# THE DESIGN AND USE OF CONTINUOUS GNSS REFERENCE NETWORKS


by

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B.S., Istanbul Technical University, 2003


Submitted to the Kandilli Observatory and Earthquake
Research Institute in partial fulfillment of the requirements
for the degree of Master of Science


Graduate Program in Geodesy

Boğaziçi University

2007

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# ACKNOWLEDGEMENTS

I would like to thank to Assoc. Prof. Dr. Haluk Özener for his great support, encouragement, and guidance since the beginning of my graduate program. With the help of his perception and notifications, the thesis could be managed to be true. His assurance, patience and valuables persistence makes me to not give up during my worse periods.

I'm very pleased to and proud to have lectures from Prof. Dr. Onur Gurkan during my gradute program period. I acknowledge his contributions on our vision of geodesy and science. I'm thankfully mentioning Dr. Onur Yilmaz, Eng. Bulent Turgut, Assist. Prof. Ugur Sanli, Research Assist. Asli Garagon Dogru, and Ahmet Altin for their encouraging supports.

I'm grateful to Assoc. Prof. Dr. Rahmi Nurhan Çelik for his valuable and leading contributions since the end of my undergraduate program. His contributions to my engineering life, helps me to understand the details of my proficiency and draw my future as never been before. I acknowledge Mustafa Tanisik on behalf of my Company Sistem A.Ş. for their support and understanding during my scientific studies. His encouragement and support makes me to believe to my studies.

Special thanks to my special family for their incomparable support, motivation, and assurance during all my life, and special thanks to my friend Merve Özyaşar's patient and perceptive suspense. The walk never starts alone. Valuable and crucial decisions require encouraging discussions and full understanding. Special thanks to my friend Research Assist. Kerem Halicioglu for his contributions and motivation that help me to believe the feasibility of the wills.

# ABSTRACT


## THE DESIGN AND USE OF CONTINUOUS GNSS REFERENCE NETWORKS

Today, through the developments in positioning technologies, coordinate information has been the information to which daily users who are not geodesists are frequently applied. Global Navigation Satellite Systems (GNSS), gives answer to the question "Where?" by defining the Earth on a reference system With the help of recent investments and future aspects of GNSS systems wide range of users trust on the reliability and accuracy of position information achieved from these systems. In order to increase the accuracy of satellite based positioning systems to centimeter levels for the end users, Countries are establishing regional and local Continuously Operating Reference Stations (CORS) stations. These stations serve to satisfy high accurate position requirement of daily users, besides they are used for the studies like disaster management, transportation planning, detection of crustal movements and monitoring critical structures.

In this study, the properties of GNSS with its future aspects, benefits of using all GNSS systems together, components required for system implementation and fields of use are presented with the proposals for the design of such systems. All components required for the CORS system are examined in two groups. First one is sites to which GNSS stations are installed and the other one is control center. Besides, the system is explained in details with its components in the scope of present technologies and techniques. The application of CORS systems are classified as RTK based applications, structural monitoring and crustal deformation. The benefits of using CORS system is mentioned, and proposals are given by regarding the technical properties of site equipments, the range of the application, economy and efficiency of the system. Examples from different studies are

given in order to improve the quality and efficiency of ongoing projects and new project in different range.

# ÖZET


## SÜREKLİ GNSS REFERANS AĞLARININ TASARIMI VE KULLANIMI

Günümüzde konumlandırma teknolojilerindeki gelişmeler sayesinde, koordinat bilgisi sadece jeodezi ile uğraşan kişilerin değil diğer tüm günlük kullanıcılarında sıklıkla başvurdukları bir bilgi haline gelmiştir. Global Navigasyon Uydu Sistemleri (GNSS-Global Navigation Satellite Systems) “Nerede?” sorusuna Dünya’yı bir referans sisteminde tanımlayarak cevap veren bir sistemdir. Son yıllarda yapılan büyük yatırımlar ve gelecek hedefleri sayesinde, geniş bir kullanıcı yelpazesi bu sistemlerden elde edilen konum bilgisinin güvenilirliğine ve doğruluğuna inanmaktadır. Uydu temelli konulama sistemlerinden elde edilen doğruluğu santimetre hassasiyetine kadar artırarak son kullanıcıya sunmak amacı ile Ülkeler, bölgesel ve yerel olarak GNSS temelli Sürekli Çalışan Referans İstasyonları (CORS-Continuously Operating Reference Stations) tesis etme yoluna gitmişlerdir. Bu istasyonlar günlük kullanıcıların yüksek doğruluklu konum gereksinimlerini karşılamakla birlikte, afet yönetimi, ulaşım planlama, kabuk hareketi belirleme çalışmaları ve kritik yapıların izlenmesi amacı ile de yaygınlıkla kullanılmaktadır.

Çalışmada, GNSS sistemlerinin özellikleri ve gelecek perspektifleri, birlikte kullanımı ile sağlanacak avantajlar, sistem kurulumu için gerekli bileşenler, ve kullanım alanları tasarım önerileri ile birlikte sunulmuştur. Çalışmada, bir CORS sistemi kurmak için gerekli tüm temel bileşenler iki grupta incelenmiştir. İlk olarak GNSS istasyonunun tesis edileceği istasyon ve diğeri ise kontrol merkezi dir. Sistem, mevcut teknoloji ve teknikler ışığında tüm muhtemel parçaları ile detaylı olarak açıklanmıştır. CORS, genel anlamda RTK temelli uygulamalar, yapısal deformasyon uygulamaları ve kabuk

deformasyonu uygulamaları olarak sınıflandırılmıştır. Her uygulama sınıfı için CORS sistemlerinin sağladığı avantajlara değinilmiş, CORS donanımlarının teknik özellikleri, uygulamanın boyutu, maliyet ve verimlilikleri de göz önüne alınarak donanım ve yazılım kabiliyetleri açısından önerilerde bulunulmuştur. Çalışma, mevcut uygulamaların kalite ve verimliliğini artırmak ayrıca farklı boyutta yeni projelere yol göstermek hedefi ile çeşitli çalışmalardan örnekler de sunmaktadır.

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| | |
|---|---|
| GPS | USA Global Positioning System |
| GLONASS | Russian Global Satellite Navigation System |
| Galileo | European Satellite Navigation System |
| CORS | Continuously Operating Reference Stations |
| IGS | International GNSS Service |
| GEO | Geostationary Orbit |
| MEO | Medium Earth Orbit |
| GNSS | Global Navigation Satellite Systems |
| KNITs | Coordination Scientific Information Center |
| A/S | Anti-Spoofing |
| RINEX | Receiver Independent Exchange Format |
| ADSL | Asymmetric Digital Subscriber Line |
| FTP | File Transfer Protocol |
| RTCM | Radio Technical Commission for Maritime Services |
| 12V | 12 Volt |
| NTRIP | Networked Transport of RTCM via Internet Protocol |
| NGS | National Geodetic Survey Office |
| PCV | Phase Center Variation |
| CPU | Central Processing Unit |
| IP | Internet Protocol |
| PC | .Personal Computer |
| LAN | Local Area Network |
| WAN | Wide Area Network |
| VDSL | Very High bit Digital Subscriber |
| GSM | Global System for Mobile |
| GPRS | General Packet Radio Service |
| MAC | Master Auxiliary Concept |
| $\Phi$ | Radius of a cylindrical shape |
| mm | Millimeter |

| | |
|---|---|
| h | Height |
| M16 | Standart for the dimentions of the screw |
| UPS | Uncorrupted Power System |
| NPS | Network Power Switch |
| SNMP | Symmetra RM Power Module |
| RAID | Redundant Array of Inexpensive Disks |
| NMEA | The National Marine Association |
| VRS | Virtual Reference Station |
| FKP | Area Correction Parameters |
| Mhz | Mega Hertz |
| GHz | Giga Hertz |
| TUBITAK | The Scientific and Technological Research Council of Turkey |
| HGK | General Command of Mapping |
| GIS | Geographic Information Systems |

# 1. INTRODUCTION

Since the position data take important role in the management and restructuring stages, today more people asks for accurate position data in real-time applications. This forces the powerful countries to think more about how to satisfy these requirements. Since the demand for accurate position data increases, the investments on positioning technology are increasing.

It is needless to say the trip to the moon opens the doors to the space also for the positioning technology. Most of the data that we are familiar with, has been reached via satellites. Since the power of technology helps the countries and unions become the power of the world, they are investing more money on technology. This brings different type of national and international positioning solutions. Rather than the national solutions this study focuses on global satellite positioning solutions.

GPS (USA Global Positioning System) was the only satellite based positioning solution on which people trusts the positioning accuracy. In this decade, more investments have been done on renovation of GLONASS (Russian Global Satellite Navigation System) launching Galileo (European Satellite Navigation System) Satellites. Additional to that, some economically and politically powerful countries like Japan have their own private systems. Having the same aim, all these systems have been named GNSS (Global Navigation Satellite Systems). In this study GNSS refers to the combination of GPS, GLONASS and Galileo which are more global and important for the region of Turkey.

The Earth is not a static object. It is living and breathing, and this creates active tectonics. Besides, Turkey is in the intersection of three main plates which are African, Arabian and Eurasian. This increases the dynamism of Anatolian plate. The end user of GNSS may not need to know the infrastructure or the design stages in the background of the system. However, the scientists who implement the system should care about the design of the system. At that stage it is import to know what the system serves for to suggest the design specifically for each aim.

GNSS aid to positioning and related applications. In this study, the use of GNSS will be examined in three main groups, which are RTK applications, crustal deformation applications and monitoring applications. Even these three applications are using GNSS, the infrastructure requirements and design of the network should be considered fully separately. In this study the general concept of Continuously Operating Reference Stations (CORS) with its basics and design stages will be explained regarding the ongoing applications and projects all over the world.

Second chapter of this study introduces the CORS concept. The differences between active and passive systems are explained in this chapter. Besides, the benefits of using GNSS instead of a single satellite system and the description of the main concept of GNSS systems are given briefly.

Third chapter explains the bases of infrastructure for sites and control center that could compliment the main equipments of GNSS. For site equipments, receivers, antennas, data storage units, communication channels, monumentation, antenna mounts and tribrachs, cabinets, lightning protections, surge arrestors, power systems and remote control modules, cables, and other data collectors are defined with their basic functionalities that improve the quality of the operation of the site. Control center equipments will not separately explained as most of the equipments are the same with sites.

Design of a CORS system for RTK based, structural monitoring, and crustal deformation is explained in chapter four. More on that, the design stage of CORS system will be simplified with examples. Main critics for selection of the equipments specifically for each application are proposed within the scope of this chapter. Some proposals will be given for each type of application for a better system design.

# 2. DEFINITION OF CORS

Geodesy concerns with measuring the earth, other objects or structures, and creating best fit models for mapping or analyzing. More realistic models could be created if the amount of data increases. Continuously observed measurements increase the productivity of the positioning systems. Here continuous systems will be analyzed through the perspective of Global Navigation Satellite Systems (GNSS). However, it should be noted that each data type could be designed to provide continuous data. This could be a Total Station with automatic target recognition functionality or a sensor that collects the inclination differences. In the next sections the combination of different type of devices will be explained and the general figure will be drawn over GNSS systems.

In Continuously Operating Reference Station (CORS) concept, the GNSS Reference Stations are operating continuously on permanent sites. The most well known and important network is International GNSS service (IGS) network. The IGS (2007) is committed to providing the highest quality GNSS data and products. However the new definition of CORS is different from these type of networks. IGS is continuous network but it is not a network operating actively for real-time or near real-time data outputs. The continuous data transmission from the receiver to a Server on which data evaluation is continuously executed differentiate active systems from the others. The accused data is stored by the Server system and analyzed in near real time to provide fast solutions for end users.

The CORS system could be carried out globally, regionally or locally depending on the aim of the application. This means, the type of application determines the dimensions of the whole system including the control center and site. This also influences the properties of CORS receivers and infrastructure capacities. The design of a CORS system should care all these details.

## 2.1. The GNSS

Finding position is a question of people since more a millennium. People define borders after big disasters by creating maps with the help of simple measurement techniques. After invitation of the telescope by Galileo, people manage to discover the earth. Finding the ways and routes was the surviving information for people who travels millions of kilometer around the world.

Today, satellite based systems provides accurate and precise positioning in real time or near real time. Satellite based systems are used in many areas spreads from basic positioning requirements to scientific applications. A tourist, who is trying to find his way and a scientist who tries to analyze the effects of earthquake activities are using the same system. The difference is the level of precision and method of evaluation.

Now, there are three main geocentric systems which are orbiting the earth in different altitudes with best coverage. US GPS (Global Positioning System), Russian GLONASS (Global Satellite Navigation System) and European Galileo (European Satellite Navigation System) are these three systems which provide global solutions.

There are some other existing geostationary satellite systems like Beidou-1 which is Chinese Navigation System. Encyclopedia Astronautica (2007) explains that experimental launch of the first two indigenous Beidou navigation satellites was in 2000. China is developing the system and the new system will be a constellation of 35 satellites, which include 5 geostationary orbit (GEO) satellites and 30 medium Earth orbit (MEO) satellites. It should be noted that this system will not serve for global users even its coverage will be global. For this reason in the concept of Global Navigation Satellite Systems (GNSS) only globally operating GPS, GLONASS and GALILEO are examined.

## 2.2. Concept of GNSS

With the use of GNSS receivers, more data can be collected at a site compared to a single system such as only GPS. Some new signals will be available in the next decade, which makes the GNSS receivers to be ready for these upcoming developments.

L2C and L5 are new signals of GPS that will be fully available in close future. By the end of 2015, GPS will serve full service also for L5 which is the other new signal. With L5 P-code provides better Multipath Performance compared to C/A. Two simultaneous satellites are required to make use of L5 (Landau, 2006). Besides, with the renewal of old satellites and the new ones GLONASS is planned to have 24 satellites in orbit at the end of 2009. Galileo prototype satellite was launched at December 2005.

### 2.2.1. GPS – NAVSTAR Global Positioning Satellite System

Department of Defense of USA is the designer of the system NAVSTAR - GPS Navigation Signal Timing and Ranging Global Positioning System. As it is first and biggest system for positioning it is the most widely used system all over the world. This is because of the coverage range of the system. The support of US government always keeps the system up to date.

There are four generations of the GPS satellite: the Block I, Block II/IIA, Block IIR and Block IIF. With the new satellites the systems is going to be improved against its competitors. GPS system has 2 different types of signals. First group is carrier signals named under L, and information codes. L1 carrier frequency 1575.42 MHz, L2 carrier frequency 1227.60 MHz., C/A Code frequency 1.023 MHz, P Code frequency 10.23 MHz are the signal types of GPS system. By the improvements and renewals in the GPS systems new age signals will be available in close future. The signal properties of GPS system is as follow (Navigation Center, 2007).

- L1 (1575.42 MHz) - Mix of Navigation Message, coarse-acquisition (C/A) code and encrypted precision P(Y) code.
- L2 (1227.60 MHz) - P(Y) code, and a second C/A code on the Block II-R and newer satellites.
- L3 (1381.05 MHz) - Used by the Defense Support Program to signal detection of missile launches, nuclear detonations, and other high-energy infrared events.
- L4 (1841.40 MHz) - Being studied for additional ionospheric correction.
- L5 (1176.45 MHz) - Proposed for use as a civilian safety-of-life (SoL) signal. This frequency falls into an internationally protected range for aeronautical navigation, promising little or no interference under all circumstances. The first Block IIF satellite that would provide this signal is set to be launched in 2008.

The altitude of the satellite orbit is 20,200 km and has 55° inclination (Block I satellites orbited at 63° inclination) (Andrews Space and Technology, 2007).

### 2.2.2. GLONASS – Russian Global Navigation Satellite System

The Russian Global Navigation Satellite System (GLONASS) is a counterpart to the United States Global Positioning System (GPS) and both systems share the same principles in the data transmission and positioning methods. GLONASS is managed for the Russian Federation Government by the Russian Space Forces and the system is operated by the Coordination Scientific Information Center (KNITs) of the Ministry of Defense of the Russian Federation.

The first GLONASS satellites were launched into orbit in 1982. Two Etalon geodetic satellites were also flown in the 19,100 km GLONASS orbit to fully characterize the gravitational field at the planned altitude and inclination. The original plans called for a complete operational system by 1991, but the deployment of the full constellation of satellites was not completed until late 1995 / early 1996. GLONASS was officially declared operational on September 24, 1993 by a decree of the President of the Russian Federation.

There were 12 functioning satellites in 2001. The Russian Space Forces plan to start flight tests of a new GLONASS-M program which was launched before 2004. The new GLONASS-M satellite have better signal characteristics as well as a longer design life (7-8 years instead of the current 3 years). In the future, plans are being developed to transition to a low mass third generation GLONASS-K satellites with a guaranteed lifespan of 10 years.The altitude of the satellite orbit is 19,100 km and has 64.8° inclination (Andrews Space and Technology, 2007).

### 2.2.3. Galileo- European Global Navigation Satellite System

Galileo is the European system of Satellite based navigation that is focusing on the private sector participation. Although it is decelerated as a civilian organization, it is the power against GPS and GLONASS. According to European Commision Directorate General Energy and Transport (2007) GALILEO comprises a constellation of 30 satellites - 27 satellites with 3 operational in- orbit spares – in medium-height circular orbits which is around 24,000 km above the Earth’s surface.

European Commision Directorate General Energy and Transport (2007) indicates that European Geostationary Navigation Overlay Service (EGNOS) is the first step in European satellite navigation. EGNOS provides a civil service and implements a warning of system malfunction (integrity) capability for both the GPS and GLONASS constellations.

Satellite navigation users in Europe today have no alternative other than to take their positions from US GPS or Russian GLONASS satellites. Yet, the military operators of both systems give no guarantee to maintain an uninterrupted service. The European Commission and European Space Agency joined forces to build Galileo, an independent system under civilian control which will be guaranteed to operate at all times. The GIOVE-A satellite is transmitting the first Galileo signals since12 January 2006. GIOVE-A was placed in orbit with altitude 23,260 km. Galileo intend to be a civilian user system, and from the beginning it defines its services in more details (Table 2.1.). So an ordinary user may benefit from the system more than it was as in others. As Galieo is a new program, the documents are based on planned system infrastructure. The frequencies used by the satellites are within the 1.1 GHz to 1.6 GHz band; a range of frequencies particularly well suited for mobile navigation and communication services. With the help of Galileo, the users' benefits from GNSS systems better than today, thanks to the pre determined services of Galileo. Its proposed services and their accuracy are well planned and will be beneficial if it will be successfully launched on time.

Table 2.1. The service groups of Galileo with their accuracy levels

| | **Open Service (OS)** | **Commercial Service (CS)** | | **Public Regulated Service (PRS)** | | **Safety of Life Service (SoL)** |
|---|---|---|---|---|---|---|
| Coverage | Global | Global | Local | Global | Local | Global |
| Accuracy horizontal (h) vertical (v) | h=4m<br>v= 8m<br>(dual frequency)<br>h= 15 m<br>v = 35 m<br>(mono frequency) | < 1m (dual frequency) | <10 cm (locally augmented signals) | h = 6.5 m<br>v = 12 m | 1 m (locally augmented signals) | 4-6 m (dual frequency |
| Availability | 99.8 % | 99.8 % | | 99-99.9 % | | 99.8 % |
| Integrity | No | Value-added service | | Yes | | Yes |

The signal properties of Galileo are summarized by European Commision Directorate General Energy and Transport (2007) as follow:

- L5 (E5a in European filings)- high chip rate, low data rate, pilot tone; Improved reception indoors
- E5b- high chip rate, high data rate, pilot tone, integrity; Fast acquisition
- L5 & E5 can also be used for aviation; Complements GPS, has no common failure modes
- E6- high chip rate restricted access signal & possible 3rd open signal
- E2/L1/E1- Complex signal…Wide Binary Offset Carrier, e.g. (14,2) plus central (2,2); pilot tones, and can be used for aviation; combinations of the signals for open and/or restricted access.

All the satellites transmit at the same frequency, that is, the Galileo signal at L1 is broadcast at 1575.42 MHz from any satellite. To allow the receivers to distinguish which satellites the signals are coming from and to allow the receivers to measure the time it took the signal to travel from the satellite to the receiver (the basic measurements used for position determination), a code is added to the signal. This code is different for each satellite. It will use a constellation of 30 satellites in medium orbit, which is 23000 km altitude, linked to a network of terrestrial command stations and centers required for the provision of services (European Commision Directorate General Energy and Transport, 2007).

The open services are realized by using the signals at L1, E5a and E5b, whether data or pilot. Several combinations are also possible, such as a dual frequency service based on using L1 an E5a (for best ionospheric error cancellation) or single frequency services (at L1, E5a, E5b or E5a and E5b together) in which case the ionospheric error is removed using a model, and even triple frequency services using all the signal together (L1, E5a and E5b), which can be exploited for very precise applications.

The safety of life services are based on the measurements obtained from the open signal and use the integrity data carried in special messages designated for this purposed within the open signals. The safety of life service is like a data channel within the open signals.

The Commercial service is realized with two additional signals in the 1278.75 MHz band plus also the capability to include commercial data within the open signals.

The Public Regulated Service is realized by two signals in the 1575.42 MHz and the 1278.75 MHz band. The signals are encrypted allowing the implementation of an effective access control scheme (European Space Agency, 2007).

# 3. COMPONENTS OF A CORS SYSTEM

The implementation of a Continuously Operating GNSS Reference Station system is different for Real Time Kinematic (RTK) based applications, structural monitoring applications, and crustal monitoring applications although the general content remains the same. In this section the equipments that will be used for all type of CORS systems will be defined without any classification. It will be classified it the Network Design sections of this study.

There are three main parts in CORS systems which are Sites, Control Centers and end users. The end users are only deals with the results of the system. In this study sites and control center equipments will be explained. Data communication issues will be explained in the content of Control Center even though there should be similar communication devices also in Sites. Another classification can be done for the processes in a CORS system as follows:

- Collection of the GNSS data at sites.
- Transmission of the CORS data to the Server,
- Production of Correction and File products
- Transmission of the final products to the end user

Leica-Geosystems AG (2006a) demonstrates the data flow of a CORS system as shown in Figure 3.1.

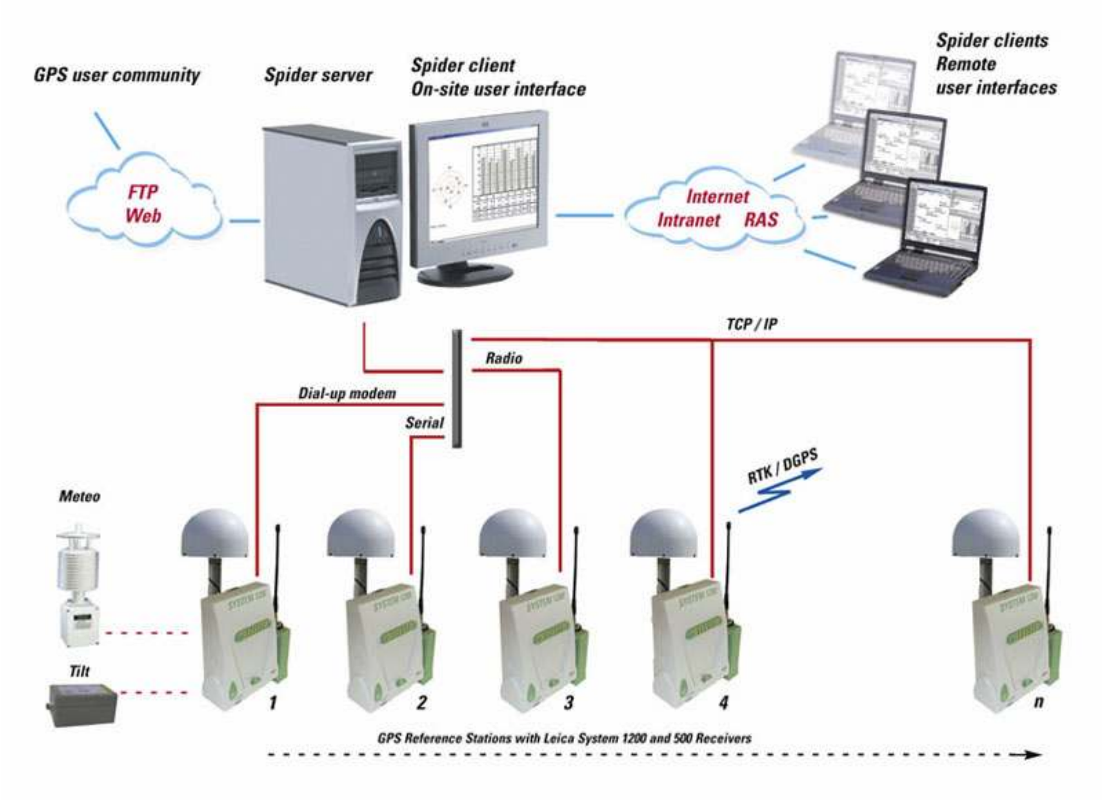


Figure 3.1. Data flow architecture of CORS systems

## 3.1. Site Equipments

Sites are the points where CORS receiver systems are mounted. At sites together with GNSS receivers, antennas, data storage units, communication channels, monumentation, antenna mounts and tribrachs, cabinets, lightning protections, surge arrestors, power systems and remote control modules, cables, and other data collectors are used.

### 3.1.1. GNSS Receiver

CORS systems can provide raw data, The Receiver Independent Exchange Format (RINEX) data, single site or network Real Time Kinematic (RTK) corrections. For RTK applications, the important point is the real time transmission of the raw data to the server.

Then the server could receive data from several sites and calculate network corrections for the field users. So, the equipments should support various data transmission channels simultaneously. Forexample, a receiver could stream data to a server over internet line, while transmitting single site corrections over radio modems.

Receiver should have fast acquisition capacity to reduce the time to fix as the GNSS data is very critical for real time applications. Besides, the antenna and the receiver should have a best multipath mitigation functions for the sites which are in populated areas. As most of the properties are common for GNSS CORS receiver, In this study the most preferred types are used to summaries the functionalities of CORS receivers. The used examples are from Leica-Geosystems AG (2007a), Trimble (2007), and Topcon (2007) of which receivers are shown in Figure 3.2.

Leica GRX1200GGPro | Leica GMX902 (Monitoring Receiver) | Trimble NetR5 | Topcon NetG3

Figure 3.2. CORS receivers of different brand

GPS receivers are commonly tracking 12 L1 and 12 L2 channels of GPS satellites. With full carrier phase a Receiver should track L1, L2 signals and C/A, P codes from GPS and GLONASS receivers independently. Besides, the receiver should be upgradeable or adaptable to track L2C and L5 future signals, and GALILEO “Open Service” (E1, E5) signals (Leica-Geosystems AG, 2007a). Today it is known that some receivers track test signals of GALILEO (Topcon, 2007) However, it should be noted that European Space Policy could change the frequency and the signal properties). True P code tracking can be performed only when Anti-spoofing is de-activated (A/S OFF). Anti-Spoofing is currently activated since more than 10 years (A/S ON) and US policy is not likely to change Anti-Spoofing.

Most of the receivers are acting like a computers and it is possible to configure the receiver to execute several tasks simultaneously. A receiver can convert raw data to Receiver Independent Exchange Format (RINEX) and send these files to an FTP (File Transfer Protocol) destination folder while the receiver is transmitting RTK data over an NTRIP (Networked Transport of RTCM via Internet Protocol). The details of communication protocols will be explained briefly in the Communication Channels part of this study.

Data logging interval of a receiver determines the application type of a receiver. A receiver with 1 Hz is enough for an RTK CORS station. However, for land slide monitoring or high rise building monitoring it is necessary to have a data interval 20 Hz which means 20 sets of GNSS data in one second. When more data collected from the site receivers, more precise information achieved for slowly moving objects.

A CORS receiver could be controlled over RS232 interface, TCP/IP Protocol, telephone line 56K modems, (Networked Transport of RTCM via Internet Protocol) NTRIP protocol, or similar property various communication channels. RTCM is the abbreviation for Radio Technical Commission for Maritime Services that provides also the standards for correction messages. Using a Controller for on site fast installation could be a good feature. However for new age receivers it is best opportunity to connect a laptop for fast on site maintenances and controls. Using a laptop provides better functionalities than a controller, because one can use various programs on a laptop to control a receiver. Besides the operator of the system can do most of the controls over these communication channels from a Control Center remotely without any requirement of a controller (Leica-Geosystems AG, 2007a).

The last but not the least, the power consumption of a receiver determines the dimensions of power system which will be used together with the receiver. As a CORS station should operate continuously with its stand alone capabilities, it should use less power to ensure long operation in the case of power cuts. Some receivers have internal batteries which increases the power consumption of the receiver. This is very critical for a site which is away from direct power sources. A receiver might need to work with a 12V or 9 V battery systems which is integrated to a solar panel. At that time the power of the batteries should run the system at least 9-12 hours. The power consumption of the system should be calculated for the receiver and all site accessories separately. For applications like crustal deformation which might not need continuous data streaming to a server, powering the communication devices continuously might not be necessary.

For some applications which do not require data logging on the receiver and for the applications where continuously streaming of the data to a server over a wired or wireless network is possible, low cost and easy to mount receivers can be used. Actually the engine of the receiver is not different from the others. However, for some applications where only little functionality is required, these types of low cost receivers can be used efficiently. Today, GMX900 from Leica Geosystems AG (2006c) is unique solutions for monitoring applications with its small design and low power consumption. It provides basic to fulfill the main requirements of monitoring applications. The thing that GMX can not handle is data logging on a data storage unit like Compact Flash or similar memory card. For this reason, GMX is used in applications where it can be connected to a Server. With the dimensions 16.7 cm x 12.3 cm x 4.0 cm GMX900 is the smallest CORS receiver. It's power consumption is very little about 2.4 W while operating. Compared to the other this value is at least 60% less than the other receivers. Nowadays Leica-Geosystems AG (2007b) has promoted a new type of only L1 frequency monitoring CORS receivers on which an antenna integrated. By this way one box can full fill the requirements of a site which does not need more functionality. This receiver is specific for monitoring applications like high rise buildings or dam monitoring. This all in one smart receiver can provide fast setup with less space requirement.

### 3.1.2. Antennas

Although a receiver has full functionality to track all channels of the GNSS systems, the availability of this function is related to the properties of the antenna. Even a receiver has the ability to track GLONASS or L5 signal, with an antenna which don't have proper band width, it is not possible to track this signals.

Accuracy of a receiver is mostly related with the type of the antenna as the design of the antenna reduces errors like multipath. Commonly used antenna type is Dorne-Margolin design Chore Ring Antenna. There are some antenna types like Trimble (2007) Zephyr. Specific antenna types also have specific bell type (dome) protectors. Types of antennas and protectors are shown in Figure 3.3.

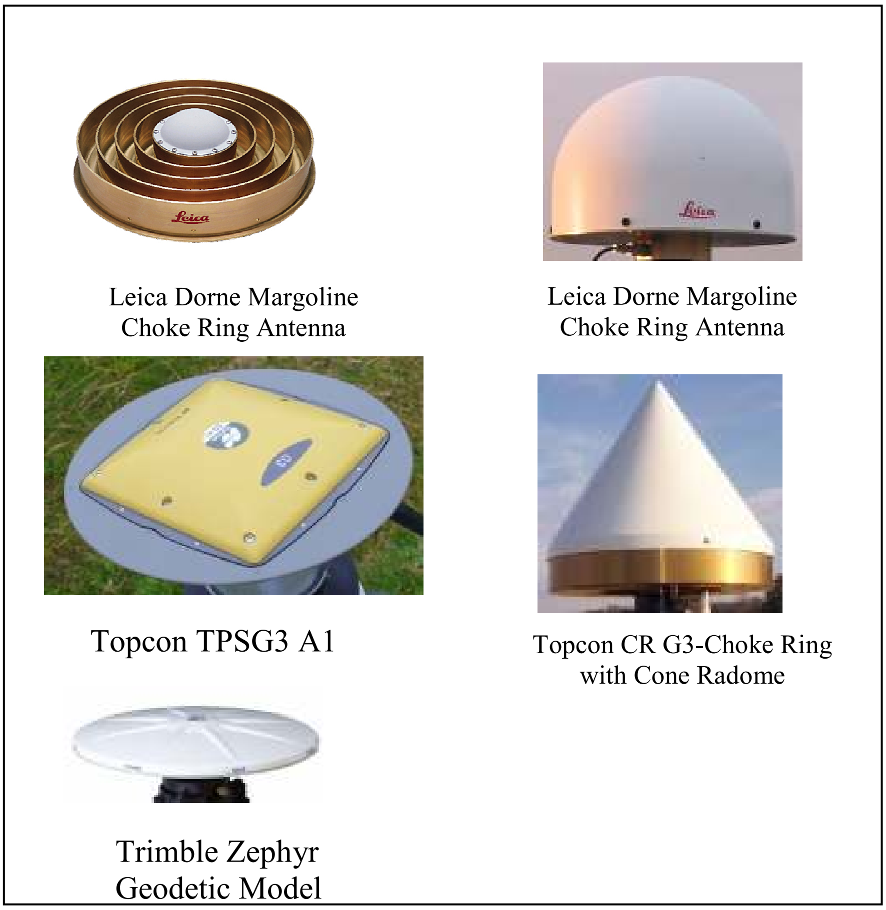


Figure 3.3. Types of antennas and dome protectors

The Antenna types used in CORS applications should complies with International GNSS Service (IGS) standards. IGS publishes the relative phase center values with specific names of the Antennas National Geodetic Survey Office (2007) publishes the antenna relative phase center values for different brands' different antenna types with and without dome. Besides the phase center is defined with drawings in order to help precise measurement of the height from the pillar to the antenna phase center (Figure 3.4.).

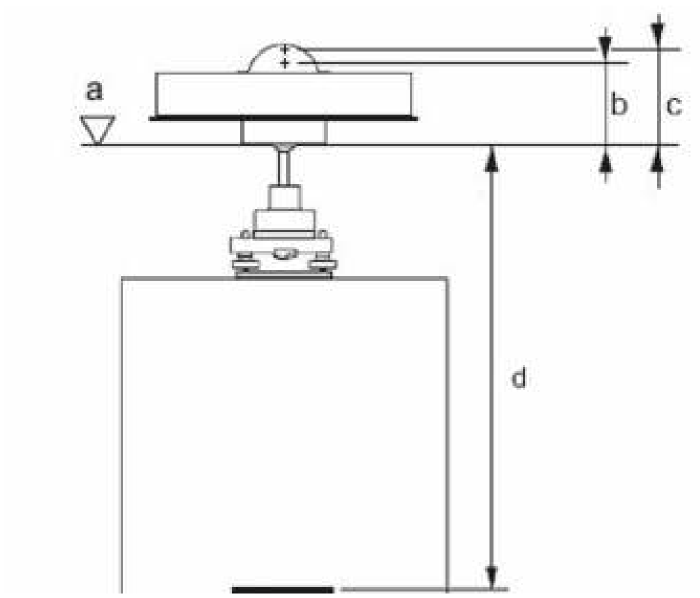


Figure 3.4. Height measurement scheme of a Choke Ring Antenna

GEO++ (2006) is the company that provides special calibrations rather than the absolute calibrations. For this purpose special bases and robots are dedicated for calibration. The calibration provides absolute offsets and absolute Phase Center Variation (PCV). Besides, special robots simulate the satellite inclinations with respect to the antenna.

### 3.1.3. Data Storage Units

The receivers of CORS system should have a storage unit which is sufficient for a limited time interval as the CORS system has full capacity to transmit the data to the server on which networking software is running.

For RTK applications it is an obligation to transmit reference station data in real time as the corrections need to be calculated simultaneously. While the Server is running, it can automatically download and delete the files in the receiver. Data storage, which is sufficient for 1 week data logging, is enough for RTK applications. It is mostly related to the data logging interval. Generally data with 10 second epoch interval is sufficient for RTK applications.

New age receivers have capability to integrate removable storage devices like Compact Flash memory cards or USB storage devices. It should be noted that a CORS station for real time applications must stream the tracked data to the Server in a time interval like 1second. This functionality minimizes the requirement of data logging and very heavy data storage units at the sites. Besides, automatic downloading of the data on the memory card or automatic FTP push functionality of a receiver provides free data space at the site. For example 1 GB data capacity is sufficient for 1152 hours GPS L1 + L2 data logging at 1s rate 17600h GPS L1+L2 data logging at 15s rate (Leica-Geosystems AG, 2007a). A removable data storage unit Compact Flash Card is shown in Figure 3.5.


Figure 3.5. A compact flash card

The receiver which has no data logging capacity there should be some other data storage units. For old receivers there had to be a site PC to collect the data. For site PC there are some industrial type computers that can operate with in the range 0 to 60 $^{o}$C. These are named as Biscuit PC. Figure 3.6., shows the box and a Central Processing Unit (CPU) of a Biscuit PC from Advantec (2006). This site computer is not a server. It is a computer of which mission is storing the data like a CF card on a new age receiver.

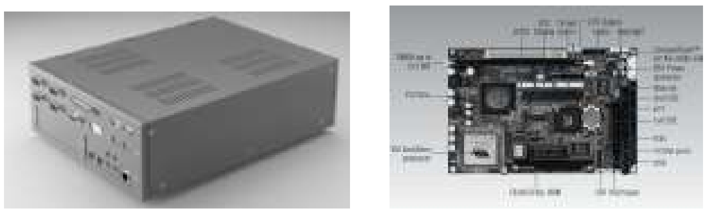

Figure 3.6. MBPC 400 Micro Biscuit PC and its CPU

Serial Data Recorders fulfills the onsite PC requirement for the receivers that has limited record capacity. The connecting with the device is over Serial cable and it can be configured for applications like data downloading issues. Accumen Instruments Corporation (2006) is one of the companies who provides a type of serial recorder that is used with GPS applications (Figure 3.7.).

Figure 3.7. A type of serial data recorder

Some receivers also have internal memory which is not removable. Generally, internal memory is not an indispensable property for CORS systems, as the internal memory and external data storage unit like CF card has the same functions. Internal memory increases the power consumption of a receiver. Power is more critical than a 128 Mb data storage space at a CORS station which is very critical for the calculation of a network solution.

### 3.1.4. Communication Channels

Until recently, real-time CORS applications had required a PC at the site to load data and converts serial data to IP (Internet Protocol) Standard. Now new age CORS receivers have integrating internet technology. This provides the server users not only collecting data but controlling the receivers over a web interface. Now it is possible to use many type of communication channels to establish connection between the receiver and the server. The communication can be establish over the site PC by direct connection to the station, IP based applications, Global System for Mobile (GSM), General Packet Radio Service (GPRS), satellite based networks, and new age Troya like secured data links. As Troya is very expensive system, today it is not logical to use in CORS applications.

As mentioned before it was an obligation to use a PC at the site for the lack of storage unit and communication channels integrated to the CORS receiver. Today, Site computers are rarely used only with old type of receivers or with receivers that has limited functionalities. The system is controlling over this PC and data transfer form the site to the server is executed by this site computer. Using a site computer the connection between the computer and the receiver is established over RS232 Serial port of the receiver (Figure 3.8.). It might be useful only when a single receiver as Data Terminal equipment (DTE) is controlled by a server computer Communication Equipment (DCE) at the same location of the site.

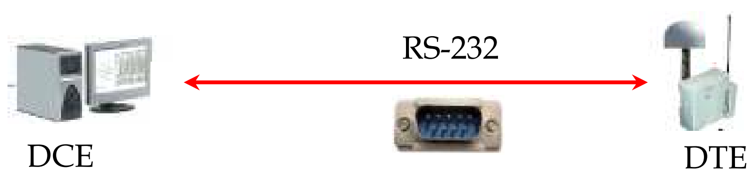


Figure 3.8. Direct serial connection between DTE and DCE

Using a telephone line is an obligation at the time when internet infrastructure was not widely used. Telephone lines are more stabilized compared to the internet lines. So, for long distances it is better to use telephone lines instead of internet cables. Yet, sometimes it might not be possible to find internet access to the receiver even it is possible to do internet cabling to the site. This is mostly because of the restrictions on the internet lines. At similar situations, 56K dial-up modems are better and best way to find direct connection from the site to the server. However, it should be noted that if no dedicated leased lines are available, data transfer could be very expensive if continuous data transfer with high frequencies is required.

IP (Internet Protocol) based communication like Local Area Network (LAN), Wide Area Network (WAN), Internet, Intranet, and Radio IP is used to transfer CORS site data to the server and to control receiver. Compared to the dial-up modem connection over telephone lines, using internet protocol is cheaper.

Asymmetric Digital Subscriber Line (ADSL) is a form of Digital Subscription Line, a data communications technology that enables faster data transmission over copper telephone lines than a conventional voice band modem can provide. It does this by utilizing frequencies that are not used by a voice telephone call. By using a splitter or micro filters this allows a single telephone connection to be used for both ADSL service and voice calls at the same time. As phone lines are so varied in quality and weren't initially provisioned with ADSL in mind it can generally only be used over short distances.

In TCP/IP networks, a port is something like a gate that defines endpoints to a logical connection. There are so specific port numbers that have already assigned for specific applications and programs. It has been defined by IANA (2006), and these are known as well-known ports (specified in RFC 1700). Port numbers range from 0 to 65536, but only ports numbers 0 to 1024 are reserved for privileged services and designated as well-known ports. Porting is something like addressing. The Operator can connect to a modem over a static IP dedicated by the telecom companies. Static IP addresses can be searched over the web pages “http://www.whatismyip.com” and “http://www.whatismyip.org”.

IP defines the address of the data. It is better to explain the process by an addressing example. Here Static IP 85.105.0.0 is the open address of the building such as Kandilli Observatory and Research Institute, Geodesy Department, and port 5001 defines the number of the room 5001. The Internal address of the device 10.0.0.20 is used for in side searches, such as the library where students are staying. A postman should only know the address of the building and the room number. However, internally it is known as library room. It is needed to attach the port number to internal IP address in order to forward the commands coming from out of the network. This property is known as port forwarding.

ADSL modems convert the ADSL data from the telephone line to the format which could be understood by devices like CORS receivers. Different brands provide different type of ADSL modems. Here the critical point which is used to select the right modem is the minimum requirement of maintenance as it might not be possible to go to site frequently.

Serial to IP converter are used with advanced receivers that have capability to integrate different type of communication devices but suffer from internet port. There are some specific modems like equipments that converts serial data to IP data and send it to the server (Coolgear, 2007).

For some applications it might not be possible to use wired connection. Some providers have special open air wireless outdoor bridge that can provide internet and IP for long distances (Airties, 2007). Similar to outdoor bridges there are wireless-G access point devices that transfers the internet and IP to another point. The range is not longer than 3km with standard antenna. Attaching an external antenna the range could be extended to 30km. (Linksys, 2007). Figure 3.9., indicates the wireless connection schema between the GNSS receiver and Controller remote PC over internet connection. These wireless devices are optimum solutions for short baseline networks like monitoring applications.

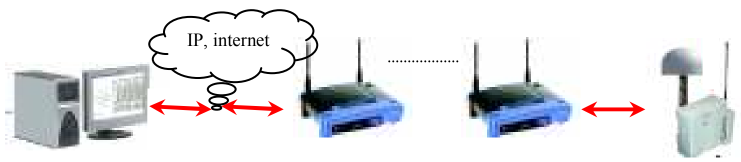


Figure 3.9. Setup schema of a wireless connection

Sometimes, transferring data over internet cables is not possible. This is because of the characteristics of the data protocol and internet cables. Besides this type of cables easily affected from weather conditions, so it is better logical to transfer the internet data over telephone lines without missing any IP protocol. There are some VDSL devices (Very High bit Digital Subscriber) that provide transferring Internet and IP data over telephone lines.

If it is not possible to use cable solutions at the site than mobile phone modems can be used to create link between the server and receiver. Global System for Mobile (GSM) is a type of circuit switch data and only one connection could be established between two sites. This provides continuity of connection. With GSM network system separate frequencies is dedicated for each cell. "Handover" function provides the continuity of the connection most when a device is moving from one cell to the other one (Avci, 2002). It should be noted that this function is import when RTK data is distributed over CORS sites to rover GNSS receivers.. General Packet Radio Service (GPRS), provides the transfer of data within 28.8 and 115 kilo bit speed over GSM infrastructure. The connection with the receiver is established over GSM/GPRS modems. Over GPRS it is possible to use internet infrastructure. In GSM connection the cost is over the connection time. Even in the case of no data transfer, if a server remains connected the user should pay for this time of connection. However GPRS connection cost is calculated over the amount of transferred data. So the user does not need to pay if no connection will be established. GPRS system providers offer some packages to minimize the cost (Avci, 2002).

Networked Transport of RTCM via Internet Protocol (NTRIP) is the name of the protocol that is mostly used to transmit correction data over internet HTTP protocol. It is accepted as an RTCM standard since 2004. NTRIP was designed by Federal Agency for Cartography and Geodesy Germany (Bundesamt für Kartographie und Geodäsie), to transfer GNSS data over internet protocol. NTRIP has Clients, Servers and Casters components. NtripServers are forwarding data from Sources. NtripCaster is the broadcasting and meta-data maintenance system component, while NtripClients is the name of the programs which are receiving data from desired sources. NTRIP provides various functionalities for reference station software to transmit correction data. It allows simultaneous PC, Laptop, PDA, or receiver connections to a broadcasting host (RTCM, 2007) (IFAG, 2007). The correction data can be sending to different users over the same IP port. The only changing the mount points of the users. It is possible to provide a password protection fort he users. This allows control of the RTK users who are using the CORS system. Different formats like RTCM 2.x, RTCM 3.0, raw data are supported by the protocol. NTRIP supports wireless access over IP Networks like GPRS and EDGE (Weber *et al.,* 2005). NTRIP radio program is a listener program acting like a NTRIP Client. The host name could be a web page or an IP address and the port number is the number where the correction data is forwarded by the NTRIP Server. The data flow is demonstrated in Figure 3.10.

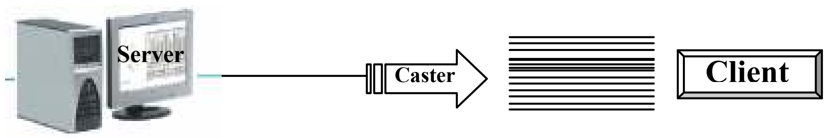


Figure 3.10. The data flow over NTRIP caster

Satellite systems are today very popular to transmit data from sites to Control Center. Mostly for applications it is not possible to provide communication lines. Earthquake studies that are based on Permanent Geophysical sensors use satellite systems to transfer the data from sites to control centers. Figure 3.10., demonstrates the data flow over satellite based communication channels (Dexar, 2006).

Radio signals are widely used by most of the applications as it is free of charge if the allowed band widths are used. The main problem is that the allowed band width is not sufficient for long distances. More on that, radio signal could not penetrate from hard obstructs. So it is hard to use radio links in urban areas. For reference station connections if multiple stations are used for applications like monitoring, than the channel of the modem should be changed. Master Stations with a single frequency have been proposed by Gunduz (2007) in order to minimize the frequency requirement. In Turkey it might not be possible to have multiple frequencies, mostly at the sites like Bridges on Bosphorus. Without master station each sensor should be attached to the server with an other dedicated radio modem. Each will have a dedicated frequency. In Figure 3.11., which is the data flow diagram with and without Master station concept, red indicated the sensor site and greens indicate controler server site.


Figure 3.11. Data flow diagram with and without Master Station

For some applications like RTK transmission a central station can transmit data for long distances over slave radio modems. It will be mentioned in next sections that some type of RTK network corrections can use radio link infrastructure. The only drawback of radio link is the coverage area. To maximize the range, repeaters and slave radio modems are used. The range of the radio link could be extended to wide areas by using repeaters and slaves as shown in Figure 3.12. (SATEL Oy, 2006).

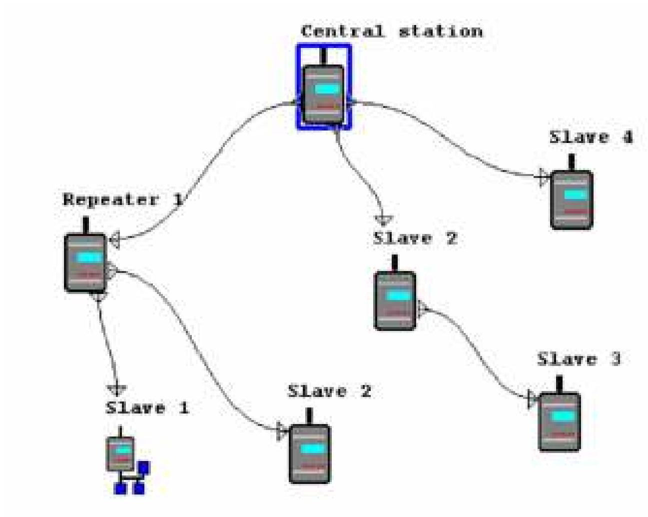


Figure 3.12. Diagram of a radio coverage extension

For RTK systems the communication channels must be separate into two classes. First one is the channel between the receiver and the Control center server. The other is the channel between Control center server and the rover.

For communication channels between receiver and control center the primary issue is providing a secured data link which is not interrupted easily. Leased telephone lines are commonly preferred for this purpose; however the cost of this infrastructure could be higher if no prior infrastructure is established.  Today ADSL lines and internet is very common for RTK systems. At that point the important thing is to provide a separate line from the other internet users at the site. For the lack of internet infrastructure, than GSM/GPRS lines could be preferred. For the points where both is available than ADSL lines and GSM/GPRS lines could backup each other. GSM is more expensive than GPRS. However it provides more secured data link. The communication channel between server and rover could be radio link, internet connection over GPRS modem and GSM connection. The radio modems could only be used either with single reference stations or with Master Auxiliary Concept (MAC) as MAC do not need to know the position of the rover. However with other correction formats it is not possible to provide one way data link as the Control Center networking program need to know the position of the rover.

### 3.1.5 Monumentation

The monument is the structure on which antenna of the CORS station is mounted. The monument should represent the movements of the structure or the earth's crust. In order to achieve this goal special types should be used which are designed for each unique site. The monument is a lasting, many times colossal, structure which serves as foundation for the marker. This monument can be in the form of a concrete pier, steel construction or rock outcrop, which is designed as to best represent the earth's crust. The design of the monument could be changed regarding the ground and site properties. Prior to the installation design stage of the pillars probing is required to understand the soil features. This is needed to be analyzed by the geologists and geophysicists (Anderson *et al.*, 2000).

Concrete Pillars are the widely preferred type among other monuments. While structuring concrete pillars the first thing is analyzing the soil or rock type and the moisture rate in the soil. The pillar could be designed after evaluation of this data. Steps of Monumentation can be summarised as follow:

- For soft soils it is required to dig a deep hole in order to maintain stability of the pillar. The pillar should reflect the movements of the ground. So it should be attached to the main body, below ground portion of the crust structure. The depth should be at least 2,5 meters, if the soil is soft. The depth could be change regarding the level of softness of the ground. Muray (2000) defines the sample drilling dimensions as shown in Figure 3.13. Figure 3.14., shows the machine used for such a task (Hoar, 2000).

- The hole width should be larger than the width of the body of the pillar which is out of the soil. The optimum width for the hole is about 60 cm and the width for concrete upper part is 30 cm.
- The upper and lower part should be concreted from a unique body.
- In order to mitigate signal multipath, the diameter of the above-surface structure was constructed with a diameter less than the dimensions of the antenna.
- Reinforcing rods with 5/8 inch dimensions are preferred. The length should be identical with the depth of the pillar.
- The concrete should be C25 concrete or equivalent quality one to provide long time stability. Table 3.1., lists the stability of C class concretes according to TS 500 standard from the Chamber of Electric Engineers (2006).
- In order to protect the equipments from lightning the pillar should also be grounded.
- Besides it should be noted that carrying the concrete from the factory to the site is also requires special care as the quality of the concrete is changing if it not mixed properly.

Table 3.1. Concrete classes and stabilities

| Classes | Characteristic Pressure Stabilities, fck MPa | Equivalant cubic (150 mm) Pressure sability MPa | Characteristic Orbital drift stability, fctk MPa | Elasticity Module for 28 days $E_c$ MPa |
|---|---|---|---|---|
| C 16 | 16 | 20 | 1,4 | 27000 |
| C 18 | 18 | 22 | 1,5 | 27500 |
| C 20 | 20 | 25 | 1,6 | 28000 |
| C 25 | 25 | 30 | 1,8 | 30000 |
| C 30 | 30 | 37 | 1,9 | 32000 |
| C 35 | 35 | 45 | 2,1 | 33000 |
| C 40 | 40 | 50 | 2,2 | 34000 |
| C 45 | 45 | 55 | 2,3 | 36000 |
| C 50 | 50 | 60 | 2,5 | 37000 |

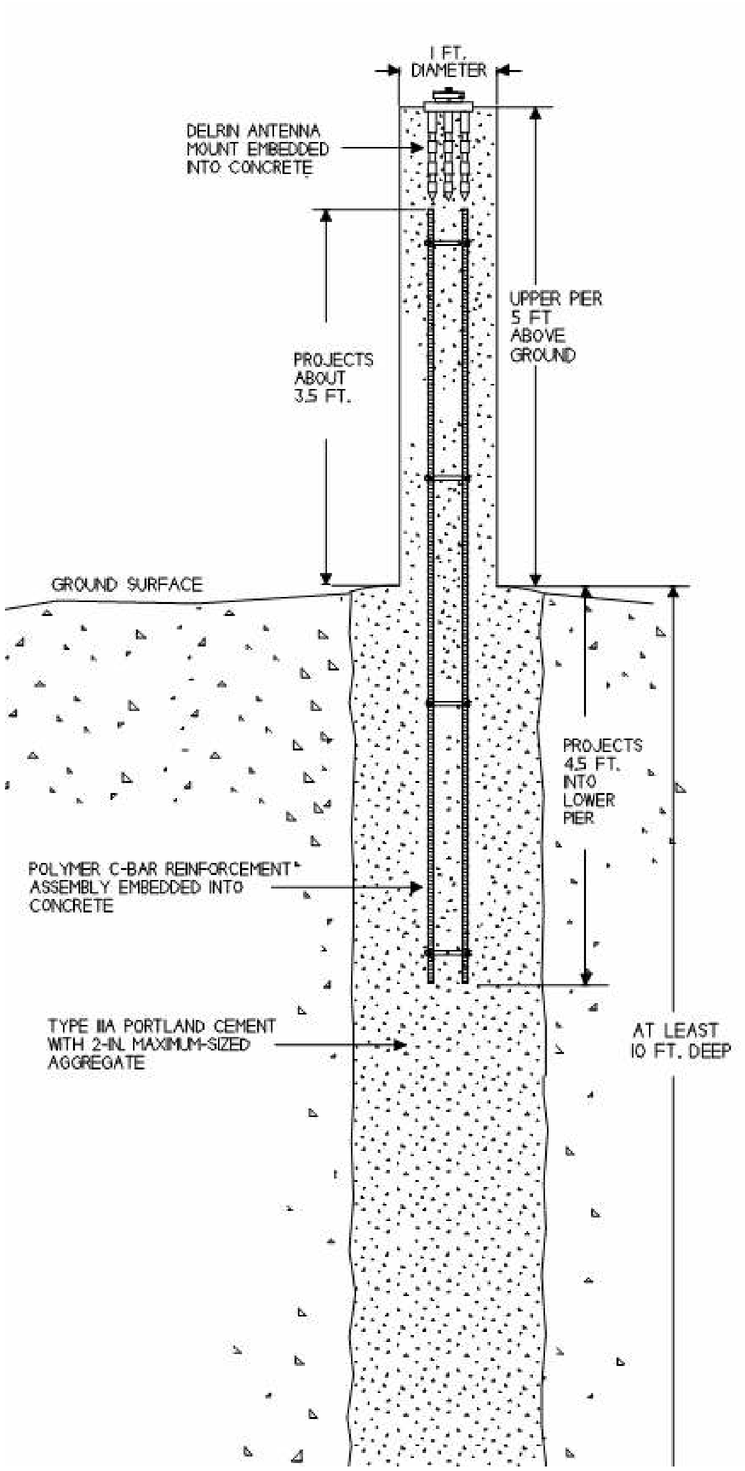


Figure 3.13. The sample drawing of a concrete pillar for soft ground (Muray, 2000)


Figure 3.14. Drilling the hole for soft ground concrete pillars

Stell pillar are commanly used for fully rocky ground where it is not possible to dig a hole. At those type of ground the pillar is fixed to the ground with fixing rods (Schmidt *et al*., 2000).

Steps of monumentation can be summarised as follows:

- First the surface of the rock should be flatened to provide maksimum surface interaction with the pillar.
- Holes are drilled to mount fixing rods of the pillar. The depth of the rod holes could be about 1,5m with a diameter of 5 cm.
- These stainless steel rods are grouted by a conductive, non-shrinking grout.
- The pillar is mounted on the rods and fixed with nuts. This step should care aproximate leveling of the pillar.
- To remove the empty space epoxy is applied between the base plate and steel plate.
- Besides, it is better to appy epoxy on the fixing nuts and other parts of the pillar to maintain long time stability of the pillar.
- Grounding should be carried out similar to the conrete pillars'.
- The hole inside the pillar steel is filled with dry sand. Dry sand provides optimal thermal moderation.

Figure 3.15. Sample of Steel Pillar for fully rocky surfaces

Similar type of pillars could be used for roof monumentations for RTK based applications. The dimentions and the metarial types need to be re engineered for each specific application.

Steel Bar Gorund stations and deep drilled braced monuments are used for places where high accuracy and long term use is required. According to UNAVCO Inc. (2007) the deeply anchored drill braced geodetic monument is perfect for the non-bedrock sites like alluvium and at sites where very stable monument requirements. It is in the form of a tripod, each leg extending into the ground at about 15 meters and welded at the top with gusset reinforcements. If site access is an issue, the Short Drilled Braced Monument is the next best alternative to this type. Figure 3.16. and Figure 3.17. show the drilling procedures.

Figure 3.16. Drilling procedures

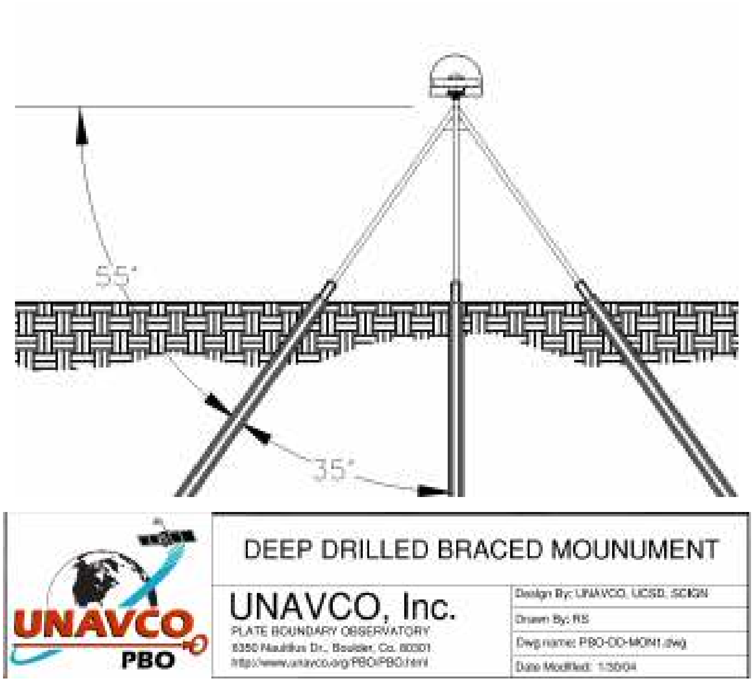


Figure 3.17. Monumentation technical drawing

Steps of monumentation can be summarised as follows:

- A vertical hole is drilled with a crawler-type drill rig.
- The positions of the legs are marked by means of a compass with equivalant angles.
- The angled holes are drilled.
- PVC cases are used to to isolate the monument from surface soil displacement.
- Steel pipe is inserted inside the casing. The steel pipes which form the legs of the monument are inserted inside the holes.
- The legs are monumented to create a tripod like shape.
- The legs are cemented in place to prevent movement.

Pipe like monuments are the monuments on the roof which are generally used for RTK based networks densification sites or structural monitoring rather than an application like crustal monitoring. The design of the pipe is depending on the required height of the pillar. So it is not easy to give specific samples for pipe or mast like monuments. If roof is used for RTK based application than the structure of the building should be suitable. Figure 3.18., shows roof monuments (Anderson *et al.*, 2000).

For teras roofs a pillar like steel bars could be used. The dimentions of the mast is depending on the obsturtions that may block the signals. The mast should be higher than the obstructions. If the steel bar is very high than, wind or heat may cause the steel bar to slope.

Figure 3.18. Texas department of  transportation

It is necessary to remind again that special applications requires special designs. The mentioned types are only samples that have been used by several applications around the world. This can only give comman idea about how a constrution of a pillar or mast could be, but no strict obligations could be provided from these data. In the Steel Pillar section instructions are given for ground applications. The only changing thing is the dimentions of the hole, as achrore rodes with 20 cm length could be enough for roof monuments. The last but not the least, the steel pillars should be anchored to the concrete of the structure. For some applications like structural monitoring smaller types of concrete pillars could also be used for the roofs.

### 3.1.6. Antenna Mount and Tribrach

According to Murray (2000) the antenna mount should minimize the amount of metal near the antenna that may cause radiometric interference. It is noted that the metallic parts below the antenna impact on the signal environment. For this reason a special type of material named Delrin is proposed by Murray as shown in Figure 3.19. The legs and the plate of the mount are made up of Delrin polymer. The only part metallic is the standard tribrach which is used to orient the antenna to the north. As the amount of metal is very small the impact on the interference is minimal. During monumentation the mount is integrated into the wet concrete (Anderson *et al.*, 2000, Hoar, 2000).

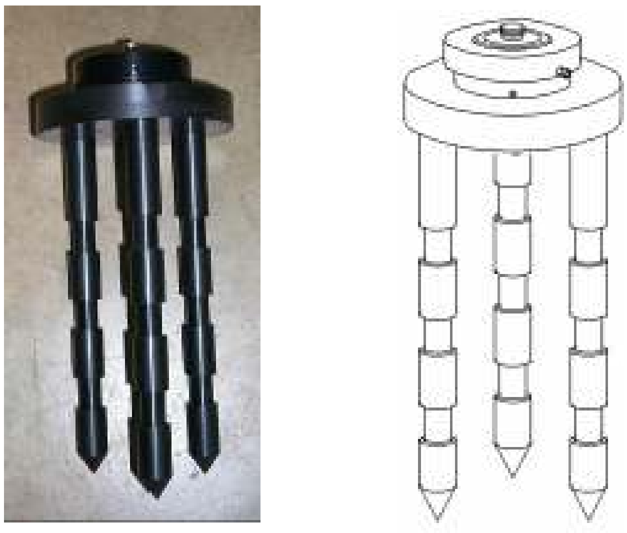

Figure 3.19. Delrin antenna mount

The mount above is serving as a tribrach as the upper part also has tribrach functionalities like orienting to the north. Leveling should be carried during establishment of the concrete when it is wet before the concrete is toughened.

If it is not possible to provide a similar type of mount then it would be a basic mount with 5/8 inch screw (Avci, 2006). Tribrach is required to mount and leveling the antenna. The mount could have a stable 5/8 inch screw or a one that could be removed from its hole. This functionality is primarily used for protection of the screw for campaign based station sites. This function provides to orient the tribrach to the north as the rotation of the lower screw helps to orient the tribrach on it. Figure 3.20., shows the side view, Figure 3.21., shows the top view of a tribrach mount, and Figure 3.22., shows the drawing of tribrach.

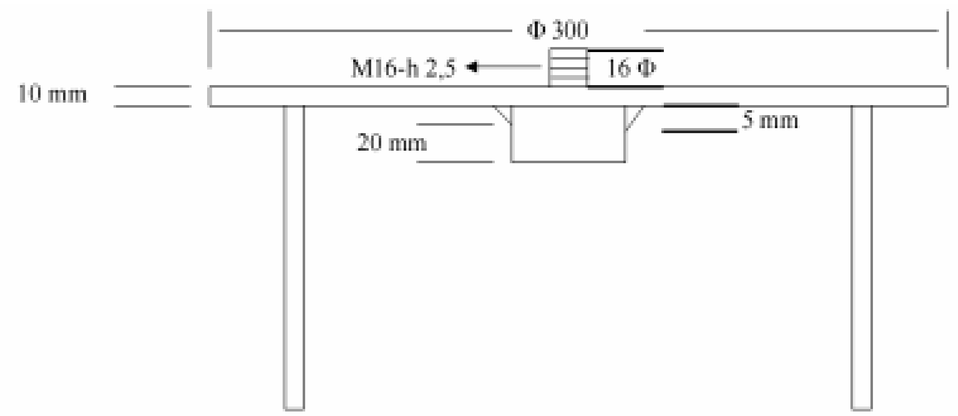


Figure 3.20. Tribrach mount side view

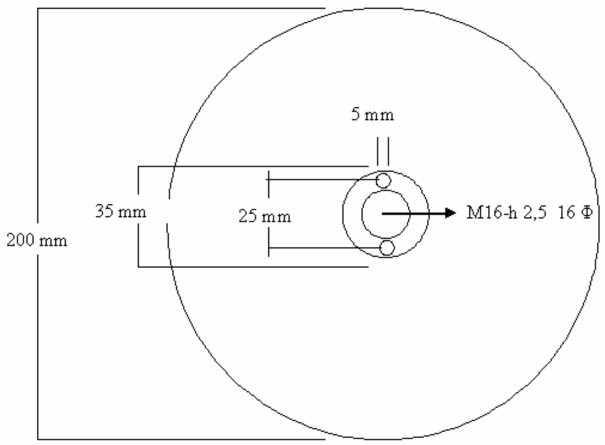


Figure 3.21. Tribrach mount top view

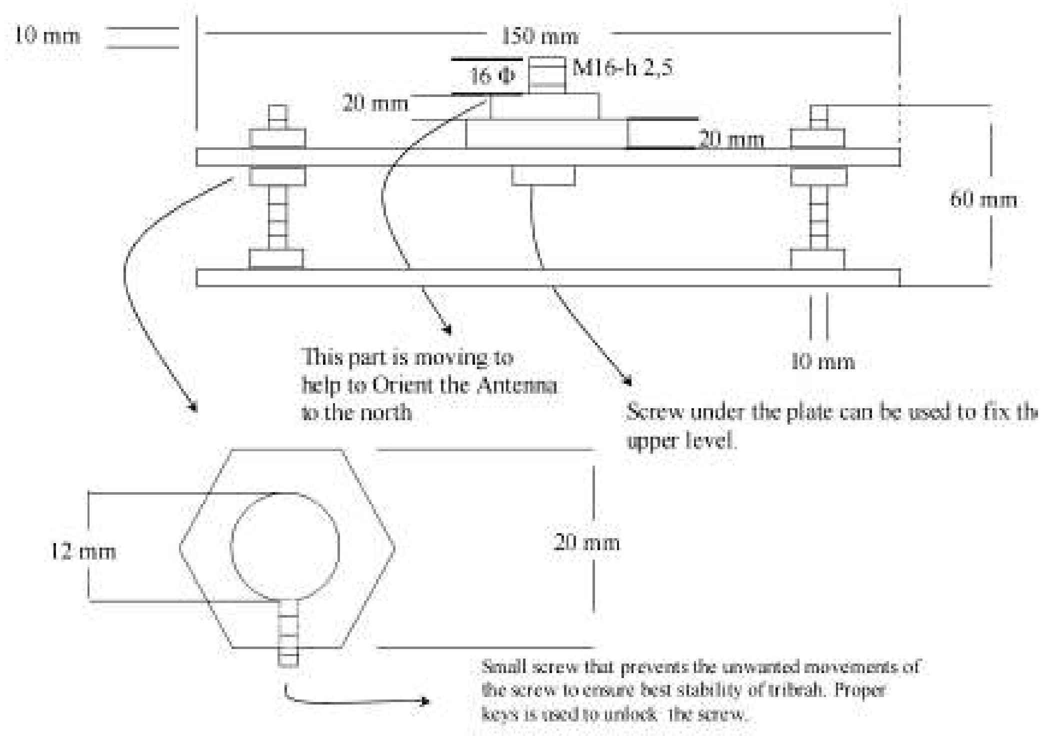


Figure 3.22. Tribrach mount technical drawing

The design of the basic tribrach should consider the functionalities like stability, orienting, and leveling capabilities. The upper level is mounted on the plate part with a screw. This will help to orient the antenna to the north. Screws on the tribrach could have special locks that prevent the tribrach from unwanted movements.

Monumentation for RTK Networking should be considered in two steps. First group is datum transformation points and the other group is the stations with best densification for RTK CORS networks. It is not logical for CORS networks to provide stations all on the ground, regarding the budget requirement for monumentation. However, points that is used to define datum transformation and monitor the velocities of the network should be mounted on the ground with best stability that fully reflect the crusts characteristics. Main reason is that it is not possible to provide best satellite visibility for ground stations close to urban areas. According to the global experiences, the corrections for RTK systems models are acting better for the areas close to the sites. Regarding the user groups distribution, most of the CORS users are working in urban areas rather than rural area. So it is better to install most sites close to urban areas. However, it is not easy to find suitable ground points for monumentation that fulfill the criteria like best satellite visibility and minimum multipath.

For monuments on the ground concrete pillars are mostly preferred. The details of installation have been given in Section 3.1.5. Among other types concrete pillars are preferred because of cost and simple installation procedures compared to the other types like deep drill structures. Deep drill monumentation is very suitable for very soft grounds. It is more stable to use deep drill monuments for soft grounds.

Pipe like monuments are mostly preferred for densification sites for RTK CORS networks and for monitoring purpose application. As mentioned before it might not be possible to provide suitable coverage and better satellite visibility is only ground stations are used. So the stations are installed on roofs or terraces to provide best and easy infrastructure for all users. However it should be noted again the distribution of the stations should be identical. There is no standard for pipe like monuments as the design of the pipe should be specific for each site location. First, it should be checked whether there is an obstruction or not at the site. The static plans of the building should be evaluated prior to the installation to understand the location of column and beams, and to understand the stability of the building. Even short buildings can slightly move if it has not built suitably.

### 3.1.7. Cabinets

Cabinets are the parts of a CORS system that protects the equipments from direct interactions and weather conditions. Indoor cabinets could be simple cabinets that fulfill basic functionalities. Both indoor and outdoor cabinets should made up of metal and well galvanized or painted in order to provide long life use of the cabinets. For in door use the difference will be the isolation material and heating/cooling system. There must be two lock systems on the cabinets. To protect the locks from rain and snow there might be a slope protector attached to the cabinet. For safety purpose there must be a fire extinguisher inside the cabinet. Cabling entrances should be covered with silicones after cabling. UNAVCO Inc. (2007) uses cabinets on a bar to protect cabinet from heavy snow and rain flows.

Heating and cooling system should be cared especially for outdoor cabinets where the weather conditions could exceeds the limits for some electronic devices like ADSL modems or UPS systems. Sometimes it is beneficial to full secure the equipment for direct interference also to the cabinet. Than underground encloses is preferred for securing the equipments. As shown in the Figure 3.23., the power enclosure and the instrument enclosure are buried underground with air exchange provided by vent tubes (UNAVCO Inc., 2007). A fan is used on the intake air inlet to draw air into the enclosure.

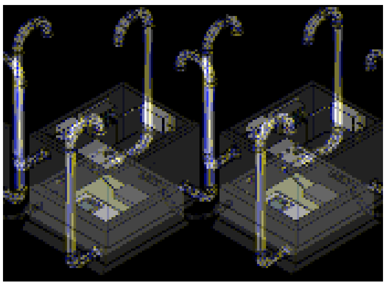

Figure 3.23. Underground cabinet for equipments and batteries

To provide optimum operation conditions for the equipments inside the cabinets, climate precautions could be considered. Heating and cooling systems can prevent the systems from extreme weather conditions.

Wire fencing should be used to protect the cabinet and antenna from intentional contact. The antenna with radome is very attractive for people and even a person near the antenna can block signals. The height of fencing should be shorter than the height of the pillar and the GNSS antenna. It is essential to prevent from multipath effect of the fencing. Figure 3.24., shows a sample installation of a fencing (Tuzun, 2006).

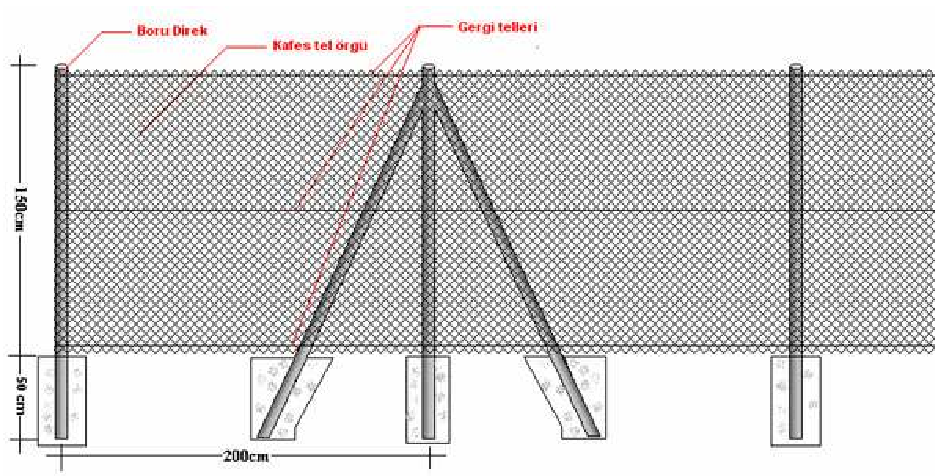


Figure 3.24. The installation of fencing

### 3.1.8. Lightning Protection

Lightning protection is very critical for the healthy of the site. Lightning protector is a device that transfers the high voltage coming from lightning event to the ground. The protector part is a gas capsule that will spark over and resulting in potential equalization to ground. It is installed between receiver and antenna by antenna coaxial cables. The flow of a lightning over the arrestor is shown in Figure 3.25. (Huber+Suhner, 2006).

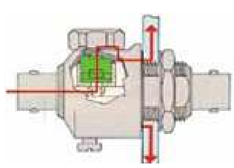

Figure 3.25. Drawing of a lightning flow

### 3.1.9. Surge Arrestor

Surge Arrestor is used to protect the site equipments from high voltage or surge. With grounding functionality the device could also protect the devices from surge coming from line connections like telephone or internet network. An optimum surge arrestor has the following specifications:

- Surge, Pik and Lightning Protection
- Grounding Error LED indicator
- EMI/RFI noise filter
- Over load protection fuse
- Fax-Modem,Telephone/Network protection
- 6 jack with grounding protection

### 3.1.10. Power System

The power requirement could either be calculated for only GNSS receiver or for all the cabinet. It depends on the application and necessity for real time data transmission. IF the CORS site is continuous operating crustal monitoring site, than the real-time data transmission could be less important. Even using a near real time monitoring program to which the CORS site is assigned, the data could be downloaded from the site when the power is available for the communication devices. For this reason, the operation conditions should be defined during the design stage. For RTK based application it is all the cabinet which has to work continuously. After calculation of the power consumption of the cabinet than the right system with optimum battery units would be proposed. In this study the types of Uncorrupted Power System (UPS) types will be summarized.

Smart charger with batteries is the basic version of UPS system that has been used in most CORS sites. The smart charger unit has the capability to charge the batteries, automatically feed the system when the direct electric is cut down. This system can work with 12 Volt or 220 Volt. In the lack of standard electrical voltage, this system provides solutions with 12 Volt electrical powers.

Outdoor UPS systems: There are some battery systems with chargers that can operate in high and very low temperature. Figure 3.26., is the example from one of the most famous outdoor UPS provider Alpha (2007). The technical specifications of an outdoor system could be as follow:

- Operating temperature: -35 deg c to +50 deg C,
- Housing: NEMA 3R, weather proof, white color

Figure 3.26. Sample outdoor UPS system

As Outdoor UPS system is very expensive, standard UPS systems could be used with in well climate cabinets. 1 KVA, 1f/1f, ON-LINE systems prevent the system from sudden voltage changes. Online system has the capability to balance the voltage and prevent the devices from this change.

Solar panels could be used alone or together with UPS systems. This system is necessary mostly for the sites where the electricity infrastructure is not sufficient to power up the system for long hours. The only problem of solar panels is that the snow should be removed over the panel.

### 3.1.11. NPS and SNMP Modules

Together with UPS systems there could be an Network Power Switch (NPS) Module (Figure 3.27.) that provides remote control of Receiver power. The GNSS receiver could be stopped and than restarted without any physical invention requirement (WTI, 2007). Besides, the Symmetra RM Power Module (SNMP) of UPS system could provide the control of the healthy of UPS system remotely. This system can be used together with advanced UPS systems only. The UPS system with batteries and chargers can not be supported by this system.

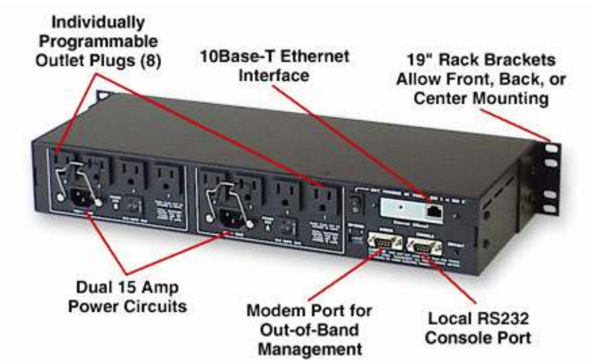


Figure 3.27. Sample Network Power Switch (WTI, 2007)

The battery switch functionality of a receiver provides best battery life and it is very critical for sites which are not possible to reach easily. This functionality provides the receiver to automatically switch from the primary power source to the other one if the main battery load is lower than critical values.

### 3.1.12. Cables

Special applications require special cabling as this is the function that influences the operation quality of the site (Table 3.2.). During cabling, special cables should be used separately for indoor and outdoor. Especially for outdoor use, special cables should be used that are compatible for outdoor conditions. Besides cable housings will protect cables from weather and human effects. This will also helps to remove bad visualization. Cabling should be carried out by at least electrical technicians. If necessary investigations should be done and special engineering projects should be carried.

Table 3.2. Different type of electric cables

| Electric Cabling, Telephone Cabling, ADSL Cabling, and cable housings | |
|---|---|
| 3.25 NYY Power Cable | for outdoor use |
| 3,25 NYM Power Cable | for indoor use |
| 2*2*0 Phone Cable | for outdoor use |
| 2*2*0 Phone Cable | for indoor use |
| CAT5 | for indoor use |
| CAT5 | for outdoor use |

### 3.1.13. Other Data Collectors

For better three dimensional evaluations of data, most of the time a total station is used together with GNSS systems. This is the case for monitoring applications as the vertical component of GNSS is not very accurate for some specific applications. For automated monitoring of a dam, landslide, high rise buildings, mining areas, roads, a motorized total station with an angular standard deviation 0.3 mgon is preferred. Besides the Total station should capable of measuring long distances in desired precision. The total station should allow integration with other monitoring software in full compatibility for better analysis (Leica-Geosystem AG, 2007c).

In the concept of this study the sensor types that are used together with GNSS systems will be mentioned. Instead of giving detailed description, the commonly used ones will only be named. A Sensor is a device that converts a signal type to another type. There are several types of sensors that have been used together with CORS stations. The mostly used ones are clinometers and meteorological sensors.

Meteorological sensors are used for correcting atmospheric delay errors on GNSS measurements. Together with these networks GNSS networks is better to use weather forecasts, air traffic security, and seismic events (Paros and Yilmaz, 2002). To detect the slow movements of a structure, inclination sensors are used together with GNSS receivers. For the applications like dam monitoring where GNSS satellite geometry is bad, the motion is very slow, and the stability of the CORS monumentation is really an issue (Cranenbroeck *et al.,* 2006) inclination sensors are used efficiently. The connection of these sensors to GNSS receivers is over serial port. Figure 3.28., shows the inclination sensor and the data flow over GNSS receiver. Vibrating wire sensors in dampened or sustain excitation mode, electrical Sensors including resistive, inductive, potentiometer, magnetoresitive types and linear variable differential transformer, fiber optic sensors, pneumatic and hydraulic sensors, tilt meter electrolytic sensors, are the type of sensors which could be used together with Geodetic techniques (Leica-Geosystems AG, 2007d).

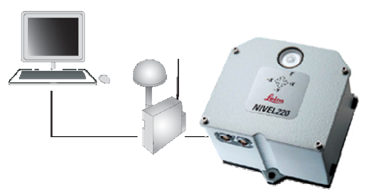

Figure 3.28. Inclination Sensor and its control over GNSS receiver

## 3.2. Control Center Equipments

Control Center is the part that all the GNSS system is monitored over a PC or complicated Server poll. The design of the Control center is mainly related to the application and services. Even a Continuous Crustal Monitoring system may need to evaluate a pool of data in a period of time and may share the results or outputs with other organizations in an automated way. Than a two step control center mechanism could be proposed. The functionality of first mechanism is logging and evaluating data in near real time, and the next one is distributing the data to the end users over a secured channel.

### 3.2.1. Server Poll

Servers could be classified according to the functionality as, site control server, archival server, and network server. A significant point for the selection of the server is the data security. A server in RAID1 (Redundant Array of Inexpensive Disks) configuration can use parallel disks and, if one of them fails without any data loosing the system goes on running.

The function of site control server is to collect all data streams from the CORS receivers and will manage the backup communications to the CORS. Than if necessary this server will distribute the data to other server mechanisms. It could be a network server for RTK Network solutions or, a archival server for distribution of the data such as over FTP.

Archival servers function is to log the data coming from Site and Network servers. With desired communication the archival server could store the raw, compressed files or other outputs for further use and distribution.

Network Server is different from the two above it is the most dependent architecture to the design of the network. The number of the sites and functionalities that a user asks determines the ranges of the network server.

### 3.2.2. Other Control Center Equipments

The equipments at the control server could have a range related with the application. Main equipments that compliment server part could be listed as firewall, access router, communication equipments and power systems.

The firewall is a device (or a software) that controls the data transmission through a computer network by defining the levels of trust. The Cisco PIX 501 is a compact, ready-to-use security appliance that delivers enterprise-class security for small offices and enterprise environments.

The access router is the point of contact for the rovers using dialup connections via phones or modems. It can handle up to 210 simultaneous users. The Cisco AS5350XM Universal Gateway eliminates the need for switches and routers to create a POP or "POP-in-a-box" solution.

Communication channels needed for Control server is similar to the ones at the sites de fined in previous chapter 3.1.4., as the Control Center will communicate with the receivers by using same type of communication channel. This communication channels has been defined while communication channels for sites introduced.

The power system for sites and Control center is different because of the power consumption of Servers. To power up a server for more than an hour may requires an integrated system. Together with UPS system a diesel power generator is required most of the time. It should be note that the UPS system should be installed under control of professional technicians or engineers who really cares about all probabilities that may harm the long use life of the whole system.

# 4. DESIGN OF A CORS SYSTEM

Design of a CORS system is a complete system starting from the site selection to the analyze of the final data. In this study design processes will be defined over the type of applications Crustal Monitoring, Structural Monitoring, and RTK Services. A single or two stations can be sufficient for small applications, however, large applications requires professional aspects that might include a GNSS network with integration of different type of sensors.

The user of a GNSS system is expected to have better accuracy in desired datum, reliability and repeatability of the precision, and corrections at the field of study. This could be provided by modeling GNSS errors. Error modeling is the main issue in network design and operation.

## 4.1. RTK Based Surveying, Engineering, and Cadastral

Network RTK is carrier phase-based positioning technique that provides centimeter (cm) accuracy in real time. Various types of applications can use RTK systems to find best coordinate quality in very short time. The application types are spreads from Cadastral applications to navigation and safety systems. Today machine guidance is very popular among RTK applications. In open area mines, agricultural activities, construction sites surveying and monitoring systems has been using to increase the productivity. Besides, RTK systems are used for fast on site for geographical data collection with high position accuracy. Maintenance of electricity, water and gas pipe lines should require precise application of the location on the ground to avoid wrong intervention.

For RTK based applications CORS systems increases the productivity of the services that requires fast on the field coordinates with required precision. The precision and reliability of an RTK system is related to the criteria like, locations of the stations to create best model, the coverage of the system, the signal quality at the site, the quality of the monumentation, and the quality of the communication link (Leica-Geosystems AG, 2006b).

By means of differential GNSS method and broadcasting RTK correction data to the field users, cm accuracy can be obtained in a range. The range of the availability of the correction is depending on the network solution quality and the media that the correction is transmitted. The differential GPS technique is based on the idea that the errors for all GNSS receivers in the same region remain the same. So if the error can be modeled for one or multiple (Network) Reference stations then it can be calculated and transmitted to the field GNSS users.

Because of the ionospheric activities which create signal latency, the precise calculation could not be achieved for long distances. Double-difference ionospheric delay correction predictions derived from the previous correctly resolved epoch were applied in order to obtain a high quality instantaneous RTK position (Gordini, 2006).

With standard DGPS most of the error sources are covered. For real-time kinematic applications the noise is lower than 1 millimeter, however code observations includes noises that is limiting the modeling. Phase measurements provide better modeling that brings better accuracy compared to the code measurements. Clock errors, the common part of atmospheric refraction and orbit errors can be removed from DGPS data. However, there are some distance depending errors which affects the quality. The distance dependent errors are the ionospheric and tropospheric refraction and orbit errors, which limit the accuracy to 1 to 10 ppm. The antenna phase center offset, and multipath effect can be locally removed from the error sources.

According to Wübbena (96) the influence of tropospheric errors depends highly on the actual correlation between different stations. Some GNSS errors can be modeled, however the corrections still includes tropospheric and ionospheric delays. GNSS Error Sources are given in Table 4.1.

Table 4.1. Magnitute of error sources of GNSS

| Error Source | Absolute Influence | Relative Influence |
|---|---|---|
| | | |
| **Satellite Orbit** | 2 - 50 m | 0.1 - 2ppm |
| **Satellite Clock** | 2 - 100 m | 0.0 ppm |
| **Ionosphere** | 0.5 >100m | 1 … 50 ppm |
| **Troposphere** | 0.01 …0.5m | 0 … 3 ppm |
| **Multipath Code** | M | |
| **Multipath Phase** | mm – cm | M |
| **Antenna** | mm – cm | mm … cm |
| Total: 1 .. 2 cm + 1 … 20 ppm | | |
| | **High Spatial Correlation** | |
| | **Local (Calibration)** | |

To calculate the Network RTK solutions there are several methods, which has different aspects to provide the solution. Basically the networking software is collecting raw data from reference stations, processes incoming data continuously, models the distant dependent errors and calculates corrections for the field user. Recently a new approached named Master Auxiliary Concept has been proposed to RTCM comity and it is accepted by all leader RTK system providers. By the help of this standard all providers will provide similar type of correction data which has unique meaning for the rovers. This help the rover providers to best understand the correction message and best adapt to their systems. Today and prior from MAC concept, each company proposes their own solution like Virtual Reference Stations (VRS), and FKP (Area Correction Parameters).

### 4.1.1. Master Auxiliary Concept

In Master Auxiliary Concept (MAC) it is the rover which applies corrections. The networking software calculates correction parameters and transmits these correction parameters and network data in RTCM V3.0 format. In order to be able to use the data, RTK rover receivers have to be RTCM V3.0 compatible. They have to understand the RTCM V3.0 format and they have to be able to apply the network correction parameters. The RTK rovers receive RTCM V3.0 network data and the network correction parameters. RTCM3.0 data contains all of the required information for the entire network. A rover should be capable of understanding and applying these parameters.

The processes inside the MAC concept are described by RTCM. This provides transparency of the software that creates corrections for the field users. No need for any additional proprietary message. It is the Rover who resolves ambiguity and calculates precise position with the information receiver from networking software. This means the quality of the Rover coordinates are independent from the networking software as all the software working in RTCM 3.X format transmit the same type of data. So, different type of Rover providers can read the same data. As it is a unique correction parameter for all users only one way of correction transmission is required. One way channels like radio links can be used to transmit MAC network data and corrections. Besides, if the internet connection or GPRS connection is used only one way connection is required to transmit data.

In other methods the corrections parameters are applied in the Software and only the corrections are transmitted. So, the networking software should know the location of the Rover to implement correction parameters specifically for each user. In order to understand the location of the rover, it should send its position to the server in The National Marine Association (NMEA) format (Cranenbroeck, 2005, Leica-Geosystems, 2005, Brown , 2006). This also creates biases for different brand rovers as they are all proprietary solutions.

### 4.1.2. Virtual Reference Stations

The main idea of Virtual Reference Station (VRS) and VRS like solutions is that the corrections for rovers are transmitted as it is coming from the closest reference station. A Virtual reference Station is generated by the networking program and the correction is transmitted over this virtual station. This virtual station is created in the same region with rover. The rover does not understand that it is receiving a network correction and receives the correction as it is coming from a single reference station. So prior to the calculation of the corrections the rover has to send its initial position to the server in NMEA data format. The server generates VRS corrections specific for that rover. RTCM2.3 correction message with message type 59, which is integrated inside is transmitted to the rover. RTCM is a format of standard corrections however for VRS only the transmitting data is standard not the content of the correction. Similar solutions have been published by different system providers as the VRS is a proprietary format (Lin, 2005, Landau *et al.*, 2003, Wanninger *et al.*, 2006).

In one VRS like solution the network corrections are coming as they are from the closest reference station. The difference from the previously explained VRS concept is the corrections are from real stations. To summaries, the rover receive network corrections from the closest real reference station instead of a Virtual Reference Station. Out of this difference the concept that covers both methods is almost the same. As there is one trade VRS solution in the marked, solutions like that is named as VRS like solutions (Lin, 2005, Landau, *et al.,* 2003).

### 4.1.3. FKP (Area Correction Parameters) Representation

FKP is a means of representing the distance-dependent errors affecting an entire network in an additional message with a simple mathematical description plane. FKP is sent to rover by Control Center (CC) together with real corrections of nearest Reference Station.

In FKP method ionospheric, tropospheric and orbit effects are modelled and calculated for each satellite to cover a specific network area. The coefficients are then transmitted to the rovers and rovers interpolate these corrections to their own corrections. End user can have information about error/correction by a specific message type 59 (containing FKP) within RTCM corrections. Similar to VRS, although the message content is known the way to implement the parameters is proprietary (Lin, 2005). The area correction parameters FKP allow the prediction of the distance dependent error term for the approximately known rover position. The FKP do also not contain absolute tropospheric information, but gradients of the troposphere. The tropospheric effect for a reference station can therefore be figured out and applied correctly to the data by the rover. In FKP methodology the representation is linear. The coverage is centralized to a real reference station and FKP describe the horizontal gradients for the geometric and ionospheric signal components in the observation space as it is simulated in Figure 4.1. (Wübbena *et al.*, 2001).

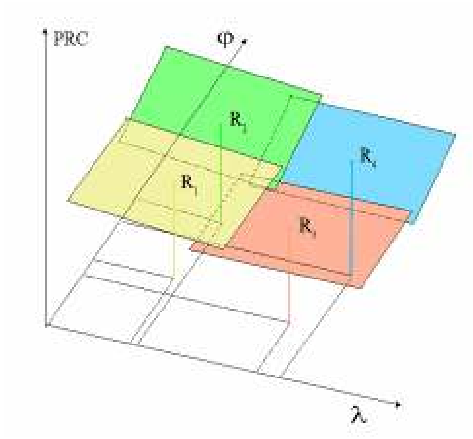


Figure 4.1. Linear FKP planes

### 4.1.4. Principle Components for RTK System

Designing an RTK system basically considers the equivalent distribution of the sites to cover the target area. However, the reliability of the system requires more than an equivalent distribution of the stations.

A single site RTK station can provide 5 cm horizontal and 10 cm vertical accuracy up to 20-25 km. This means the distance between CORS stations could be about 40-50 km. This is because of the correlation of the GNSS signals with distance. If a network algorithm is used, centimeter accuracy could be achieved over 40 km range. Here the distance between the stations is about 80 km. Within this distance, the reliability of a network is mostly related with the quality of the stations in the network. Besides, to provide a network solution, the raw data from CORS sites has to be streamed to the server on which the network software running. For the case of failure in communication lines, it might not be possible to provide any solution to the field users. To increase the reliability there must be some overlaps in the range of coverage with some sub networks. To each sub network up to several stations could be attached (about 30 to 50). If these sub networks are designed with overlaps then the reliability could spreads to all network regions (Figure 4.2.).

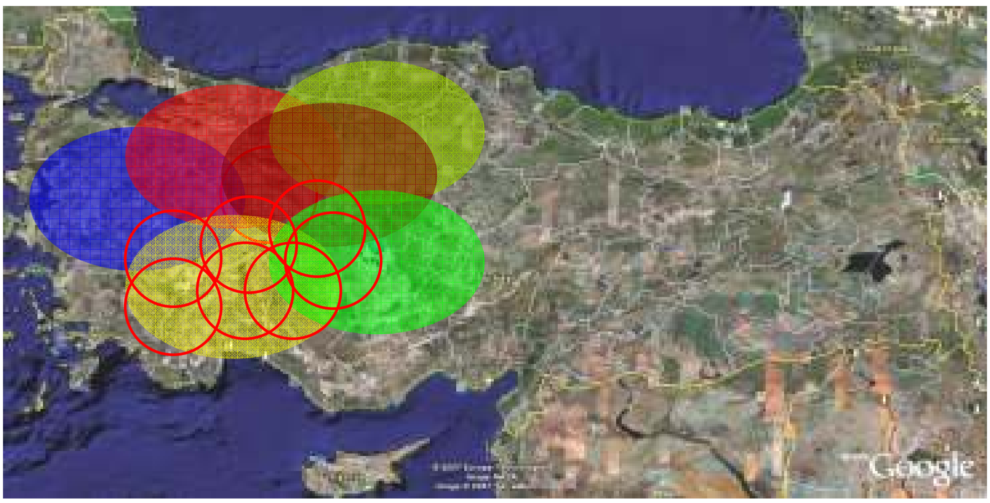


Figure 4.2. The representation sub networks with overlaps

Calculation of RTK parameters should also consider the datum transformation as countries like Turkey use different types of coordinate systems and datum for several years. Installation of a CORS system should care about the transformation between different datum. For this reason in order to implement two systems, some stable ground stations which are properly distributed to all network area needs to be established which are shared by two coordinate system.

Turkish National Permanent GPS Network (TNPGN-TUSAGA) is the mother network for GPS studies in Turkey. It has been establishing since 1999 to solve datum transformation problems of Turkey. Currently it has 19 operating stations, and today new stations are being added to the network (Kilicoglu *et al.*, 2003). Establishing a new network should consider the locations of these currently running stations. Besides, the integration of new network to this operating one should be evaluated before the site selection of new stations.

Today RTK systems are more important for Geographic Information Systems applications. In most countries several type of emergency systems based on real time field monitoring. An ambulance could find best road to the destination scene by using real time control systems. To improve the coordinate quality of these systems RTK systems are better to use. Today the flow of traffic is controlled by traffic lights. There are some examples from developed countries which use remote control systems that are integrated with the GNSS system on the ambulance. When the ambulance drives towards a traffic light the system automatically change the light to green on the way to ambulance. Another example can be given from underground applications. Most of the infrastructures such as electrical, gas pipes, water channels are under ground. When a new building is structured it is necessary to know where these infrastructures are in order to orient digging processes for the building. Besides, in Turkey it is common to build new roads and change infrastructure. If there were no information, the underground systems could be damaged during excavations. So the excavation points should be applied to the ground precisely in very short time as the time on the field is very valuable. Using RTK systems provide precise on site coordinates which is very essential for Geographic Information Systems (GIS).

## 4.2. Structural and Land Slide Monitoring Applications

Improvements on construction technology and techniques together with the urbanization in metropolis, brings the vertical structuring requirement to front. Besides engineering structures like dams, tunnels, bridges, mining areas and oil and gas pipes are constructed to satisfy the requirements of this growth.

Why scientists are interested in observing earthquakes is to well understand the characteristics of earthquake and construct cities, as to compatible with earthquake activities. However, rapidly developing and constructed structures could not consider this natural phenomenon. So, the only possibility to reduce the effects of damages is to know the characteristic influences of crustal movements on structures. Besides, some other natural activities such as wind loading, temperature loading and water pressure can damage the structures. The last but not the least, monitoring historical structures provides to control the structure. This could be a mosque tower on an old aqueduct which will be subjected to structural monitoring.

Today, monitoring systems has been used to detect the movements and the effects of natural phenomena. Monitoring systems has been established on and around the structures. With the help of these monitoring systems scientists or authorized people can take precautions. Actually the monitoring system should take a part during the planning stage of a structure. Monitoring the structure for as-built performance can give opportunity to compare with design criteria. Moreover, long period monitoring can help scientists to determine anomalies or novelties for loading conditions (Ogoja *et al.*, 2001a).

The system infrastructure covers geodetic systems with the integration of other systems. Some specific systems that has been used together with GNSS systems are summarized as electronic distance and angle measurements, leveling and trigonometric height, photogrammetric methods, geotechnical measurement techniques, extension and strain measurements, tilt and inclination measurements, accelerometers, laser interferometers, dynamic pressure transducers, and temperature transducer.

In the scope of this study, the priority will be given to Continuous GNSS monitoring systems and their integration with other geodetic, geotechnical, geophysical techniques. In most of the systems, geodetic techniques are preferred to provide the main data set as they are providing information related to positioning. Defining a deformation with coordinate or position data makes the study more meaningful to understand the movement characteristics. In this study geodetic techniques which are integrated with CORS systems and automated systems will be mentioned.

Continuous GNSS systems are not a new approach, however in Turkey for many years it rarely takes a part. This was because of the lack of infrastructure at the sites and expensive geodetic devices for such applications. However, it was understood that the cost of controlling the health of structure is nothing compared to the structure itself. Besides, some companies promote single frequency or double frequency GNSS sensors with sufficient functionalities make the systems cheaper than it was. Then, the remaining budget could be used for establishing infrastructure for the site.

Today in Structural and Land Slide Monitoring Applications Continuous GNSS systems has been using in two ways. First one is based on RTK-GNSS monitoring and the other is central near real time post processing monitoring.

### 4.2.1. RTK Based Systems

RTK based systems are based on the idea that a base station transmits correction data to the monitoring receivers on the structure and these receivers log the data with these corrections. Than the computer at the site or a remote control computer get the data from monitoring receivers to provide further analyses. In RTK based Continuous applications a reference GNSS station is transmitting the corrections to the monitoring GNSS receivers and these receivers are collecting and loading the corrected coordinates. The logged data is than transmitted over a data link to the control center in NMEA format as X,Y,Z. The diagram of data flow for RTK based monitoring systems is demonstrated in Figure 4.3.

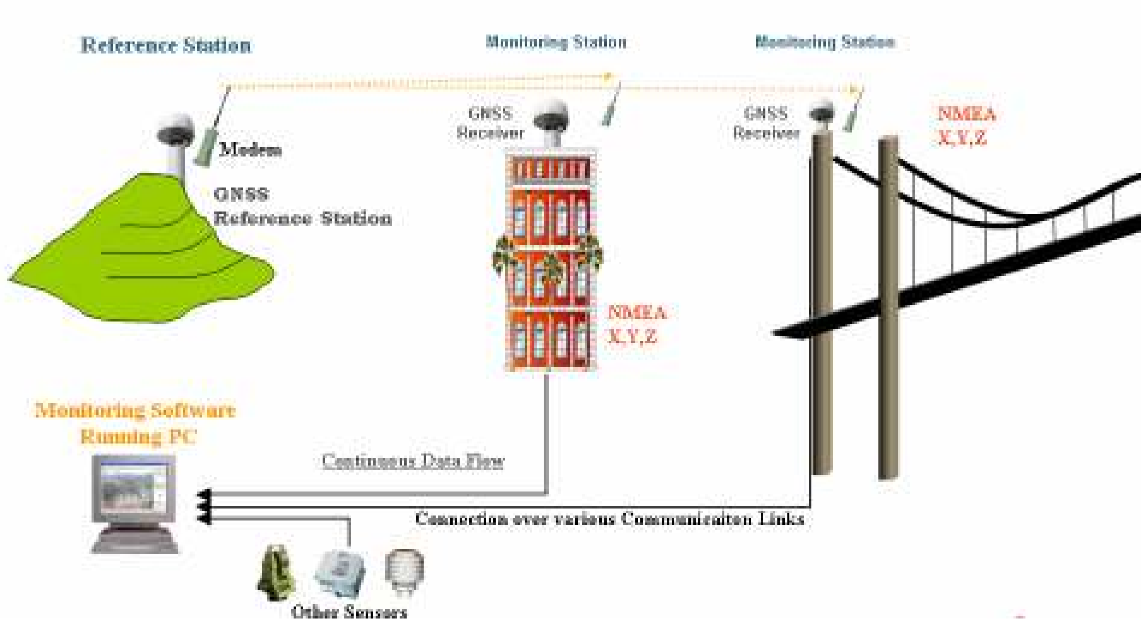


Figure 4.3. The diagram of data flow for RTK system

At the Control Center the transmitted NMEA data could only be logged by a PC or a the PC on which the monitoring program is running can analyze and provides outputs for the end users. The RTK concept is mostly depended to one reference station corrections and the user has to trust on this reference station.

### 4.2.2. Central Processing Systems

Central Processing Concept covers the idea that all the raw data is collected by a Control Center Server Program and provides baseline solutions with near real time processing. The main merits of this system is that the system could be designed with multi GNSS control points. However in RTK based system it is an obligation to provide a RTK correction over a single GNSS receiver. It should be remind that Network RTK corrections could be used however, the accuracy of network RTK systems for critical monitoring application is reasonable. With Central Processing all data is logged by the computer and using baseline solutions multiple calculations can be executed to find the best result checks. The data flow for Central Processing concept is demonstrated in Figure 4.4.

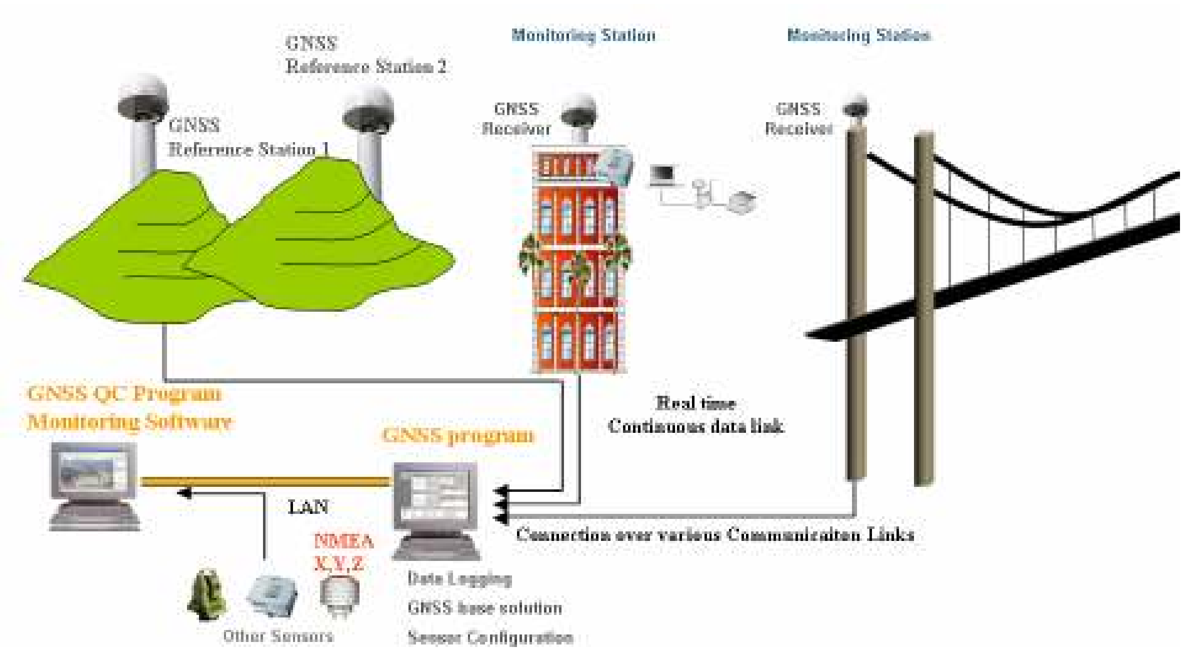


Figure 4.4. The diagram of data flow for Central Processing Concept

If a continuous data link could be provided than the Central Processing system provides better reliability and control mechanisms than the other.

Most of the time, the distance between the monitoring sites are not to much. This provides better modeling in GPS applications. As the system is continuous system than generally single frequency (Only L1) receivers will be enough for sufficient information related with the site activity. Monitoring with dual-frequency GPS receivers relatively cost more and this asses the number of stations in the network (Brown *et al.*, 2006).

High data sampling rates (more than 10 Hz) capacity of new GPS sensors provides the availability of slowly moving structural deformation detection (Ogaja *et al.*, 2001a). Simultaneous computation of 3-D millimeter level accuracy positions can be available with new age software programs which can use both single and double frequency receivers together (Ogaja, 2002, Brown, 2006). In this system the raw data is processes in a centralized computer instead of in the rover monitoring GNSS receiver. Triple and double differenced data are processed to provide epoch-by-epoch Kalman-filtered solutions (Ogaja, 2002).

Single frequency monitoring with quasi-static initialization designed for single frequency monitoring. Quasi-static approach assumes lower dynamics as it is in most monitoring applications (Brown, 2006).

L1 receivers are cheaper and more energy efficient and also do not require proprietary algorithms to extract high-quality measurements from the encrypted code on the L2 frequency. The disadvantage of single frequency receivers is that much less measurement data is available to help resolve the carrier phase ambiguities and to model the ionosphere. Also, many lower cost single frequency receivers have poor multipath mitigation capabilities (Brown, 2006).

During network design if the site selection considers these drawbacks than single frequency receivers could be used to increase the probability of availability of continuous stations.

### 4.2.3. Principle Components for Deformation Monitoring

To eliminate noise from data prior to the model development for monitoring the Finite Impulse Response Median Hybrid (FMH) filter is used to reduce the noise to preserve sudden jumps in the data.

The Wavelet transformation which is the second methodology represents general functions as fixed blocks at different scales and positions. Wavelet transforms are differentiated whether the time and scale parameters are continuous or discrete. Continuous Wavelet Transforms (CWT) are the results of Continuous signals. Haar Wavelet Transform is a form of CWT whose continuous form is known (Ogaja *et al.*, 2001b).

In 2001, a study has been carried out on the roof of the Geography and Surveying (GAS) Building at The University of New South Wales (UNSW) (Ogaja *et al.*, 2001b). The structure of the installation is given in Figure 4.5.

Ogaja (2001b) has applied 'Time-Frequency' wavelets to the fast GPS-RTK results to automatically detect 'low' and 'high' frequency components embedded in the noisy time series, frequency changes and their onset times. The estimation of 'instantaneous frequencies' using the wavelet transform is used in the algorithm with the change detection schemes.

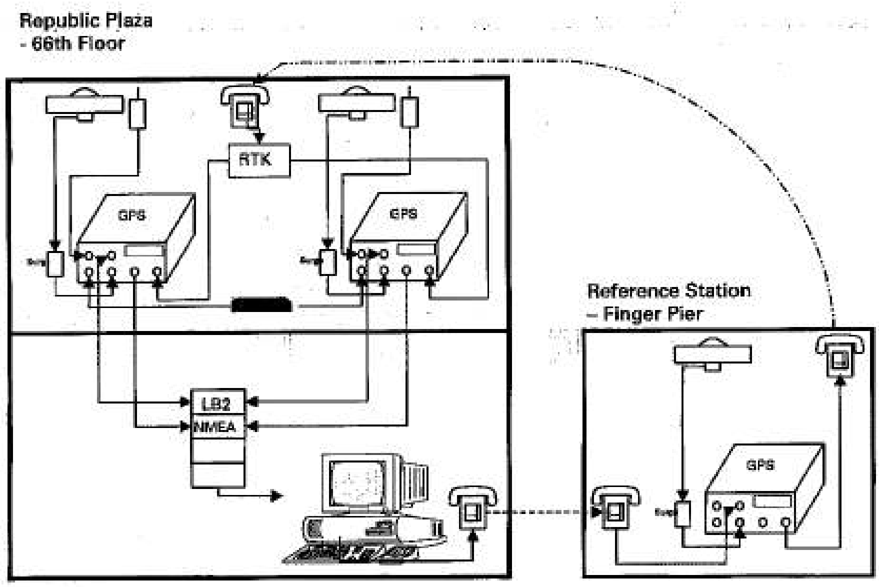


Figure 4.5. The RTK system design

According to Ogaja (2001a) one objective of long term monitoring will be to identify 'anomalies' that may signal unusual loading conditions or modified structural behavior. And Ogaja adds that the secondary objective is to calibrate local building design codes.

Wavelet transform gives the time location of each frequency while Fourier analysis only gives frequency composition of a signal. Wavelet transform allows visualization of transient frequencies and the determination of the occurrence of discontinuities in the signal.

The design of the system is based on only GPS monitoring with RTK system the corrections are sent to the monitoring site stations over a line connection and the corrected data is logged on a computer. The study was based on continuous monitoring however, not on real time analyses (Ogaja *et al.*, 2001a).

Because of the random observational noises the frequency analyses could not clearly observed from noisy GPS RTK data. The Fourier analyses reveal the occurrence of different frequencies, however doesn't indicate when the particular components occur within the signal. In Ogaja's study instantaneous frequencies obtained by wavelet transform by using a time and frequency resolution of 60 samples and 256 points respectively. The change has been detected by using CUSUM algorithm (Ogaja *et al.*, 2001b). CUSUM algorithm is very sensitive to small persistent changes in the mean or standard deviation of measurements (Ogaja, 2002). Real-time quality monitoring of GPS coordinate time series by applying different Quality-Control algorithms provides automatic and reliable results on mean locations, and on variance (Mertikas, 2006).

The design of algorithm is based on monitoring signals (residuals) to detect changes, developing statistical tools to detect shifts& measurement failures, estimating magnitude of shift (delta) and time of occurrence. Detection of shift is related with the measurement type (Phase, phaserate, pseudo-ranges) and chose of model (Linear model, Kalman Filter, auto-regressive) (Mertikas and Damianidis, 2006).

CUSUM algorithm is classified as one-sided and two-sided CUSUM. First one is used when before and after change values of means is known. The second is used when change magnitude is known. Ogaja (2002) proposes to use both algorithms in parallel. One side test is proposed to detect increase in the mean and two sided test detecting decrease.

### 4.2.4. Examples that Integrates GNSS Systems with Other Systems

Dam monitoring is the forefront example of which applications is rising in Turkey. Initially, dams has been constructed to satisfy water reserve requirements, today they are used as hydro electrical power sources as mush important as being a water reserve. The deformation monitoring is a process starting with the reservation of water and continued during the operation phase, and regarding the type of dam it will continuously execute periodically. According to the reports of International Commission on Large Dams (ICOLD) There has been more than 18600 dams all around the world (updated 1984) (Kalkan and Alkan, 2005).

The method for deformation procedures is given as below:

- Performance analyze of the structure
- Precision requirement and selection of the technique,
- The type of measurements and number,
- Selection of equipment pool for deformation,
- Execution of surveying and collecting information,
- Evaluation and analyze of data,
- Modeling and reporting of the deformation in time position, frequency domains.

There are mainly three types of dams regarding the construction shape and type which are Arc or Multiple-Arch Concrete Dam, Gravity Dams, Earth and Rock fill Dam. Embankment type is rock fill with inclined clay core (Joseph,  2006). Ataturk Dam which is the largest dam is Turkey is a type of Emberkment type dam.

In Turkey, Dams are built either in Rock fill or Concrete Arc type. The deformation methods basically divided into two group Rock fill and Concrete Arc as in Table 4.2.

Vibrating wire sensors in dampened or sustain excitation mode, electrical Sensors including resistive, inductive, potentiometer, magnetoresitive types and linear variable differential transformer, fiber optic sensors, pneumatic and hydraulic sensors, tilt meter electrolytic sensors, are the type of sensors which could be used together with Geodetic techniques. The installation methods for different sensors are given in Figure 4.6.

Table 4.2. Monitoring types for concrete and rock fill dams

| **Concrete Arc** | **Rock Fill** |
|---|---|
| - Horizontal displacement | - Horizontal displacement |
| - Vertical displacement | - Vertical Displacement |
| - Space water pressure | - Space water pressure |
| - Leakage | - Leakage |
| - Temperature changes on the body | a) During Construction |
| - Tension of the concrete | - Horizontal displacement: 10 mm |
| | - Vertical Displacement: 5-10mm |
| - Horizontal displacement: 1- 1.5 mm | b) During Operation |
| - Vertical displacement: 1- 1.5 mm | - Horizontal displacement: 5 mm |
| | - Vertical displacement: 3-5 m |

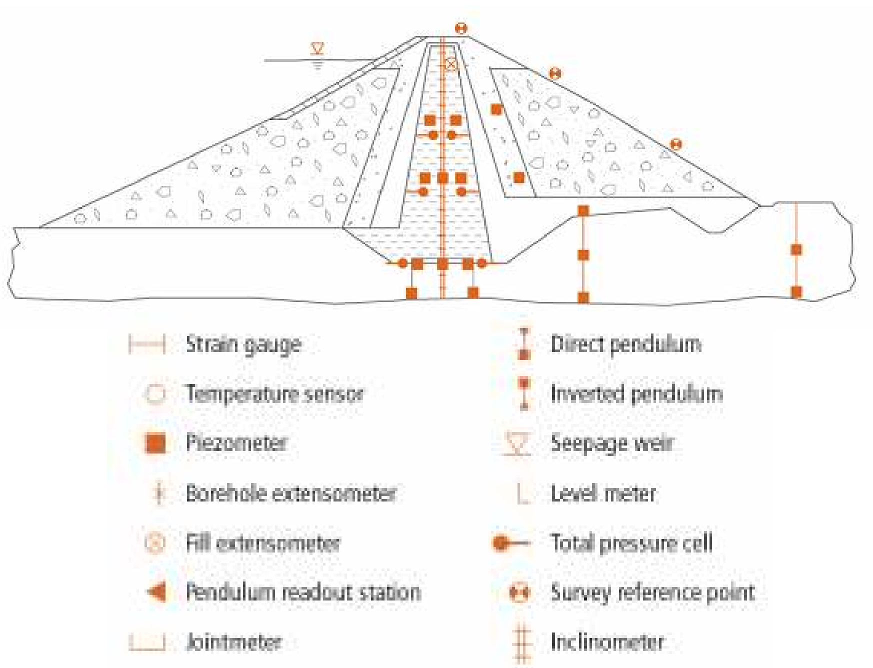


Figure 4.6. The installation methods for dam monitoring

Selection criteria for dam monitoring instrumentation are related to the reliability of the measurements, instrument longetivity, and ease of readout automation (Joseph, 2006). GNSS receivers and accessories are more redundant than the other type of sensor in consideration of these criteria.

Monitoring methods considers the characteristics such as dam height and type, extent of potential damage to people in the flood zone, site sismicity, foundation weakness (Joseph, 2006). On Embarkment type dam, the GNSS receivers could be installed on the top part of the dam together with other control points around the stable ground. Besides, Automated total stations is used to measure points at which GPS will have poor satellite visibility on two sides of the dam. The data collection and evaluation will be automated by a control center computer as defined in previous sections.

Pocahoma Dam is a famous Arc Concrete Dam on which a Continuous GPS monitoring system installed. Figure 4.7., shows the monitoring and reference points around Pacoima Dam. Some SCIGN stations close to the DAM region is used to evaluate base solutions for deformation analysis. It is a joint 'pilot' study in collaboration with Los Angeles County and other researchers within the Southern California Integrated GPS Network (Behr, 1999).

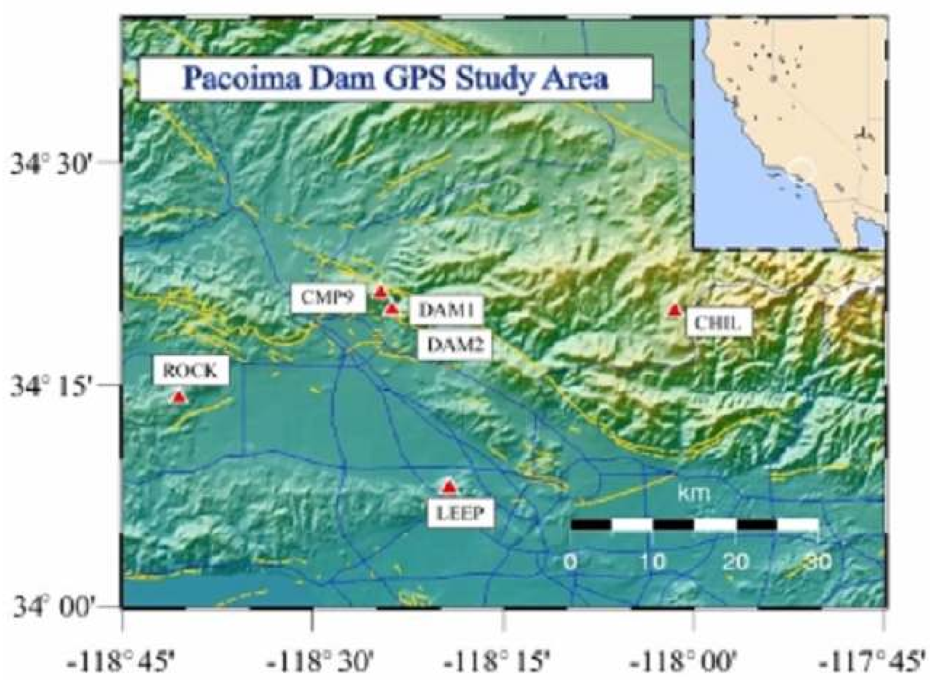


Figure 4.7. Monitoring and reference station installation around Pacoima Dam

For many years high rise buildings are constructed to satisfy the business and settlement requirements. In Turkey since 2000s' some specific high rise buildings started built mostly in Istanbul. After 1999, the effect of earthquake phenomenon is better understood as the epicenter is close to this financial capital city Istanbul. It is known that the importance of geodetic, geophysical, and geological researches rises after the earthquake. However, the risks on high rise building are not only related with earthquakes.

The monitoring of high rise buildings is primarily for a better construction processing, and after earthquake analysis.

Cranenbroeck (2006) has implemented a new application that integrated GNSS with total stations and inclination sensors. This example covers the idea to monitor the structure starting from the construction. Actually the system is built to construct the high rise structures accurately. The process is started to build control points around framework.

These external frameworks are available to use in lower levels of the building. When the building rises, the total station resections from existing control points which are on the ground level out of the frame work area. However, above Level 20 the possibility to see the control points on the ground is not possible or not reliable because of decreasing sight of view (Figure 4.8.).

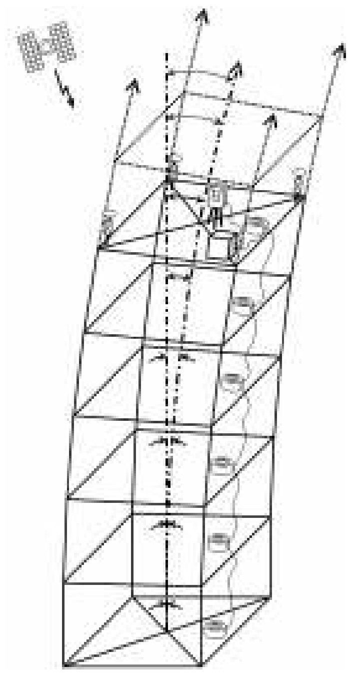

Figure 4.8. Data flow chart of structural monitoring

It is proposed to installed a different type of system work such structures construction monitoring. After 20th floor level the structures is moving because the wind, temperature loading etc. Static GPS system is to establish survey control at the upper levels. At least 3 receivers and antenna are mounted on the top level of framework and below these antenna the reflectors of total station is mounted. While GPS is measured in static mode several observations carried out to the reflectors which are below the antennas of GPS (Cranenbroeck, 2006).

After processing the data the quality control of the newly installed control points has executed. Then total station start measuring application points. To align the building clinometers have been using together with the system mentioned (Cranenbroeck *et al.*, 2006).

The positioning quality of GNSS systems is suffers from some error sources. Besides, the control of this system is under control of some powerful countries. Recently new approaches have been for fronted to satisfy the reliable data requirement of critical structures.

In a deformation monitoring equal precision for all components of position is desired which does not includes the errors of existing GNSS systems. Geometric distribution for vertical precision of GNSS systems is less than horizontal component. This case is worse when the GPS satellites visibility is reduced by some blocking objects such as the side surface of the dam. This minimizes the possibility of GPS usage out of the top surface of the structure. In our previous examples this case was solved by integrating total stations and other sensor types to the deformation processes. For this type of critical monitoring applications Locata Technology Australia has developed a system that uses a network of ground-based transceivers that cover a specific area (Barnes and Cranenbroeck, 2006).

In this approach the monitoring receivers on the monitoring objects receives the signal from ground-based transceivers together with GPS signals. The ground stations of the system is transmitting L1 C/A code signal. To use this system efficiently known point initialization is required in order to resolve carrier phase ambiguities. New signal type of locata is transmitting in the 2.4 GHz Industry Scientific and Medical (ISM) band. The 2.4 GHz ISM band has a bandwidth of approximately 80 Mhz (2.4–2.4835 GHz). This will allow to receive the signal up to 10 km (Barnes and Cranenbroeck, 2006). This ground based stations is also a big opportunity for applications in the city where only few satellite with week geometry is tracked by the receivers. To improve the availability of ranging signals is to use ground-based transmitters of GPS like signals called “pseudolites (Barnes e*t al.*, 2003). Similar studies on ground based studies have been carried out for bridge and dam monitoring applications.

### 4.3. Crustal Deformation Monitoring

Continuously Operating GPS Networks has been using in crustal deformation applications for many years. There are several organizations of whose aim is to use and control national based crustal activities. Besides, some organizations like United States Geological Survey whose focus is on crustal and boundary monitoring. They implement different techniques together with GPS networks in order to understand the behaviour of network.

In Turkey, Kandilli Observatory and Research Institute, TUBITAK (The Scientific and Technological Research Council of Turkey), and General Command of Mapping (HGK) are three main organizations who are working on Crustal Deformation. As geodetic techniques provides reliable information about crustal movements other disciplines interest on geodesy and geodetic studies rises since more than 10 years. TUBITAK who is the scientific organisation is Turkey has established a control network to monitor the activities of Marmara region. Although it is not very dense network, together with campaign based studies the results provided by using this network data is appreciated. Besides TNPGN which is the Continuously Operating GPS Network aimed to spread all Turkey. One purpose of this network is providing reliable data for crustal deformation studies and implements solutions for the mother network of the country (Kilicoglu *et al.*, 2003).

North Anatolian Fault which is the most active fault in Turkey is a strike-slipe fault. The release of fault strain occur earthquakes. In the coseismic phase the fault breaks during an earthquake. Bock (1991), notes that this part of the earthquake is best measured by seismic instruments which can determine the depth, fault geometry and magnitude of the earthquake. Second phase is the interseismic cycle; the strain accumulates until the next eathquake. During the interseismic period the earth moves very little. On the other hand, during cosismic period the movement of the crust is dramatically large. Bock fore front two other stages which are postseismic and preseismic cycles. The effects of post seismic activity can be detected near the fault. Preseismic cycle occurs close to the end of interseismic period and creates variations in strain. To well understand this complete behavior it is the single solution to use continuous reference stations. The use of Continuous reference stations in large areas is not easy to control regarding safety issues. Besides, dual frequency receivers are more expensive compared to the single frequency receivers

Today for short base lines, single frequency receivers are used to densify the larger network with dual-frequency receivers. This integration provides better information with optimum network. An application has been carried out by Rizos (2000) for natural hazard mitigation. The spatial resolution of the network is about 30km. As the cost of dual-frequency GNSS receivers is very high, the network may not be established in a dense enough. Monitoring of preseismic or postseismic faulting, requires sub-km resolution as indicated by the faulting length.

One option for increasing the geodetic network's spatial resolution is using low-cost receivers to densify the dual-frequency network. The dual- and single-frequency stations are treated as reference and user stations respectively (Rizos *et al.*, 2000).

Based on the approximate position of any single-frequency receiver, the linear combination coefficients can be derived. The second step is to apply this correction term to the double-differenced carrier phase observations between the one primary reference receiver and a single-frequency receiver. The standard rapid static positioning procedure can then be used to resolve integer ambiguities and derive the ambiguity-fix solution for the coordinates. This correction term can also be applied to two single-frequency receivers for determining the baseline between these receivers (Rizos *et al.*, 2000).

A single-frequency, carrier phase-tracking system is appropriate for small-scale continuous GPS networks if the baseline lengths are no longer than 10 kilometers. This 'rule-of-thumb' implies that the differential ionospheric and tropospheric delays between the two receivers is essentially zero, and therefore does not impact on the baseline result. Orbit bias over such short distances can also be ignored (Janssen *et al.*, 2002).

In order to ensure cm-level accuracy for baseline lengths (particularly those exceeding 10km), the single-frequency network has been augmented by the addition of an outer network of dual-frequency GPS receivers. This dual-frequency network surrounding the deformation zone of the volcano is used in order to improve the accuracy of the single-frequency baselines (Figure 4.9.) (Rizos *et al.*, 2000).

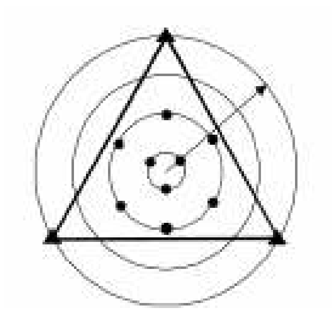

Figure 4.9. A densified network with single frequency receivers

Most of the time, in order to modeling the movement characteristics of the fault the points could be selected on places where there is no possibility to provide best infrastructure. At that point establishing the best infrastructure could be more difficult compared to the other RTK and monitoring applications like land slide monitoring or structural monitoring. To minimize the difficulties the monumentation and installation should be cared in the same concept of network design.

# 5. FUTURE ASPECTS AND CONCLUSION

Today, GNSS systems have been using by wide range of applications. With the new improvements on GNSS signals and new satellite systems, the functionality and benefits of GNSS is discovered by different user groups more than today. Why GNSS systems are preferred rather than the other systems is that they provide on side coordinates with full dependency to a datum. Although all systems are named under GNSS, these systems would not likely to combine to create a single powerful one. This is because of that, each system is controlled by different powerful countries or unions. With new signals and Galileo signal it might be possible to reach high accuracies in more efficient way. By following up the upcoming events and technologies parallel to this events, scientists and civilian users will seems to benefit from this competition on the sky. Development in technology and requirements are inter-dependent points that carry each other. If requirement for accurate positioning increases more investments would done on positioning technology.

Analyzing strategies by means of Geographic Information Systems (GIS) provides more flexibility for the decision makers. RTK data provides reliable real time coordinate information for GIS applications.

GNSS systems are also very valuable for monitoring purpose applications. Today, the integration of GNSS with other techniques provides huge amount of data for the scientists to well understand the behavior of the structure. More on that, scientists and engineers trust on geodetic systems and implement other systems as supplementary options, as position data is very critical for better analyzing. Structural monitoring is taken a part in disaster management for safety purpose applications. For such cases technology provides us cheaper solutions such as L1 frequency GPS receivers. Selection of the device and technique requires better understanding about the behavior of the structure. This means that interdisciplinary study is required for the selection of the technique, data collection equipments, and evaluation of the results. Besides, some analyzing and visualization methods provide the scientists near real time results to create alarming systems. This helps the decision makers to take precautions about the health of the structure

Understanding the behavior of fault and its impacts on people is the main concentration of scientific and governmental organizations who are working on crustal deformation. Multi-disciplinary studies have been carried out in different time intervals with different type of techniques to acquire the best evaluation. However, recent studies show that continuous data is beneficial for full time interval analyses along the earthquake. The cost is also essential for crustal deformation studies to implement the strategy for understanding the behavior of the fault. Densification of the monitoring point around the fault zone requires a scientific approach, and today GNSS is very popular among all disciplines that study on earth. As GNSS provides data with position scientists could be sure about the behavior of the fault mechanism. The other geological and geophysical studies are used to implement GNSS systems. Recent approaches show that the points close to the station and the points out of this region provide different types of information. Implementation two level of monitoring stations requires more receivers. As the same concept in structural monitoring L1 frequency receivers are used for this level of densification. By the help of technology, receivers can be easily monitored remotely which provides flexibility for the selection of the site.

# REFERENCES


Accumen Instruments Corporation, *Data Bridge SDR technical datasheet's web site*, http://www.acumeninstruments.com, 2006.

Advantech, *The MBPS-400 Micro CPU boxes series technical datasheet's web site,* http://www.advantech. com/ePlatform, 2006.

Airties, *Web page of Airties wireless outdoor bridges*, http://www.airties.com, 2007.

Alpha, *Web page of NOVUS XT outdoor cabinet with UPS from The Alpha Group*, http://www. alpha.com/us/ 92_1_220/AC-Power-and-UPS/Outdoor-UPS.aspx, 2007.

Anderson, R., Chin M., Cline M., Hoar D., Murray O., Stone W., Turpin J., and Milbert D., "National Continuously Operating Reference Station (National CORS) Site Monumentation Final Report" *National Geodetic Survey*, 20, December, 2000.

Andrews Space and Technology, *Web page for Space Activities and Technology,* http:// www.spaceandtech.com/spacedata/constellations/navstar-gps_consum.shtml, 2007.

Avci, O., "*Fleet Management System Design*", B.S. Theses, Istanbul Technical University, 2002.

Avci, O., *Technical Drawing for Tribrach Design for CORS Infrastructure*, Sistem Computer and Technical Services Corporation, 2006.

Barnes, J. B. and Cranenbroeck, J., "The Potential of a Ground Based Transceivers Network for Water Dam, Deformation Monitoring", *Proceedings of The International Commission on Large Dams ICOLD*, Barcelona, Spain, 17-21 July 2006.

Barnes, J. B., Rizos, C., Wang J., Meng, X., Cosser, E., Dodson, A. H., and Roberts, G. W., "The Monitoring of Bridge Movements Using GPS and Pseudolites" *, Proceedings of the 11th FIG Symposium on Deformation Measurements,* Santorini, Greece, pp. 563-572, 2003.

Behr, J. A., Hudnut, K. W., and King, N. E., *Monitoring Structural Deformation at Pacoima Dam, California Using Continuous GPS*, United States Geological Survey, 1999.

Bock, Y., *Continuous Monitoring Crustal Deformation*, Reprinted from GPS World, 1991

Brown, N., Geisler, I., and Troyer, L., "RTK Rover Performance using the Master-Auxiliary Concept", *Proceedings of Journal of Global Positioning Systems,* Vol. 5, pp. 135-144, 2006.

Brown, N., Troyer, L., Zelzer, O., and Cranenbroek, J., "Advances in RTK and Post Processed Monitoring with Single Frequency GPS", *Proceedings of Journal of Global Positioning Systems,* Vol. 5, pp. 145-151, 2006.

Coolgear, *Web page of Coolgear Serial to IP converter*, http://www.coolgear.com, 2007.

Cranenbroeck, V. J., Hayes, D., Hayes, I. S., 2006, "Driving Burj Dubai Core Walls With an Advanced Data Fusion System" *Proceedings of the 3rd IAG 12th FIG Symposium*, Baden, May, 22-24 2006, Vol. 1, pp. 52-56, 2007.

Cranenbroeck. J., "An innovation in GPS network RTK software and algorithms", *Proceedings of the Map Middle East Magazine*, September-October, 2005.

Dexar, *Web page of Dexar Multimedia and Communication Corp.* http://www.dexar.com, 2006.

Encyclopedia Astronautica, *Web page for Astronomic Activities*, http://www.astronautix.com/craft/beidou.htm, 2007.

European Commision Directorate General Energy and Transport, *The Web site for the Implementation of the Galileo Projects,* http://ec.europa.eu/dgs/energy_transport/galileo/programme/index_en.htm, 2007.

GEO++, *Web page of the company Geo++® Gesellschaft für satellitengestützte geodätische und navigatorische Technologien mbH* http://www.geopp.de, 2007.

Gunduz, R.,, *Personal Contact with Gunduz R., at Bilko, Satelline Radio modems distributor*, 26th January 2007.

Gordini, C., Kealy, A. N., Grgich, P. M., and Hale, M. J., "Testing and Evaluation of a GPS CORS Network for Real Time Centimetric Positioning - The Victoria GPSnet™" *The International Global Navigation Satellite Systems Society* (*IGNSS) Symposium 2006 ,* Australia, 17-21 July 2006.

Hoar, D., 2000, "Report On the Installation of the National CORS Prototype Monument", *National Geodetic Survey*, 20th July 2000.

HUBER+SUHNER, *Web page of HUBER+SUHNER Group*, http://www.hubersuhner.com, 2006.

IANA, *Web page of the Internet Assignet Numbers Authority-Internet Corporation for Assigned Names and Numbers*, http://www.iana.org/, 2006.

IFAG, *Web page of NTRIP documentation of International Federation Association of Geodesy*, http://igs.ifag.de/index_ntrip.htm, 2007.

IGS, *Web site of International GNSS Service*, http://igscb.jpl.nasa.gov/, 2007.

IMO, *Web site of Chamber of Civil Engineers*, http://www.imo.org.tr, 2006.

Janssen, V., Roberts, C., and Rizos, C., Abidin H.Z., "Low-Cost GPS-Based Volcano Deformation Monitoring at Mt. Papandayan, Indonesia" *Journal of Volcanology and Geothermal Research*, Vol. 115, No. 1, pp. 139-151(13), 2002.

Joseph, C., *Dam Safety and Monitoring Instrumentation*, Roctest Telemac, USA, 2006.

Kalkan, Y. and Alkan, R., 2005, "Deformation Measurements at Engineering Structures" (in Turkish), *Proceedings of HKMO 2nd Engineering Surveys Symposium*, pp. 64-74, Istanbul, 23-25, November, 2005.

Kilicoglu, A., Kurt, A.İ., Tepekoylu, S., Cingöz,A., Akça,E., "Turkish National Permenant GPS Network (TUSAGA)" *1st Session of TUJK Scientific Metting, Geographic Information Systems and Geodetic Networks Workshop,* Konya, 24-25-26, September 2003.

Landau H., "GNSS Modernization and Network RTK", *Presentation at CORS TR 1st Workshop,* Istanbul, 15 May, 2006.

Landau, H., Vollath, U., and Chen, X., "Virtual Reference Stations versus Broadcast Solutions in Network RTK-Advantages and Limitations", *paper submitted to GNSS 2003*, Graz, Austria, April, 2003.

Leica-Geosystems AG, *Technical Data of GMX901 single frequency GPS antenna for monitoring,*http:\\www.leica-geosystems.com/corporate/en/ndef/lgs_360.htm, 2007b.

Leica-Geosystems AG, *An introductory guide to Leica GPS Reference Stations and Networks*, 2006b.

Leica-Geosystems AG, *Brochure of Leica GPS Spider,* 2006a.

Leica-Geosystems AG*, Brochure of Leica GRX1200 Series High Performance GNSS Reference Receivers*, 2007a.

Leica-Geosystems AG, *Leica Network Reference Stations take it to the max White paper*, June 2005.

Leica-Geosystems AG, Product Brochure of TCA1201M Total Station, 2007c.

Leica-Geosystems AG, Product Brochure of Technical Nivel210/Nivel220, Precision inclination sensor for structural monitoring, 2007d.

Leica-Geosystems AG, *Technical Data of GMX902 monitoring Receiver,* http:\\www.leica-geosystems.com/corporate/en/ndef/lgs_41922.htm, 2006c.

Lin, M., “RTCM 3.0 Implementation South Alberta Network”, *ION GNSS 18th International Technical Meeting of the Satellite Division*, Long Beach, CA, September, 2005.

Linksys, *Web page of Cisco Link system modems,* http://www-tr.linksys.com, 2007.

Mertikas S. P., and Damianidis K. I., “Monitoring Quality for the GPS coordinates in Real Time”, *Proceedings of IGS2006 Workshop*, Darmstadt, Germany, 8-11 May, 2006.

Murray, O. W., “Guidelines For Setting a National CORS Monument”, *National Geodetic Survey,* 20, July, 2000.

Navigation Center, *Web page of US Coast Guard Navigation Center of Excellence,* http://www.navcen.uscg.gov/, 2007.

NGS, *Web page of National Geophsical Survey (NGS),* http://www.ngs.noaa.gov, 2007.

Ogaja, C., *A framework in Support of Structural Monitoring by Real Time Kinematic GPS and Multisensor Data*, PhD Thesis, NSW Syney, 2002.

Ogaja, C., Rizos, C., and Wang, J., "Toward the Implementation of On-Line Structural Monitoring Using RTK-GPS and Analysis of Results Using the Wavelet Transform", *Proceedings of the 10th FIG International Symposium on Deformation Measurements*, Orange, California, USA, 19-22 March 2001a.

Ogaja, C., Wang, J., and Rizos, C., "Principal Component Analysis of wavelet transformed GPS data for deformation monitoring" *Proceedings of. IAG Scientific Assembly*, Budapest, Hungary, 2-7 September, 2001.

Paros, J., and Yilmaz, M., "Broadband Meteorological Sensors Co-located with GPS receivers for Geophysical and Atmospheric Measurements" *Proceedings of IEEE Position Location and Navigation Symposium*, Palm Springs CA, , Vol. 1, pp. 134-141., 15-18 April, 2002.

Rizos, C., Han, S., Ge, L., Chen H., Hatanaka, Y., and Abe, K., "Low-Cost Densification of Permanent GPS Networks for Natural Hazard Mitigation: First Tests on GSI's GEONET Network" Tsukuba, *Proceedings of Earth Planets Space*, pp. 52, 867–871, 2000.

RTCM, *Web page of NTRIP documentation of RTCM Commitee,* http://www.rtcm.org, 2007.

SATEL, Oy., "User Guide of SATELLINE-3AS(d), 869 and Epic RADIO MODEMS, VERSION 2.6", 2006.

Schmidt, M., Dragert, H., Hill, W., Courtier, N., 2000, "New GPS monument design for permanent GPS installations in the Western Canada Deformation Array", *Proceedings of the IGS Network Workshop*, Soria Moria, Oslo, Norway, 12 - 14 July 2000.

Topcon, *Brochure of NET-G3 Reference Station Receiver*, 2007.

Trimble, *Brochure of NET R5 Reference Station Receiver*, 2007.

Tuzun, *Web page of Tuzun Woven Wıre Industry and Trade Limited Company*, Technical drawing for fencing, http://www.tuzuntel.com.tr, 2006.

UNAVCO Inc., *Web site of UNAVCO Inc., for permanent station installation, equipment, maintenance, and support issues,* http://facility.unavco.org/project_support/ permanent/permanent.html, 2007.

Wanninger, L., *Introduction to Network RTK*, http://www.network-rtk.info, 2006.

Weber, G., Dettmering, D., Gebhard, H., Kalafus, R., 2005, "Networked Transport of RTCM via Internet Protocol (Ntrip) – IP- Streaming for Real-Time GNSS Applications," *Proceedings of the ION GNSS 18th International Technical Meeting of the Satellite Division*, Long Beach, California,13-16 September, 2005.

WTI, Web page of Network Power Switch from Western Telematic, Inc., USA, http://www. wti.com/nps.htm, 2007.

Wübbena, G., Bagge, A., and Böder, G., "Reducing Distance Dependent Errors for Real-Time Precise DGPS Applications by Establishing Reference Station Networks" *ION-GPS96*, Kansas City, September, 1996.

Wübbena, G., Bagge, A., Schmitz, M., "RTK Networks based on ® GNSMART-Geo++, Concepts, Implementation, Results", Garbsen, Germany, *Presented at the International Technical Meeting, ION GPS-01*, pp. 368 – 378.Salt Lake City, Utah, 11-14 September, 2001.

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