The paper presents theoretical and practical aspects of the GNSS augmentation systems and services. As today the people know what is GPS and how can be used in navigation, in general aspects of the GNSS augmentation systems are unknown or poor. Definition and implementation of GNSS augmentation systems are presented at global, regional and national level. With the help of GNSS augmentation systems, the position determination is improved from metre level (for GNSS standalone systems) to decimetre, centimetre up to millimetre level (GNSS standalone plus augmentation system). The benefits of such systems and services are emphasized. As realizations there are mentioned the most known as EGNOS (in Europe), ROMPOS, Trimble VRS Now and Leica TGRef (in Romania), OMNISTAR and STARFire (at global level). Depending on the area and application, the users can choose between these augmentation systems or others available. The paper presents considerations especially for the centimetre level position accuracy determination based on DGNSS/RTK services.

Keywords: DGNSS, RTK, absolute/relative positioning

INTRODUCTION
Today in the Geodesy applications there are often applied GNSS technologies and methods for positioning. Coordinates are determined in specific reference systems with m, dm, cm and mm accuracies. Depending on the application, different methods are available. For navigation m and dm accuracies are good enough, but for other applications as geodetic networks or cadastre positioning cm and mm accuracies should be achieved. At the international and national level there are now available GNSS specific services based on GNSS permanent stations networks. These services acts as augmentation systems providing additional information for GNSS users in order to improve positioning accuracy in comparison with standalone (absolute) positioning. The paper presents considerations on the status of GNSS augmentation services available in Romania with focus on geodetic users and RTK (Real Time Kinematic) positioning.

MATERIALS AND METHODS
1. Considerations on GNSS Augmentation Systems
GNSS (Global Navigation Satellite Systems) have a continuous evolution since 1980s. Based on navigation satellites, other domains benefits today of that positioning technologies: geodesy, geodynamics, meteorology, civil engineering, topography and cadastre et al. Satellite positions are known and ranges measured from ground antennas to the broadcasting satellites are measured by methods as code correlation or carrier phase observations. Ground positions are determined as absolute (point positioning) or relative positions. In general absolute positioning (origin in the centre of mass of the Earth or geocentre) it is specific for navigation with meter or decimetre accuracies and relative positioning (origin chooseed arbitrary) it is specific for more accurate applications with centimetre or millimetre accuracies (Fig.1) [1].

Positions determined by GNSS are expressed in different Coordinate Reference Systems (CRS) or datums as ITRS (International Terrestrial Reference System), ETRS89 (European Terrestrial Reference System 1989), WGS84 et al. For daily applications coordinates expressed in such reference systems can be transformed in local datums, as S42 (Krasovski ellipsoid 1940) in...
Romania. According to 2007 European Directive *INSPIRE*, for EU Member States, the ETRS89 CRS with latest realization should be used.

![Fig.1. Principles of GNSS positioning (absolute vs. relative)](image1)

The most known GNSS systems available today are GPS or NAVSTAR-GPS (USA) and GLONASS (Russia). New GNSS systems are going to be realized in Europe – named GALILEO and in China – named COMPASS/BeiDou. Similar systems will be realized in Japan and India. Each such a system includes three major components: space segment, control segment and user segment (Fig.2).

![Fig.2. GNSS segments and augmentation systems](image2)

A *satellite-based augmentation system* (SBAS) is a system that supports wide-area or regional augmentation through the use of additional satellite-broadcast messages. Such systems are commonly composed of multiple ground stations, located at accurately-surveyed points. The ground stations take measurements of one or more of the GNSS satellites, the satellite signals, or other environmental factors which may impact the signal received by the users. Using these measurements, information messages are created and sent to one or more satellites for broadcast to the end users [2].
In addition to GNSS systems, there are realized augmentation systems providing additional information for GNSS users in order to improve positioning accuracy in comparison with standalone (absolute) positioning. Additional information includes mainly differential corrections calculated based on the GNSS permanent station networks. If corrections are calculated based on code observations at permanent stations they are named D-GNSS corrections and if are calculated based on phase observations, they are named RTK (Real Time Kinematic) corrections. Today there are available two concepts for corrections calculation: based on a single base station or based on a network of GNSS permanent stations [1].

An example of GNSS permanent network at global level it is the IGS (International GNSS Service) network (Fig.3a, Fig.3b). For Europe was realized such a network named EUREF-EPN (European Reference Frame – Permanent Network, Fig.4). Romania contributes at these networks with one station (named BUCU – Bucharest) for IGS and five stations for EUREF-EPN. At national level in Romania was realized by National Agency for Cadastre and Land Registration (ANCPI) a GNSS permanent station network including 60 stations (2011) up to 75 stations (2012) [3]. Private companies realized more sparse GNSS permanent networks in Romania. Trimble company operates 9 stations and Leica company operates 8 stations.

Differential corrections are disseminated by various means such as radio transmitters, GSM, internet, satellite communications. At global and regional level DGNSS corrections are broadcasted via satellites. For GPS as regional augmentation system in North America was realized WAAS – Wide Area Augmentation System including 2 geostationnary satellites. A similar augmentation system it is available in Europe by EGNOS (European Geostationary Navigation Overlay System) including 3 geostationnary satellites.
Based on GNSS permanent network stations there are available different kind of services. In general GNSS services includes raw data services (in RINEX or Virtual-RINEX form) and DGNSS/RTK services. In addition, automatic data processing and meteo data services can be provided to the users.

2. GNSS Augmentation Systems available in Romania

2.1. ROMPOS Services

According to the global and European trends in the field of modern geodetic networks, Romania followed this trend by promotion and implementation of a new high accurate geodetic network in the time interval 2004-2010. The new geodetic network it is build as an active continuously operating network. As technological equipments the GNSS (GPS and GPS+GLONASS) receivers are included into the network.

Starting in 1991 with first GPS equipments and continued in 1999, when it was installed the first GPS permanent station in Romania (BUCU) at the Faculty of Geodesy - Technical University of Civil Engineering Bucharest in cooperation with Federal Agency for Cartography and Geodesy Frankfurt a.M. (Germany), the new methods of global satellite positioning were introduced in Romania. In present Romania realized a GNSS permanent network including 60 stations (75 stations at the end of 2012, Fig.5a) and provides GNSS augmentation services under ROMPOS – Romanian Position Determination System. ROMPOS it is a part of the Central and East Europe ground station augmentation system named EUPOS (Fig.5b). ROMPOS services includes DGNSS service (dm accuracy), RTK service (cm accuracy) and GEO (geodetic service – cm/mm accuracy). DGNSS/RTK services can deliver augmentation data (corrections) based on single base or network (FKP, VRS, and MAC) concepts. Data are transmitted continuously by internet and NTRIP protocol. These services are still free of charge. GEO (postprocessing) service provides raw GNSS (RINEX) data by internet and it is charged. An overview of ROMPOS services it is presented in Table 1.
2.2. TRIMBLE VRS NOW Services

Trimble company realized in USA and Europe, GNSS services based on GNSS permanent station networks. Trimble services are known under the name „Trimble VRS Now” due to the VRS (Virtual Reference Station) concept implemented for the first time by this company. Trimble VRS Now includes realtime services DGNSS and RTK. Starting with 2012, Trimble VRS Now services are available in Romania. These services are provided in Romania based on a GNSS permanent network including 9 GNSS permanent stations installed in the area (Fig.6). There are a various number of GNSS receivers able to work with Trimble VRS Now services, able to process CMR and CMR+ data formats. Such equipments are provided mainly by GISCAD SRL company in Arad. Access to these services can be realized by SYSCAD SRL company in Bucharest. There are available few types of registration (monthly, yearly). There are first private DGNSS/RTK services provided in Romania by a private company with full country coverage.

With the support of GISCAD SRL company, we performed GNSS RTK tests using Trimble VRS Now services. Few tests were performed in order to compare absolute known coordinates (in ETRS89 reference system) with coordinates determined for the same points with these services. In the same time we compare coordinates obtained by use of Trimble VRS Now services and ROMPOS similar services. Connection to the data server and initialization time was investigated for the new services. The results indicate a good (short) initialization time and a good agreement with ROMPOS solution. Further investigations are necessary to analyse services working in difficult conditions: long distances from the GNSS permanent stations, ionospheric high activity, worse internet data communication, VRS method compared with other concepts (FKP, MAC) etc.
2.3. Leica TGREF Services

Leica Geosystems company realized in last few years DGNSS/RTK services based on GNSS permanent networks under the name of „Leica SmartNet“ in Europe and other areas [http://www.smartnet-eu.com/]. In Romania, Leica Geosystems represented by TopGeocart SRL company established a GNSS permanent station network named TGRef including 8 stations (Fig.7) and DGPS, RTK (single base) and postprocessing services. RTK service transmits corrections in Leica proprietary format.

2.4. EGNOS Services

Known as a satellite-based augmentation system (SBAS), EGNOS (European Geostationary Navigation Overlay System) provides both correction and integrity information about the GPS system, delivering DGPS corrections for Europeans and improving existing services or developing a wide range of new services and applications. In the future EGNOS will be able to augment GNSS - GALILEO in Europe. The EGNOS signal is broadcast by 3 satellites: two Inmarsat (one positioned east of the Atlantic, and the other above Africa) and by ESA’s Artemis satellite, which is also above Africa. The orbits of these satellites are in the equatorial plane, at three different
longitudes, with each able to broadcast EGNOS services across Europe. “Unlike GPS, EGNOS will offer integrity of signal, increased accuracy, coverage and a service level agreement. This makes it suitable to provide a number of navigation services. For the most common applications, EGNOS gives a positioning accuracy of one to three metres, compared to the less accurate 10 to 15 m provided by GPS alone. The three services available are: Open Service, Safety-of-Life Service, EGNOS Data Access Server (EDAS)” [10].

The EGNOS Open Service has been available since 1st of October 2009. EGNOS DGPS corrections are freely available in Europe through geostationary satellite signals. Every user equipped with an EGNOS capable GPS receiver can determine a position without any direct payment. “Since 1st of March 2011, EGNOS Safety-of-Life (SoL) signal was formally declared available to aviation. For the first time, space-based navigation signals have become officially usable for the critical task of vertically guiding aircraft during landing approaches” [11]. EGNOS provides also a terrestrial commercial data service called the EGNOS Data Access Service (EDAS). EDAS provides postprocessing and realtime data collected and generated by the EGNOS infrastructure.

In Romania EGNOS system it is at present less used and needs a better promotion in order to inform the potential beneficiaries of services. According to geographic position of Romania, at the eastern border of EGNOS services, a better coverage would be necessary in the future if uniform services should be provided for all EU countries. As an example, GNSS permanent station in Bucharest (BUCU) it is able at present to track EGNOS signal in addition to GPS and GLONASS signals.

2.5. OMNISTAR Services

OmniSTAR is a leader in providing high accuracy positioning data via satellite, including Differential GNSS (DGNSS) positioning technology. Using over 100 reference stations, 6 high power satellites and 2 global network control centers, OmniSTAR delivers real-time and highly reliable positioning services for land and air applications worldwide (Fig.8), 24hrs a day 365 days a year. Available services are:

- OmniSTAR HP: 2- 4" (6-10 cm)
- OmniSTAR XP: 4 - 6" (10-15 cm)
- OmniSTAR G2: 4 - 6" (10-15 cm)
- OmniSTAR VBS: < 1 meter

![Fig.8. OmniSTAR coverage area](12)
2.6. StarFire Services

StarFire is a wide-area differential GPS developed by John Deere's NavCom and precision farming groups. StarFire broadcasts DGPS correction information over satellite L-band frequencies around the world, allowing a StarFire-equipped receiver to produce position measurements accurate to well under one meter, with typical accuracy over a 24-hour period being under 4.5 cm. “StarFire has developed through two versions. The first, retroactively known as SF1, offered 1-sigma accuracy of about 1 m. This system was first offered in 1998. The newer system, SF2, was introduced in 2004. It dramatically improves accuracy, with a 1-sigma absolute accuracy of about 4.5 cm. The relative accuracy is likewise improved, to about 2.5 cm.” [13]. In Europe, StarFire services are offered by Trimble and Fugro companies.

CONCLUSIONS

Today GNSS systems and their augmentation systems are very important tools for various applications. DGNSS/RTK systems and services are more and more spreaded all around the world. In Romania GNSS augmentation systems are developed by state or private companies. According to European standards, in Romania was realized ROMPOS augmentation system with DGNSS/RTK free of charge services and postprocessing charged services. In addition, private companies realized or are going to realize similar services based on private GNSS infrastructure, as Trimble VRS Now or Leica TGRef networks and services. Other GNSS augmentation systems are available but rarely applied, as EGNOS, OmniSTAR or StarFire. A better future can be available in Romania for private GNSS augmentation systems as Trimble VRS Now and Leica SmartNet if we consider the large area of GNSS applications.

REFERENCES

1. RUS T. (2012), Space Geodesy I, Lecture Notes, Technical University of Civil Engineering, Bucharest, Romania.
11. *** http://www.egnos-pro.esa.int/ viewed at 12 Sep 2012.