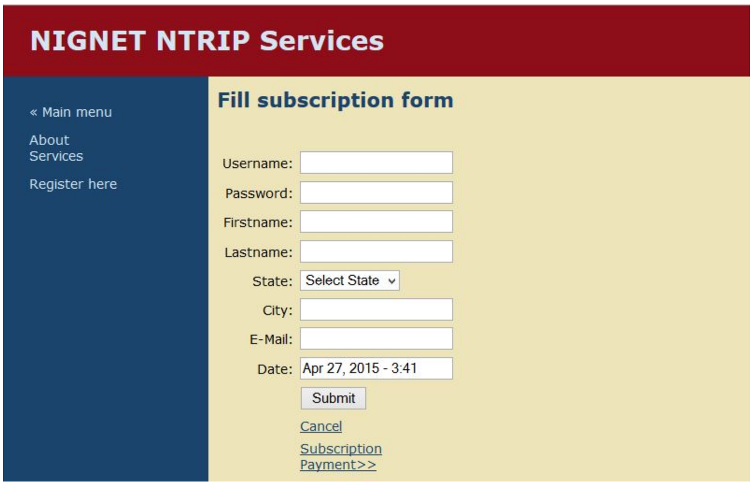


Figure 4.7: Subscription Form Web Interface

This form is then submitted and is stored in the Myqsl database of the NTRIP and Management System. The information are used by the administrator to configure the NTRIP Caster so that a registered user can have access to the Caster's RTK correction data when carrying out RTK positioning with a rover GNSS receiver. In this way, the Clients information are incorporated in the log file being generated by the NTRIP Caster. These web interfaces are described as follows:

1. Manage Clients Web Interface

   The mange clients web interface refers to the web page in the administrator's interface where subscribed Client's details are presented to the administrator. This provides information that helps in the administrative management of the system such as username, location, e-mail, and the flexibility to delete a Client as illustrated in Figure 4.8.

Figure 4.8: Manage Client Web Interface

2. Update NTRIP Caster

   Update NTRIP Caster is a web page that allows the administrator to edit the "ntripcaster.conf" file maintained by the Caster. It is accessed and presented at the web interface using the PHPStorm GET/POST request functions. This file enables the Caster to authenticate GNSS reference sources and users access to the system. In view of this, it is important to update it whenever a user registers by assigning username and password to that user. It also offers the administrator the option to grant the user access to a particular station(s) or to all the stations maintained by the NTRIP and Management System. In addition, new GNSS reference sources are added through this web interface. Figure 4.9 illustrates a typical ntripcaster.conf file ready to be updated on the "update NTRIP Caster's" web interface.

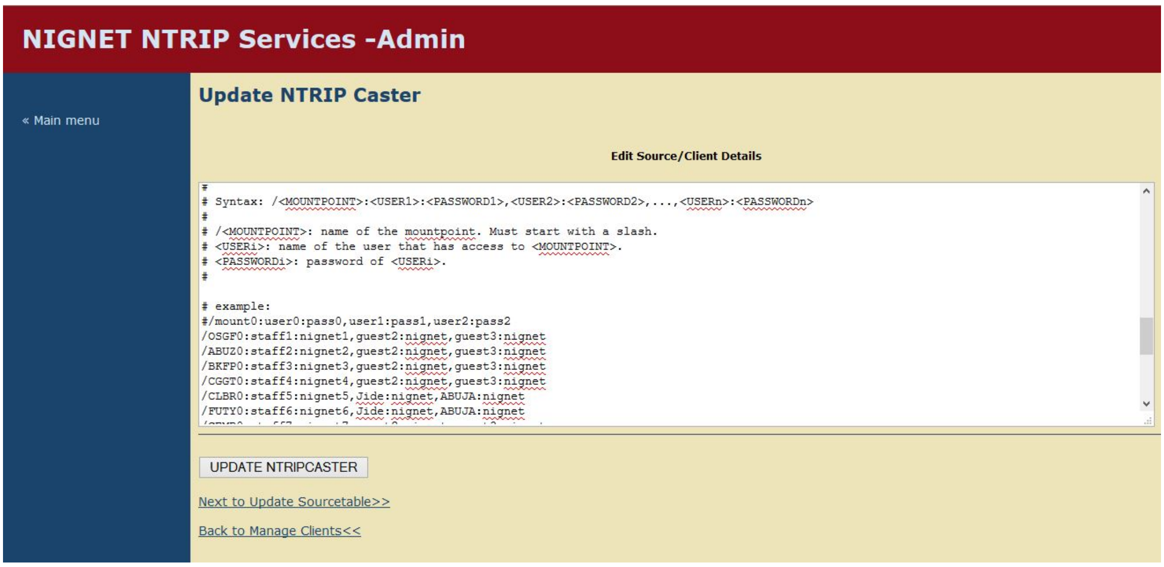


Figure 4.9: Update NTRIP Caster Web Interface

3. Update Sourcetable

   Whenever a new NTRIP Source is added to the NTRIP Caster, there is need to update the Sourcetable. As early on mentioned in subsection 4.2.2, the sourcetable is maintained by the Caster, and contains information about the NTRIP generating sources. It is important to point out that, the Baud Rate defined in the sourcetable is what the NTRIP Caster is going to use to transfer the GNSS correction data in real time. Therefore, it is recommended that the Baud Rate should be set high like 115200, where bandwidth management is not an issue, to allow the Clients the flexibility to choose the Baud Rate that their systems support. This file is usually being transferred to user/client by the NTRIP Caster whenever they establish connection to the Caster.

   The "Update Sourcetable Web Interface", offers the administrator the opportunity to edit this file as illustrated in Figure 4.10.

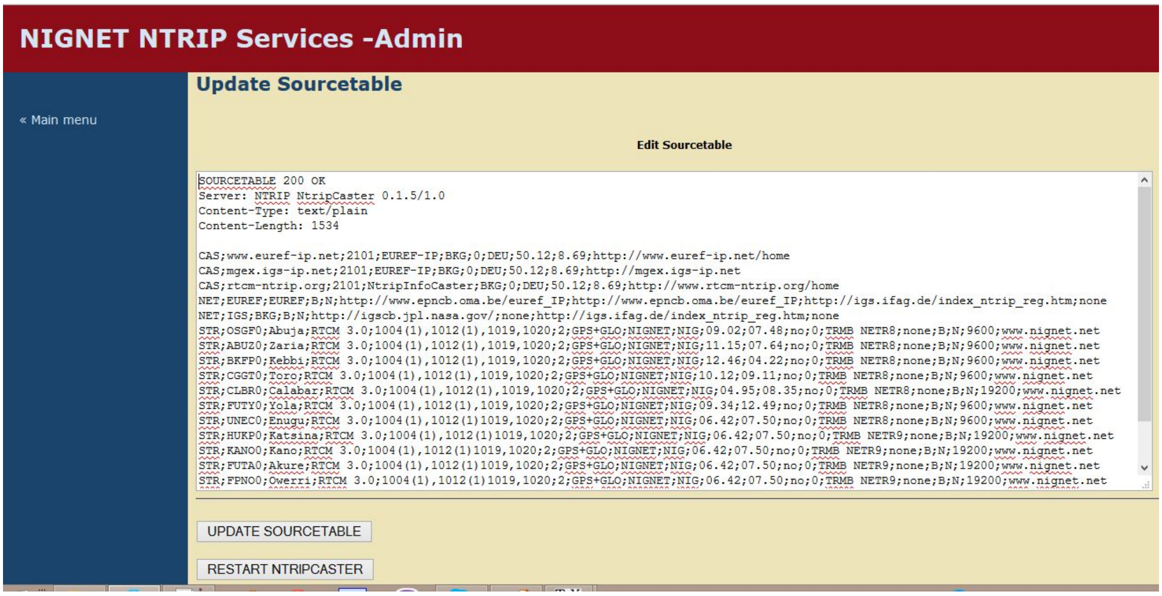


Figure 4.10: Update NTRIP Sourcetable Web Interface

4.3.3.2 Statistical Analysis Web Interface

This subsection presents the statistical analysis web interface, which are web pages maintained by the NTRIP and Management System at the administrator's web interface, aimed at giving the administrator several information regarding the overall activities of the NTRIP system. They are four different analysis options provided by the NTRIP and Management System namely: Client Statistical Analysis, Summary of Clients Statistical Analysis, NTRIP Sources Frequency of use Analysis, Summary of NTRIP Sources Statistical Analysis. These statistical information are presented in a responsive Bar Chart forms at the administrative web interface. The Bar Charts are generated by integrating some codes from Google Chart Developers [Goo15].

These are described as follows:

1. Client Statistical Analysis

   The Client statistical analysis web interface provides the administrator the possibility of knowing the overall activities of any client that is making use of the NIGNET NTRIP Services. This is done by submitting a GET/POST request function to the database and the StatisticalUserMount file generated by the NTC application after selecting the client's name of interest, time interval in month/months and year. The summary of the clients activities within the period in question will be display in a responsive Bar Chart, revealing information about the bytes and duration that has been used by that client, as illustrated in Figure 4.11. These information could be used by the administrator to prepare client bill within a chosen period of time.

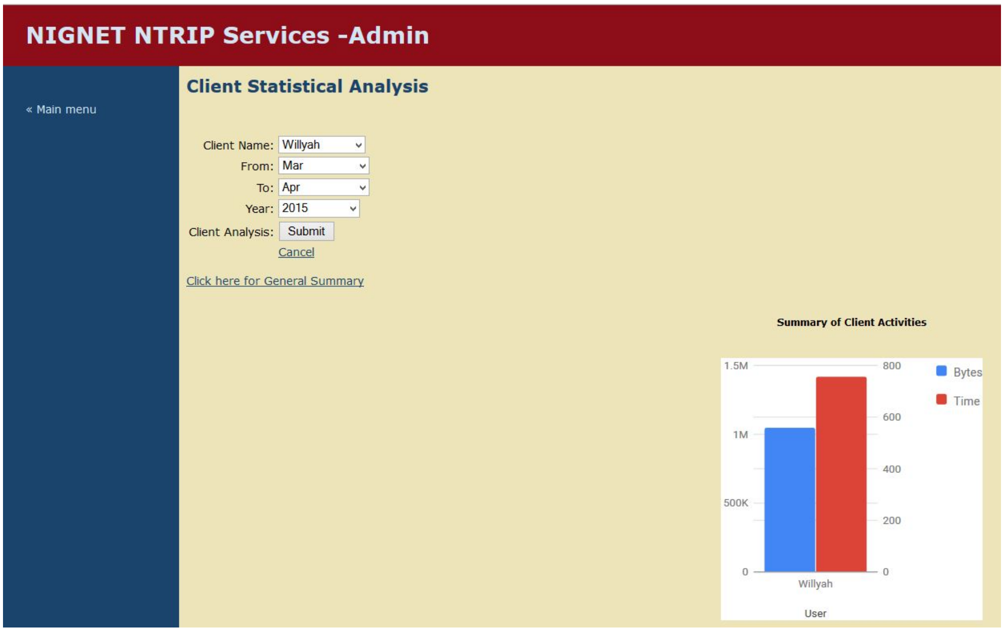


Figure 4.11: Admin Web Interface Showing Client Statistical Analysis

2. Summary of Clients Statistical Analysis

   The summary of Clients statistical analysis refers to a web page that presents the total number of clients that have used the NIGNET NTRIP Services with their corresponding bytes of data size received and the duration in a Bar Chart form. It provides the options to carry out analysis within a chosen month/months and year of interest.

   It also helps to give the administrator the overall activities of clients using the system at a glance, which can improve management and decision making. Figure 4.12 below shows the summary of clients statistical analysis web interface.

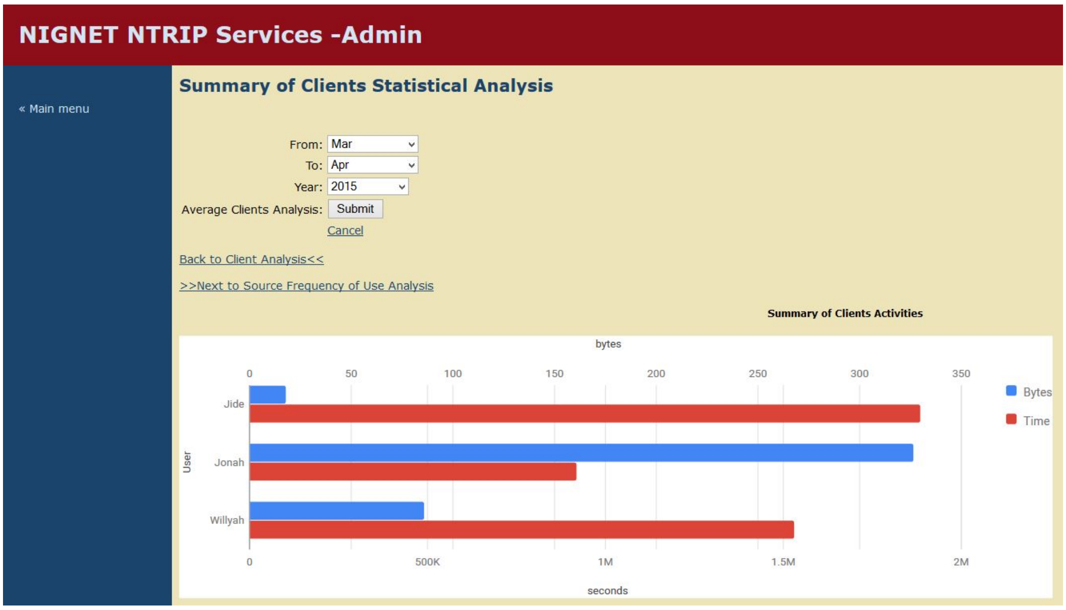


Figure 4.12: Web Interface Showing Summary of Clients Statistical Analysis

3. NTRIP Sources Frequency of Use Analysis

   A statistical analysis to know how frequently each of the NTRIP sources are being used by clients and their connection durations is provided at the NTRIP sources frequency of use analysis web interface. It offers the administrator the options to analyse sources frequency of use based on month(s) and year of interest. The statistical information are presented in a Bar Chart for easier interpretation as shown in Figure 4.13

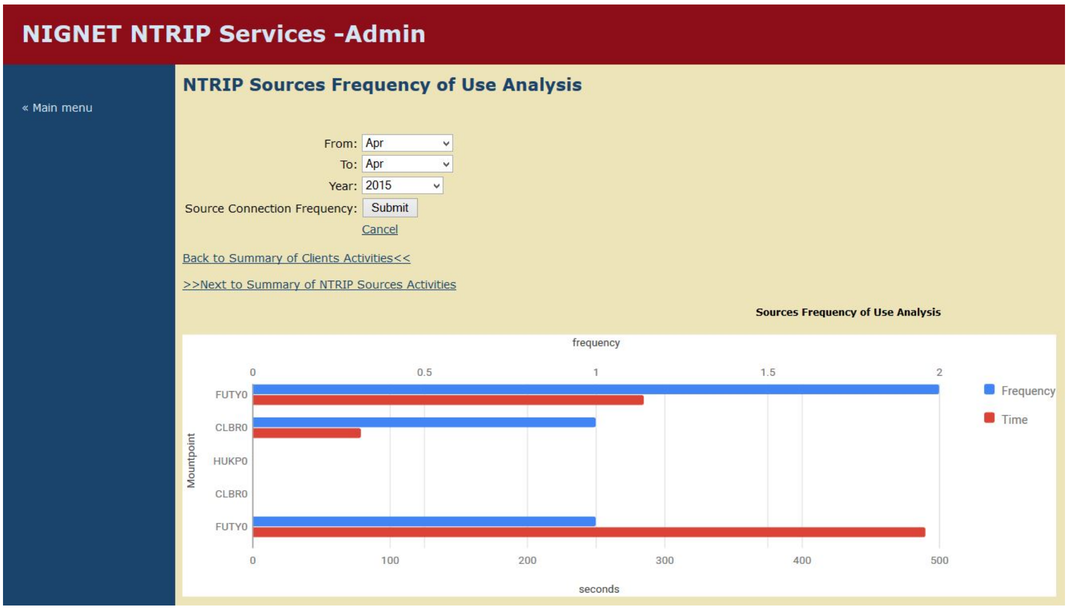


Figure 4.13: Web Interface Showing NTRIP Sources Frequency of Use Analysis

4. Summary of NTRIP Source Statistical Analysis

   The Summary of NTRIP sources analysis web interface offers the administrator information about the activities of all the NTRIP sources maintained by the NTRIP and Management System in a Bar Chart form. These information are the sources mountpoints, the total bytes of correction data being transferred and duration of connection on each of these sources. In addition, it gives the administrator the flexibility to carry out analysis within a chosen time interval and year as shown in Figure 4.14.

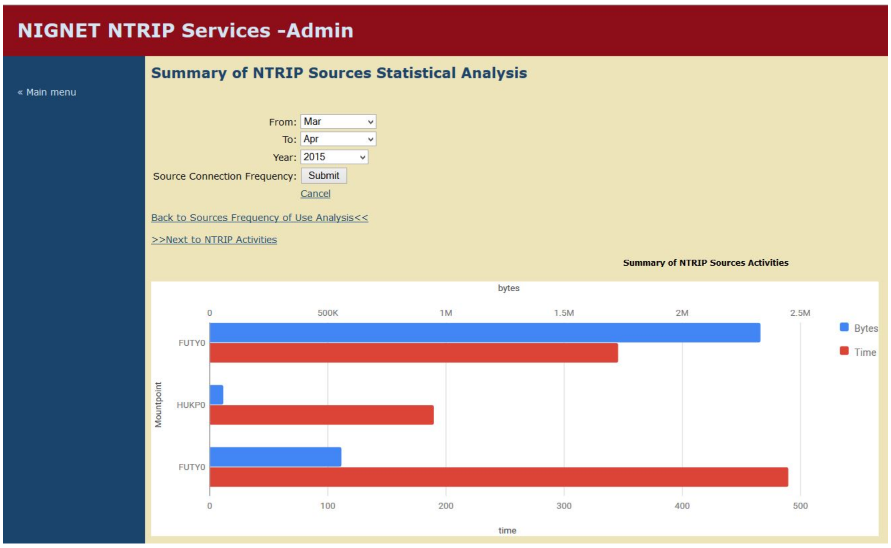


Figure 4.14: Web Interface Showing Summary of NTRIP Sources Statistical Analysis

4.3.3.3 Subscription Payment Mechanism

In addition to the statistical analysis and other functions provided by the NTRIP and Management System, a subscription payment mechanism was implemented for current or future use, in the event of commercialisation of the NTRIP services. This payment mechanism refers to the integration of the web interface with PayPal online payment platform. The integration was done by implementing a PayPal encrypted subscription button in a form action in the web interface. In the event of commercialising the services, customers would be expected to pay subscription fee depending on their chosen subscription plan. The subscription plan offers monthly, six months and yearly subscription options as illustrate in Figure 4.15. Upon selecting any of these options and clicking the subscribe button, the customer is redirected to the NIGNET NTRIP Services PayPal platform. This is illustrated in Appendix A.2.

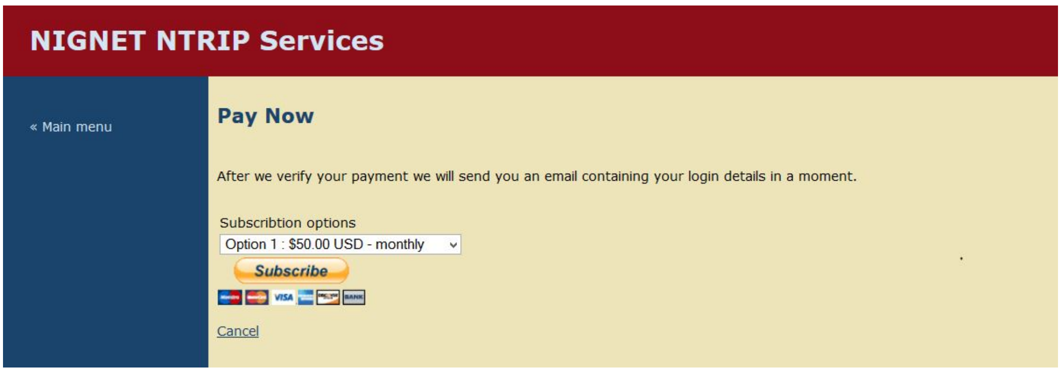


Figure 4.15: Web Interface Showing Subscription Payment Platform

4.4 Summary

The approach used in the implementation of the NTRIP and Management System is presented in this chapter. It examines the research location, hardware and software used, installation and the architecture of the NTRIP and Management System. Furthermore, the management system, which is a web interface aimed at improving the BKG Standard NTRIP Caster by offering various statistical analysis web interfaces in a user friendly manner was presented. In addition, the implemented online PayPal payment platform was equally described.

Chapter 5

Field Experiment Test and Analysis of Result

5.1 Introduction

As was already pointed out in chapter one, the "Implementation of NTRIP and Management System in NIGNET Network" is aimed at distributing Global Navigation Satellite System (GNSS) correction data to Real Time Kinematic (RTK) application users in real time via the Internet, in order to improve the accuracy of their positioning solution. Therefore, there is a need to test the viability of the implemented system to stream GNSS data in real time. The field experiment test and the analysis of the results were designed to accomplish this objective. More specifically, a verification test exercise was carried out in Nigeria, the location of the NIGNET Network, in order to validate the "NTRIP and Management System" implemented in the network. The test exercise and its outcome are presented in this chapter. The exercise is divided into field and office phases. The field phase consisted of observations using a Trimble R8-GNSS receiver, which was used to carrying out RTK test using the services of the implemented system. This exercise was aimed at confirming that the system was capable of distributing GNSS correction data in real time to rover GNSS receivers. In the second phase, the data generated by the NTRIP and Management System during the field exercise, was submitted to a statistical analysis of the activities of the user and the NTRIP and Management System. Also the Internet bandwidth, GNSS data correction size and Baud Rate were measured in order to examine the end-to-end bandwidth consumption with respect to the various Baud Rates tested. Baud Rate is a term in communication, which refers to the rate at which information is transferred in a given communication channel, and is measured in bits per seconds. This chapter presents the test exercise and the result of the analysis.

5.2 Field Experiment Test

The field experiment test as mentioned in section 5.1 involved a field exercise carried out using a Trimble R8-GNSS receiver and a Mobile phone to test the implemented system in NIGNET network. It involves the configuration of the GNSS receiver, for RTK observation, and its in-built NTRIP Client, enabling the GNSS receiver's Internet connectivity and carrying out a test exercise in RTK mode within the Office of the Surveyor General of the Federation (OSGoF), Abuja.

5.2.1 GNSS RTK Observation

The term GNSS RTK Observation is used here to refer to the GNSS observation test carried out in RTK mode using the services of NTRIP and Management System during the field exercise. This exercise was important in order to make sure that the implemented system was capable of streaming GNSS correction data to the rover GNSS receiver in real time. In addition, to examine the end-to-end bandwidth consumption and correction data size with respect to the various

Baud Rates tested.

The GNSS receiver was configured in real time kinematic mode and the Internet communication was enabled via a mobile phone that is Bluetooth enabled, which supports Serial Port Profile (SPP)/Tethering and Portable Hotspot. These are mobile phone functionalities that allow one to share ones phones Internet data connection in a wireless form to any nearby device that supports these services. This is important to enable connection with the "NTRIP and Management System", and subsequent transferring of GNSS correction data through the Internet to the GNSS receiver in real time.
The following NTRIP Caster parameters obtained from the administrator of the NTRIP and Management System were configured in the rover GNSS receiver:

- Protocol
- IP Address
- Port
- Username
- Password
- Mountpoint

The CORS mountpoint used for the exercise was CLBR, which is the NIGNET CORS identification code, for the station in Calabar. Having finished the configuration and clicking connect, connection was established with the NTRIP and Management System, and thereafter, GNSS correction data started streaming from the implemented system to the rover GNSS receiver in real time. It is worthy to point out that, the RTK observation test were carried out in different Baud Rates such as 19200, 38400, 57600 and 115200 bits per second. This variation in Baud Rate during the RTK observation test is important in order to examine its effect on the Internet end-to-end bandwidth and data size being transferred to the rover GNSS receiver. Although during the test exercise, we were able to receive GNSS correction data in real time via the Internet from CLBR which is about 465km from OSGoF but for real RTK survey, users are expected to be within 40-50km from the CORS station that would be generating the correction data [MY08].
At the end of the exercise, the data generated by the NTRIP and Management System was analysed. This is presented in the section that follows.

5.3 Analysis of Result

The analysis of the result of the RTK test exercise focuses on the effect of Baud Rate with respect to the bandwidth used during the test. Bandwidth, in computer networks is synonymous with data transfer rate. It is the amount of data that can be transported from one point to another within a given network path in a given period. A given network path normally consists of succession of links, each with its own bandwidth. Therefore, the end-to-end bandwidth is limited to the bandwidth of the lowest speed link [TCO15]. Since the NTRIP and Management System distributes the GNSS real time correction data to the RTK users via the Internet, therefore, there is a need to examine the minimum end-to-end bandwidth used during the test exercise, although this is just a preliminary test. Table 5.1 presents the information generated from the NTRIP and Management System during the test exercise.

Table 5.1: Baud Rate, Bandwidth, Data Size and Time Analysis

Baud Rate (bps)	Bandwidth (byte/Sec.)	Data Size(bytes)	Time(s)
19200	3.966666	11762	60
38500	4.183333	18762	60
57600	4.533333	36000	60
115200	5.966667	63299	60

It was observed that the end-to-end bandwidth and data size increases with an increase in the Baud Rate within the same time period as shown in Table 5.1. This means that the NTRIP and Management System would requires higher bandwidth when put to commercial use, because as more and more users are connected simultaneously to the system the bandwidth would increase accordingly.

To manage the use of the bandwidth fairly, there is the possibility of configuring the NTRIP and Management System to limit the number of simultaneous users connection to the system, also fixing the Baud Rate to a predetermined value which equally used to produce good RTK result might be of help. Although we could not determine this value due to logistic constraints. However, where the management of the bandwidth is not an issue, the system could be left at 115200 Baud Rate in order to grant the users several choices during their RTK positioning applications.

5.4 Summary

The test exercise of the NTRIP and Management System capability to distribute GNSS real time correction to a Rover GNSS receiver was presented in this chapter. It consists of field and office task. The exercise reveals that the implemented system achieved its intended purposes. The need to maintain a higher bandwidth at the implemented system was highlighted because of the corresponding increase in bandwidth when the Baud Rate was increased, as this would keep on increasing when more simultaneous connections from RTK users are made. Possible ways to manage the bandwidth at the implement system, when the bandwidth management becomes an issue, was suggested such as limiting the number of simultaneous connections to a particular number and fixing the Baud Rate to a determined value.

Chapter 6

Conclusions and Recommendations

This thesis presents the research work carried out in order to implement NTRIP system in NIGNET network, which is Nigerian Permanent GNSS Network made up of CORS, located in Nigeria, West Africa. This is aimed at distributing Global Navigation Satellite System (GNSS) correction data from the network to RTK users, in real time, via the Internet, to improve their RTK positioning solutions. The implemented system was described as "NTRIP and Management System", because of the additional functionalities adapted to the NTRIP Caster that improves its management in a more user friendly manner. The research work was successfully implemented and a preliminary test exercise was carried out in Nigeria to ensure that it conformed to the intended purposes. This chapter presents the overall conclusions of the major tasks that were carried out and reasons for some of the decisions taken during the implementation process. Furthermore, it summaries the main features integrated into the NTRIP Caster. In addition, recommendations drawn from the conclusions are presented.

6.1 Conclusions

This section presents the summary of main conclusions from the literature review and the preliminary research investigations as follows:

- The advancement in Internet and mobile communication technology, with their accompanying wider network coverage, have motivated the interest of researcher in using the Internet to stream multi-media contents and GNSS correction data in real time. In addition, GNSS, which proved to be the best positioning systems in a global scale, has experienced a high demand for positioning in real time, due to several applications that require real time GNSS corrections in order to optimise their performance. These issues led to the development of Network Transport of RTCM via Internet Protocol (NTRIP), which has proved to be an effective, efficient and cost effective way of distributing GNSS correction data in real time through the Internet, to improve RTK positioning solutions. It was adopted for NIGNET Network real time GNSS data distribution because of these reasons and several implemented prototypes in various countries that proved successful.

- Investigating the facilities currently maintained in NIGNET Network with respect to implementing an NTRIP system in the network, we concluded that, it is capable of supporting the intended application.

- The NTRIP and Management System was successfully implemented in NIGNET Network. The Standard BKG NTRIP Caster was adopted for the implementation after considering some factors like design and development of the NTRIP protocol, the mandate of the developer, human and financial resources for update and cost. The preliminary test exercise carried out within OSGoF in Nigeria using a Trimble R8-GNSS receiver on mountpoint CLBR located in Calabar, after the implementation, confirmed that connection was established with the

NTRIP and Management System, domiciled at SEGAL, Portugal, and subsequent transmitting of GNSS correction data from the implemented system to the rover GNSS receiver. Therefore, we conclude that the location of the NTRIP and Management System does not matter provided that there is good Internet services. In addition, despite the fact that corrections were received from the station in Calabar which is about 465km from the test location, but for real RTK applications, the RTK users are expected to be within 40-50km from the CORS GNSS that would be generating the real time correction. The performance of the implemented system was satisfactory during the test exercise. In addition, the NTC application, which was developed in order to integrate the NTRIP Caster with the developed website, performed equally satisfactorily by generating the data needed for the statistical analysis at the website. The website developed and integrated into the NTRIP Caster actually improved the management of the Standard BKG NTRIP Caster by providing the administrator several statistical analysis in form of responsive charts and interface to configure the NTRIP Caster. This provides an improved way of monitoring and managing the NTRIP activities and rover GNSS users.

In addition, the implemented payment mechanism which was an integration of the website with PayPal online payment platform, was also tested using the PayPal sandbox testing platform and it was confirmed satisfactory.

- During the preliminary test exercise carried out in Nigeria, the bandwidth maintained by the implemented system and the allowed Baud Rate indicated to be an issue that has to be addressed, when it is put to use in commercial scale, because the test result reveals an increase in bandwidth when the Baud Rate used for the test was increased. This means, as more and more users connect simultaneously to the system, the bandwidth would equally increase and might reach to a point that the services would be degrading.

6.2 Recommendations

In this section, we present the recommendations based on the experience acquired during the research work and the preliminary investigation conducted on the implemented system. These are outlined as follows:

1. Despite the fact that the preliminary test proved satisfactory, the system should be subjected to rigorous test by allowing several simultaneous connections for a period of time. This would help to better validate the viability of the system more and draws attention to any issue that might need to be fixed. It would also help to note some possible issues that might be expected in case the system's services is implemented in an operational mode at NIGNET.

2. Baud Rate test exercise should be conducted to determine the minimum value at which better positioning solutions are equally achievable, in order to restrict users to that value, in the even that bandwidth consumption of the implemented system becomes an issue. In addition, configuring the system to allow a particular number of simultaneous connections could equally help to address this issue.

3. To conform to best practise and achievement of better result, GNSS rover user's of the NTRIP and Management System are expected to be at most 40-50km from the CORS mountpoint that would be generating the GNSS real time correction data for the RTK applications. In view of this, the Federal Government of Nigeria through OSGoF should intensify effort to establish more CORS in line with international best practise, for effective coverage of the country. This would help to improve the services of several sectors of the Country that require RTK application to achieve better service delivery.

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Appendix A

Anexos

A.1 A Typical Configured Ntripcaster.conf File

This shows an example of a configured ntripcaster.conf file maintained by the NTRIP and Management System. The file contains information about the location of the NTRIP and Management System, server url, maximum clients connection to the system, maximum clients connection per source, the encode password which is used for NTRIP Source authentication and the port number. Furthermore, the NTRIP Source mountpoints, username and password of the registered users are equally maintained in this configuration file.

```
####################################
# NtripCaster configuration file #
##########################################################################################
############### Server Location and Resposible Person ##########################
# Server meta info with no fuctionality.

location SEGAL
rp_email willy@nignet.net
server_url localhost
############################ Server Limits ########################################
# Maximum number of simultaneous connections.

max_clients 100
max_clients_per_source 100
max_sources 45
########################## Server passwords ########################################
# The "encoder_password" is used from the sources to log in.

encoder_password sesam01

#################### Server IP/port configuration ###############################
# The server_name specifies the hostname of the server and must not be set to
# an IP-adress. It is very important that server_name resolves to the IP-adress
# the server is running at.
# For every port, the server should listen to, a new port line can be added.

server_name localhost
port 2101
#port 80

######################## Main Server Logfile ###################################
# logfile contains information about connections, warnings, errors etc.

logdir /usr/local/ntripcaster/logs
logfile ntripcaster.log

############################ Access Control #####################################
# Here you specify which users have access to which mountpoints,
# one line per mount.
#
# Syntax: /<MOUNTPOINT>:<USER1>:<PASSWORD1>,<USER2>:<PASSWORD2>,...,<USERn>:<PASSWORDn>
#
# /<MOUNTPOINT>: name of the mountpoint. Must start with a slash.
# <USERi>: name of the user that has access to <MOUNTPOINT>.
# <PASSWORDi>: password of <USERi>.
#

# example:
#/mount0:user0:pass0,user1:pass1,user2:pass2
/OSGF0:guest1:nignet,guest2:nignet,guest3:nignet
/ABUZ0:guest1:nignet,guest2:nignet,guest3:nignet
/BKFP0:guest1:nignet1,guest2:nignet2,guest3:nignet3
```

A.2 NIGNET NTRIP Services Online Payment

This shows the PayPal online payment platform integrated into the NTRIP and Management System. It supports online payment with PayPal account and Bank master card. However, it requires that you have a PayPal account for you to use this services.