The Turkish CORS Network (TUSAGA-Aktif)

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SUMMARY

This paper details the infrastructure of the Turkish RTK CORS Network called TUSAGA-Aktif established by Istanbul Kultur University in association with the General Directorate of Land Registration and Cadastre of Turkey and the General Command of Mapping of Turkey and sponsored by the Turkish Scientific and Technical Research Agency (TUBITAK). The network constitutes 147 Continuously Operatiing Reference Stations controlled by two control stations, the Master Control Station at the Photogrammetry and Geodesy Administration of the General Directorate of Land Registration and Cadastre and the Auxiliary Control Station at the Headquarters of the General Command of Mapping of Turkey.

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1. INTRODUCTION

Surveyors, GIS designers and users, engineers, geomatics and earth scientists and to sum it all public making use of GPS data have begun to use Continuously Operating Reference Stations (CORS) networks for the last two decades in almost every developed and some developing countries. These CORS Networks deliver Global Navigation Satellite System (GNSS) data which support three dimensional positioning not only for surveyors but also for any works in need of cm accuracy and time efficiency such as meteorologists, geophysical and geological engineers, construction engineers and so on (http://www.ngs.noaa.gov/CORS/).

CORS have been implemented to contribute towards very high accuracy geodetic tasks since the late 1980s (Evans et al, 2002). Network based positioning provides geometric strength, reference datum stability and of course redundancy to geodetic methods; this is why CORS have become popular globally. Although these CORS networks are extremely useful in providing high accuracy positioning, they are not time efficient, that is, it is not possible to obtain instantaneous accurate positions, requiring static positioning hours of point occupations and later post-processing. This made CORS networks unpopular for engineering-type surveys (Mekik, 2004)

At the beginning of 2000, the engineering and scientific community managed to add Real Time Kinematic positioning ability to their CORS networks (or rather passive/static CORS networks) and this made a worldwide breakthrough in concept and efficiency of positioning (Bock et al, 2002; Rizos et al., 2003; Eren, 2005; Rizos, 2007; Grejner-Brzezinska et al. 2007). These types of CORS Networks are called RTK CORS, CORS-Active and so on to distinguish them from the old type of passive CORS networks. (Rizos et al, 2003, Wübbena et al, 2001, Retscher, 2002).

A CORS Service Provider, who sells user subscriptions, manages the CORS. The CORS Service Provider chooses the Network RTK method the server will use. Therefore, this choice will ultimately influence the quality of RTK solution that can be achieved at the rover. The CORS Network is designed to provide data to GPS rover receivers by continuously monitoring and correcting the positional data from the GNSS satellite constellations. The transmission of the correction factors via the internet and monitoring and reporting the timing errors to the central computing component allows for real time correction and adjustment of the coordinates to allow the rover to perform the its job higher level of accuracy (Lachapelle et al, 2002; Cruddace et al, 2002; Bray and Greenway, 2004)

If RTK could be carried out in a perfect environment, with no atmospheric biases and no satellite orbit bias, there would be no need to restrict the range between a base station and the rover. Unfortunately, the Earth’s environment is never a perfect environment for GPS. This environment leads to distance dependant errors which restrict the range at which a rover can compute an RTK position fix. Atmospheric delays are the main error sources for medium-range relative positioning, hence the main challenge for a NRTK system is the computation and representation of atmospheric delay errors for users. The major difference between the methods is that they use different approaches to make corrections for the rovers. (URL2)

Every CORS network consists of several GNSS stations interconnected by reliable communications to enable real time computations and control. Each station, as a minimum, requires a receiver, an antenna, communications and a power supply. In most cases a computer is installed additionally for data transmission and control. In ideal cases a supplementary configuration is used for reliability or 'back up' reasons. Additionally a user interface is required to configure and maintain the network. This may be realized remotely e.g. by radio communication or by mobile phones or via internet connection. If we are talking about an offline network that provides the information to the user for post-processing, the stored data files use 'RINEX' format (Wübbena and Willlgalis, 2001).

The RTK CORS server collects satellite observations from the CORS Network, performs calculations, and sends RTK corrections to the rover. There are a few RTK correction techniques available, namely Virtual Reference Station method, FKP method and MAC method (Wanninger, 2002). The Virtual Reference Station (VRS) corrections are optimized for the rover position at the beginning of the RTK session. If the rover then moves a considerable distance within the same session (i.e. without disconnecting and reconnecting) the corrections might not be appropriate for the new rover location (Landau et al., 2003). With the Virtual Reference Station method the rover does not receive any observations related to a real reference station. This means that the baseline between the virtual reference station and the measured point cannot be directly remeasured. This violates the fundamental surveying principles of traceability and repeatability (Wanninger, 1999; Vollath et al 2000, 2001, 2002, 2003; Roberts et al, 2004).

The FKP (Flächen-Korrektur Parameter or Area Correction Parameters) method creates area correction parameters represented as simple planes (East- West and North-South gradients) that are valid for a limited area around a single reference station. The FKP method is a broadcast method and does not require the RTK rover to send its current position to the network central server. Instead, the server models the distance dependant errors and sends RTK data from one reference station within the network to the rover, along with the model (Wübbena et al., 2001). In this method the server calculates the network solution (area correction parameters) to reduce the distance dependent errors. This means the network solution is not optimized for the rover's position and might be limiting the RTK solution. Typically the correction parameters calculated at the server are based on the assumption that the distance dependent errors change linearly between reference stations. However, interpolation errors will occur at the rover if the true errors are non-linear. This can result in poor position quality or problems in the ambiguity fixing. To resolve this issue, the user can disconnect and start a new session to generate a new reference station, or the server may automatically generate a new reference station. However, (in either case) generating new reference stations can cause jumps in position and accuracy. Therefore, the user can end up with inconsistent positions and accuracies throughout their survey. (Wubbena et al., 2001, 2004; Vollath et al., 2000, 2001, 2002, 2004).

In the Master Auxiliary Concept (MAC), the RTK CORS server sends full raw observations and coordinate information for a single reference station, the Master Station, for all other stations in the network (or a suitable subset of stations), the ambiguity-reduced data of every reference station. Therefore, it maximizes the use of all satellite data to calculate the best possible RTK solution. The Master Auxiliary Concept gives the rover the flexibility to perform either a simple interpolation of the network corrections like FKP, or a more rigorous calculation (e.g. calculate multiple baselines from the auxiliary reference stations). This means the rover can monitor the RTK solution and change its calculation on-the-fly to optimize the RTK solution. The rover has the possibility to adapt to the prevailing atmospheric conditions by using an appropriate number of reference stations (e.g. to model larger scale atmospheric activity). The MAC corrections allow the rover to measure a baseline to the master station – a real reference station. Therefore, the measurements are traceable and repeatable (Brown et al., 2006)

This article gives a detailed information on the Turkish RTK CORS Network, CORS-TR Network, later changed its name to TUSAGA-Aktif Network, and its infrastructure. TUSAGA-Aktif Network has been established by Istanbul Kultur University in association with the General Directorate of Land Registration and Cadastre of Turkey and the General Command of Mapping of Turkey and sponsored by the Turkish Scientific and Technical Research Agency (TUBITAK).

As with all CORS networks established all around the world, TUSAGA-Aktif (CORS-TR) aims to determine positions fast, economically and reliably with cm accuracy within minutes even seconds. However, TUSAGA-Aktif also targets to provide a means to model the atmosphere (troposphere and ionosphere), to predict weather (Roberts et al, 2005; Musa et al, 2005) and to monitor plate tectonics with mm-level accuracy leading to improvement of earthquake prediction and early warning systems (Brownjohn et al, 2004) and to determine datum transformation parameters between the old system ED50 (European Datum-1950) and ITRF97 (NADCON, 2004; Kempre et al, 2006).

2. PLANNING AND ESTABLISHING TUSAGA-AKTIF (CORS-TR) NETWORK

A comprehensive prototype test was carried out in Turkey in the Marmara region (roughly 300 x 150 km) in order to optimize the network design, to test different RTK techniques, and to market the GNSS receivers and control center software packages. As far as the network-base RTK CORS is concerned, this is probably one of the most comprehensive prototype tests in the world (see Eren et al, 2009). After conducting the prototype test, it is decided, accounting for geographical conditions of Turkey, that reference stations are a) to be established in city centers in order to meet intense user demands and b) to be on rigid grounds c) easily accessible for logistic purposes d) close to energy and communication facilities e) to be situated in a way that plate tectonics are suitable to monitor and f) to be apart less than 100 km ibid, 2009). According to these criteria a total of 147 reference station locations are determined (see Fig.1).

Figure 1. Locations of TUSAGA-Aktif (CORS-TR) reference stations

All TUSAGA-Aktif reference stations are named in accordance with IGS regulations having only four characters. Table 1 lists all the station names and locations including the four in Northern Cyprus.

Table 1. Station names and their locations (on the next page)

No	Station Name	Province	County	No	Station Name	Province	County	No	Station Name	Province	County
1	ADAN	Adana	Yüregir	51	ERZR	Erzurum	Merkez	101	MIDY	Mardin	Midyat
2	ADIY	Adiyaman	Merkez	52	ESKS	Eskisehir	Merkez	102	MUGL	Mugla	Merkez
3	AFYN	A.Karahisar	Merkez	53	DINA	Afyon	Dinar	103	MURA	Van	Muradiye
4	AGRD	Agri	Merkez	54	FASA	Ordu	Fatsa	104	MUUS	Mus	Merkez
5	AKDG	Yozgat	Akdagmadeni	55	FEEK	Adana	Feke	105	NAHA	Ankara	Nallihan
6	AKSI	Antalya	Akseki	56	FETH	Mugla	Fethiye	106	NEVS	Nevsehir	Merkez
7	AKHR	Konya	Aksehir	57	FINI	Antalya	Finike	107	NIGD	Nigde	Merkez
8	AKSR	Aksaray	Merkez	58	GEME	Sivas	Gemerek	108	ONIY	Osmaniye	Merkez
9	AMAS	Amasya	Merkez	59	GIRS	Giresun	Merkez	109	OZAL	Van	Özalp
10	ANMU	Içel	Anamur	60	GUMU	Gümüshane	Merkez	110	POZA	Adana	Pozanti
11	ANRK	Ankara	Merkez	61	GURU	Sivas	Gürün	111	RDIY	Tokat	Resadiye
12	ANTL	Antalya	Merkez	62	GYUR	KKTC	Güzelyurt	112	RHIY	Erzincan	Refahiye
13	ANTE	Gaziantep	Sehitkamil	63	HAKK	Hakkari	Merkez	113	RZE1	Rize	Merkez
14	ARPK	Malatya	Arapkir	64	HALP	Konya	Halkapinar	114	SALH	Manisa	Salihli
15	ARDH	Ardahan	Merkez	65	HARC	Bursa	Harmancik	115	SAMN	Samsun	Merkez
16	ARTV	Artvin	Merkez	66	HATA	Hatay	Antakya	116	SARY	Tekirdag	Saray
17	AYD1	Aydin	Merkez	67	HYMN	Ankara	Haymana	117	SARV	Karaman	Sariveliler
18	AYVL	Balikesir	Ayvalik	68	HEND	Sakarya	Hendek	118	SEND	Hakkari	Semdinli
19	BALK	Balikesir	Merkez	69	HINI	Erzurum	Hinis	119	SIHI	Eskisehir	Sivrihisar
20	BAND	Balikesir	Bandirma	70	HORS	Erzurum	Horasan	120	SIRT	Siirt	Merkez
21	BTMN	Batman	Merkez	71	IGIR	Igdir	Merkez	121	SLEE	Istanbul	Sile

22	BAYB	Bayburt	Merkez	72	INEB	Kastamonu	Inebolu	122	SILF	Mersin	Silifke
23	BEYS	Konya	Beysehir	73	ISPA	Isparta	Merkez	123	SINP	Sinop	Merkez
24	BILE	Bilecik	Merkez	74	ISTN	Istanbul	Bakirköy	124	SIRN	Sirnak	Merkez
25	BING	Bingöl	Merkez	75	IZMI	Izmir	Konak	125	SIVS	Sivas	Merkez
26	BOGZ	Yozgat	Bogazliyan	76	IZMT	Kocaeli	Izmit	126	SIVE	Sanliurfa	Siverek
27	BOLU	Bolu	Merkez	77	KRBK	Safranbolu	Merkez	127	SUNL	Çorum	Sungurlu
28	BOYT	Sinop	Boyabat	78	KAMN	Karaman	Merkez	128	SURF	Sanliurfa	Merkez
29	BURS	Bursa	Osmaniye	79	KAPN	Konya	Karapinar	129	SSEH	Sivas	Susehri
30	CMLD	Ankara	Çamlidere	80	KARB	Istanbul	Karaburun	130	TVAN	Bitlis	Tatvan
31	CANA	Çanakkale	Merkez	81	KRS1	Kars	Merkez	131	TEKR	Tekirdag	Merkez
32	CANK	Çankiri	Merkez	82	KSTM	Kastamaonu	Merkez	132	TOKA	Tokat	Merkez
33	CATK	Van	Çatak	83	KAYS	Kayseri	Melikgazi	133	TRBN	Trabzon	Merkez
34	CAVD	Burdur	Cavdir	84	KESA	Edirne	Kesan	134	TUFA	Adana	Tufanbeyli
35	CESM	Izmir	Çesme	85	KLIS	Kilis	Merkez	135	TNCE	Tunceli	Merkez
36	CIHA	Konya	Cihanbeyli	86	KIRL	Kirklareli	Merkez	136	UDER	Erzurum	Uzundere
37	CORU	Çorum	Merkez	87	KIRI	Kirikkale	Merkez	137	USAK	Usak	Merkez
38	DATC	Mugla	Datça	88	KIKA	Manisa	Kirkagaç	138	VAAN	Van	Merkez
39	DEIR	Manisa	Demirci	89	KIRS	Kirsehir	Merkez	139	VEZI	Samsun	Veziköprü
40	DENI	Denizli	Merkez	90	KNYA	Konya	Selçuklu	140	VIRA	Sanliurfa	Viransehir
41	DIDI	Aydin	Didim	91	KLUU	Konya	Kulu	141	BASK	Van	Baskale
42	DIPK	KKTC	Dipkarpaz	92	KURU	Bartin	Kurucasile	142	YENC	Çanakkale	Yenice
43	DIVR	Sivas	Divrigi	93	KUTA	Kütahya	Merkez	143	YOZT	Yozgat	Merkez
44	DIYB	Diyarbakir	Merkez	94	LEFK	KKTC	Lefkosa	144	YUNK	Konya	Yunak
45	EDI	Edirne	Merkez	95	MGO	KKTC	Mago	14	ZO	Zongu	Merkez

	R				S		sa	5	NG	ldak	
46	EKIZ	K.Maras	Ekinözü	96	MALY	Malatya	Merkez	146	AHGK	Ankara	Merkez
47	ELAZ	Elazig	Merkez	97	MALZ	Mus	Malazgirt				
48	EMIR	Afyon	Emirdag	98	MARA	K.Maras	Merkez				
49	ERGN	Diyarbakir	Ergani	99	MARD	Mardin	Merkez				
50	ERZI	Erzincan	Merkez	100	MRSI	Mersin	Merkez				

The type of monumentation of all 147 reference stations are decided upon ground and regional conditions. Concrete pillar are chosen for rigid ground stations while galvanized steel pillars are constructed for roof tops and roof terraces.

However, the heights of pillar change in terms of where they are put up. 86 of them are 2m tall concrete pillar, including ground pillars (see Fig. 2) while 58 pillars on roof terraces are 3m (see Fig. 3) and only 3 of them on roof tops is 4 m galvanized steel pillars (see Fig. 4)

Figure 2. Concrete pillar (2 m)

Figure 3. Galvanized steel pillar (3 m)

Figure 4. Galvanized steel pillar (4 m from the base of roof)

3. CONTROL CENTERS

Two control stations (Master and Auxiliary) are established both in the capital city Ankara. Master Control Station is situated in the Photogrammetry and Geodesy Administration of the General Directorate of Land Registration and Cadastre of Turkey and the Auxiliary Control Station in headquarters of the General Command of Mapping of Turkey (see Fig. 5).

All the data from TUSAGA-Aktif reference stations are automatically sent via internet to these control centers in which the network computations and positioning corrections are carried out and send them to users in the field. Control centers have a robust central software as well as servers. This software carries out these functions:

- Connecting all reference stations and transferring observations,
- Computing coordinates of reference stations ,
- Modeling errors, computing corrections and broadcasting to rover stations (users),
- RTK services,
- Web services,
- Monitoring rovers,
- Storing all the data,

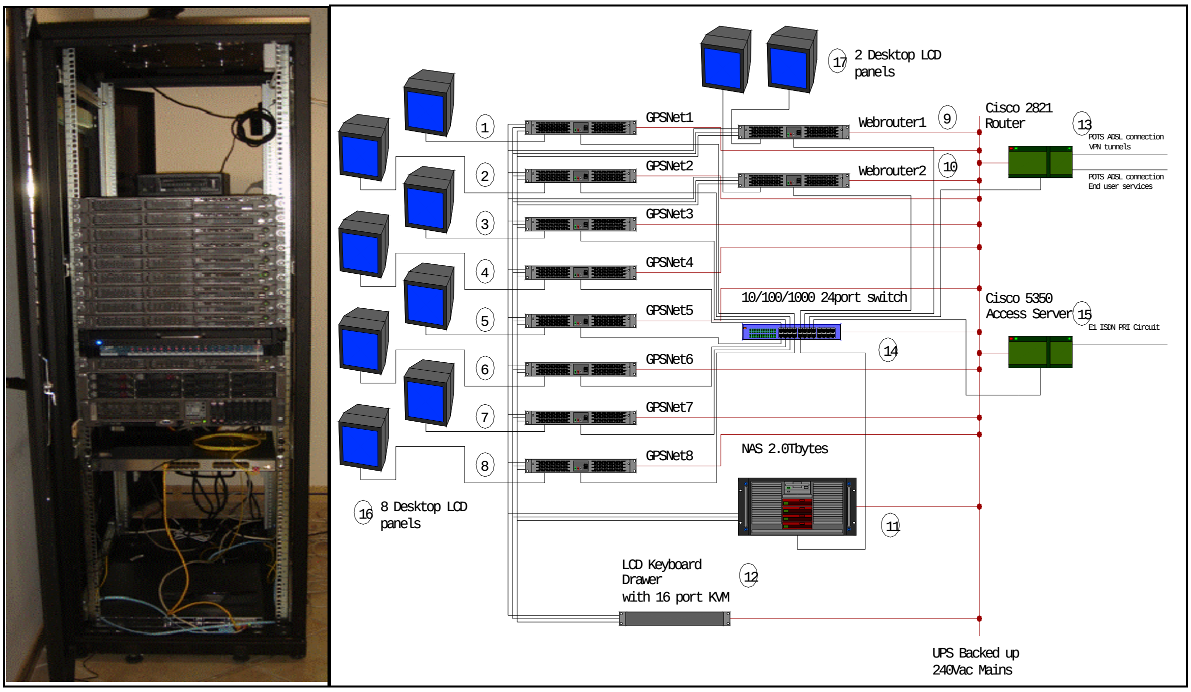

Figure 5. Master Control Station and its schematic representation

Table 2 lists all the hardware and software contents of both Master and Auxiliary Control Stations which both have a capability of computing and sending real time kinematic GPS corrections. The software for control stations is provided by Trimble VRS SW and originally designed for 250 NetR5 reference stations and consists of GPSNet, RTKNet, Webserver, Rover Integrity, Coordinate Monitor and Data Storage modules. It is capable of computing corrections for ionosphere, troposphere, multipath and orbit, and also can broadcast positional correction computed using FKP, VRS and MAC techniques.

For the communication between the control center and rovers RTCM 3.0 and higher protocols are used and thus GSM (cellular phones), NTRIP over GPRS/EDGE and radio links are utilized. NTRIP NTRIP is a protocol for streaming Global Navigation Satellite System (GNSS) data over the Internet. Based on the Hypertext Transfer Protocol HTTP/1.1. NTRIP began as an RTCM standard designed for disseminating differential correction data (e.g in the RTCM-104 format) or other kinds of GNSS streaming data to stationary or mobile users over the Internet, allowing simultaneous PC, Laptop, PDA, or receiver connections to a broadcasting host. NTRIP is designed to be an open non-proprietary protocol and has gained word-wide recognition as a useful means of transporting GNSS data. Wireless Internet services and Mobile IP Networks like GSM, GPRS, EDGE, or UMTS are all quite capable of carrying NTRIP streams.

The TUSAGA-Aktif (CIRS-TR) network equipped with NetR5 reference stations and control centers provides RTK GPS positioning 24 hours a day all over Turkey and the North Cyprus.

Table 2. Contents of Master and Auxiliary Control Stations.

Contents	Mstr	Aux
DL140G3 Dual-Core X5110 3.00 GHZ-1x4mb 1gb 80gb SATA 1U Rack; Windows 2003 Server	8	4
DL140G3 Dual-Core 2x X5110 3.00 GHZ-1x4MB 1GB 80GB SATA 1U Rack; Windows 2003 Server; 2x1GB FBD	2	1
NAS HP DL380 2TB SATA Storage Server; Dual-Core; 1GB DIMM; 2x1GB FBD	1	1
StorageWorks Backup Unit with Smart Array	1	1
17" LCD TFT Flat Panel Monitor	10	5
CISCO 2811 Router with VPN encryption; 2x DSL interface	1	1
24-port unmanaged switch	1	1
19" 16-port KWM switch	1	1
19" 42U Server Max cabin with FAN and Thermostat module	1	1
19" Rack console with 17" TFT display, keyboard, mouse, touchpad	1	1
HP A4 laser printer	1	1
Trimble VRS SW (including GPSNet, RTKNet, webserver, Rover Integrity, Coordinate Monitor and data storage) for 150 GNSS stations/nodes	1	1
Microsoft Office (including MS Access)	1	1
Working table	3	3
VNCe SW	11	5
IPCluster SW	2	1

All the reference stations is geographically divided into four regions and thus four GPSnet servers (plus 4 auxliary servers) in the Master Control Center (Fig.6). Each server is backed with an auxiliary server which automatically takes over the work in case of any failure in the main server. The control centers collect RINRX data from the reference stations in 1 second interval for an hour and 30 seconds intervals for 24 hours, and precise ephemerid data are automatically uploaded by the system.

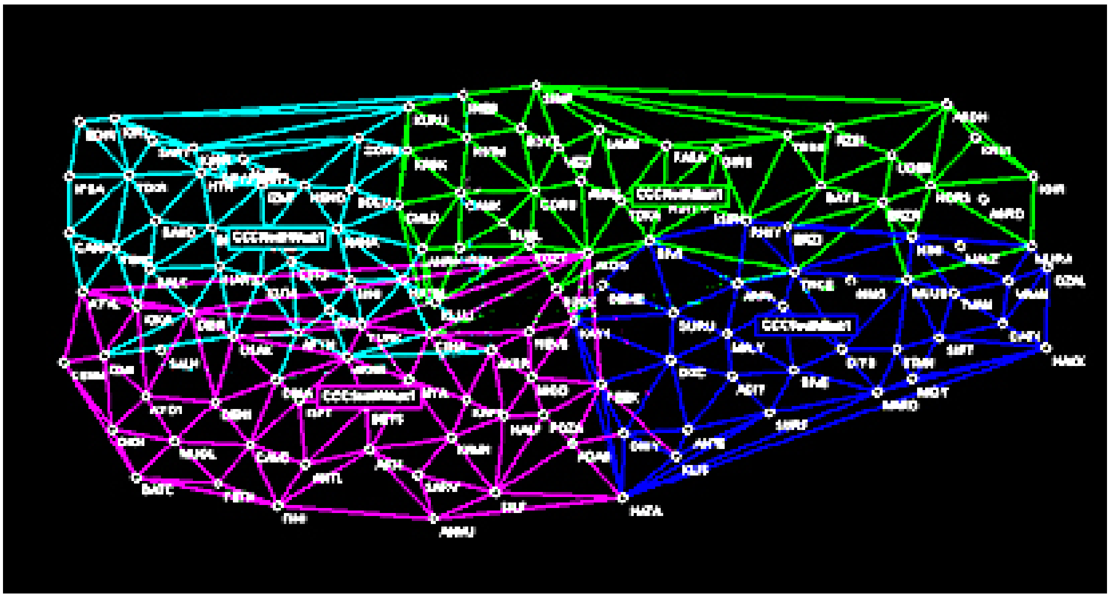

Figure 6. Reference stations and their server regions

The Master and Auxiliary Control Centers broadcast the coordinate correction using VRS CMR+, VRS RTCM 3.1, SAPOS FKP 2.3, RTCM3Net (MAC) and DGPS techniques. A separate webrouter transfers all the data from the reference stations to the main GPSnet servers and auxiliary webrouter in real time. A secondary webrouter is designed to step in as an auxiliary in case of any failure. All the correction broadcasting is maintained through NTRIP Caster and CORSIZ program developed by GRAFTEK INC. manages the users and records all the user information. Furthermore, user or rovers are monitored by the software called CORSTAK implemented by GRAFTEK INC. over Google Earth^{TM} in real time (Fig. 7)

Figure 7. Monitoring users in real time

For static GPS data, a webserver software is run on webrouter and users can obtain RINEX data for observation time and time interval for any reference station. A TB hotswap RAID (plus an auxiliary) is formed on a NAS (Network Attached Storage) server, storing RINEX data (in Hatanaka format), reports, log files and hourly registry back-ups from all the servers.

4. REFERENCE STATIONS

A total of 147 The TUSAGA Aktif reference stations are established in the field with baseline separation of 70-100 km as deduced from the prototype test. (Fig. 8)

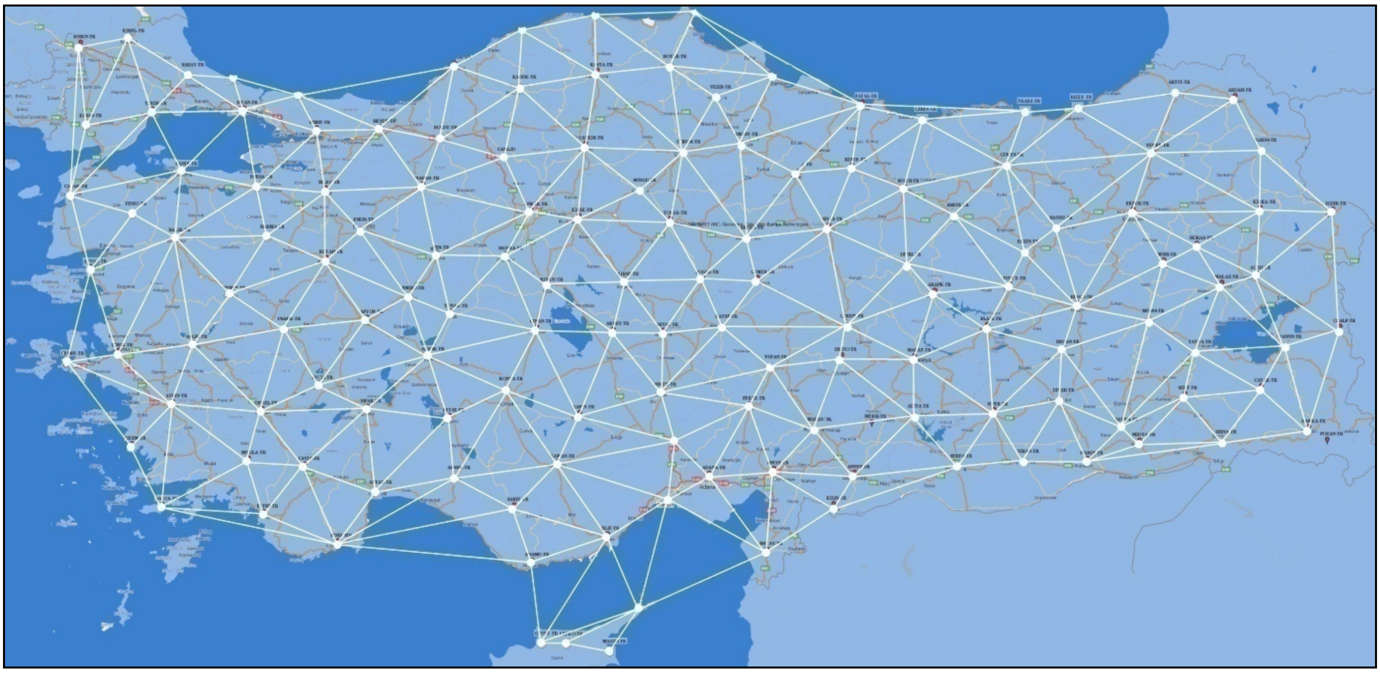

Figure 8. The network of TUSAGA Aktif reference stations

For every reference station, a GPS cabinet is specially designed for TUSAGA Aktif project. These cabinets have glass doors when used indoors or steel doors on outside use. They are designed to work independent of mains electricity problems, fed on 12 Volt DC batteries; in other words, main grid electricity is only used for charging these batteries which can go on working for 48 hours without any electricity charging. Naturally different battery amperes had to be applied depending on the general temperature values of the region where reference stations are. (Fig.9 left)

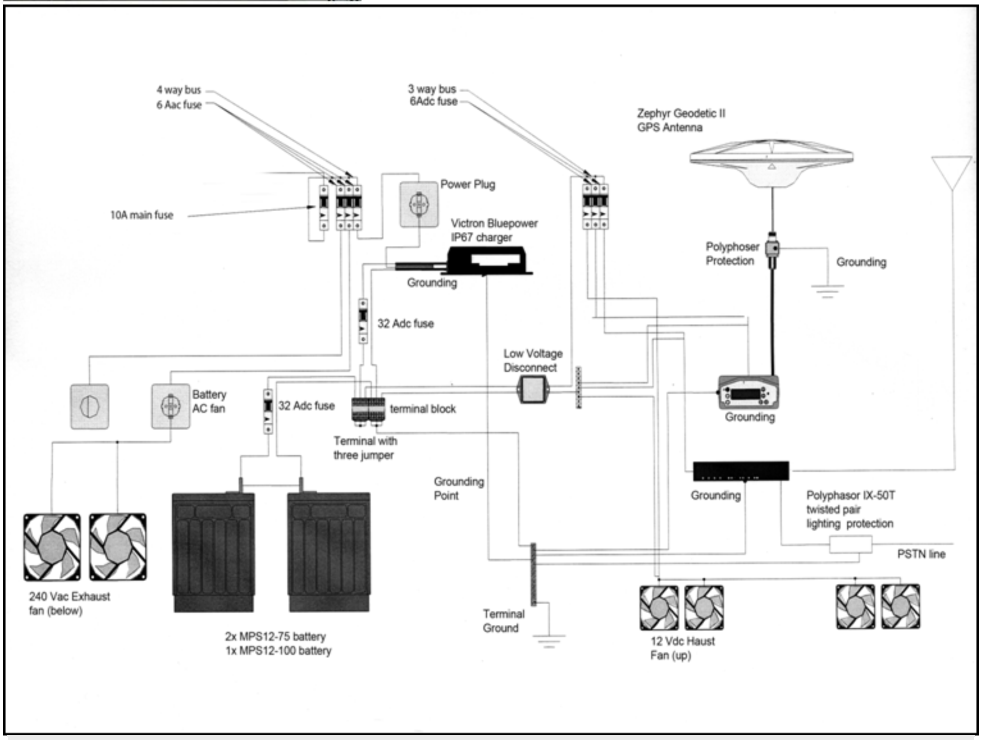

Figure 9. Reference station cabinet (left) and schematic representation of cabinet components (right)

Each cabinet contains a) 1 Victron Bluepower charger/power unit, b) 1 Trimble NetR5 GNSS receiver, c) 1 Sarian DR6410 Router/switch (ADSL/EDGE), d) 1 LVD voltage protection detector, e) lightning arrester for telephone and antenna lines and f) fuses and electronic cabling assembly. (Fig.9 right)

The antennas used on all the reference stations are Trimble Zephyr Geodetic II™ and Radome is also installed on antennas where snow load is expected. All the antennas are placed on pillars leveled by special tripods with fixed height, yielding an extremely precise and standard antenna height.

All the stations possess static IPs and VPN tunnel (internal IP) communication via CISCO routers. However, in case of any router problem, the system is planned to also work with static IPs through a standard regular router.

5. COMMUNICATION

The communication between the control centers and stations are maintained by duplex ADSL and GPRS/EDGE. For this purpose, the Master Control Center has 20Mbit and the Auxiliary 10 Mbit metro internet connection. Moreover it is possible to connect each reference station via GPRS/EDGE.

After carrying out intensive test it is found out that approximately 15 stations do not high quality line connections as the other. The metro connections in the control centers experience some data loss and slowing down especially during the peak times; however, this does not affect the RTK GPS tasks badly because the missing RINEX data are automatically replaced by the back-up ones kept in the centers.

The data send by each reference stations are about 700 byte per second and the total amount data from the stations to the control centers is approximately 1.2 Mbit; concurrently daily RINEX data recorded at 1 second interval 20 Gb while RINEX data (in Hatanaka format) at 30 sec interval is 239 Mb.

6. CONCLUSION

The Turkish RTK CORS Network TUSAGA-Aktif has been serving increasing number of users since at the beginning 2009 and the number has reached over 2100 as of July 2010. It made an enormous impact on around nationwide 4000 GNSS receivers by enhancing their performance %50, and presents a great advantage of establishing a base for all kinds of geographical information systems and technologies. Nationwide cadastral and geodetic tasks will be carried out fast, economically and reliably without the necessity of local reference points. Furthermore, the velocities of the national geodetic points will be determined on daily basis and tectonic plate movements will be monitored effectively because of the fact that Turkey is on active earthquake bearing faults such as the North Anatolian Faults and South Anatolian Fault.

The nationwide cadastre renewal tasks worth 220 million US Dollars has been initiated and the geodetic infrastructural works constitute 20% of these tasks and is estimated to bring about a saving of 35 million US Dollars which is about the seventh of the cost of establishing all the TUSAGA-Aktif network. In the first year the network has already compensated the money that went into establishing and running the system. Apart from the countless professional benefits and applications that this kind of system provides, the financial benefit alone is worth considering for all developing countries all around world.

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