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Data communication for real-time navigation in global navigation satellite systems

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Today, global navigation satellite systems (GNSS), real time differential correction techniques, CORS networks, GNSS user equipments, wireless communications and networking (WCN) systems, cellular systems, mobile navigation and Internet GPS are the systems used for different purposes in scientific, commercial and daily life areas. The latest innovations and developments in these systems play vital role in human life. Especially real-time positioning and navigation applications, mainly in terms of spatial-based applications, networking and telecommunication technologies usage integrated GNSS/CORS networks are increasing in every area. In this paper, we present the classification of GNSS, past and present of GNSS/CORS networks, spatial geodetic infrastructure works in the world, real-time positioning techniques, and communication systems used for them.

Key words: Global navigation satellite systems (GNSS), continuously operating reference station (CORS), GNSS/CORS networks, communication technology, real-time applications, positioning, navigation, data transmitting.

INTRODUCTION

For navigation, point positioning etc. applications, satellite-based surveying systems have been used effectively (operatively) for many years. Today, satellite based systems compute any point's position, velocity and time information on earth, are known as Global Navigation Satellite Systems (GNSS). Generally, GNSS system is divided into three main categories, namely global, regional and augmentation systems.

In the frame of global system, the most known satellite base systems are the USA's GPS and Russian's GLONASS. The other systems, which will be active in the near future, are the GALILEO implemented as a European Union Project and China's compass.

In GNSS regional system, the most developed systems are Japan's Quasi-Zenith Satellite System (QZSS), India's Indian Regional Navigational Satellite System (IRNSS) and China's Beidou systems. Beidou will stop its activity when the Compass is completed.

In the development of GNSS, Satellite Based Augmentation Systems (SBAS) include American Wide Area Augmentation System (WAAS), Europe's European Geostationary Navigation Overlay Service (EGNOS), Japan's Multi-Functional Satellite Augmentation System (MSAS), and Indian GPS Aided Geo Augmented Navigation (GAGAN) System have an active role for supplementing the main satellite systems that are GPS, GLONASS and GALILEO.

These systems have worked regional and non-commercial. In addition, there are globally worked and commercial systems into SBAS, Omnistar, Starfire, Veripos.

The Ground Based Augmentation Systems (GBAS) have been used for SBASs continental, regional and local terrestrial-based applications. The most known GBAS systems at regional scale are the Australia's Ground-Based Regional Augmentation System (GRAS) and the U.S. Nationwide Differential Global Positioning System

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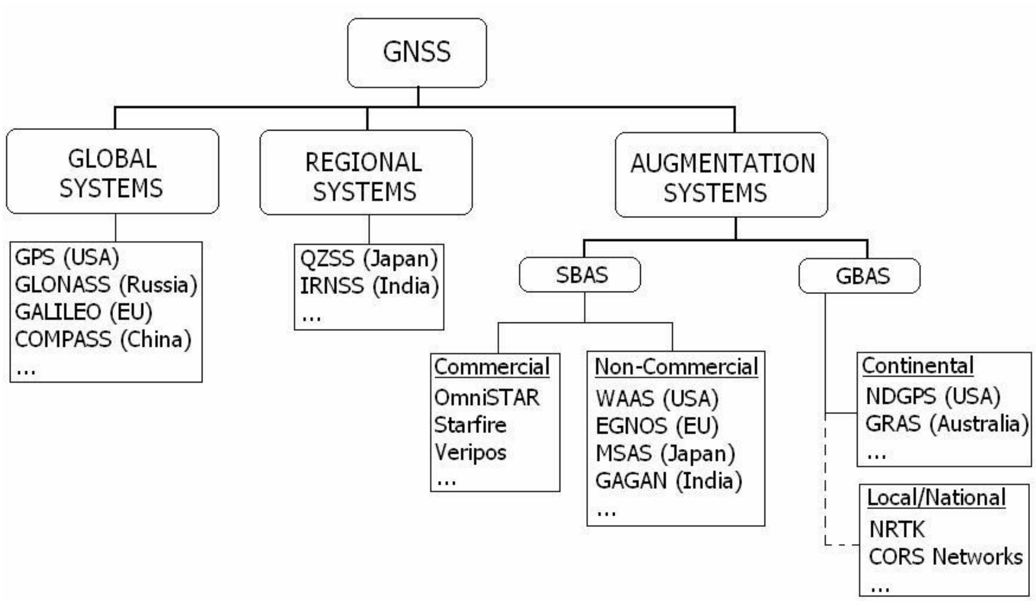

Figure 1. GNSS classification.

(NDGPS) service. CORS networks are both regional and local scale systems at national wide. Figure 1 represents the GNSS classification with its sub-sections.

All these systems discussed above give the most effective, efficient and optimum solutions and are commonly used and applied in many different projects, notably in commercial and scientific applications in global, regional and local scale.

The widespread use areas of these technologies can be listed as precise point positioning, vehicle navigation, transit systems, tracking systems (monitoring structural deformations, crustal monitoring, land and marine seismic surveying, etc.), transportation systems, the utility and the retail industry, forestry and natural resource, precision farming, civil engineering applications, airborne and seafloor mapping, etc.

Many global, regional and local applications of GNSS would be associated with the telecommunication technology. In addition to communication between space, control and user units of GNSS; telecommunication systems are also actively used for data communications in real time applications.

The latest innovations of GNSS or satellite-based system technologies play an important role in improving the quality and safety of modern life. Most of the applications evolved from the integration between GNSS and wireless communications networking (WCN) systems (Sadoun and Al-Bayari, 2007). Although these systems have various application areas, they are commonly used for positioning and determining the fixed or moving object locations, and navigation utilities. Especially, transmitting the correction data for the real-time applications, GNSS and digital wireless communication systems enable to obtain the precision timing synchronization and position information.

WCN systems play vital role for completing these applications in optimum conditions in terms of time, cost and accuracy. In today's technology, WCN included in the network-based services began to be used effectively in real-time GNSS active control systems, CORS networks and mobile location or positioning applications.

GNSS/CORS NETWORKS Background

to GNSS/CORS networks

All over the world, to increase the use of GPS/GNSS technology operatively, permanent GPS/GNSS stations and networks are being developed. Many permanent GPS/GNSS stations and networks are established in various countries and regions in the world with global, regional and local scales for providing current, continuous and dynamic use of GPS/GNSS. For high-accuracy positioning, GPS/GNSS users may use one of the highly precise permanent GPS/GNSS reference station networks established by several organizations around the world (El-Rabbany, 2006).

The permanent GPS/GNSS stations have many significant functions especially such as determination of the crustal deformations, updating the fundamental geodetic networks and studies about the earthquakes and geodynamics. Furthermore, GPS/GNSS provides correction data with the available hardware for the application of differential GPS/GNSS (DGPS/DGNSS) and real time kinematic GPS/GNSS (RTK GPS/GNSS). In this respect, satellite and wireless ground-based communication systems (radio modem-VHF or UHF radio frequency, mobile telephones-GSM/GPRS, wireless networking-internet, satellite communication link-leased lines, etc.) become indispensable systems for transmittting the correction data to the end-user in order to obtain location, navigation and position.

Depending on these network systems, GPS/GNSS provides different products for users by two methods: (a) the passive control networks and (b) the active control networks (Hofmann-Wellenhof et al., 2001).

Passive control networks

These networks perform the permanent stations' data or products in recent real-time or post observation time interval, and represent them to the users. In global scale, International GNSS Service (IGS) is the most known passive control network. The IGS network serving as a passive control network may also be considered as an active control network on global scale. The measured code and phase range data at each tracking site are made available to all users through the IGS information system to allow for relative positioning in post processing mode (Hofmann-Wellenhof et al., 2001). Also, another well known passive network in regional scale is European Reference Frame (EUREF) Permanent GPS Network (EPN).

Active control network

These networks transmit the correction data to the all users completely real-time via the data links and communication systems. The system consists of a number of automated GPS/GNSS tracking stations, which continuously record carrier phase and pseudo-range measurements for all GPS/GNSS satellites in view. Today, most of the active control networks offer DGPS/DGNSS or RTK services where pseudorange corrections or observed carrier phases are transmitted in real time to the user (Hofmann-Wellenhof et al., 2001).

The Network RTK (NRTK), which is an active system, had been developed in order to determine high precise position data in short time intervals to the surveyors, GIS/LIS (Geographic Information Systems/Land Information Systems) professionals, engineers, scientist and other users since 1990s.

CORS Networks measure data for duration of 7-day and 24-h due to the NRTK method. They are established by active permanent GPS/GNSS stations. In literature, Active GPS/GNSS Stations, Active Control Points, or Permanent GPS/GNSS Reference Stations have been used in order to describe CORS.

In many countries and regions, CORS Networks have been established for collecting, accessing and processing data to the users. These networks, which provide three-dimensional position information and cm-level real time position accuracy, make important contributions to the several users. Through CORS network approach and integrated use of communication systems within them, the position information could be provided for short durations in frame of real time applications. The system is also web-based, so it can be utilized for the post processing applications.

The Canadian Active Control System (CACS), the National Geodetic Survey (NGS)-CORS Network in USA and Satellite Positioning Service of the German State Survey (SAPOS) in Germany, GEONET in Japan and CORS- TR in Turkey are examples of the national active control networks. In addition, China, Korea, Belgium, Switzerland and many several countries have established their active control networks.

A reference network comprised of permanent stations operating GNSS receivers on a continuous basis provides the fundamental infrastructure required to meet the needs not only of geodesy and geosciences, but also of professional GPS/GNSS users in areas of surveying, mapping and navigation. Nevertheless, increasingly, CORS network operators have sought ways of making their network infrastructure the basis of a profitable business. These high accuracy applications can only be satisfied by the carrier phase-based, differential GPS/GNSS technique, whereby the "reference" or "base" receiver is located at a station whose coordinates are known in a geocentric datum or reference frame (Rizos, 2007).

Geodetic infrastructure studies for GNSS/CORS networks

Variety of GNSS applications are satisfied with using permanent GNSS stations, global, regional and local scale use of continuous, current and dynamic structural control (reference) networks. Consequently, there is a need for a space-time system and reference networks based this system to satisfy the effective utilization of GNSS/CORS and use for navigation, traffic, transportation, and traveling utilities.

Many years ago, these needs emerged, and geodetic infrastructural studies compatible with the current technology had been started at global, regional and local levels, and were concluded. For this purpose, many international and regional institutions are conducting multi purpose and multi disciplinary activities.

Due to the need for establishing precise coordinate systems and reference networks for high accurate positions by using satellite base systems, international terrestrial coordinate systems and reference networks were constituted in global scale. In this context, International Terrestrial Reference Frame (ITRF-yy) is the most operative and existing established network. Co-ordinates of the reference network (X, Y, Z) and velocity vectors (Vx, Vy, Vz) had been computed in Geodetic

Table 1. Comparison of global and regional coordinate systems.

	ITRF-yy	WGS-yy	ETRF-yy
Versions	ITRF89, ITRF2000, ITRF2005	WGS60, WGS72, WGS84	ETRF89, ETRF2000, ETRF2005
Producer	International earth rotation and reference systems service (IERS)	National geospatial-intelligence agency (NGA)	International association of geodesy (IAG)
Ellipsoid	Geodetic reference system 1980 (GRS80)	World geodetic system 1984 (WGS84)	Geodetic reference system 1980 (GRS80)
Methods	VLBI, SLR, LLR, DORIS, GPS	GPS	GPS
Parameter	GRS80 a = 6378137,00 m f = 1 / 298,257222101	WGS84 a = 6378137,00 m f = 1 / 298,257223563	GRS80 a = 6378137,00 m f = 1 / 298,257222101

Reference System, 1980 (GRS80) datum. ITRF consists of nearly 300 points. To increase accuracy by using GPS techniques, densification is aimed by IGS. Another global terrestrial coordinate system is the World Geodetic Systems- 1984 (WGS84). In Table 1, global and regional coordinate systems with used parameters, methods, ellipsoids and producers that are the most significant ones used in GNSS application can be seen.

Generally, WGS84 is being used for military and civil applications as well as ITRF is used for geodetic and geodynamic researches. Nevertheless, with the latest developments, these two systems are overlaid to each other and given same accuracy (Aksoy et al., 1999).

Studies for development of regional and country networks have started due to navigation facilities of global networks, global geodetic and geodynamic researches, and effective utilizations from satellite techni-ques. European Reference Frame (EUREF) is an example of this. According to this, European Terrestrial Reference Frame (ETRF-yy) network based on ITRF network was established with global- scale GPS/GNSS technique. The European countries had established country GPS/GNSS networks by densification of the network that consist of up to 100 points. With this densification, these countries had started utilizing the permanent GPS/GNSS record stations by compatibility of the region's tectonic structure. Some of these stations are taken from EUREF and ITRF points, so densification of these networks had also been done.

To design the country GPS/GNSS networks as determined by the regions' tectonic behaviors by establishing and working the permanent GPS/GNSS stations, the sustainability of the country GPS/GNSS network as a dynamic network system has been satisfied. These studies are continuing at a great rate, settling the parallel and similar in developed and developing countries.

CONVENTIONAL SOLUTIONS FOR REAL-TIME DIFFERENTIAL POSITIONING TECHNIQUES

The real time differential positioning can be investigated into two categories: The real-time kinematic (RTK) and differential GPS/GNSS (DGPS/DGNSS). RTK and DGPS/DGNSS systems are used for determining the real time positions. Figure 2 shows all used positioning techniques together titled as GPS/GNSS positioning. Nowadays, both standalone positioning systems and DGPS/DGNSS systems are used commonly for navigation (Aktug and Celik, 2003). Positioning systems with DGPS/DGNSS give more accurate results than standalone positioning systems. Especially, in boat, car and aircraft navigation systems; DGPS/DGNSS technique is used effectively. However, RTK system is especially used in high accurate surveying studies. In DGPS/DGNSS systems, the accuracy of the positioning is in meter or decimeter level, and in RTK applications, the accuracy of the positioning is in cm level. The main concept of the RTK and DGPS/DGNSS are formed by known point coordinates of GNSS receiver, aimed to have real time position of rover GNSS receiver and transmitting the data. Figure 3 shows fundamental DGPS/DGNSS system and correction data transmit. While pseudorange measurements are used in DGPS/DGNSS systems, in RTK systems carrier phase measurements are used. The vital factor on rover receivers positioning is to take the correction data from

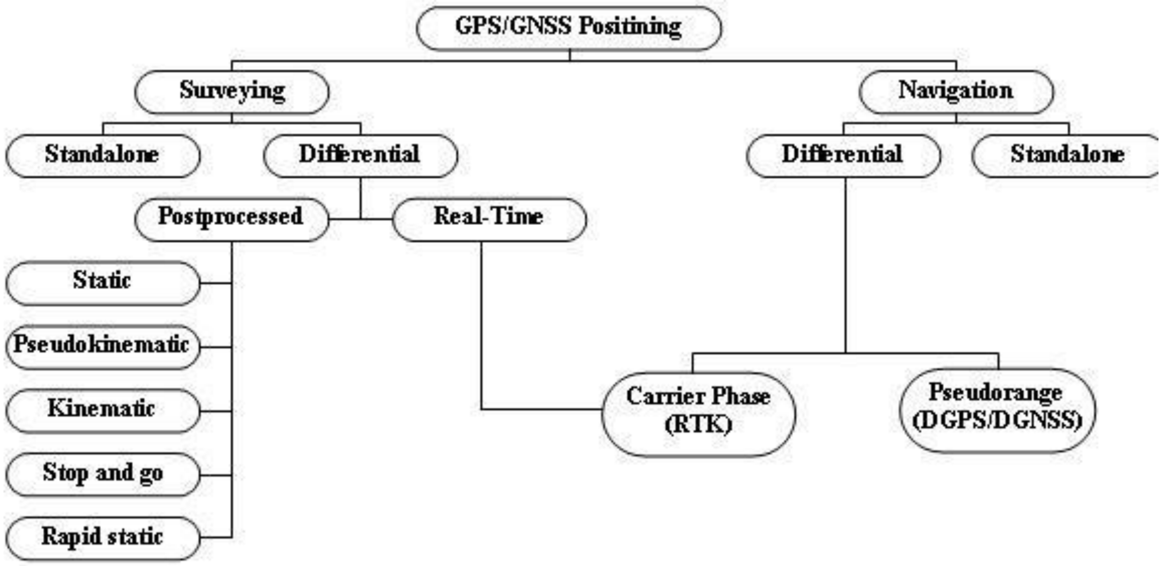

Figure 2. GPS/GNSS positioning techniques (Langley, 1998).

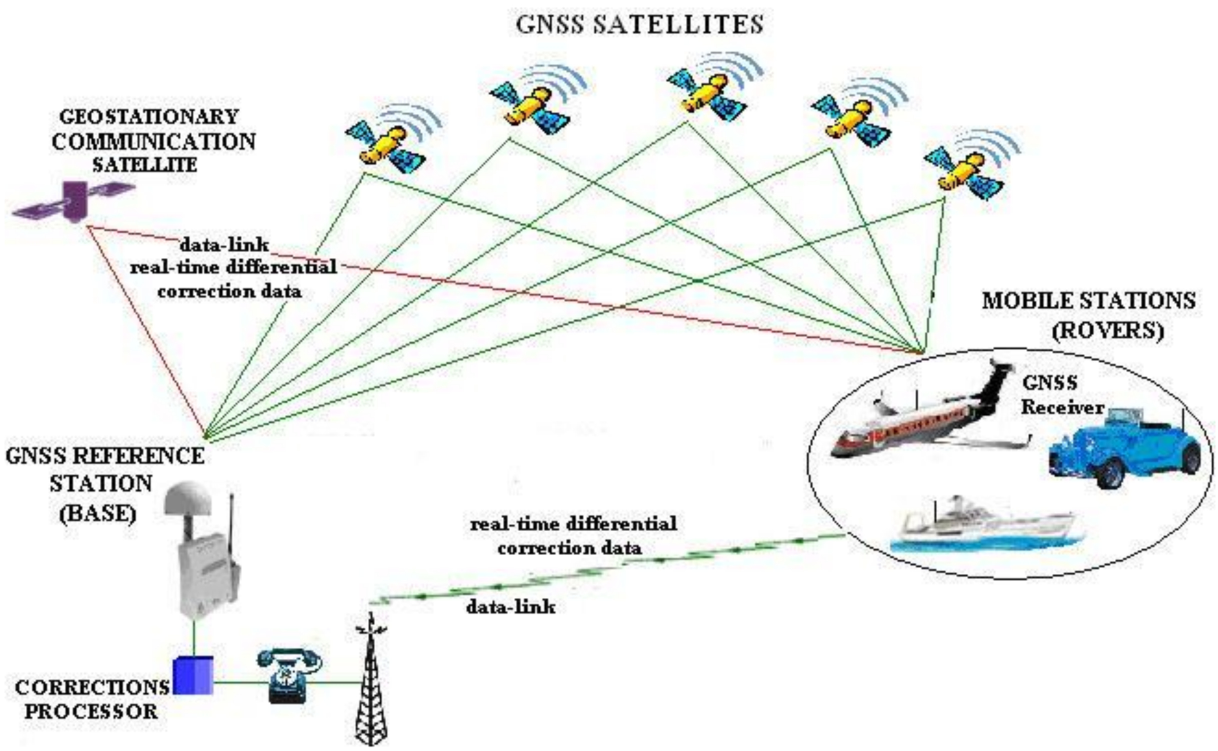

Figure 3. Fundamental DGPS/DGNSS system and correction data transmit.

the reference stations. These data are transmitted to the GNSS users' receivers by using the different communication systems.

Studies about the data transmitting especially in DGPS/ DGNSS are major on transmitting the correction data, and the requirement for the transmission of the positioning information become an important problem in RTK applications and vehicle tracking systems (URL-1, 2009).

Because of the environmental effects, data link systems used for the differential corrections are located within limited areas. Therefore, the systems for broadcasting the local and wider areas are established (Local Area DGPS - LADGPS and Wide Area DGPS -

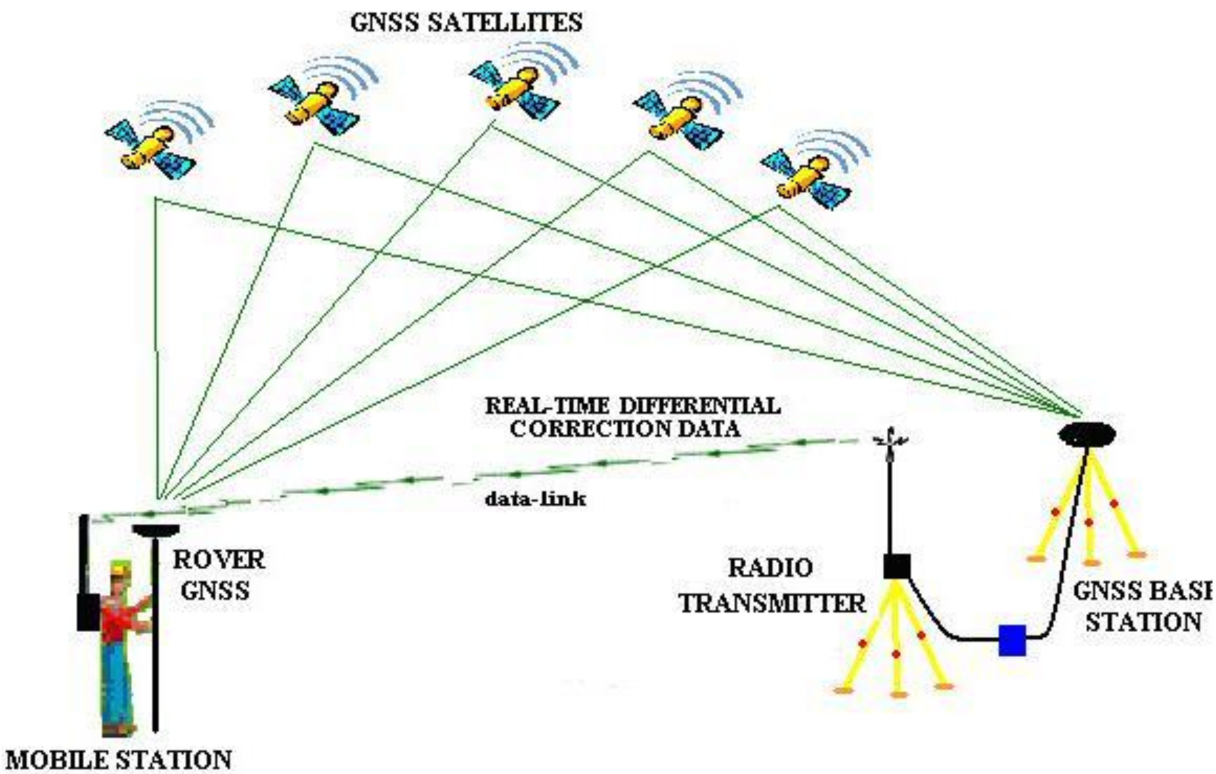

Figure 4. Standard (single-base station) RTK.

WADGPS) (URL-1) . Thereby, multiple rover receivers can use these free corrections via the data transmitting systems.

In 'standard RTK' (single-base RTK) applications represented in Figure 4, the distance between the reference station which transmits the correction data and rover receiver(s) is limited to 15 to 20 km. This limitation is caused by environmental barriers such as high buildings, mountains, forestlands etc. Generally, for transmitting the correction data, radio modems (UHF, VHF, Spread Spectrum etc.) are used in standard RTK applications. Different methods (GSM/GPRS, communication satellites etc.) can be used for the solution of the limitation problem described above. On the other hand, in recent years, use of internet protocol (IP) becomes widely used for real time data transmitting. NTRIP Protocol can be given as an example (Kahveci, 2009).

The most applied type of NRTK technique is permanent GNSS Networks (CORS). In 'network RTK (NRTK)' and 'CORS' applications represented in Figure 5, distance between reference and rover receivers rise to 50 to 100 km by the help of network approach, calculation and transmission methods (Virtual Reference Stations-VRS, Network Area Corrections-FKP, Master Auxiliary Concept-MAC) of the network. In NRTK technique, all the observation corrections taken from entire reference stations are calculated in the evaluation centre, and these network corrections are broadcasted to all users with appropriate communication techniques.

COMMUNICATION SYSTEMS FOR REAL-TIME APPLICATIONS

Today, it is possible to investigate used data communication systems into two categories; "broadcast systems" and "data transmission systems". Broadcast systems basically are based on broadcasting the data by given frequency via the radio-modem, and taking these data via the radio modem on the other side and demodulating. It is possible to perform the broadcasting data via the general television frequency (Television Vertical Blanking Interval- VHF/UHF bands) or specific functional satellites (Mobile Satellite Communications). In other words, multiple users can use data broadcasted from one center. Therefore, this is available for the common systems such as differential correction data used by multiple users (URL-1, 2009).

GSM and satellite telephones can be given as an example of data transmission systems. In these systems, the data is not broadcasted, only sent to a particular address. They are not preferred frequently due to expensive operating costs. Data transmission systems, then especially is formed by the wireless networks. Today, there are many types of cooperative wireless networks such as cellular 2nd-2.5rd-3rd Generation

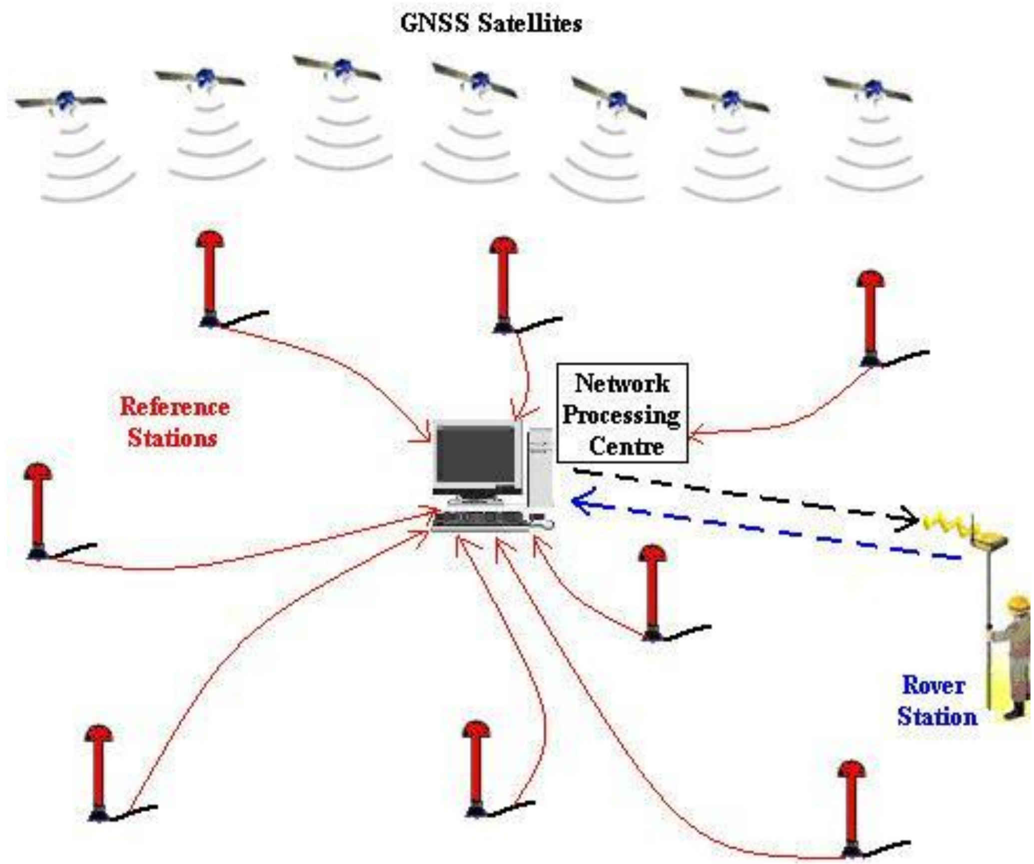

Figure 5. Network RTK (NRTK) and CORS systems.

(2G/2.5G/3G) mobile networks (GSM, GPRS, EDGE, UMTS), wireless local/metropolitan networks (WLANs/ WMANs), wireless personal area networks (WPANs), short-range communications and multi-hop wireless networks.

3G and beyond 3G (B3G) cellular systems start to use position information for synchronization and locating users. Providing position information is advantageous for many applications such as providing Internet services for mobile users (cars, trains, etc.) (Sadoun and Al-Bayari, 2007). RTK and real-time DGPS/DGNSS operations require a communication, or radio, link to transmit the information from the base receiver or control center to the rover receiver. Both ground- and satellite-based communication links are used for this purpose (El-Rabbany, 2006). Often, in ground-based communication links, GPS/GNSS users utilize their own dedicated radio links to transmit base station information. Dedicated ground-based GPS/GNSS radio links are mostly established using the very high and ultrahigh frequency (VHF/UHF) band (El-Rabbany, 2006). More recently, some GPS/GNSS manufacturers adopted cellular technology; the digital personal communication services (PCS) and the third generation (3G) wideband digital networks, as an alternative communication link. The 3G technology uses common global standards, which reduces the service cost. In addition, this technology allows the devices to be kept in the "on" position all the time for data transmission or reception, while the subscribers pay for the packets of data they transmit/receive (El-Rabbany, 2006).

TRANSMISSION OF REAL-TIME DATA IN GNSS/CORS NETWORKS

Today, for GNSS users, CORS Networks, NRTK, mobile internet and other communication systems are mature technologies. In this context, to serve seamlessly of CORS Networks, provide effective and optimal benefits for users, be sustainability depend on better managing of the system and running smoothly of communications infrastructure. CORS design is very important to have effective and sustainable system. This design consists of distribution of CORS stations, equipment and tools of CORS, networking software of CORS, the control center and data communications components. In these components, technologies used for data communications are the most important components of CORS system because, the success of a network of reference stations

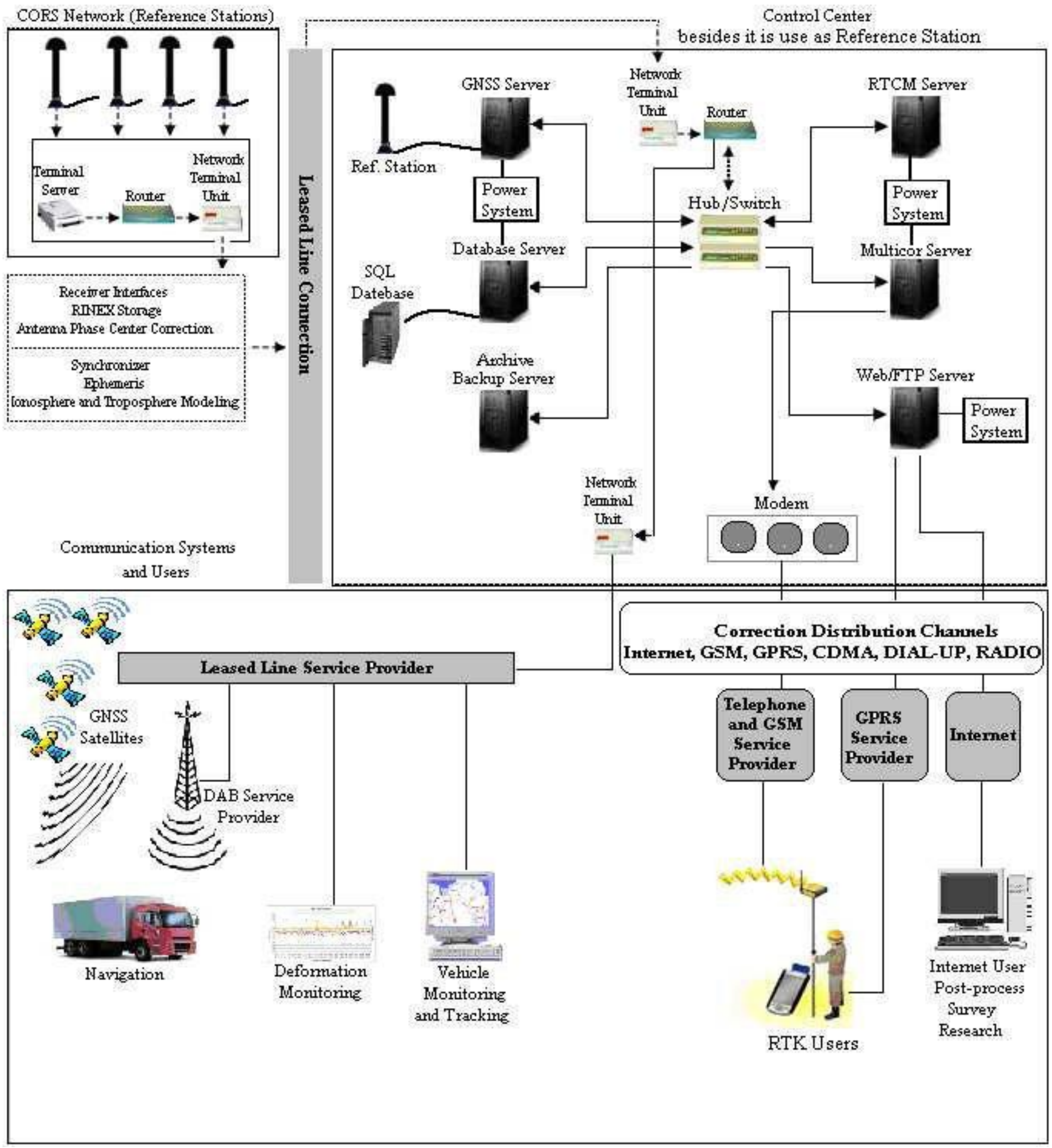

Figure 6. CORS data communication system.

is directly related to communication system. In Figure 6, the main working structure of CORS network and data communication system can be seen.

Real-time data (DGNSS/RTK GNSS data) transfer protocols

Started to be established of CORS networks in all countries and the obtained data broadcasted via the internet, radio modem or satellite channel to other national or international users has enabled the creation of GNSS-based standard data format. The efficient use of these systems for the purpose of real-time surveys and navigation is possible with the efficient use of tele-communication technologies and data transfer protocols. Therefore, some companies and institutions/ organiza-tions have developed various data transfer protocols for users of GNSS. These protocols can be classified as manufacturer-defined protocols, international standard protocols, internet protocols (Kahveci, 2009).

In general, the GNSS receiver manufacturers have custom data transfer protocols. Some of these protocols are being broadcasted in "binary" format, in a section is also available in ASCII format. Although there are several GNSS data transfer protocols, the two of them became the standard. These are NMEA 0183 (or NMEA for short) produced by the National Marine Electronics Association and RTCM SC104 (or RTCM for short) produced by The Radio Technical Commission for Maritime Services. These protocols are open to all users, and are generally used by all companies. The most basic feature of these protocols is the use of only one-sided communication. In other words, mutual connection or communication with rover GNSS receivers is not required (Kahveci, 2009). NMEA 0183 is only being used for navigation purpose applications, and is not suitable for RTK applications. This format, which is standard for nearly all GNSS receivers, is ASCII format. The RTCM SC104 is an international standard for real-time data transfer. Its data is in "binary" format. It has different versions. To date, seven different standards have been published, and these different standards are RTCM v2.0, RTCM v2.1, RTCM v2.2, RTCM v2.3, RTCM v3.0, RTCM v3.1 and NTRIP (Networked Transport of RTCM via Internet Protocol) version 1.0 (URL-2, 2009; URL-3, 2009). Besides, classical methods are used for communicating the real-time GNSS data and correction information to users, nowadays high-speed internet and satellites are also used. In addition, network ports have started to take place of serial ports in GNSS receivers. These developments have yielded new data protocols to come into being, for example, internet-based NTRIP and RT-IGS (Real Time-International GNSS Service).

NTRIP developed by BKG (Federal Agency for Cartography and Geodesy) is a protocol open to all users and used in transmission all kind of GNSS data over the internet. It is not a GNSS data format. It is only a protocol adopted as RTCM standard and describes how the data will be broadcasted via internet. NTRIP runs http base, and uses Transmission Control Protocol/Internet Protocol (TCP/IP). Therefore, it can transmit data to mobile IP networks. It supports mobile IP networks such as GSM, GPRS, EDGE and UMTS (URL-4, 2009). The RT-IGS is a new unequivocal protocol with known message frequency developed by IGS. To run faster and better of the data at internet based and real time applications, User Datagram Protocol (UDP) is used for transmitting the RT-IGS data (URL-5, 2009).

CORS data communication systems

The effective use of CORS system requires seamless transmission of the data in GNSS reference stations to control center and correction data calculated in control center to the rover receivers. However, here, determination of the data communication techniques used to transfer the RTK and DGPS/DGNSS information, technical issues such as the distance, coverage area, bandwidth, reliability, etc. and economic and administrative issues are factors. The main point for selecting the data transmitting hardware is the radio systems service areas and defunct areas due to the study areas size and the physical difficulty on the environment. Therefore, selection of the CORS communication system is significant.

Communication between control center and GNSS reference stations

Reference stations in the worldwide applications are directly connected to the control center. Thanks to the control center server and software, GNSS data are recorded, stored, converted; coordinates and corrections are calculated and then transmitted to rover receivers. An illustration of communication between control center server and reference stations can be seen in Figure 7. The communication between the control center and GNSS reference stations are provided with the fixed telephone lines (Modem, ISDN), leased lines , ADSL internet, GSM / GPRS / EDGE, communication satellites, radio communications technologies. Here the communication has to be continuously on (CORS-TR Inception Report, 2006).

Communication between control center and rover receivers

Messaging to rover receivers of the RTK and DGPS/DGNSS correction data of the raw data incoming from reference stations to control center obtained by using different calculation (VRS, FKP, MAC etc.) and transmission methods are provided with various data transfer protocols and communication technologies. Here, in spite of using different data communication tools, especially in the world, the IP-based methods (LAN, WAN, WLAN, Internet, Intranet, Radio) usage is preferred. However, one of the IP based method formed by improvement of NTRIP namely Internet is more preferred because of user and prevalence conditions.

Conclusion

Besides needs on real time positioning and navigation information in many applications such as civil, military and scientific studies, the GNSS technologies has become widely used in our daily lives. While developed countries have designed their satellite navigation systems that work global and regional in view of this increasing need, many countries has also established their CORS

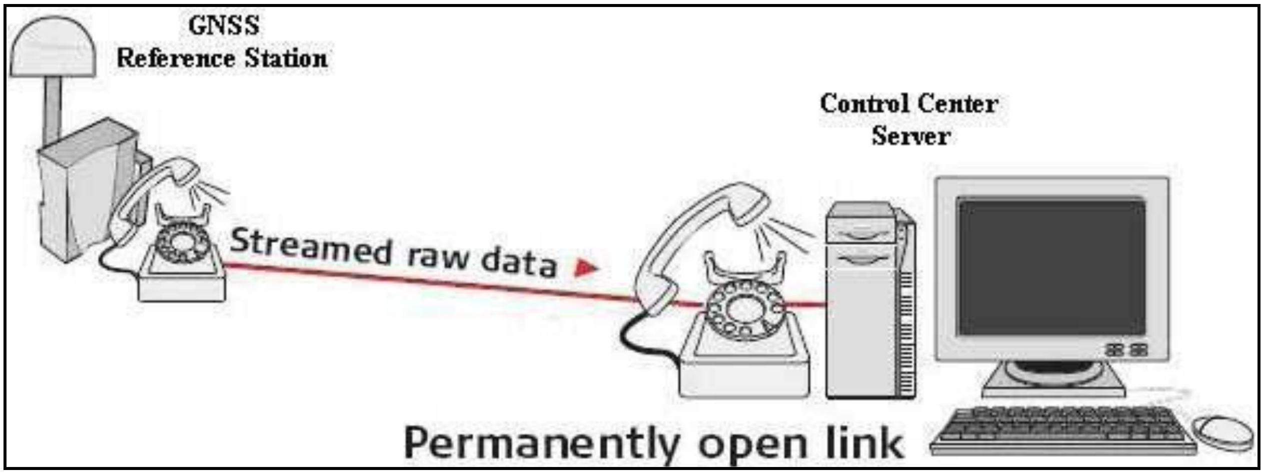

Figure 7. Communication between control center server and reference stations (URL-2, 2009).

networks in national aspect for being benefit from applications of GNSS. Being effective and functional of GNSS/CORS systems used by many different disciplines is provided by rapidly developing telecommunication technologies.

Today, many (geo)spatial technologies and solutions such as especially 'Spatial Information System (SIS)', 'Location-based Services (LBS)', 'Geographic Information System (GIS)', 'Ubiquitous GIS (U-GIS)', 'Assisted GPS (AGPS)' and now 'BGPS', 'mobile navigation' and 'Internet GPS' are becoming true by combination and integration of GNSS systems and communication technologies. The real time representation of these spatial based applications will be accelerated by commonly use of 3G systems and in near future 4G systems, and so functionality of GNSS/CORS networks will increase more than expected. In this context, spatial based technologies and communication systems compose one of the basic principles of sustainable development.

The widening of GNSS, the establishment of CORS networks by each country and rapid developments on wireless communication and network systems need certain standards for integration of these systems. Consequently, not only for a need of rapid, precise and real time positioning and navigation information; but also making correct, reliable and rapid decisions for (geo)spatial informatics applications such as surveying, construction, vehicle navigation and tracking, infrastructure, agriculture, emergency state management, traffic management, mobile applications, city and regional planning, forest and environmental management, e-government, these systems have become indispensible of human lives. Finally, for being sustainable of operations of GNSS/CORS networks with high installation costs and providing practical solutions to all users, the investment and more resources should be allocated, and the cost of real time data obtain to each user must be minimized.

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