ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE

Fakulta elektrotechnická

Katedra telekomunikační techniky

Přenos polohové informace
prostřednictvím datové sítě

květen 2016   **Bakalant:**   **Anastasiya Shkalikava**

                Vedoucí práce: **Ing. Pavel Puričer**

Čestné prohlášení

Prohlašuji, že jsem zadanou bakalářskou práci zpracoval sám s přispěním vedoucího práce a konzultanta a používal jsem pouze literaturu v práci uvedenou. Dále prohlašuji, že nemám námitek proti půjčování nebo zveřejňování mé bakalářské práce nebo její části se souhlasem katedry.

Datum: 27.5.2016

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České vysoké učení technické v Praze
Fakulta elektrotechnická

katedra telekomunikační techniky

ZADÁNÍ BAKALÁŘSKÉ PRÁCE

Student: **Shkalikava Anastasiya**

Studijní program: Komunikace, multimédia a elektronika
Obor: Síťové a informační technologie

Název tématu: **Přenos polohové informace prostřednictvím datové sítě**

Pokyny pro vypracování:

Prostudujte obsah, formáty dat a rozhraní pro výstup dat navigačních systémů GNSS. Na základě tohoto seznámení proveďte analýzu prostředků pro přenos polohové informace v datové síti (např. síti Internet) a její zobrazení ve vzdáleném terminálu. Dále proveďte návrh nebo kvalifikovaný výběr stávajícího takového prostředku umožňujícího periodický přenos polohové a rychlostní informace datovou sítí a její následný příjem, zobrazení a záznam ve vhodném formátu. Analyzujte a vyhodnoťte parametry přenosu.

Seznam odborné literatury:

[1] El-Rabbany, A.: Introduction to GPS: The Global Positioning System, Artech House; 2nd Revised edition edition (1 Oct 2006), ISBN: 1596930160.
[2] DePriest, D.: NMEA data. Dostupné na http://www.gpsinformation.org/dale/nmea.htm [online] [cit. 18.10.2013]
[3] BKG. Networked Transport of RTCM via Internet Protocol. Dostupné na http://igs.bkg.bund.de/root_ftp/NTRIP/documentation/NtripDocumentation.pdf. [online] [cit. 25.10.2014]

Vedoucí: Ing. Pavel Puričer

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Finally, my thanks goes to my family for their continuous support in every difficult moment that I had.

Anotace:

Tato bakalářská práce je rozdělena do dvou částí. První část práce se zabývá teoretickým popisem GNSS standardů vytvořených pro různé účely, rozborem typů chyb, které vznikají při přenášení signálu z družice ke konečnému uživateli a zahrnuje metody zpřesňování polohy GPS přijímače. Druhá část práce se zabývá praktickým měřením polohy bez a s použitím různých druhů korekcí, konkrétně SBAS a korekcí přenášených Ntrip protokolem. V této části je také popsán software použitý na určení polohy.

Klíčová slova: GPS, RINEX, RTCM SC-104, Ntrip, NMEA, chyby GPS, DGPS, real-time, postprocessing, EUREF, BNC, u-center.

Summary:

This bachelor project is divided into two parts. The first one, which is theoretical, describes the most commonly used GNSS standards for different purposes, types of errors which appear while the signal from satellite is transmitted to rover users and correction methods which are used to get rid of these errors and get accurate position. The second, practical, part represents measured results, where are opposed plain GPS positioning and GPS positioning using SBAS corrections and corrections transmitted over Ntrip protocol.

Key words: GPS, RINEX, RTCM SC-104, Ntrip, NMEA, errors in GPS, DGPS, real-time, postprocessing, EUREF, BNC, u-center.

Contents

I. THEORETICAL PART

1. GNSS standard formats

There have been developed different standards for different purposes, like transmission of GPS position between electronic devices or GPS receivers, data processing, transmission of GPS correction from reference stations to rover receivers and so on. In order for too much of almost the same standards not to appear, there had been conducted attempts to freely distribute some of the standards in order to unify the field. In this chapter are listed and described in detail some of the most commonly used standards, namely, RINEX, RTCM SC-104, NMEA and Ntrip protocol, which was developed by RTCM SC-104.

1.1 RINEX standard

1.1.1 General information and message types

The RINEX standard was developed by a group of researchers of Astronomical Institute at the University of Berne with the aim of using it worldwide as a means to simplify data collection from different receivers. RINEX was released in 1989. It has its own history of addition and removal of different message types, and of transforming some of them into separate formats. The current RINEX version 3.02 defines three different ASCII RINEX file types. Each of these consists of a header and a data section:

1. Observation data file, containing observation information such as C – code/pseudorange, L-phase, D – Doppler, S – raw signal strength, I – ionosphere phase delay, X – receiver channel numbers;
2. Navigation message file, containing the satellite information;
3. Meteorological data file, containing the time-tagged information such as dry temperature, pressure, relative humidity, wind azimuth from where the wind blows, wind speed, etc.

1.1.2 Contents and example of an RTCM observation type message

An observation type message header contains some basic information, which is:
- RINEX VERSION / TYPE – format version (3.02), file type (O – observation data), satellite system code (G – GPS, R – GLONASS, E – Galileo, J – QZSS, C – BDS, S – SBAS payload, M – mixed);
- PGM / RUN BY / DATE – name of program created this file, name of user created this file, date of file creation;
- COMMENT – some additional information such as decoder name, Broadcaster name, etc.;
- MARKER NAME;
- MARKER NAMBER;
- OBSERVER / AGENCY;
- REC # / TYPE / VERS – receiver number, type and version;
- ANT # / TYPE – antenna number and type;
- APPROX POSITION XYZ – geocentric approximate marker position;
- ANTENNA: DELTA H/E/N – height/east/north antenna position relative to the marker;
- SYS / # / OBS TYPES – satellite system code, number of active observation types, observation type codes, all of them are shown in the data section in the same sequence.

Each observation type code consists of a type (C – Code/ Pseudorange, L – Phase, D – Doppler, S – Raw signal strength (carrier to noise ratio), I – ionosphere phase delay, X – receiver channel numbers), a band (1/2/5/6/7/8/0, for example for GPS "1" means L1, "2" means L2, "5" means L5-frequency respectively) and an attribute (P/C/Y/M for respective code-based signals, D for semi-codeless signals, N for "codeless", A/B/C/I/Q/S/L for respective channels, X/Z for channel combinations, W – based on Z-tracking)

- TIME OF FIRST OBS;
- END OF HEADER.

```
 ACOR298T33.15O  ×

    3.02          Observation data    Mixed        RINEX VERSION / TYPE
BNC 2.11.0        anastasiya          20151025 193244 UTC PGM / RUN BY / DATE
PORTIONS OF THIS HEADER GENERATED BY THE EPN CB FROM     COMMENT
SITELOG acor_20140915.log                               COMMENT
RTCM_3 www.euref-ip.net/ACOR0                           COMMENT
ACOR                                                    MARKER NAME
13434M001                                               MARKER NUMBER
Pedro Gonzalo Lopez IGN-E                               OBSERVER / AGENCY
459187            LEICA GRX1200PRO    8.20/2.127        REC # / TYPE / VERS
103033            LEIAT504         LEIS                  ANT # / TYPE
   4594489.9390   -678368.0730   4357065.9000           APPROX POSITION XYZ
        3.0460         0.0000         0.0000             ANTENNA: DELTA H/E/N
G    6 C1C L1C S1C C2W L2W S2W                           SYS / # / OBS TYPES
   2015    10    25    19    33    0.0000000    GPS      TIME OF FIRST OBS
                                                        END OF HEADER
> 2015 10 25 19 33  0.0000000  0  7
G13  22606133.730  118796073.375        46.750   22606134.370   92568394.475        40.500
G09  23287851.306  122378539.586        43.500   23287854.686   95359939.418        41.750
G02  21518192.998  113078930.950        48.750   21518191.178   88113477.853        46.000
G30  20587446.804  108187873.203        50.750   20587449.364   84302299.391        50.500
G07  21191879.960  111364210.454        49.000   21191880.240   86777364.267        47.750
G05  20860150.282  109620909.669        50.000   20860150.602   85418933.637        50.000
G06  23586022.124  123945418.506        42.750   23586026.984   96580878.647        40.750
> 2015 10 25 19 33  1.0000000  0  7
G13  22605640.290  118793480.280        46.500   22605640.910   92566373.879        40.500
G09  23288387.726  122381358.374        43.250   23288391.066   95362135.874        41.500
G02  21518559.038  113080854.492        48.750   21518557.218   88114976.717        46.250
G30  20587280.484  108186999.141        50.750   20587283.044   84301618.304        50.500
G07  21192134.840  111365549.852        49.250   21192135.120   86778407.954        47.750
G05  20859838.202  109619269.720        50.000   20859838.522   85417655.754        50.250
G06  23586716.804  123949069.061        43.000   23586721.664   96583723.237        40.250
> 2015 10 25 19 33  2.0000000  0  7
G13  22605146.870  118790887.375        46.750   22605147.510   92564353.436        40.250
G09  23288924.146  122384177.238        43.250   23288927.486   95364332.392        42.750
G02  21518925.178  113082778.534        48.750   21518923.358   88116475.973        46.000
G30  20587114.264  108186125.693        50.750   20587116.824   84300937.698        50.500
G07  21192389.820  111366889.757        49.250   21192390.100   86779452.038        47.750
G05  20859526.202  109617630.144        50.000   20859526.522   85416378.164        50.000
G06  23587411.504  123952719.734        42.750   23587416.364   96586567.913        41.500
> 2015 10 25 19 33  3.0000000  0  7
G13  22604653.510  118788294.777        46.750   22604654.150   92562333.233        40.500
G09  23289460.586  122386996.231        43.000   23289463.906   95366529.010        42.500
G02  21519291.418  113084703.167        48.750   21519289.598   88117975.683        46.000
G30  20586948.184  108185252.945        50.750   20586950.744   84300257.634        50.250
G07  21192644.900  111368230.267        49.000   21192645.180   86780496.589        47.750
G05  20859214.282  109615991.040        50.000   20859214.602   85415100.943        50.250
G06  23588106.244  123956370.594        43.000   23588111.104   96589412.733        41.750
> 2015 10 25 19 33  4.0000000  0  7
G13  22604160.230  118785702.578        46.750   22604160.870   92560313.342        40.500
G09  23289997.086  122389815.476        43.250   23290000.386   95368725.826        42.250
G02  21519657.778  113086628.468        48.750   21519655.978   88119475.919        46.000
G30  20586782.244  108184380.964        50.750   20586784.804   84299578.166        50.250
G07  21192900.140  111369571.470        49.250   21192900.400   86781541.682        47.750
```
Fig. 1.1.2.1: Example of RTCM Observation Type Message

The data section is divided into epochs, which contain the time tag of each observation. The data section begins with the record identifier (symbol >), which helps to define the start of each record in case of data corruption. Then follows the date and time of each measurement, the epoch flag (0: OK; 1: power failure between previous and current epoch; >1: special event), and the number of satellites observed in the current epoch. For epoch flag = 0, each line consists of the satellite number and observation types listed in the header section – e.g. C1C, L1C, S1C, C2W, L2W, and S2W *(fig. 1.1.2.1)*. [1]

1.2 RTCM SC-104 standards

1.2.1 General information

The Radio Technical Commission for Maritime Services (RTCM) was established in 1947 as a US government advisory committee to investigate issues related to maritime telecommunications. It is now an international non-profit scientific, professional, and educational organization, supported by its members all over the world. The RTCM is involved in maritime radio navigation and radio communication policy issues, regulatory changes, and technical standards development for marine electronics – such as Emergency Position Indicating Radio Beacons (EPIRBs), Personal Locator Beacons (PLBs) and Satellite Emergency Notification Devices (SENDs), Digital Selective Calling (DSC) equipment, Global Navigation Satellite Systems and various VHF requirements, among other things. The RTCM has more than 130 member organizations, both government and non-government, including:

- Manufacturers of radionavigation and radiocommunication systems,
- Government agencies concerned with standards for maritime radionavigation and radiocommunication systems,
- Government agencies and commercial entities involved in operation of maritime radionavigation and radiocommunication systems,
- Associations with an interest in maritime radionavigation and radiocommunication systems and related public policy,
- Ship owners and operators,
- Educational institutions,
- Sales and service providers. [2]

1.2.2 RTCM special committees

The special committees are groups of government and non-government members that work together on different tasks specific for each committee. Their goal is to develop technical standards and consensus recommendations with regard to issues related to telecommunications. The Special Committees are:

- Special Committee (SC) 101 on Digital Selective Calling (DSC)
- Special Committee (SC) 104 on Differential Global Navigation Satellite Systems (DGNSS)
- Special Committee (SC) 109 on Electronic Charting Technology
- Special Committee (SC) 110 on Emergency Beacons (EPIRBs and PLBs)
- Special Committee (SC) 112 on Ship Radar
- Special Committee (SC) 117 on Maritime VHF Interference
- Special Committee (SC) 119 on Maritime Survivor Locator Devices
- Special Committee (SC) 121 on Automatic Identification Systems (AIS) and Digital Messaging
- Special Committee (SC) 123 on Digital Message Services over Maritime Frequencies
- Special Committee (SC) 127 on Enhanced Loran (eLoran)
- Special Committee (SC) 128 on Satellite Emergency Notification Devices (SEND)

- Special Committee (SC) 129 on Portrayal of Navigation-Related Information on Shipboard Displays
- Special Committee (SC) 130 on Electro-Optical Imaging Systems
- Special Committee (SC) 131 on Multi-system Shipborne Navigation Receivers
- Special Committee (SC) 132 on Electronic Visual Distress Signalling Devices
- Special Committee (SC) 133 on Data Exchange for Navigation-Related Applications for Mobile Devices [2]

1.2.3 RTCM SC-104 standards for GNSS services

Special Committee 104 started work in the year 1983 to develop recommendations for transmitting different corrections to GPS users. In 1985, draft recommendations were published, followed by a series of updated versions:

- RTCM Recommended Standards for Differential Navstar GPS Service, Version 2.0 (1990); This increased the number of messages available from 16 to 64 and added flexibility. Many of the ancillary messages have been streamlined and shortened.
- RTCM Recommended Standards for Differential Navstar GPS Service, Version 2.1 (1994): This fixed some message types and added new messages that support real-time kinematic applications. Service providers were allowed to define the meaning of the station health field.
- RTCM Recommended Standards for Differential GNSS Service, Version 2.2 (1998): This added several messages to support differential GLONASS operation. It also added messages and guidance material for supporting combined GPS/GLONASS operations, a message to provide time of year/month/day/hour to support data logging, a message to provide the datum and the associated coordinate conversions for operations not utilizing WGS-84 or PE-90, and a message to provide higher resolution in reference station antenna phase centre coordinates, in support of high-accuracy kinematic operations.
- RTCM 10410.0 (RTCM Paper 200-2004/SC104-STD, Version 1.0), with Amendment 1, Standard for Networked Transport of RTCM via Internet Protocol (Ntrip): This is an application-level protocol based on the Hypertext Transfer Protocol (HTTP) streaming standard. It and supports streaming GNSS data over the internet and is meant for mass usage.
- RTCM 10410.1 Standard for Networked Transport of RTCM via Internet Protocol (Ntrip) Version 2.0 with Amendment 1 (28 June, 2011): This cleared and fixed design problems as well as HTTP violations, replaced non-standard directives, added chunked transfer encoding, improved header records, and provided for source-table filtering and for Real Time Streaming Protocol (RTSP) communication.
- RTCM 10402.3 RTCM Recommended Standards for Differential GNSS Service, Version 2.3 with Amendment 1 (21 May, 2010): This added several messages to improve the potential accuracy of real-time kinematic operations (particularly in defining the ground station reference point), added an entire set of messages and guidance material for utilizing Loran-C as a medium for the broadcast of differential GNSS corrections, and added a new radio-beacon almanac message that supports multiple reference stations. Amendment 1 revises Message Type 27, changing it from Tentative to Fixed.

    The most frequent messages are given in *fig.1.2.3.1* and *fig. 1.2.3.2*.

- RTCM 10403.2, Differential GNSS (Global Navigation Satellite Systems) Services - Version 3 (1 February, 2013): The main changes are that the parity scheme now uses bandwidth more efficiently, parity is now independent from word to word, the new integrity of the message is higher, new messages were developed and are still being developed, and Multiple Signal Messages (MSM) was added, including five amendments that were made in Version 3.1. [2]

Message type number	Description
1	DGPS corrections
2	Delta DGPS corrections
3	GPS reference station parameters
6	GPS null frame
9	GPS partial correction set
16	A text message entered by the user, transmitted from the base station to the rover
18	RTK uncorrected carrier phases
19	RTK uncorrected pseudoranges
20	RTK carrier-fase corections
21	RTK/high PRC account
22	Extended reference station parameters
23	Antenna type defination used on the reference station
24	Coordinates of the installed antenna's ARP (Antenna Reference Point) parameter

Fig. 1.2.3.1: RTCM 2 most frequent message types [3]

Message type number	Description
1001/1009	GPS/GLONASS L1 code and phase
1002/1010	GPS/GLONASS L1 code and phase and ambiguities and carrier-to-noise ratio
1003/1011	GPS/GLONASS L1 and L2 code and phase
1004/1012	GPS/GLONASS L1 and L2 code and phase and ambiguities and carrier-to-noise ratio
1005	Station coordinates XYZ for antenna reference point
1006	Station coordinates XYZ for antenna reference point and antenna height
1007	Antenna descriptor and ID
1008	Antenna serial number
1019	GPS ephemeris
1020	GLONASS ephemeris
1045	Galileo F/NAV ephemeris
1046	Galileo I/NAV ephemeris
SSR (State Space Representation)	
1057/1063	GPS/GLONASS orbit corrections to Broadcast Ephemeris
1058/1064	GPS/GLONASS clock corrections to Broadcast Ephemeris
1059/1065	GPS/GLONASS code biases

Fig. 1.2.3.2: RTCM 3 most frequent message types

Message type number	Description
1060/1066	Orbit and clock corrections to GPS/GLONASS Broadcast Ephemeris
1061/1067	GPS/GLONASS User Range Accuracy (URA)
1062/1068	High-rate GPS/GLONASS clock corrections to Broadcast Ephemeris
MSM (Multiple Signal Messages)	
1071/1081/1091/1121	Compact GPS/Glonass/Galileo/BeiDou pseudo-ranges
1072/1082/1092/1122	Compact GPS/Glonass/Galileo/BeiDou carrier phases
1073/1083/1093/1123	Compact GPS/Glonass/Galileo/BeiDou pseudo-ranges and carrier phases
1074/1084/1094/1124	Full GPS/Glonass/Galileo/BeiDou pseudo-ranges and carrier phases plus signal strength
1075/1085/1095/1125	Full GPS/Glonass/Galileo/BeiDou pseudo-ranges, carrier phases, Doppler and signal strength
1076/1086/1096/1126	Full GPS/Glonass/Galileo/BeiDou pseudo-ranges and carrier phases plus signal strength (high resolution)
1077/1087/1097/1127	Full GPS/Glonass/Galileo/BeiDou pseudo-ranges, carrier phases, Doppler and signal strength (high resolution)

Fig. 1.2.3.2: RTCM 3 most frequent message types (cont.)

1.2.4 Structure of RTCM message type 1

Fig. 1.2.4.1: Structure of a four-satellite message type 1 [3]

The message type 1 frame length is 30 bits, while the frame height depends on the number of satellites visible at the reference station – e.g. if the number of satellites is four, the frame height is nine words; if the number of satellites is five, then the frame height is 11 words. Every word ends with a 6-bit parity, which is used to check for errors. The sequence of 1 – 24 bits of the first

two words is *(fig. 1.2.4.1)*:

- Preamble (bits 1–8) – is used for synchronization between the sending and receiving device. Essentially, the first few bits tell the receiver to get ready to receive a new frame. The preamble sequence is 01100110;
- Message type (bits 9–14) – message type identifier, e.g. 000001;
- Reference station ID (bits 15–24);
- Modified Z-count (bits 1–13) – transmitted message time reference;
- Sequence number (bits 14–16) – is used to identify the start of the next frame;
- Length of frame (bits 17–21);
- Station health (bits 22–24).

All the information about the visible satellites is contained in the rest of the frame, starting from the third word. The satellites are described in a series, one by one. Each satellite requires a total of 40 bits for the correction, placed in the following sequence *(fig. 1.2.4.1)*:

- S, or scale factor (1 bit) – assigns a value to the least significant bit (LSB) used by he corrections. If the scale factor is 0, then the LSB of the PRC is 0,02 m and LSB of RRC is 0,002 m/s. Similarly, if the scale factor is 1, then the LSB of the PRC is 0,32 m and LSB of RRC is 0,032 m/s;
- UDRE (User Differential Range Error, 2 bits) – indicates ranges of expected errors of the PRC;
- Satellite ID (5 bits);
- Pseudorange correction (PRC, 16 bits);
- Range-rate correction (RRC, 8 bits);
- Issue of data (8 bits) – identifies the navigation message that the reference station used to calculate the satellite position and clock offset.

The fill is the sequence of alternating ones and zeros: 10101010 or 1010101010101010. The length depends on the number of described satellites – i.e. the number of bits left at the end of the frame. [3]

1.3 NTRIP protocol

1.3.1 Introduction

Nowadays standalone GPS receivers typically detect positions with an error of 10–15 metres, which may be a very low accuracy for some applications. In such situations, when accuracy of no more than an error of one meter is required, a Differential Global Navigation Satellite System (DGNSS) is used. A DGNSS reaches this high accuracy by providing correction data from one or more (if the distance between a user and reference station is large enough) reference stations.

There are about 15 current technical standards developed by the RTCM Special Committees (SC). The RTCM-104 DGNSS standard is used around the world for differential satellite navigation systems, both maritime and terrestrial, and it accepts differential correction messages and RTK messages. The messages under the RTCM-104 DGNSS standard are transmitted over communication links – e.g. via radio transmission, or via a mobile communication network. The Ntrip protocol (Network Transport of RTCM via Internet Protocol) is based on HTTP and its messages are broadcast to stationary or mobile receivers over the Internet. [4]

1.3.2. General information

The Ntrip System is based on the HTTP streaming standard. HTTP was originally designed for bulk traffic, but it is also used for IP streaming applications, like the RTCM application. The major purpose of the Ntrip System is making the RTCM corrections (or other types of GNSS streaming data) available in real-time for mobile users.
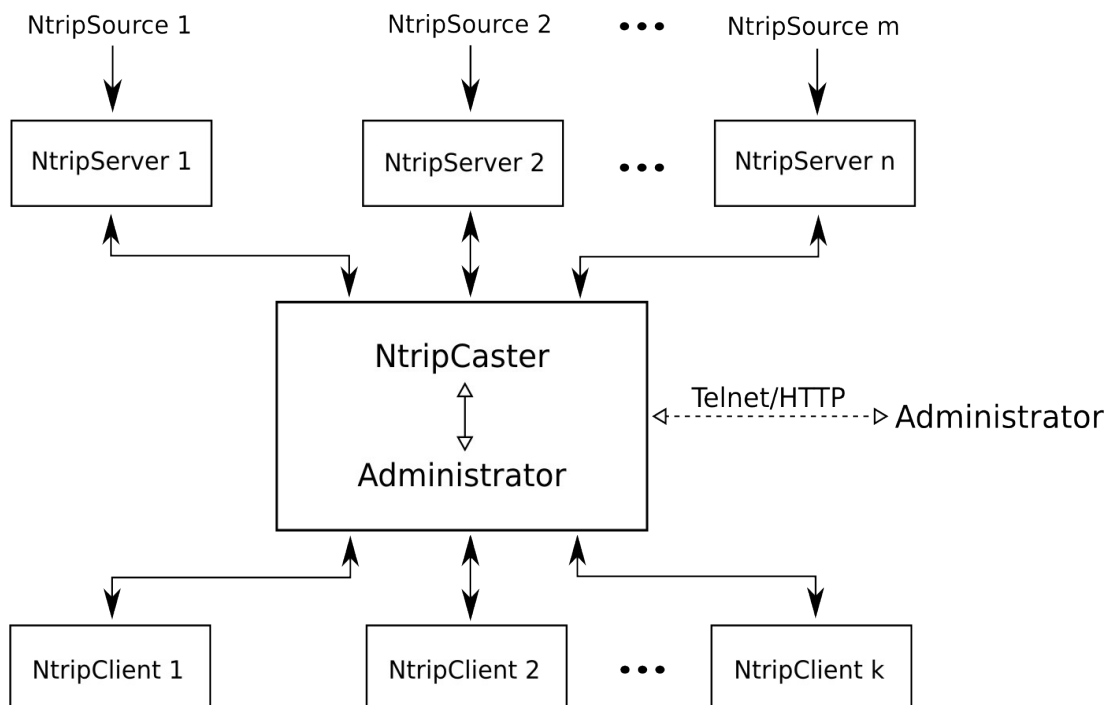

Fig. 1.3.2.1: Ntrip System Concept

Ntrip is meant to be an open non-proprietary protocol. Here are some major characteristics of the Ntrip System:

- Ntrip is an application-level protocol that supports streaming any kind of GNSS data over

the internet;

- It is based on the HTTP streaming standard;
- Ntrip supports wireless internet access through any mobile IP networks (like GSM, GPRS, EDGE, or UMTS) because it uses TCP/IP;
- The system is meant for mass usage;
- Regarding security needs, stream providers and users are not necessarily in direct contact, and streams are usually not blocked by firewalls or proxy servers protecting local area networks;
- The Ntrip software components are NtripSources, which provide data streams, NtripServers, which transfer the data streams from an NtripSource to the NtripCaster, NtripCaster, which is the administrator, the major system component, and NtripClients, which receive the data streams of the desired NtripSources *(fig. 1.3.2.1)*. [4]

1.3.3. NtripSource

NtripSources are devices that generate GNSS streaming data at specific locations. This data is then sent by NtripServers to the NtripCaster, which is the main system component. NtripServers define an NtripSource ID called 'mountpoint', which must be unique for every single NtripSource. It is recommended to use a four-character ID, followed by an integer value (e.g. BUCU0 for Bucharest), as a mountpoint name. According to the data provided by the NtripSource, a source-table is created, which includes information about the mountpoint ID, the format in use (e.g. RTCM 2.3, RTCM 3.2, CMR, RAW), the recognized navigation system (e.g. GPS, GPS+GLONASS), location coordinates (country, latitude, longitude), and other details. [5]

1.3.4. NtripServer

The NtripServer is designed to be a server for a single NtripSource. It is used to transfer the GNSS data of an NtripSource (the NtripServer grabs a serial GNSS byte stream via a COM-port) to the NtripCaster, using the TCP/IP connection.

1.3.5. NtripServer on Windows

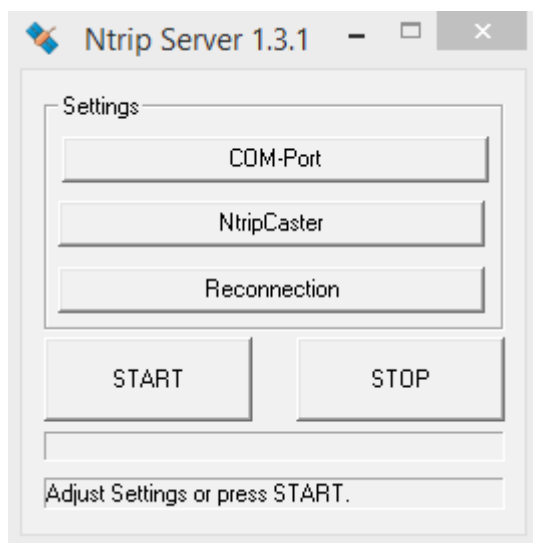Ntrip Server 1.3.1 allows COM-port, NtripCaster, and Reconnection options *(fig. 1.3.5.1)*.

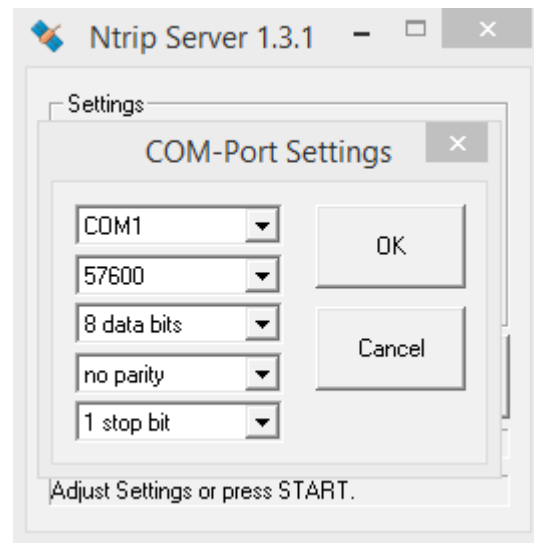*Fig. 1.3.5.1: Ntrip Server 1.3.1 options*

Fig. 1.3.5.2: Ntrip Server 1.3.1 COM-port option

When configuring the COM-port *(fig. 1.3.5.2)*, you will have to choose the port name, a baud rate (using a high baud rate is recommended – e.g. 57600), the number of data bits for serial input (usually 8), parity, and the number of stop bits for serial input (usually 1).

The NtripServer must connect to the NtripCaster using the IP and the specified listening port of the NtripCaster *(fig.1.3.5.3)*. This means that the NtripCaster must be 'up and running' before any source can connect. Passwords and mountpoints are defined and can be changed only by the administrator of the NtripCaster.
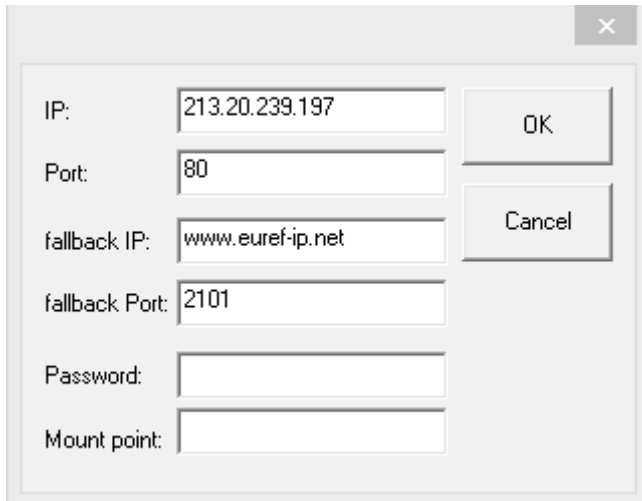

Fig. 1.3.5.3: Ntrip Server 1.3.1 NtripCaster option

It is possible to configure an automatic reconnection to the NtripCaster *(fig. 1.3.5.4)* in case it is down, where the NtripServer operator can set a desired number of reconnection attempts, the time between them, and the time for waiting for the data on the COM-port. There is also a 'Use Autostart' option, which means that the program will automatically start running after a system reboot. In the latest version, the NtripServer operator can set a time for auto disconnection from the NtripCaster.
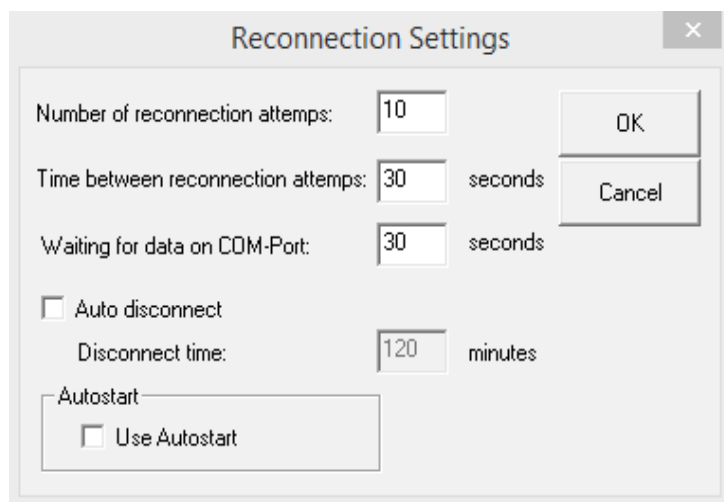

Fig. 1.3.5.4: Ntrip Server 1.3.1 reconnection option

1.3.6. NtripCaster

The NtripCaster, as the main system component, works as a server accepting request messages on a single port from both the NtripServer and the NtripClient, and deciding whether to receive or send the incoming information. The NtripCaster administrator is responsible for handling mountpoints for NtripSources, passwords, NtripClient access rights, billing, statistics, and so on.

The NtripCaster is based on the Icecast software, which is a streaming media server developed under GNU GPL (General Public License). Its purpose is to duplicate the incoming data for a large number of clients accessing the desired mountpoints. The Icecast server is capable of streaming audio content as Opus or Vorbis over standard HTTP, video as WebM or Theora over HTTP, MP3 over the communications protocol used by SHOUTcast, and AAC (Advanced Audio Coding) and NSV (Nullsoft Streaming Video) over the SHOUTcast protocol (Theora, AAC, and NSV are only supported in version 2.2.0 and newer). The NtripCaster (with about 0.5 to 10 Kbit/s transmission rate) is a re-designed Icecast, which, unlike the Icecast, supports the GNSS data streams like:

- RTCM corrections, DGNSS,
- RTCM corrections, RTK,
- RTCA corrections, EGNOS & WAAS,
- RAW data,
- SP3 ultra-rapid orbits,
- RINEX observations.

There are two different NtripCaster versions – a standard and a professional version – both of which use the same principle. The professional version, unlike the standard version, guarantees a larger amount of simultaneous connections and is meant for mass usage. [5]

1.3.7. NtripClient

To start the session the NtripClient software must send the correct request message. That means the NtripClient operator needs to choose the desired Caster host, Caster port, and NTRIP version, then enter username and password, and download the source-table, where he will select the desired mountpoints. It is possible for several NtripClients to access the data of a desired NtripSource at the same time. [5]

1.4. NMEA protocol

1.4.1. General information

The NMEA protocol was developed by the National Marine Electronics Association. It defines the interface shared by various pieces of marine electronic equipment. This NMEA protocol describes not only the data taken from GPS receivers, but also metering taken from sonars, radars, electronic compasses, barometers and other marine navigation equipment. The majority of navigation programs representing data in real time understand and support the NMEA protocol. This data includes the complete PVT: position, velocity, and time. [6]

1.4.2. NMEA message structure

Each NMEA message is complete and doesn't depend on other messages. It begins with '$' and ends with '\n' (next sentence), and can be no longer than 80 symbols. The data there is divided by commas. The message includes the headline, the body, and the checksum field.

The headline consists of five symbols. The first two letters define the device that uses that sentence type (for all GPS NMEA messages the prefix is GP), while the last three letters define the sentence name. The messages not described in the NMEA specification, but realized in GPS receivers according to general rules have the prefix P, followed by the company's three unique symbols (NMEA Garmin message has the prefix PGRM, Magellan has PMGL).

The body contains information that is written in ASCII code and it does not need any decryption. If there is not enough place for the whole data, then it will be divided into several messages.

The checksum field is at the end of every NMEA message, separated from the data by ' ', followed by a two-digit hexadecimal number. The checksum is the bitwise XOR of ASCII codes of all characters between the '$' and ' '. This field is required on some sentences for completeness control. [6]

1.4.3. NMEA message types

There are many sentences in the NMEA standard for all kinds of devices. The sample below is for Garmin g12, version 4.57. [6]

$GPRMC,183729,A,3907.356,N,12102.482,W,000.0,360.0,111215,015.5,E*6F
$GPRMB,A,,,,,,,,,,,,,V*71
$GPGGA,183730,3907.356,N,12102.482,W,1,05,1.6,646.4,M,-24.1,M,,*75
$GPGSA,A,3,02,,,07,,09,24,26,,,,,1.6,1.6,1.0*3D
$GPGSV,2,1,08,02,43,088,38,04,42,145,00,05,11,291,00,07,60,043,35*71
$GPGSV,2,2,08,08,02,145,00,09,46,303,47,24,16,178,32,26,18,231,43*77
$PGRME,22.0,M,52.9,M,51.0,M*14
$GPGLL,3907.360,N,12102.481,W,183730,A*33
$PGRMZ,2062,f,3*2D
$PGRMM,WGS 84*06
$GPBOD,,T,,M,,*47
$GPRTE,1,1,c,0*07
$GPRMC,183731,A,3907.482,N,12102.436,W,000.0,360.0,111215,015.5,E*67
$GPRMB,A,,,,,,,,,,,,,V*71

The messages here are updated every two seconds. If we change the bit rate from 4800 kbit/s to 9600 kbit/s, the messages will be updated every second.

The most frequent sentences are listed below.

AAM	Waypoint Arrival Alarm
ALM	Almanac data
APA	Auto Pilot A sentence
APB	Auto Pilot B sentence
BOD	Bearing Origin to Destination
BWC	Bearing using Great Circle route
DTM	Datum being used
GGA	Fix information
GLL	Geographic Position - Latitude/Longitude
GRS	GPS Range Residuals
GSA	GPS DOP and active satellites
GST	GPS Pseudorange Noise Statistics
GSV	Satellites in view
MSK	Send control for a beacon receiver
MSS	Beacon receiver status information
RMA	Recommended minimum – Loran data
RMB	Recommended minimum – navigation data for gps
RMC	Recommended minimum – data for gps
RTE	Route message
TRF	Transit Fix Data
STN	Multiple Data ID
VBW	Dual Ground / Water Spped
VTG	Vector track and Speed over the Ground
WCV	Waypoint closure velocity (Velocity Made Good)
WPL	Waypoint Location information
XTE	Measured cross track error
ZTG	UTC & Time to Destination Waypoint
ZDA	Date & Time

1.4.4. Examples of NMEA messages

Some NMEA messages may include the same data fields or may contain other message data, but are of a smaller size. [6]

- GGA message: The most popular and the most frequently used message, it includes information about fixed data, such as horizontal coordinates, height value, quantity of used satellite, and the decision type.

Example of GGA message:

$GPGGA,123519,4807.038,N,01131.000,E,1,08,0.9,545.4,M,46.9,M,,*47

Where:

GGA	Global Positioning System Fix Data
123519	Fix taken at 12:35:19 UTC
4807.038,N	Latitude 48 deg 07.038' N
01131.000,E	Longitude 11 deg 31.000' E
1	GPS Quality Indicator
	0 - fix not available
	1 - GPS fix
	2 - Differential GPS fix (values above 2 are 2.3 features)
	3 - PPS fix
	4 - Real Time Kinematic
	5 - Float RTK
	6 - estimated (dead reckoning)
	7 - Manual input mode
	8 - Simulation mode
08	Number of satellites being tracked
0.9	Horizontal dilution of position
545.4,M	Antenna Altitude above/below mean-sea-level (geoid)
46.9,M	Geoidal separation, the difference between the WGS-84 earth ellipsoid and mean-sea-level (geoid)
(Empty field)	Time since last DGPS update, seconds
(Empty field)	Differential reference station ID, 0000-1023
*47	Checksum, always begins with *

- RMC message: This is the recommended minimum. It has its own version of essential GPS PVT data.

Example of RMC message:

$GPRMC,123519,A,4807.038,N,01131.000,E,022.4,084.4,111215,003.1,W*6A

Where:

RMC	Recommended Minimum – data for GPS
123519	Fix taken at 12:35:19 UTC
A	Status A - active or V – Void
4807.038,N	Latitude 48 deg 07.038' N
01131.000,E	Longitude 11 deg 31.000' E
022.4	Speed over the ground, knots
084.4	Track angle, degrees
111215	Date - 11th of December 2015, ddmmyy
003.1,W	Magnetic Variation, degrees
*6A	Checksum, always begins with *

- GSA message: This NMEA message includes the satellites that are used in counting the value of the position and the DOP's geometrical factors, which define the precision when counting the position. The satellite's geometrical position in the sky defines the DOP's parameters. The better the satellite's position in the sky, the less the DOP is and the more precise is the position evaluation. When one of the satellites is definitely over the user and three others are arranged around it on the horizontal level, the value of the PDOP is 1 (the minimum value).

Example of GSA message:
$GPGSA,A,3,04,05,,09,12,,,24,,,,,2.5,1.3,2.1*39

Where:

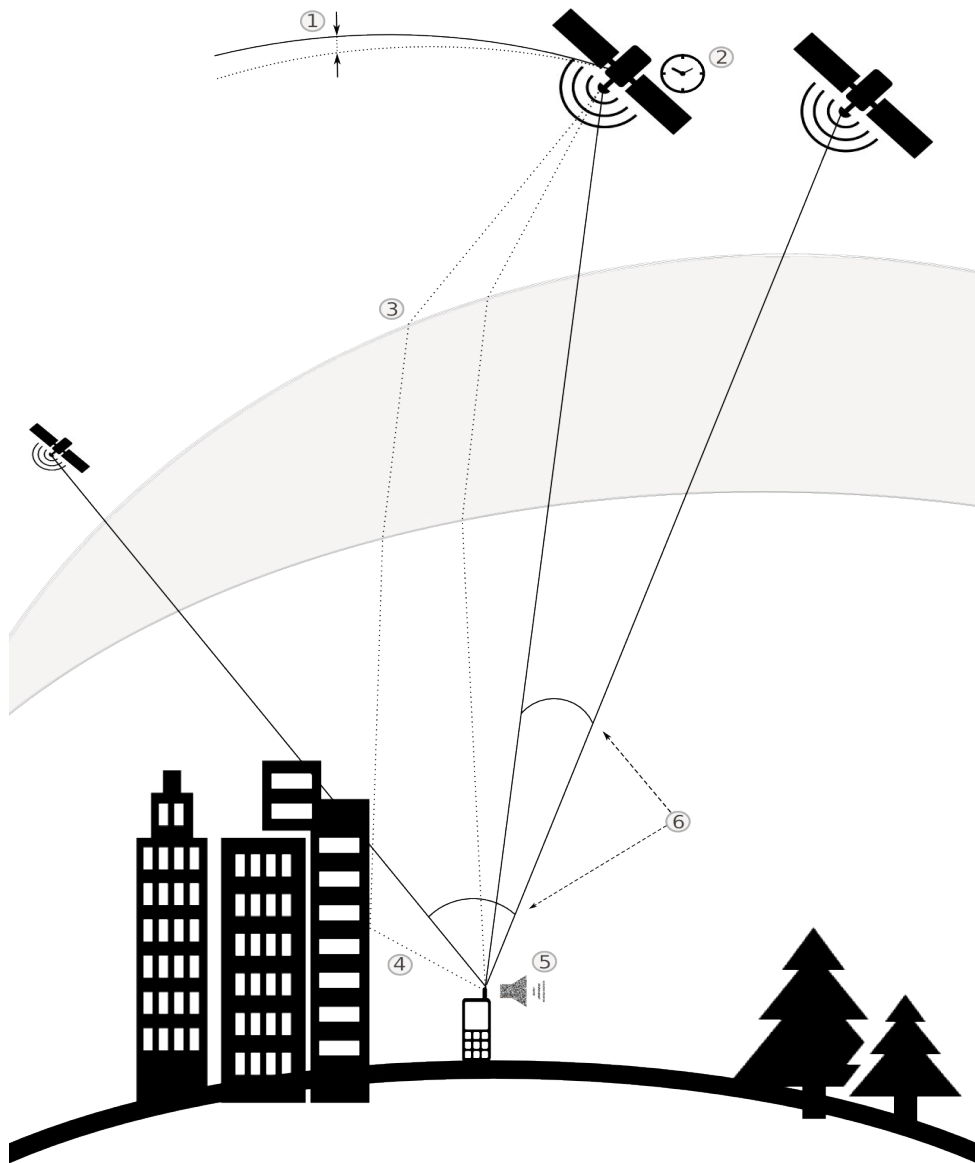|	
GSA	GPS DOP and active satellites
A	Auto selection of 2D or 3D fix (M = manual)
3	3D fix - values include
	1 - no fix
	2 - 2D fix
	3 - 3D fix
04,05...	IDs of satellites used for fix (space for 12 satellites)
2.5	PDOP (dilution of precision)
1.3	HDOP (Horizontal dilution of precision)
2.1	VDOP (Vertical dilution of precision)
*39	Checksum, always begins with *

2. Types of errors in GPS

Fig. 2.1: Errors occuring in GPS: 1 - ephemeris (dotted line - predicted trajectory, solid line - real trajectory), 2 - satellite clock, 3 – ionospheric, 4 - multipath, 5 - receiver noise; 6 - GDOP: acute angle - bad GDOP, obtuse angle - good GDOP

2.1 Ephemeris data errors

Satellite orbits are not perfectly aligned. Moreover, they are constantly changing their directions slightly *(fig. 2.1)*. This is why the ephemeris predictions are made every hour based on

actual observed positions from the past four-hour period given by Jet Propulsion Laboratory, USA. The reasons for such constantly changing orbits are a very complicated gravitational model, and the effect of such forces as solar radiation pressure and atmospheric drag. Although the ephemeris error for a particular satellite is the same for any GPS user using it, the error has a different impact on positioning errors depending on an actual receiver position due to different view angles.

2.2 Satellite clock errors

Every satellite has a very precise atomic clock installed but it cannot be perfectly precise, which is an essential parameter for accurate GPS positioning. Errors can appear even in this kind of clock and every microsecond of this error can lead to a positioning error of 300 metres. The equation below shows how it is calculated:

$$l_{ec} = \varepsilon_c * c \quad [\text{m}; \text{s}, \text{m/s}]$$

where l_{ec} is the pseudorange calculation error depending on satellite clock error only, ε_c is the satellite clock error, and c the velocity of light $3*10^8$ m/s.

Satellite system time will almost never be exactly the same as GPS system time. This mistiming is predicted to a limited extent using the calculated parameters a_0, a_1, a_2, which are transmitted as part of a navigation file to help a receiver reduce the error. After automatic correction is completed, the positioning is made using the T_{GPS} parameter:

$$T_{GPS} = t_s - \varepsilon_c \quad [\text{s}; \text{s}, \text{s}]$$

where T_{GPS} is the corrected GPS time of transmission, t_s the satellite time of transmission, and ε_c the satellite clock error.

The parts of the equation above are calculated in the following way:

$$t_s = t_{rr} - \frac{l}{c} \quad [\text{s}; \text{s}, \text{m}, \text{m/s}]$$

where t_s is the satellite time of transmission, t_{rr} the signal reception time at receiver, l the pseudorange, and c the velocity of light $3*10^8$ m/s;

$$\varepsilon_c = a_0 + a_1 * dt + a_2 * dt^2 \quad [\text{s}; \text{s}, \text{s/s}, \text{s}, \text{s/(s*s)}, \text{s}]$$

where ε_c is the satellite clock error, a_0 the clock bias, a_1 the clock drift, a_2 the frequency drift, and dt the satellite clock offset;

$$dt = t_s - t_{sr} \quad [\text{s}; \text{s}, \text{s}]$$

where dt is the satellite clock offset, t_s the satellite time of transmission, and t_{sr} the time of satellite receiving request. [7]

2.3 Atmospheric errors

The signal from a satellite does not only travel through vacuum but also through the atmosphere, which can be divided into two layers – the ionosphere and the troposphere.

The ionosphere represents the layer consisting of rarefied gas that, due to interactions with ultraviolet and X-ray radiations coming from the sun, is becoming ionized – i.e. electrons are separated from atoms, leaving free negatively charged electrons and positively charged atom cores. Since this electron separation needs energy, the said energy is taken from solar radiation, gradually weakening it; therefore, different ionosphere sub-layers can be distinguished.

This kind of environment has a different refraction coefficient than that of vacuum. So, the signal trajectory inside the ionosphere layer can have slight random instabilities but the error it

gives is negligibly small. Besides, its trajectory is refracted into a slightly different angle over the border between two environments *(fig. 2.1)*, but it only makes a notable difference, whereas a satellite is lower than five degrees over horizon. The greatest impact on signal passage through the ionosphere is due to change in the velocity of light. The total ionospheric delay is highly dependent on a number of free electrons along the signal's path, which is called the total electron content (TEC). TEC is affected by a variety of parameters, such as time of day, time of year, point in 11-year solar cycle, and geographic location. TEC has its maximum at the poles and around the equator, at midday or during increased solar activity with peak ionospheric delay over 150 metres, whereas under normal conditions it is in the order of 10 metres.

Since the ionosphere delay depends on carrier frequency, different ways to combine the L1 and L2 carriers can be used to eliminate or at least reduce it. Users with single-frequency receivers – in the absence of the ability to make their own dual-frequency corrections – can use any one of the empirical ionospheric models, such as the Klobuchar model, coefficients of which can be found in the navigation message, or they can receive pre-calculated corrections from the closest reference station.

Unlike the ionosphere, the troposphere is a non-dispersive medium for frequencies used in GPS. This means that the signal velocity will be the same for every code or carrier frequency. As a result, it is impossible to compensate for troposphere delay by combining the L1 and L2 observations. Meanwhile, a delay depends on temperature and pressure – together called the delay's dry component – and humidity – i.e. the wet component. About 90 per cent of the tropospheric delay consists of the dry component, which can be accurately predicted using mathematical models. The remaining 10 per cent – the wet component – is not easy to predict. The delay also greatly depends on the satellite's elevation angle, from about two metres at the zenith to 20–30 metres at five degrees over the horizon. [3]

2.4 Multipath errors

Multipath error is an error caused by the fact that the signal from the satellite not only travels straight to the antenna but also can be reflected off some surfaces, such as water or buildings *(fig. 2.1)*. In this case, the reflected signal takes more time to be caught by the antenna than the direct signal. Therefore, they overlap with each other, making it harder to distinguish actual pseudorange or carrier-phase. The easiest and most obvious way to get rid of this error is to use a place without any reflective objects around. If this is not an option, then a user may use some special antennas, such as a chock ring antenna (a ground plane that has several concentric metal hoops to attenuate the reflected signals) or an antenna with the same polarization as the GPS signal (the GPS signal has right-handed circular polarization while reflected signals have left-handed polarization). But it will not work in case the signal reflects twice or an even number of times because the polarization will again become right-handed.

2.5 Receiver errors

Any GPS receiver would have some level of internal noise *(fig. 2.1)*. Obviously, the lower the noise is, the better the positioning accuracy is. In order to evaluate the noise level for specific receiver, two tests can be performed: zero baseline and short baseline test. Zero baseline test consists of position measure through one antenna and two or more GPS receivers. As one antenna is used, any difference between receivers' positioning is only created by receiver noise, which is inconvenient in the way, that the antenna noise would not be measured. In order to also measure antenna noise, short baseline test is performed. It means the position measure over two consecutive days with antenna being moved for a couple of metres for the second day. After this

much time almost every error would cancel out, leaving only the system noise and multipath error, which can be eliminated by differencing the first and second day's measures. [3]

2.6 Satellite geometry

The positioning accuracy is not only decreased by errors affecting the signal, but also by possible bad satellite geometry *(fig. 2.1)*. A bad satellite geometry means, that the satellites are placed on a narrow viewing angle so that the uncertainty region is elongated and occupying a relatively large area instead of being square with smaller area. The named uncertainty region represents the area closed between major and minor radii corresponding to the estimated distance. In general, the best GDOP occurs while the satellites used are 90° apart as seen from receiver. Geometric dilution of precision (GDOP) is divided into several components, which are time dilution of precision (TDOP) and position dilution of precision (PDOP), which in its turn id divided into horizontal dilution of precision (HDOP) and vertical dilution of precision (VDOP). The smaller GDOP is, the better accuracy is obtained: an excellent level of GDOP coefficient is up to 2, a good level is up to 5 and is not recommended when it is more than 5. [3]

2.7. DGPS correction of individual kinds of errors

Since satellite errors are fully common for reference stations and rover receivers, they can be completely corrected by DGPS. Ionospheric errors depend on receiver's location, so in case that the reference station used is placed within a distance of cca. a hundred kilometres, it can also be assumed, that the errors are corrected completely but it is not true in case of reference station located significantly further. However, multipath errors and receiver noise are unique to every specific receive, so DGPS can not compensate for these effects. This is why in order to acquire the most accurate position possible, a user not only has to use DGPS corrections, but also to pick a place that would not create much of signal reflection and to use more precise hardware.

3. Correction methods distinguished by evaluation speed

The GPS signal from a satellite goes through numerous interferences that cause different errors, such as ephemeris data errors, satellite clock errors, ionosphere and troposphere errors, multipath errors, and receiver errors, as discussed in Chapter 2. It is important to take these errors into account because any of them can lead to an enormous mistake of a couple kilometres away from an actual point. To bring these errors down to more reasonable levels or to avoid them completely, correction methods are used. This works much more efficiently if the user is close to the reference station. Then the corrections needed for them both are not too different and the user can receive them almost immediately.

3.1 Real-time and postprocessing methods

Two basic ways of realizing correction methods are identified: a real-time method when data is corrected in real time and a method of better accuracy, which is called postprocessing DGPS when data is corrected afterwards. The main difference is that real-time corrections only consist of predicted data calculated using corrections from a few seconds before, while postprocessing measurements are also collected at a later time to achieve the best accuracy. This difference will be explained in detail in the picture below.

Real-time DGPS is used when the speed of obtaining the results is important – e.g. when a rover receiver is moving. This is why corrections must not have latency in them. To meet this condition, corrections are sent by the reference station some seconds before they are measured so as to compensate the time used to send, and then receive and calculate the corrections on the other side. This means they are only predictions based on the last measured corrections.

Postprocessing is a more complex process than the real-time differential correction method. It is based on sending raw GPS rover data to the central server with operational postprocessing software where the sent data is corrected using raw GPS base data and its known position. Postprocessing techniques are used in case a user does not need to know his position immediately but is able to wait for the server to collect base data taken after the rover positioning time, to calculate the corrections and send them back. The algorithm used in this postprocessing software is expected to be very precise, and, therefore, relatively complex and powerful, which is the second reason for better postprocessing accuracy.

3.2 Example in detail

Fig. 3.2.1 shows a simplified example of the working order of real-time and postprocessing methods. Please note that the example does not represent exactly how these systems work but is just a schematic illustration of the difference between their main principles of operation.

The reference station (8;2) receives its own GPS position every two seconds (*fig. 3.2.1* - marks 0s, 2s, and 4s, placed at (2;1), (3;6), and (10;7) respectively). A vector from the reference station to a mark is an error vector – i.e. the difference between the received and the real GPS position – while the reverse vector is the correction vector. The rover receiver obtains its GPS position at the moment of 3s and, at the same time, requests for a correction.

As mentioned earlier, the real-time method is based on correction predictions, or the data calculated by the reference station using the last acquired real marks. In the example, only two marks are obtained (0s, 2s) before the moment of 3s. So, the correction trajectory from 2s to 4s (4;11) is predicted based on marks 0s and 2s, and then is sent to the rover receiver where the required point on this trajectory is calculated. In the figure, the prediction trajectory and the

predicted mark are highlighted in orange; the estimated GPS position as if it was measured at the moment of 3s, and the correction vector at the moment of 3s, which is the same for both the reference station and the rover receiver, are marked in red.
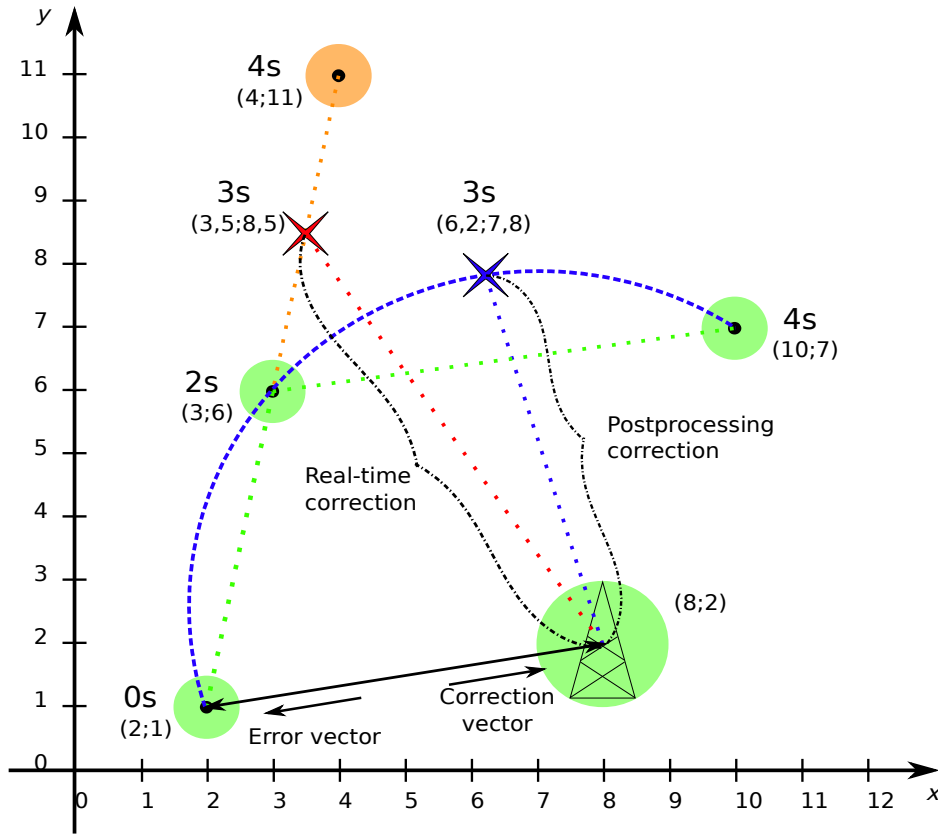

Fig. 3.2.1: Schematic representation of difference between real-time and postprocessing methods

In contrast to the real-time method, where the data is predicted in order to save time, postprocessing software gathers the GPS position of the rover receiver and measured position of the reference station before and after the positioning time. In this case, it is a blue trajectory calculated using not only the marks 0s and 2s, but also the mark 4s (10;7) (measured after the positioning time) and a blue cross representing a very accurately measured correction, which is then sent to the rover receiver.

As a result, there are two different corrections calculated with different accuracy and a different amount of time spent on carrying out the calculations.

4. Correction transfer methods

There have been developed two main augmentation systems for positioning accuracy improvement: the satellite based augmentation system (SBAS) and the ground based augmentation system (GBAS). Both of them calculate corrections by means of reference stations and their precisely known positions. Reference stations analyze the condition of satellites and ionosphere and then transfer calculated corrections to the receivers. The main difference between these two systems is that SBAS system transfer their corrections through geostationary satellites while GBAS system - straight to the rover receivers using radio- or mobile-networks.

4.1 SBAS

SBAS comprises a number of services, the first of which, Wide Area Augmentation System (WAAS), was developed by the US Federal Aviation Administration for the purpose of improving aviation positioning, but has been opened for free use since 2003. Other governments have developed their own SBAS systems: Europe has the European Geostationary Navigation Overlay Service (EGNOS), Japan is covered by the Multi-functional Satellite Augmentation System (MSAS) and India developed its GPS Aided GEO Augmentation Navigation (GAGAN) *(fig. 4.1.1)*. The System for Differential Correction and Monitoring (SDCM) is currently being developed in Russia. Both Korea (2013) and China (2014) announced the creation of their own SBAS systems. All the systems follow the same global standard. This is why they are compatible and interoperable, which means that a user with a standard receiver can use any of these systems while being in the corresponding zone and will not lose a signal due to being in the intersection of different systems' function area. The base stations of these systems receive and correct GPS data, and send it to users that have an SBAS-capable GPS receiver. There is an advantage of the same equipment being needed for SBAS as for GPS because of SBAS corrections being transmitted over the same L1 GPS frequency. The correction service is free and provides data with sub-metre accuracy. [9]

There have been developed not only regional SBAS systems like WAAS or EGNOS, but also global commercial systems, such as OmniSTAR, StarFire and StarFix. Next will be described one of these systems - OmniSTAR.
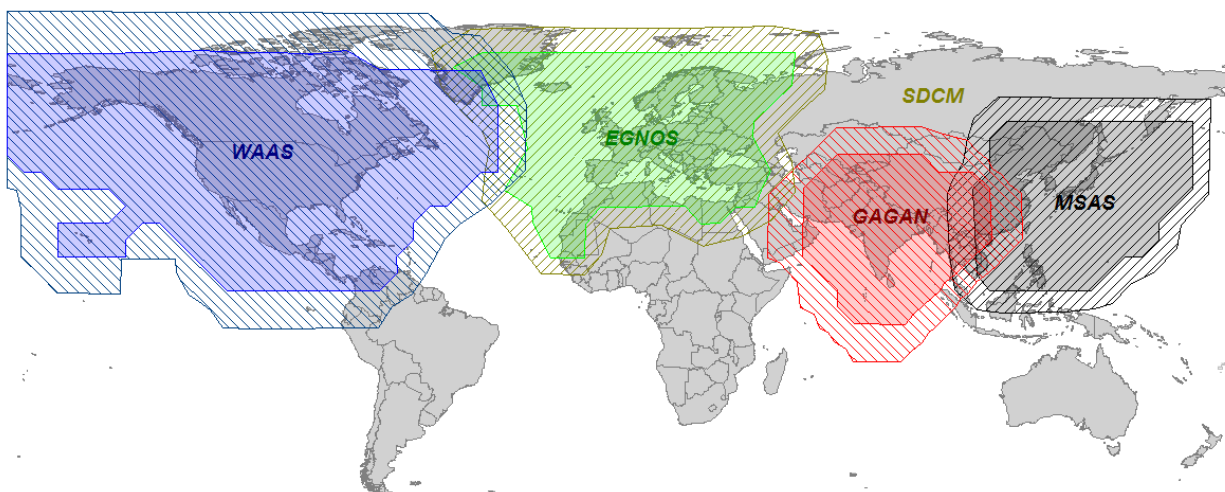

Fig. 4.1.1: Regional SBAS systems [9]

4.1.1 OmniSTAR

OmniSTAR is a commercial SBAS system that is available wirelessly through satellite and mobile phone technologies. It offers real-time DGPS services of different kinds, depending on specific region, time of correction acquisition, and desired accuracy. The level of desired accuracy can range from a radius of a sub-metre to a few metres when a quick start-up time is desired or even to 5 cm accuracy, with full accuracy available within 45 minutes. The system improves and facilitates railway and aviation operations by providing appropriate companies with the software needed to monitor the accurate position of railway trains and aircrafts respectively. In agriculture, position corrections provided by OmniSTAR can be of help in applications like farm mapping and farm machinery movement, especially in case of automated systems when planting, seeding, spraying, harvesting, and so on. In mining, it can be used in data collection for tenement pegging, drilling boreholes, identification surveys, and soil sampling. In mapping and GIS, it helps with the acquisition of data needed to make any kind of map, including boundary, irrigation, landscape, and agriculture and forestry condition surveys, maps of resources, utilities, cables, pipelines, and so on.

OmniSTAR has reference stations all over the world. It has offices in USA Texas 77063 for North, Central, and South America and the Caribbean, in Australia WA 6021 for a zone stretching from India and China to Australia, the Netherlands Leidschendam 2266 KA for Europe, Middle East, Russia, and CIS, and in South Africa 7925 Cape Town for Africa. OmniSTAR reference stations send a corrected GPS position to a stationary OmniSTAR satellite which then sends those signals on both single-frequency (L1 only) code phase pseudo-range solutions and dual-frequency (L1/L2) carrier phase solutions to roving GPS receivers. [10]

4.2 GBAS

GBAS system contains three operational segments: the Space Segment, the Ground Segment and the Aircraft (or User) Segment. The most distinctive is the Ground Segment, which in its turn contains at least 4 reference GNSS receivers, reference stations subsystem, used to gather GNSS signals and monitor their quality, processor subsystem responsible for calculating corrections and data broadcast subsystem. There are regional networks of reference stations, that may be of help to rover users. They contain different number of stations, work with different navigation systems (usually GPS and GLONASS) and different format versions, they may also be free of charge or not. Examples of these networks are EUREF (EU), IGS (EU), CZEPOS (CZE), SAPOS (DEU) and so on. Next is described a huge GBAS network - EUREF.

4.2.1 EUREF Permanent Network (EPN)

EPN is a voluntary federation of more than 100 self-funding European agencies, universities and research institutions in more than 30 European countries. Its activities are coordinated by EUREF. EPN is a network of more than 270 continuously operating GPS, GLONASS and Galileo reference stations organized mainly for European Coordinate System ETRS89 (European Terrestrial Reference System 1989). The purpose of EPN is not only the maintenance of the ETRS89 geodetic system, but also usage for different scientific applications such as the monitoring of ground deformations, sea level, ionospheric analysis, space weather and numerical weather prediction. [11]

EPN components [11]:
- GNSS Tracking Network
- Operational Centres

- Data Centres
- Analysis Centres
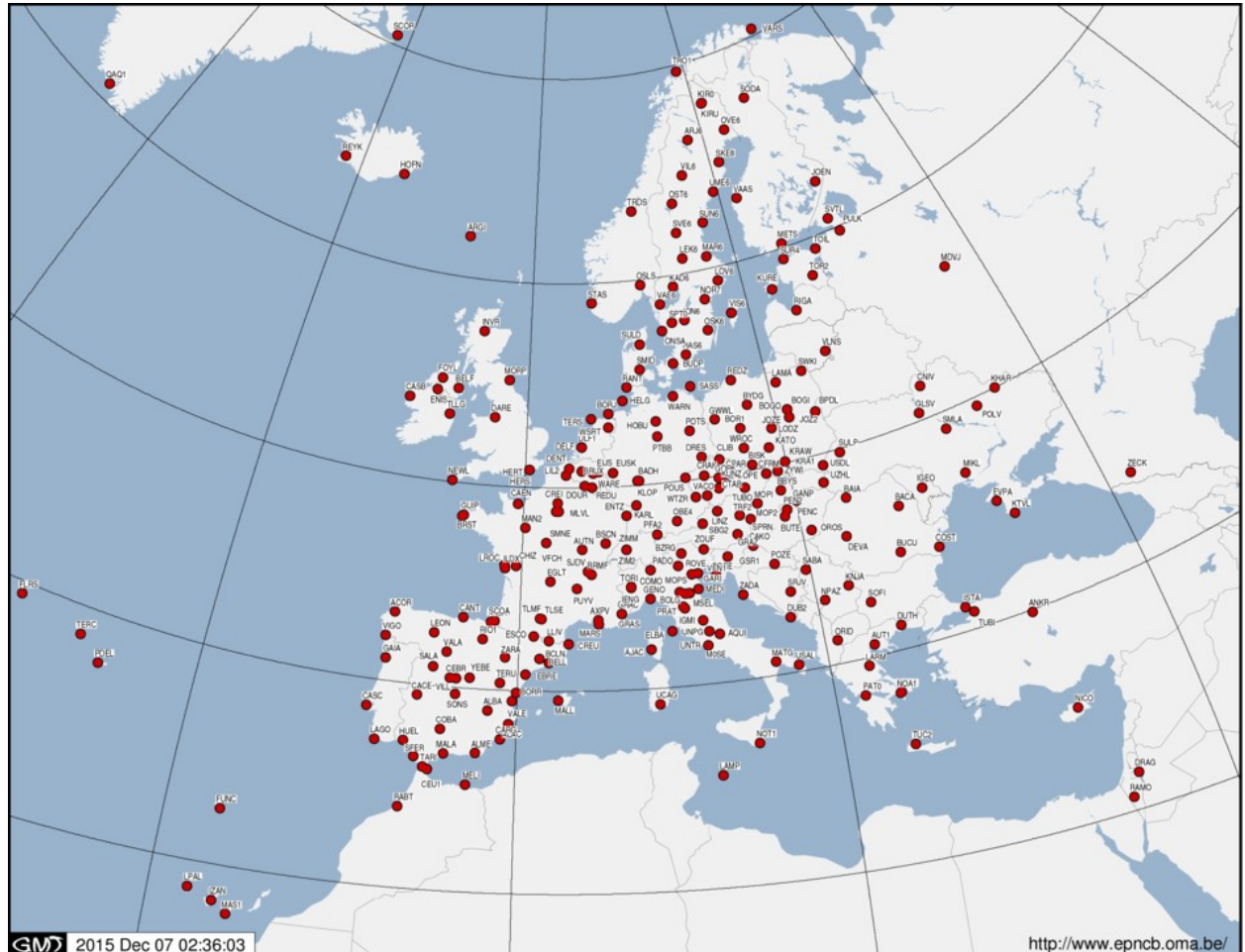
GNSS tracking network

Fig. 4.2.1.1: Network of EUREF Network Stations

The number of tracking stations is steadily growing: There were about 50 stations in 1996 and now there are more than 270 stations *(fig. 4.2.1.1)* of the EPN, including the so called '*Associated EUREF stations'* from outside Europe (North Africa, Middle East, Greenland) and their inclusion in the EPN should allow more precise control over tectonic movement of the European plate. Half of the stations belong also to the IGS network. The EPN tracking network consists of geodetic GNSS receivers and antennae that are installed at stable geodetic markers.

Stations must be operated following certain guidelines, which specify, e.g. the GNSS observed signal format, the maintenance of station meta-data, the station location, the procedure for uploading the data to EUREF (format, frequency, latency), and so on. The GNSS data is freely available to EUREF and its users.

Operational centres

Operational centres (87 at the moment) are responsible for data validation, conversion of raw data into the RINEX format, data compression, and uploading data from the EPN-tracking stations to the data centres.

Data centres

Local data centres (LDCs) collect the data from the stations of a local network, and make it available for local and EUREF users. The data is then sent to the regional data centres (RDCs), which make the data available for local, regional, and IGS users. RDCs then collect the data from all the EPN stations. If there is no LDC for a particular station, then the data will be sent from the OC directly to the RDC. The EPN data is available in daily, hourly, and 15-min RINEX files, and for many stations as a real-time data stream in RTCM format via NTRIP.

Analysis centres (18 at the moment)

Local analysis centres (LACs) process the data from a particular subnetwork of EPN stations and are responsible for quality control. The LACs products are weekly network solutions of their local subnetwork, which must be delivered within one month to the regional analysis centre (RAC). RACs combine the weekly subnetwork solutions into one official European solution.

The terminology 'local analysis centre' does not mean 'local' in a geographical sense, but in a hierarchical one: LACs process a subnetwork, that can geographically cover different countries involved in the EPN.

II. PRACTICAL PART

5. Software used

5.1 Open source Ntrip software

In order to start testing data streams using Ntrip transport protocol, you should download Ntrip Client software from the official page http://igs.bkg.bund.de/ntrip/download. You can also download Ntrip Server software or Multi-Function software.

Ntrip Client Software:
Ntrip Version 2.0 Command Line Client, reading from Ntrip Version 1.0 or 2.0 Caster – for Posix Windows.

Ntrip Server Software:
Windows Server, reading from Serial Port for Windows 98/2000/NT/XP, Command Line Server; reading from TCP/IP Port for Windows 98/2000/NT/XP, Ntrip Version 2.0 Command Line Server; reading from SISNeT Server, TCP/UDP IP Port, Serial port, or NtripCaster to support an Ntrip Version 1.0 or 2.0 Caster – for Posix Windows.

Multi-Function Ntrip Software and Assisting Tools:

for different operating systems:
BKG Ntrip Client (BNC), Decoder, Converter and Monitor reading RTCM 2.x and RTCM 3.x formats, supporting Real-time PPP, High-rate RINEX Data Centers, Real-time GNSS Engines and Real-time Combination Centers;

for Windows Systems:
GNSS Surfer, Ntrip Client and Server, RTCM 2.x and 3.x Encoder & Decoder, Topcon/Javad Raw Decoder, RINEX Generator, Web-Monitoring, Backup-System;
RTKLIB, Open Source Program Package for RTK-GPS;
RTCM 2.x Decoder, reading from local IP Port;
Ntrip built-in RTCM version3, decodes to RINEX, GPS + GLONASS observations, antenna information, Decode Message Type 1001 ~ 1012;

for Linux Systems:
Ntrip Client, converts RTCM 3.x to RINEX;
Ntrip Client, GPS Service/Monitor Daemon;
Professional Ntrip v2 Broadcaster;

for Unix/Linux, Distributions: SUSE, Fedora, Mandriva:
NtripClient, NtripServer, and NtripCaster Repositories, search for 'ntrip'.

5.2 BKG Ntrip Client (BNC): A detailed review

The purpose of BNC is to get the real-time GNSS streams from Ntrip Broadcaster using the Ntrip transport protocol, to get the real-time GNSS streams via TCP directly from an IP address without using the Ntrip transport protocol, or to get the real-time GNSS streams from a local UDP or serial port without using the Ntrip transport protocol. [13]

The authors also provide BNC program configuration, where a user gets a lot of possibilities. Some of them are:
- to save Broadcast Corrections from RTCM SSR messages in a plain ASCII format as hourly files;
- to feed a serial-connected receiver with observations from a reference station for conventional RTK;
- to track BNC's point-positioning solution using Google Maps or Open StreetMap as background;
- to get continuous quality checks of the Broadcast Corrections through observing coordinate displacements;
- to pull a number of streams from reference stations to get hold of contained Broadcast Ephemeris messages.
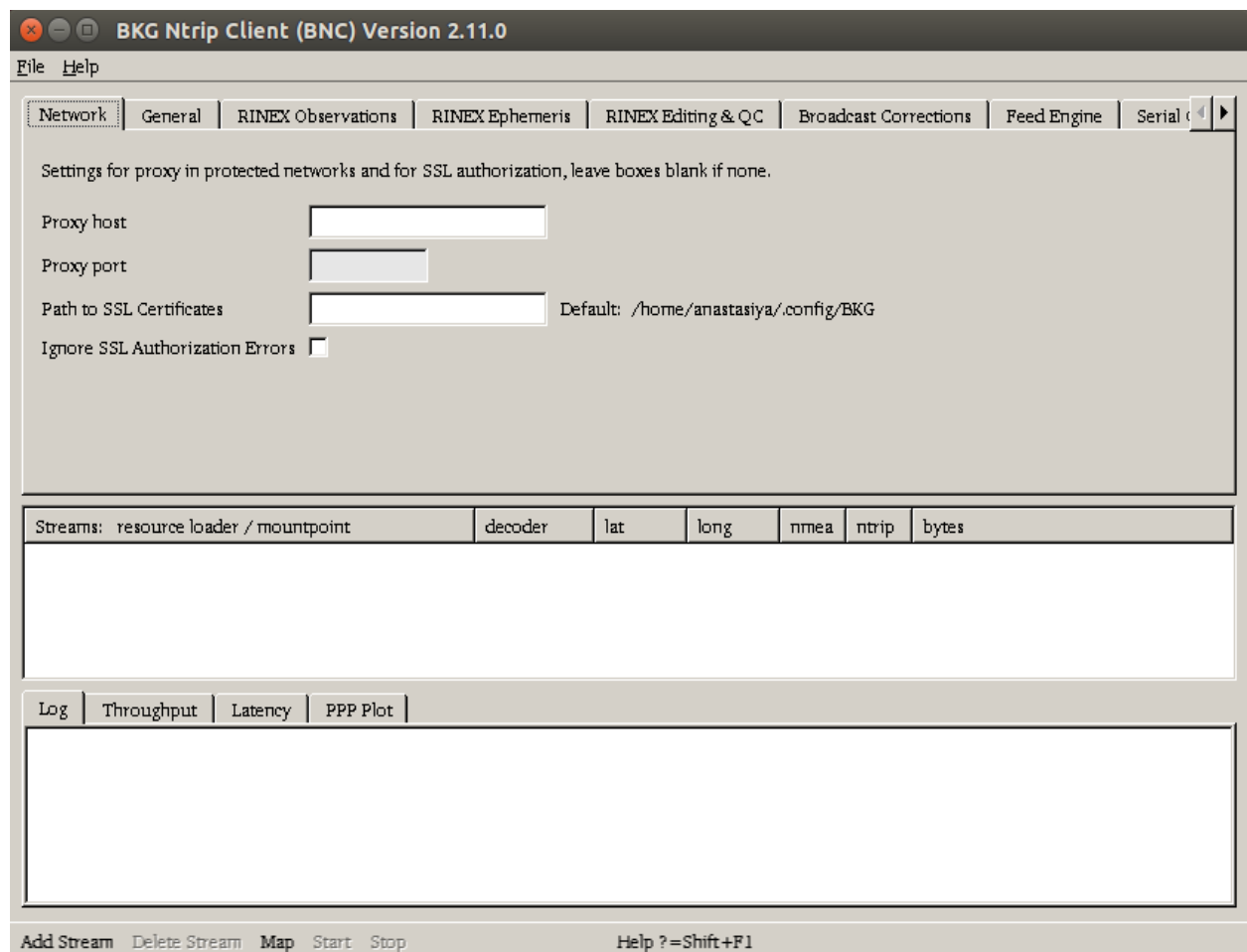
Fig. 5.2.1: BNC's main window

Most of the data streams are available free of charge. It is necessary to apply for free registration at http://register.rtcm-ntrip.org, so as to get access to EUREF and IGS Broadcasters, and test the data streams.

The top menu bar *(fig. 5.2.1)* allows the selection of an appropriate font, saving configurations, and quitting the program. It also provides the program documentation.

The bottom menu bar *(fig. 5.2.1)* allows adding or deleting the streams you want to work with and to start or stop the program. After clicking on the 'Add Stream' button, you have to choose one of several communication links, which are Ntrip Broadcaster, TCP/IP port, UDP port, and Serial port, as shown below.

Add stream

1. Caster *(fig. 5.2.2)*
   It uses Ntrip transport protocol and wants the user to select data streams from Ntrip Broadcaster according to their mountpoints.
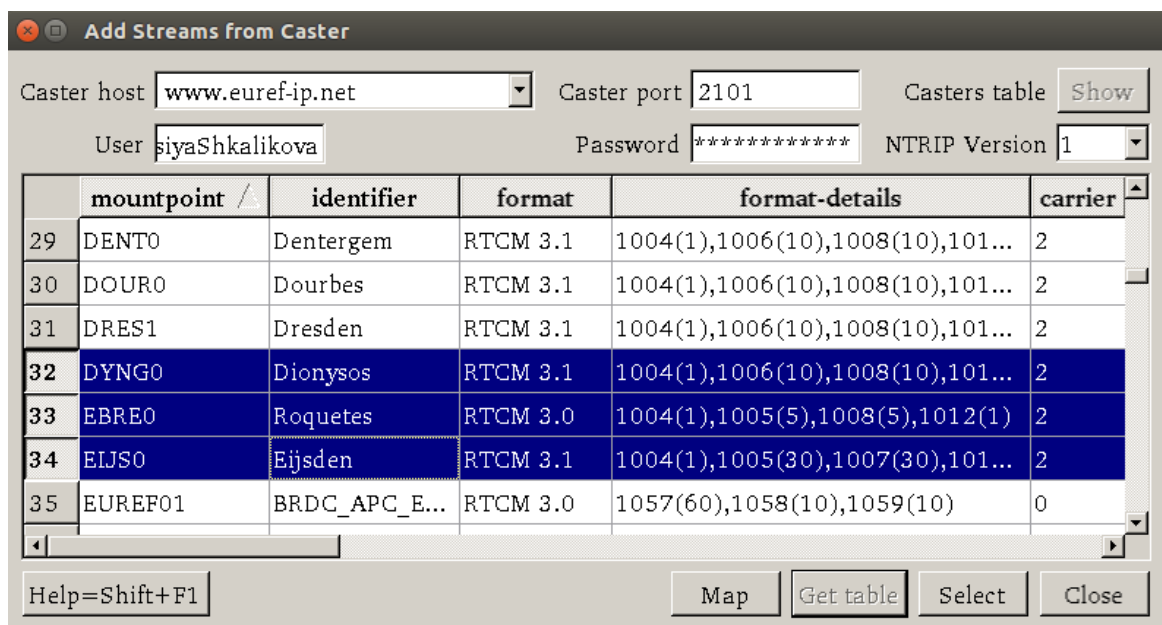
Fig. 5.2.2: Stream source: Caster option

- Caster host, port
  Write the Ntrip Broadcaster host IP and port number. EUREF and IGS Broadcasters are available at http://www.euref-ip.net/home, http://www.igs-ip.net/home, http://www.products.igs-ip.net/home and http://mgex.igs-ip.net/home at ports 80 or 2101. You may also receive data through port 443 instead of 2101 and 80 if your Ntrip client supports https.
- User, password
  Some streams are secured by passwords. Enter user ID and password to get access to protected streams. Registration at http://register.rtcm-ntrip.org allows access to protected streams from EUREF and IGS.
- Casters table *(fig. 5.2.3)*
  The button 'Casters table' will show a table of all NtripCaster implementations known for today. This table is also available at http://www.rtcm-ntrip.org/home.

Here you can choose the Ntrip Broadcaster. EUREF and IGS Broadcasters are available at www.euref-ip.net:2101 and www.euref-ip.net:80, www.igs-ip.net:2101 and www.igs-ip.net:80, mgex.igs-ip.net:2101 and mgex.igs-ip.net:80, products.igs-ip.net:2101 and products.igs-ip.net:80.

Select Broadcaster

List of NTRIP Broadcasters from www.rtcm-ntrip.org

	host	port	identifier	operator	nmea	country	lat	long	link
1	agros.rgz.gov.rs	2101	AGROS	REPUBLIKA SRBIJA	yes	SRB	44.83	20.62	http://www.rgz.gov.r...
2	banian.gouv.nc	8000	BANIAN	BANIAN	yes	NCL	-22.26	166.44	http://www.dittt.gou...
3	caster.crs.inogs.it	2110	Frednet	CRS/OGS	no	ITA	46.03	13.25	http://www.crs.inogs...
4	caster.fgi.fi	80	Nordic-iDiff	FGI	no	FIN	60.10	24.50	http://www.fgi.fi
5	catnet-ip.icc.es	8080	CATNET-IP	ICC	yes	ESP	41.00	2.10	http://catnet-ip.icc.es
6	cddis-caster.gsfc.nasa....	80	CDDIS	GSFC	no	USA	38.99	283.14	http://cddis-caster.gsf.
7	cgps-streaming.geonet...	8888	GEONET	GeoNet New Zealand	yes	NZL	-36.87	174.75	http://www.geonet.o...
8	corsnet.nsw.gov.au	2102	CORSNET	CORSNET NEW SOU...	no	AUS	-33.96	151.11	http://www.lpi.nsw.g...
9	czeposr.cuzk.cz	2101	CZEPOS	Zememericky urad	yes	CZE	49.90	14.80	http://czepos.cuzk.cz
10	c4gnet.lsu.edu	9000	C4GNET	LSU CENTER FOR GE...	no	USA	30.42	268.86	http://c4gnet.lsu.edu
11	ergnss-ip.ign.es	2101	Instituto Geografico N...	IGNE	no	ESP	40.40	356.30	http://www.fomento...
12	euref-ip.asi.it	2101	EUREF-IP-ASI	ASI	no	ITA	40.65	16.07	http://www.e-geos.it
13	geotradegnss.hu	2101	GeotradeGNSS	Geotrade	yes	HUN	47.50	19.01	http://www.geotrade...

Help=Shift+F1   Cancel   OK

Fig. 5.2.3: Casters table

- Ntrip Version
  1: Ntrip Version 1, TCP/IP.
  2: Ntrip Version 2 in TCP/IP mode. Can be accepted by proxy servers.
  2s: Ntrip Version 2 in TCP/IP mode via SSL. Can be accepted by proxy servers.
  R: Ntrip Version 2 in RTSP/RTP mode. The latency here is lower than in any TCP/IP version.
  U: Ntrip Version 2 in UDP mode. The latency here is lower than in any TCP/IP version.
  It is better to select version 1 if you are not sure whether your broadcaster supports version 2.
- Map *(fig. 5.2.4)*
  If you want to look at all the chosen mountpoints' positions at the same time, then click on the 'Map' button. To zoom in, draw a rectangle using the left mouse button. To zoom out, use the middle button. To restore, use the right button.
- Get table
  Once you click on the 'Get table' button, the source-table will be downloaded from the Ntrip Broadcaster that you entered in the 'Caster Host' field, where you can choose the desired mountpoints *(fig. 5.2.6)*. EUREF and IGS Broadcasters are also available at www.euref-ip.net:2101 and www.euref-ip.net:80, www.igs-ip.net:2101 and www.igs-ip.net:80, mgex.igs-ip.net:2101 and mgex.igs-ip.net:80,
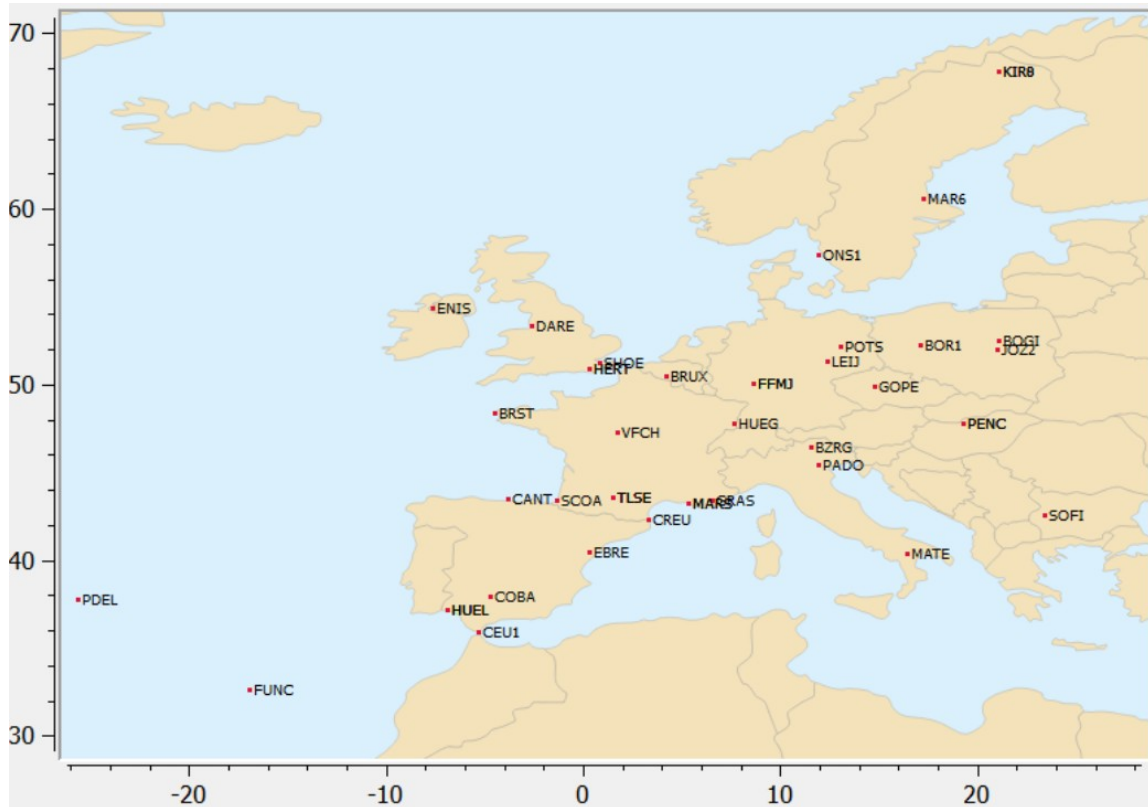
Fig. 5.2.4: Selected mountpoint map

2. TCP/IP port

Instead of using Ntrip transport protocol to retrieve streams from the NtripCaster, it uses the TCP/IP port to directly get the streams from an IP address. As long as it does not use Ntrip transport protocol, it will take an 'N' for 'No NTRIP' in the 'Streams canvas' field. Note that no proxy server can be involved in the communication link; otherwise, it will not work. *(fig. 5.2.5)*

Fig. 5.2.5: Stream source: TCP/IP option

You will have to enter:
- IP address of the Broadcaster host
- IP port number of the Broadcaster host
- a mountpoint (a four-character word is recommended), e.g. GOPE

- the stream format, e.g. RTCM_2, RTCM_3, RTNET, ZERO
- the latitude of the mountpoint – e.g. 49.91
- the longitude of the mountpoint – e.g. 14.79

Fig. 5.2.6: Specific Broadcaster mountpoint table

Fig. 5.2.7: Stream source: UDP option

3. UDP port
   Instead of using the Ntrip transport protocol to retrieve streams from the NtripCaster, it gets streams directly at one of the local Broadcaster host's UDP ports *(fig. 5.2.7)*. As long as it does not use the Ntrip transport protocol and gets streams at the UDP port, it will take 'UN' for 'UDP, No NTRIP' in the 'Streams canvas' field. You will have to enter:
   - a local UDP port number where a stream arrives
   - a mountpoint (a four-character word is recommended), e.g. MARS

- the stream format, e.g. RTCM_2, RTCM_3, RTNET, ZERO
- the latitude of the mountpoint – e.g. 43.27
- the longitude of the mountpoint – e.g. 5.35

4. Serial port

This option does not use the Ntrip transport protocol but picks up the streams from a GNSS receiver via a serial port *(fig. 5.2.8)*. In the 'Streams canvas' field, the letter 'S' stands for 'Serial Port, no NTRIP'. You will have to enter:
- a mountpoint (a four--character word is recommended), e.g. MALL
- the stream format – e.g. RTCM_2, RTCM_3, RTNET, ZERO
- the latitude of the mountpoint – e.g. 39.55
- the longitude of the mountpoint – e.g. 2.62
- port name on your host for communication with the receiver in according to the OS:
  - Windows: COM1, COM2
  - Linux: /dev/ttyS0, /dev/ttyS1
  - FreeBSD: /dev/ttyd0, /dev/ttyd1
  - Digital Unix: /dev/tty01, /dev/tty02
  - HP-UX: /dev/tty1p0, /dev/tty2p0
  - SGI/IRIX: /dev/ttyf1, /dev/ttyf2
  - SunOS/Solaris: /dev/ttya, /dev/ttyb
- baud rate for the serial input. High baud rate is recommended, e.g. 57600
- number of data bits for the serial input. Usually it's used 8 data bits
- parity for the serial input. Usually 'NONE'
- number of stop bits for the serial input. Usually it's used 1 stop bit
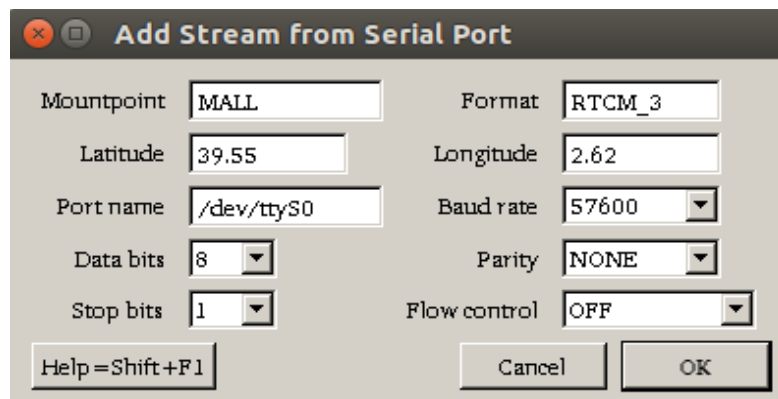- flow control for the serial link. Usually 'OFF'

Fig. 5.2.8: Stream source: Serial port option

Every mountpoint you select is described in the 'Streams' window by these parameters:
- resource loader:
  - Ntrip Broadcaster host and port, or
  - TCP/IP host and port, or
  - UDP port, or
  - Serial input port specification
- mountpoint

- decoder: name of decoder used to handle the incoming stream content according to its format; to get the raw data, specify the decoder as 'ZERO'
- lat: latitude of reference station in degrees
- long: longitude of reference station in degrees
- nmea: if there is a need to send NMEA-GGA message with position coordinates inside in order to initiate the streaming, then 'yes', otherwise 'no'
- ntrip:
  - Ntrip protocol version (1, 2, 2s, R or U), or
  - 'N', which means 'No Ntrip' - for TCP/IP streams, or
  - 'UN', which means 'UDP, No Ntrip' - for UDP streams, or
  - 'S', which means 'Serial, No Ntrip' - for serial input streams
- bytes: number of bytes received

The logging window provides information about BNC's activities, which are:

1. Log *(fig. 5.2.9)*: logs that BNC gets from Ntrip Broadcasters, which can be saved into a file; to get it, enter the path to a file you want to create with these logs in the 'Logfile (full path)' field;

Fig. 5.2.9: BNC Log tab

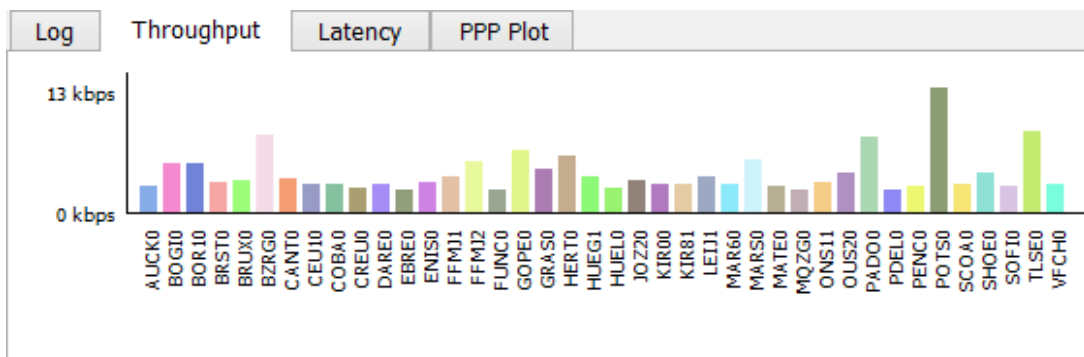2. Throughput *(fig. 5.2.10)*: bandwidth of incoming streams in kbits per second (kbps);

Fig. 5.2.10: Bandwidth of incoming streams

3. Latency *(fig. 5.2.11)*: latency of incoming streams in seconds;

4. PPP Plot (Precise Point Positioning Plot) is a series of North (red), East (green) and Up (blue) coordinate components.
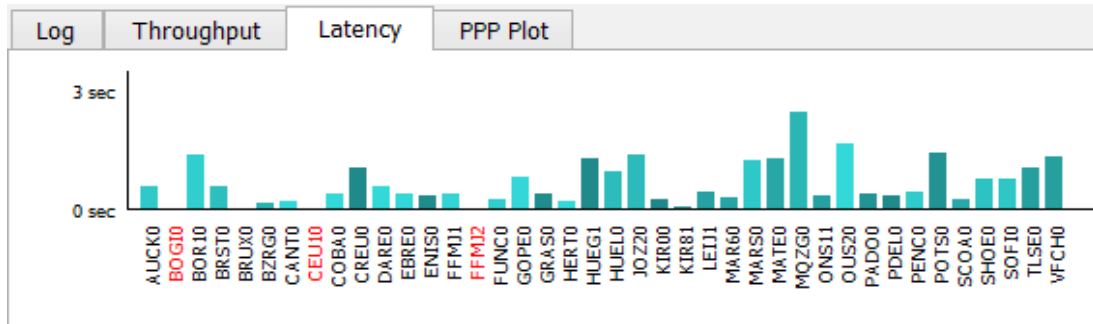

Fig. 5.2.11: Latency of incoming streams

You can also configure the BNC program using configuration examples, which are available in the BNC program suit. They are:
1. RinexObs.bnc
2. RinexEph.bnc
3. BrdcCorr.bnc
4. RinexConcat.bnc
5. RinexQC.bnc
6. RTK.bnc
7. FeedEngine.bnc
8. PPP.bnc
9. PPPQuickStart.bnc
10. PPPPostProc.bnc
11. PPPGoogleMaps.bnc
12. SPPQuickStartGal.bnc
13. Sp3.bnc
14. Sp3ETRF2000PPP.bnc
15. Upload.bnc
16. UploadPPP.bnc
17. Combi.bnc
18. CombiPPP.bnc
19. UploadEph.bnc
20. Empty.bnc

5.3 Mountpoint description examples

With the BNC program and the Caster table, it is possible to describe different mountpoints by a list of parameters. You can see it in the table below *(fig. 5.3.1)*. For example, a mountpoint called MALL0 belongs to the Caster host called www.euref-ip.net and can be read at port 2101. The Caster's position in degrees is north: 50.12; east: 8.69; located in Germany. The mountpoint's position is latitude: 39.55; longitude: 8.69; located in Spain, Mallorca. MALL0's Ntrip Server transmits GPS and GLONASS data, using the RTCM Version 3.1 encoder, which handles message types 1004(1) (GPS L1 and L2 code and phase and ambiguities and carrier-to-noise ratio), 1006(10) (station coordinates XYZ for antenna reference point and antenna height), 1008(10) (antenna serial number), 1012(1) (GLONASS L1 and L2 code and phase and ambiguities and carrier-to-noise ratio), 1019(120) (GPS ephemeris), 1020(120) (GLONASS ephemeris), 1033(10) (receiver for antenna and receiver descriptor). 'Nmea – no' means that a stream retrieval will not be started in the usual way of BNC sending an NMEA-GGA message carrying approximate position coordinates. Carrier phase information: 2 (0: 'No', 1: 'Yes, L1', 2: 'Yes, L1 and L2'). The bit rate of the data stream is 5 kbit/s. The Ntrip version is 1. Access to mountpoint: authentication is basic ('B': basic, 'N': none, 'D': digest), usage is free. The messages are not compressed or encrypted.

1	Mountpoint name	MALL0	TUBO0	SISNET0	HELG1	UCAL0	PRSOC
2	Caster host	www.euref-ip.net				mgex.igs-ip.net	czeposr.cuzk.cz
3	Caster port	2101				2101	2101
4	Caster latitude	50.12				50.12	49.90
5	Caster longitude	8.69				8.69	14.80
6	Caster country	DEU				DEU	CZE
7	link	euref-ip				mgex	czepos
8	Mountpoint latitude	39.55	49.20	52.25	54.17	51.08	49.50
9	Mountpoint longitude	2.62	16.59	4.43	7.89	245.87	15.50
10	Mountpoint country	ESP	CZE	EUR	DEU	CAN	CZE
11	Nav-system	GPS + GLO	GPS + GLO	GPS	GPS + GLO	GPS + GLO + GAL + BDS + QZS	GPS
12	RTCM version	RTCM 3.1	RTCM 2.3	RTCA	RTCM 3.1	RAW	RTCM 2
13	RTCM version details (message number)	1004(1), 1006(10), 1008(10), 1012(1), 1019(120), 1020(120), 1033(10)	1(1), 3(15), 18(1), 19(1), 22(15), 23(15), 24(15)	*MSG(1)	1004(1), 1006(10), 1008(10), 1012(1), 1019, 1020, 1033(10)	BINEX	3(10), 20(1), 21(1), 22(10), 23(10), 24(10)
14	Nmea	no	no	no	no	no	yes
15	Carrier	2	2	0	2	2	2
16	Bitrate	5000	3500	500	2400	9600	9600
17	Ntrip	1	1	1	1	1	1
18	Authentification	B	B	B	B	B	B
19	Fee	N	N	N	Y	N	Y
20	Compression-encryption	none	none	SINCA	none	none	none

Fig. 5.3.1: Latency of incoming streams

5.4 U-center

U-center is u-blox's software made to translate different formats of raw data into user-friendly information, such as satellites in view, signal strength and its history for every observed satellite, movement direction and speed, exact map points, and so on. U-center application allows testing not only u-blox devices but also other GNSS devices. When the program is started and the position is being evaluated, a user can find a lot of useful windows, bars, and tabs, some of which are shown in the picture below *(fig. 5.4.1)*. They are basic information (latitude, longitude, altitude, fix mode, PDOP, HDOP, number of satellites in view), observed satellites on the map, signal strength and its history for every observed satellite, meter, speed meter, compass, watch, Google Earth view, and so on.
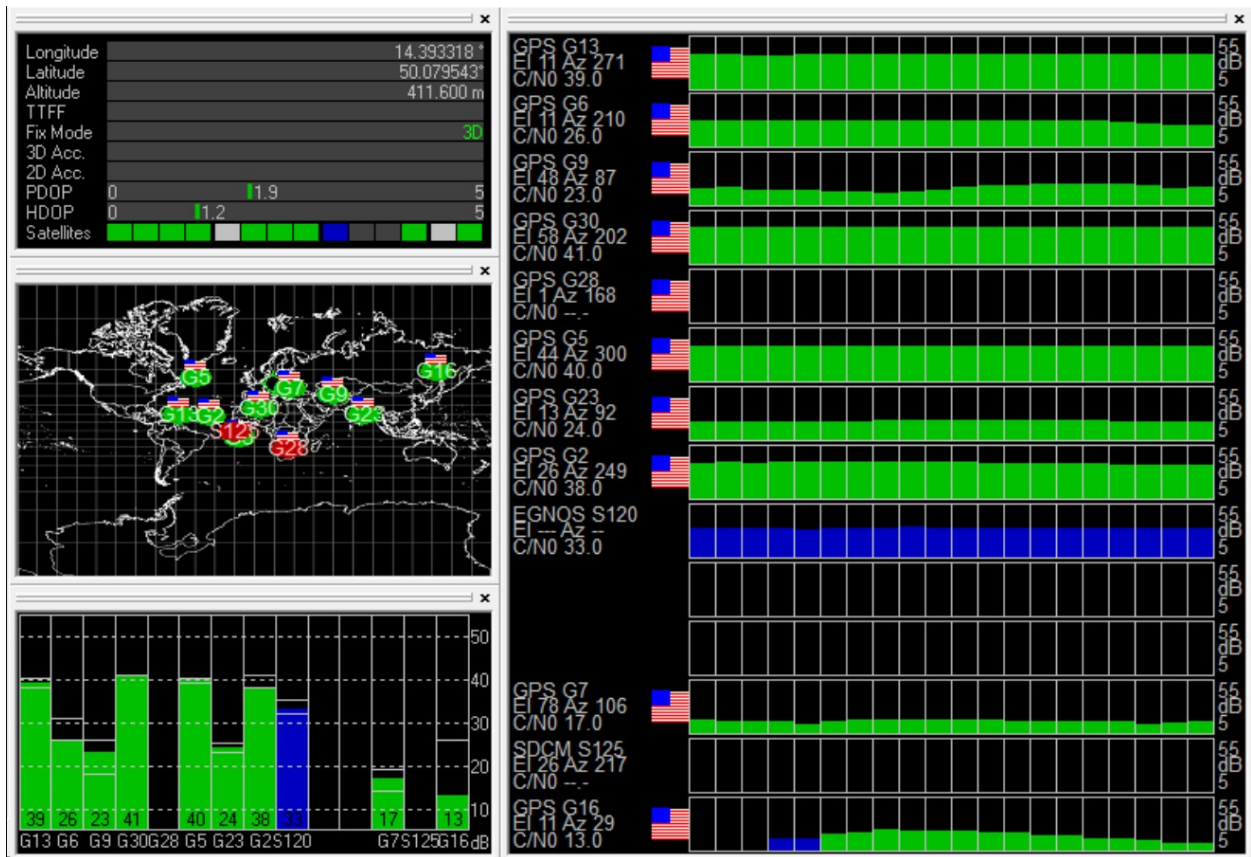

Fig. 5.4.1: U-center main window

Another useful window is the text console, where a user can observe NMEA messages along with their contents, sent or received at the exact moment *(fig. 5.4.2)*. The packet console shows message names and their meaning. The binary console shows each NMEA message in binary code. The message view expands messages and their items into readable sentences.

The sky view shows observed satellites and their paths around a user's antenna *(fig. 5.4.3)*. The deviation map shows position points as a usual map, but over a radial scale to determine the precision easily.

```
16:03:19   $GPZDA,160319.00,21,12,2015,00,00*6C
16:03:20   $GPRMC,160320.00,A,5004.77952,N,01423.63269,E,0.030,9.32,211215,,,A*64
16:03:20   $GPVTG,9.32,T,,M,0.030,N,0.056,K,A*35
16:03:20   $GPGGA,160320.00,5004.77952,N,01423.63269,E,1,06,1.92,327.2,M,45.5,M,,*55
16:03:20   $GPGSA,A,3,07,05,13,30,20,02,,,,,,,2.96,1.92,2.25*03
16:03:20   $GPGSV,4,1,13,28,15,164,18,23,01,099,,07,67,067,17,09,35,097,*7A
16:03:20   $GPGSV,4,2,13,38,26,217,31,05,56,286,25,33,26,217,33,16,02,021,23*7E
16:03:20   $GPGSV,4,3,13,13,23,280,39,30,74,198,35,27,04,050,22,20,11,316,37*7F
16:03:20   $GPGSV,4,4,13,02,15,237,42*4D
16:03:20   $GPGLL,5004.77952,N,01423.63269,E,160320.00,A,A*6C
16:03:20   $GPZDA,160320.00,21,12,2015,00,00*66
16:03:21   $GPRMC,160321.00,A,5004.77961,N,01423.63259,E,0.029,11.98,211215,,,A*57
16:03:21   $GPVTG,11.98,T,,M,0.029,N,0.054,K,A*06
16:03:21   $GPGGA,160321.00,5004.77961,N,01423.63259,E,1,06,1.92,327.0,M,45.5,M,,*55
16:03:21   $GPGSA,A,3,07,05,13,30,20,02,,,,,,,2.96,1.92,2.25*03
16:03:21   $GPGSV,4,1,13,28,15,164,18,23,01,099,,07,67,067,16,09,35,097,*7B
16:03:21   $GPGSV,4,2,13,38,26,217,31,05,56,286,25,33,26,217,33,16,02,021,23*7E
16:03:21   $GPGSV,4,3,13,13,23,280,39,30,74,198,35,27,04,050,23,20,11,316,37*7E
16:03:21   $GPGLL,5004.77961,N,01423.63259,E,160321.00,A,A*6E
16:03:21   $GPZDA,160321.00,21,12,2015,00,00*67
16:03:22   $GPRMC,160322.00,A,5004.77971,N,01423.63249,E,0.017,,211215,,,A*76
16:03:22   $GPVTG,,T,,M,0.017,N,0.032,K,A*24
16:03:22   $GPGGA,160322.00,5004.77971,N,01423.63249,E,1,06,1.92,326.8,M,45.5,M,,*5F
16:03:22   $GPGSA,A,3,07,05,13,30,20,02,,,,,,,2.96,1.92,2.25*03
16:03:22   $GPGSV,4,1,13,28,15,164,19,23,01,100,,07,67,067,15,09,35,097,*78
16:03:22   $GPGSV,4,2,13,38,26,217,29,05,56,286,25,33,26,217,33,16,02,021,23*77
16:03:22   $GPGSV,4,3,13,13,23,280,39,30,74,198,35,27,04,050,23,20,11,316,37*7E
16:03:22   $GPGSV,4,4,13,02,15,237,42*4D
16:03:22   $GPGLL,5004.77971,N,01423.63249,E,160322.00,A,A*6D
16:03:22   $GPZDA,160322.00,21,12,2015,00,00*64
```
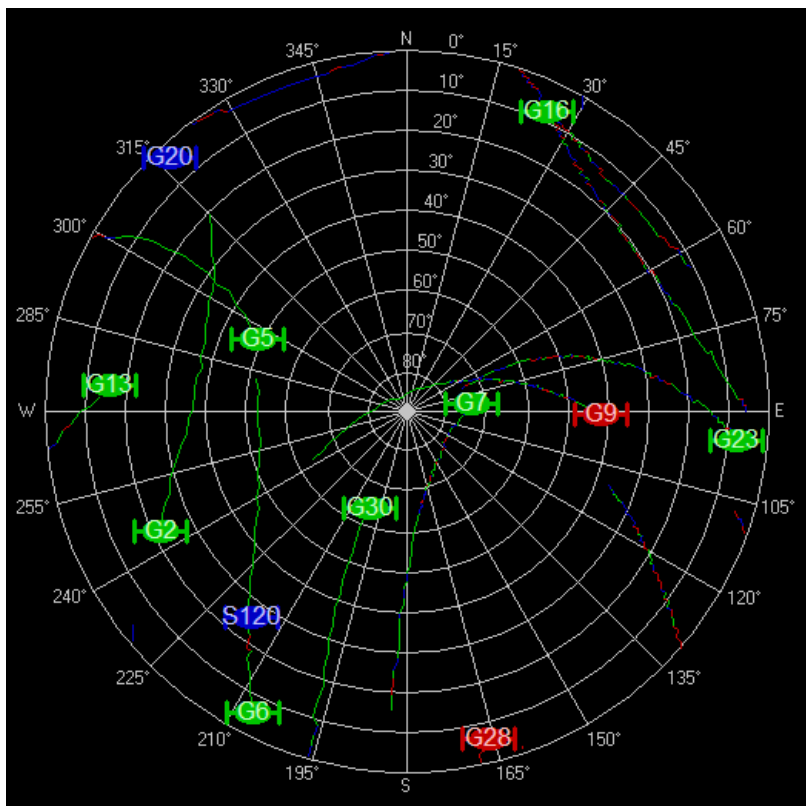
Fig. 5.4.2: U-center text console

Fig. 5.4.3: U-center sky view

6. Measurements

This chapter are demonstrates the actual position evaluations for different positioning methods and their further comparison. In order to take the measurements a u-blox GPS receiver and antenna were used, along with software named u-center made by u-blox. At first, the position measurement was taken using plain GPS without additions (*fig. 6.1a*). Then, the same position measurement was taken with SBAS correction (hereinafter referred to as SBAS) (*fig. 6.1b*). Finally, the measurement was repeated using GBAS corrections, which were received by BNC software using Ntrip protocol and were transferred to the GPS receiver (hereinafter Ntrip) (*fig. 6.1c*).
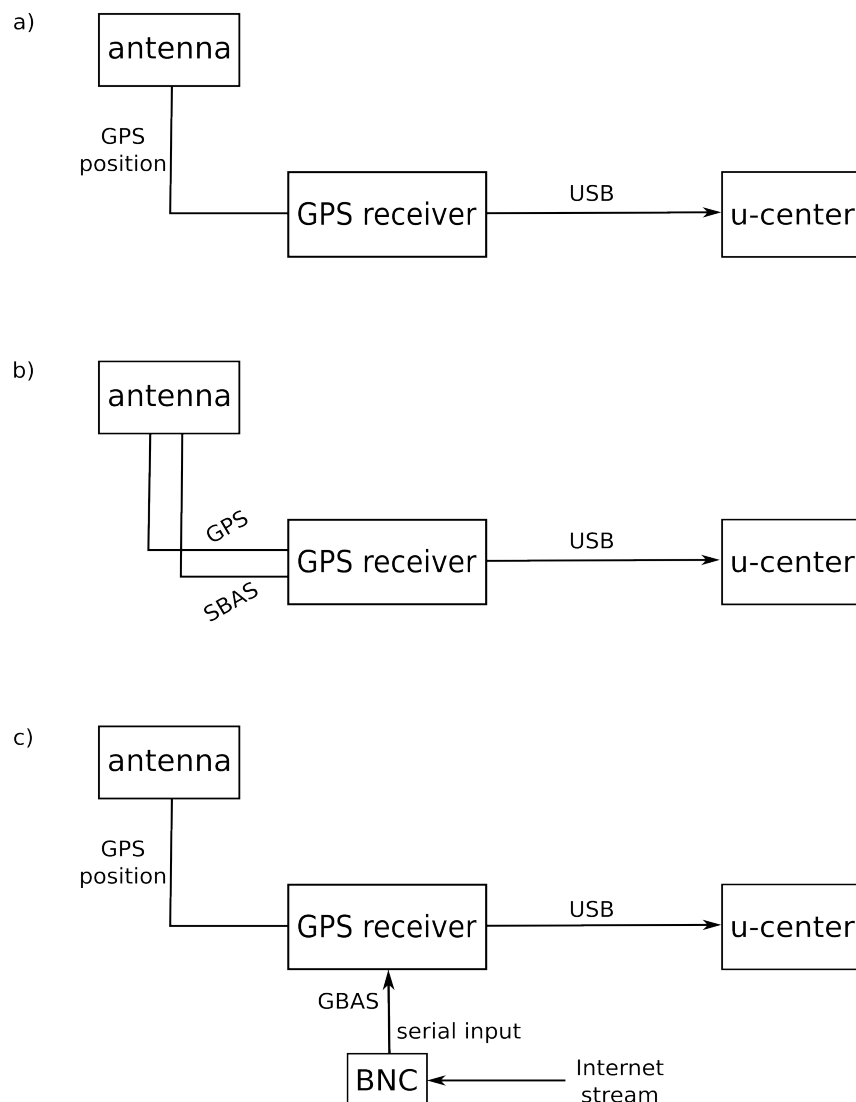
Fig. 6.1: schemes of elements arrangement used for position evaluation: a) GPS, b) GPS+SBAS, c) GPS+Ntrip

Each measurement lasted one hour and the position was taken every two seconds, which means a total of 1800 samples. At the end of each measurement, a table containing latitude-longitude pairs for each sample was created. In the Ntrip measurement was used the following mountpoint: BOR10 Borowiec, located in Poland at lat: 52,28°; lon: 17,07°; and supporting the RTCM 2.3 format.

The left side of *fig. 6.2* shows all the measured samples centred around the average of all previously measured positions, around which is also shown the deviation ellipse. The GPS deviation ellipse has the least rounded shape, with the ratio of the lengths of the minor and major axes as approximately 1:14 (measured at about 2 and 28 metres respectively). This ratio for SBAS is about 1:2.5, while the same ratio of the deviation ellipse axes for Ntrip is 1:1.3. The latter has the most rounded shape.

On the right side of *fig. 6.2,* all the measured samples were moved so as to place all the points inside the outer radius. The widest radius was acquired from a GPS measurement reaching 47 metres, an Ntrip measurement radius of 31 metres, and an SBAS measurement of 25 metres. As may be seen from these pictures, plain GPS has not only a wider sample scatter but also an irregular, stretched shape, whereas GPS using corrections has a narrower and more rounded scatter.
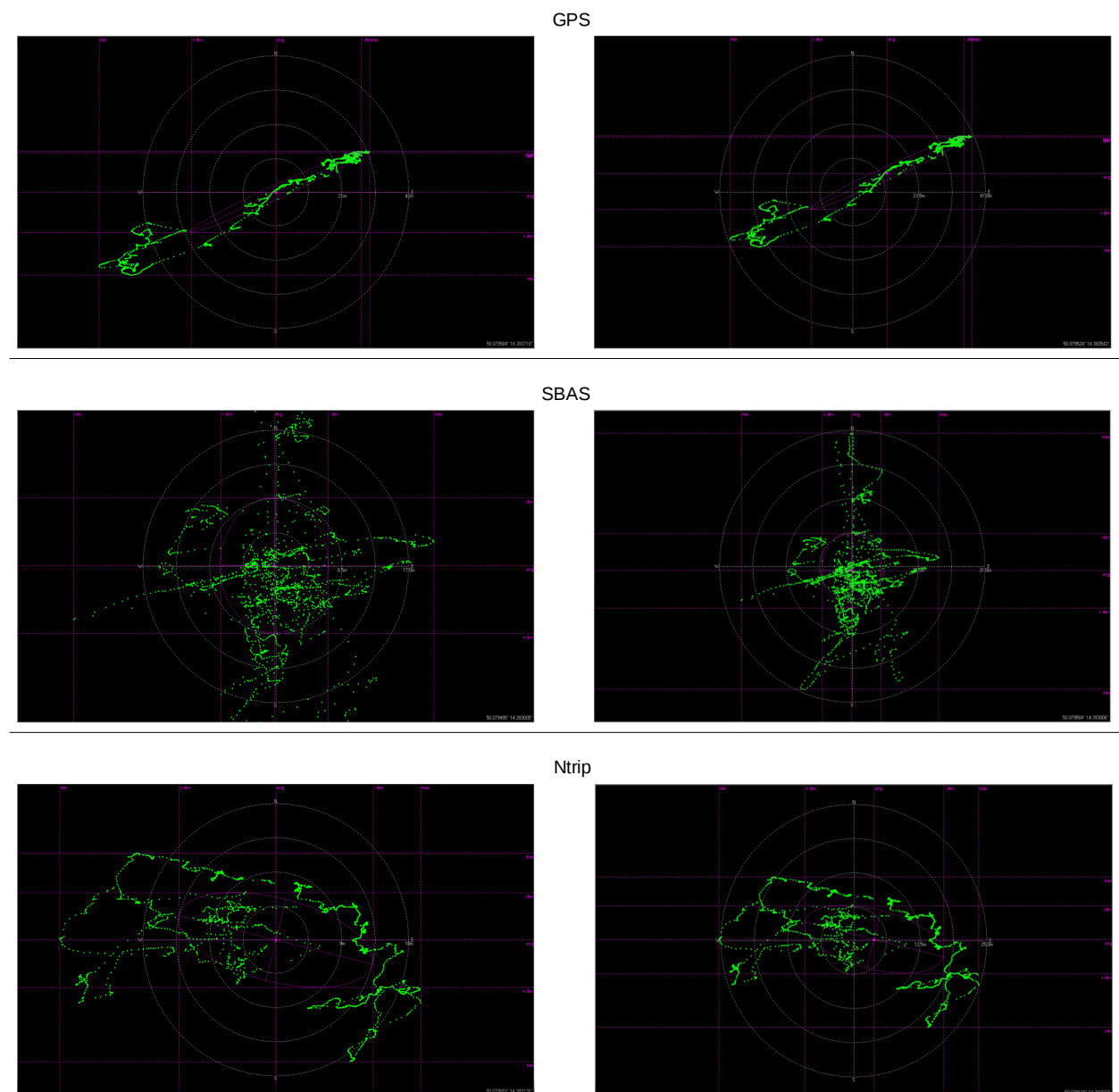

Fig. 6.2: Deviation maps of GPS, SBAS, Ntrip: left - average centred, right - fit inside outer radius

To ensure a more precise comparison of the different positioning methods, the average radius was chosen as the main comparison parameter. This was calculated using tables of latitude-longitude pairs in the following way:

1. The average point was calculated using the arithmetic mean in degrees

$$x_0 = \frac{\sum_{i=1}^{n} x_i}{n} \quad [°; °, -]$$

$$y_0 = \frac{\sum_{i=1}^{n} y_i}{n} \quad [°; °, -]$$

where (x_0, y_0) – average point coordinates (latitude, longitude), (x_i, y_i) – coordinate for a specific sample, n – count of samples.

Average points:

$$(x_{0GPS}, y_{0GPS}) = (50.07958, 14.39372)$$

$$(x_{0SBAS}, y_{0SBAS}) = (50.07965, 14.39313)$$

$$(x_{0NTRIP}, y_{0NTRIP}) = (50.07948, 14.39300)$$

2. For each latitude-longitude pair, a radius was calculated relative to the average point and converted to metres by multiplying degree distances by numbers corresponding to the latitude in question

$$r_i = \sqrt{((x_i - x_0) * 111230.31)^2 + ((y_i - y_0) * 71577.31)^2} \quad [m; °, °, °, °]$$

where r_i – distance between the average point and the specific sample, (x_0, y_0) – average point coordinates (latitude, longitude), (x_i, y_i) – coordinate for a specific sample.

3. The average radius was calculated using all the radii

$$r_{av} = \frac{1}{n} \sqrt{\sum_{i=1}^{n} r_i^2} \quad [m; -, m]$$

where r_{av} – the average radius, n – count of samples, r_i – distance between the average point and specific sample.

The average radii:

$$r_{0GPS} = 0.6895 \text{ m}$$

$$r_{0SBAS} = 0.3448 \text{ m}$$

$$r_{0NTRIP} = 0.2507 \text{ m}$$

As may be seen from these results, corrections heavily improve the positioning accuracy in our case: SBAS sees a 50% improvement and Ntrip a 63.6% improvement. Ntrip has better accuracy mostly because GBAS systems have more reference stations than SBAS systems. Since ionospheric errors vary from place to place, the greatest impact on the error correction results from the ground station located at the position closest to the measured position. Hence, the denser the station grid is the more chance there is to have a signal from the least distance and, therefore, to locate the position with better accuracy.

Fig. 6.3 indicates the count of samples located in between specific radii around the average point, with these radii located five metres apart from each other. All three methods are compared. The first thing worthy of attention is the maximum radius: SBAS is less than 30 metres, Ntrip is

less than 35 metres, and GPS is more than 60 metres. There is also an obvious difference among the sample concentration distributions – namely, a relatively level GPS curve peaking between 15 and 30 metres, a bell-like SBAS curve peaking between 10 and 20 metres, and the Ntrip curve exponentially decreasing after peaking below the five-metre radius. All of the measurements have shown little to no samples inside the respective r_{av}; therefore, it is not advisable to assume that if some positioning method guarantees, for example, a sub-metre accuracy it means that every positioning sample would fall into a one-metre radius.
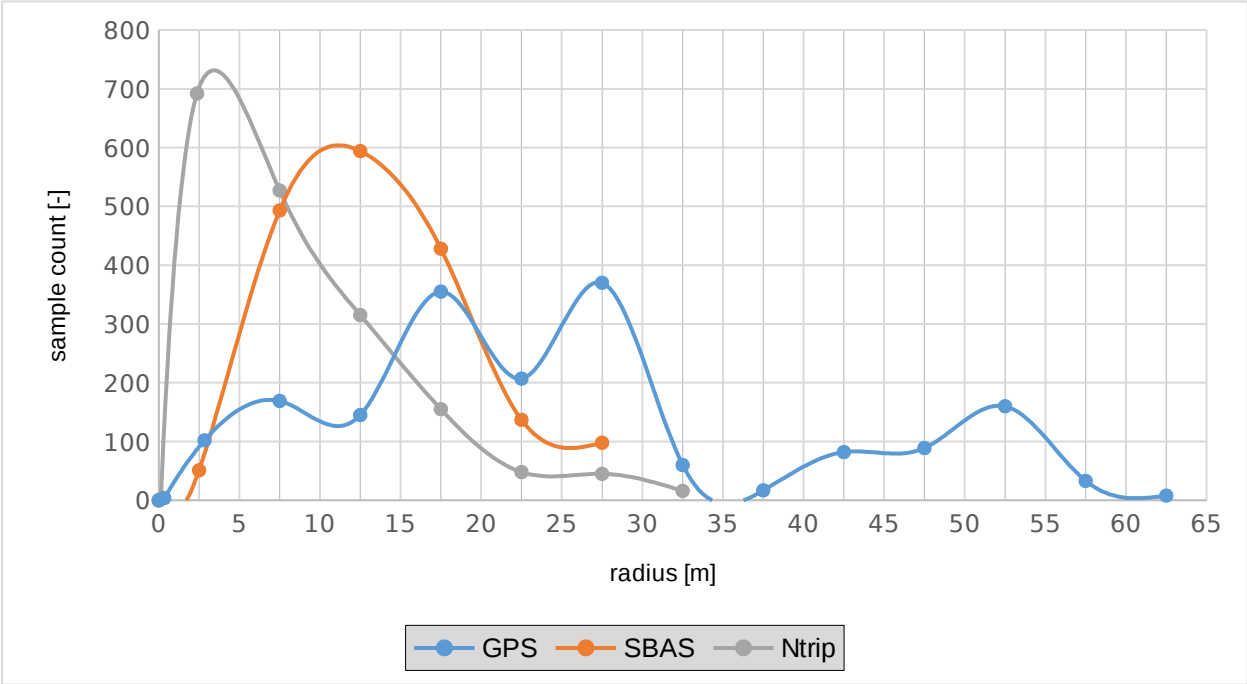

Fig. 6.3: Sample count over radius ranges

Conclusion

The main goal of this bachelor thesis is to demonstrate the position evaluation using plain GPS and differential GPS (DGPS) and then to compare them. DGPS was developed to improve GPS positioning. DGPS can be divided into satellite based augmentation system (SBAS) and ground based augmentation system (GBAS). Each system has their own definite standards and formats, which are described in the Chapter 1.

In the Chapter 6 'Measurements' were compared different methods of position evaluation, namely, plain GPS, GPS+SBAS and GPS+GBAS (using Ntrip protocol to get a broadcaster's stream from the Internet). As it was expected, the measurements using correction methods turned out to be more accurate: SBAS sees a 50% improvement and Ntrip a 63,6% improvement. There is a difference between SBAS- and GBAS correction improvement of more than 13% mostly because of station grid density: in case of GBAS there is a bigger chance to use the best suiting reference station by possibility to choose them, while SBAS positioning only informs the user which station it uses. The average radii (r_0 or r_{av}) are: r_{0GPS} = 0.6895 metres, r_{0SBAS} = 0.3448 metres, and r_{0NTRIP} = 0.2507 metres. The most noticeable difference among these methods may be seen in *fig. 6.3*, which is the maximum radius of each method: plain GPS has max. radius at about 60 − 65 metres, Ntrip at about 30 − 35 metres, and SBAS at about 25 − 30 metres.

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Appendix

Attached CD contains the following data:
- this bachelor thesis in .pdf format
- the software used in this work (BNC, u-center)
- the data obtained during the measurements
- all the images and graphs used in this thesis