

# **The Kingdom Of Saudi Arabia GNSS Real Time Kinematic Network (MRTN) And Beyond**

## **(A Case Study for High Accuracy VRS Correction Test)**

Ali ALOMAR, Saudi Arabia, Dr. Ramazan YANAR Turkey, Sami ALBALAWI, Saeed ALZAHrani, Saudi Arabia.

**Key words: GNSS Network, Real-Time Kinematic, Positioning**

### **SUMMARY**

The Ministry of Municipal and Rural Affairs, Department of General Directorate for Surveying and Mapping, KSA (MOMRA DGSM) is the competent authority in speeding up the surveying activities of cadastre. This is carried out through the setting up of a surveying infrastructure that includes GNSS horizontal (passive) and Network RTK throughout the country for the eventual purpose of collecting all kinds of geographic data, assuring organized urbanization, constituting the spatial infrastructure for Land Information System (LIS) and relevant works of local municipalities. In line with the government's efforts to enhance its 3D-cadastral system, one of the many initiatives undertaken by MOMRA DGSM is through the use of real-time GNSS survey technology for the dissemination of various geodetic products and services for local municipalities, other governments and companies clients. Since 2014, DGSM has been developing the capability for real-time data streaming from a network of continuously operating reference stations. Currently there are more than 200 stations, with spacing of between 20 to 75 km, providing real-time corrections with a latency of under two second using Virtual Reference Station (VRS) technique. Each station of the network is equipped with a high precision dual frequency GNSS receiver that is operational 24 hours daily. The acquired GNSS data is transferred on a daily basis to the Data Processing Centre at DGSM's Department in Riyadh via the internet. This network is known as the MOMRA Real-Time Network (MRTN), designed to cover most of urban areas . In addition to enhancing and maintaining the GNSS geodetic reference system, applications of MRTN include a critical role in supporting cadastre initiative, land survey activities and the ability to characterize the free electron content (FEC) of the ionosphere. This paper introduces GNSS positioning by way of RTK (VRS) using MRTN services as provided by DGSM. It also outlines the chronicle development and some potential applications of MRTN.

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## **(A Case Study for High Accuracy VRS Correction Test)**

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### **1. BACKGROUND**

#### **1.1 Introduction**

The Ministry of Municipal and Rural Affairs, Department of General Directorate for Surveying and Mapping, KSA (MOMRA DGSM) is the competent in providing both horizontal and vertical survey control for the purpose of 3D cadastral development system and land survey by setting up surveying infrastructure throughout the country. In line with the government's endeavor to improve its cadastral system mechanism, there have been many initiatives made by DGSM. One of them is the effort made to use real-time survey technology for the improvement of its many services and dissemination of various geodetic products rendered by MOMRA for local municipalities, other governments and companies users. In 2014 MOMRA DGSM has implemented a real-time kinematic network project that is known as MOMRA Real-Time Kinematic GNSS Network (MRTN), designed to cover most of urban areas. The system then has around two hundred RTK stations with spacing of between 20 to 75 km, forming the network as a first phase that covering the Major cities in The Kingdom. In an effort to give better services to the user, the MRTN system was expanded and upgraded by including the densifications CORS stations of local municipalities. Under this project, services provided are free of charge throughout the country.

#### **1.2 Scope**

Network Real-Time Kinematic (NRTK) measurements are now widely used for surveying and other precise positioning applications. The single base RTK technique requires that GNSS data can be transmitted from a single base receiver to one or more roving receivers. RTK can provide centimeter position accuracy, but the accuracy and reliability of the single base RTK solution decreases with increasing distance from the Base Station. This limitation on the distance between the roving GPS receiver and the RTK Base Station is due to the systematic effects of ephemeris, tropospheric, multipath and ionospheric errors (Hasan et al, 2010). These systematic errors result in reduced accuracy and increasing initialization time as the distance between base and rover increases. The solution to mitigates the distance dependence errors of the RTK system, is the

Network Real-Time Kinematic that its principle begins with all reference stations within the RTK Network continuously streaming satellite observations to a central server running Network RTK software.

### **1.3 Objectives**

MRTN has been designed with the following objectives in order to take full advantage of the real-time capabilities of the RTK network in 3D cadastral development system and land survey.

- To establish a network of permanently running GNSS base stations, at a spacing of 20 to 75 km, feeding GNSS data to a processing centre via frame-relay Saudi Telecommunications infrastructure network.
- To establish a central facility that will model the spatial errors which limit GNSS accuracy through a network solution and generate corrections for roving receivers positioned anywhere inside the network with an accuracy better than a few centimeters (dense network) to a few decimeters (sparse network) in real time.
- To establish an archive that will make available reference station data (24 hours) to the clients for post-processing throughout the country.

## **2. SYSTEM DESIGN**

### **2.1 Objectives**

The primary purpose in designing the system were for efficient and easy operations, facilitate user understanding of the network and for expandability. The networking protocol used is the Internet Protocol (TCP/IP).

### **2.2 MOMRA Real Time Kinematic GNSS Network (MRTN)**

The RTK Network Solution concept is based on having a network of around 200 GNSS reference stations continuously connected via IP to a Control Centre (Figure 2.1). The computer processor at the Control Centre continuously gathers the information from all GNSS receivers, and creates a living database of Regional Area Corrections (Alomar et al, 2015).

### **2.3 Telecommunications**

The physical telecommunications infrastructure is provided by the Saudi Telecom. This system works by connecting any respective site into the Saudi Telekom frame relay network. The service

is available throughout The Kingdom except for some isolated locations. A connection comprising of a modem and separate dual fixed leased line (ADSL/3G, 4G) for each station as primary and backup link for providing the continuity of streaming the data. A schematic representation of the system communications is shown in Figure 2.2.

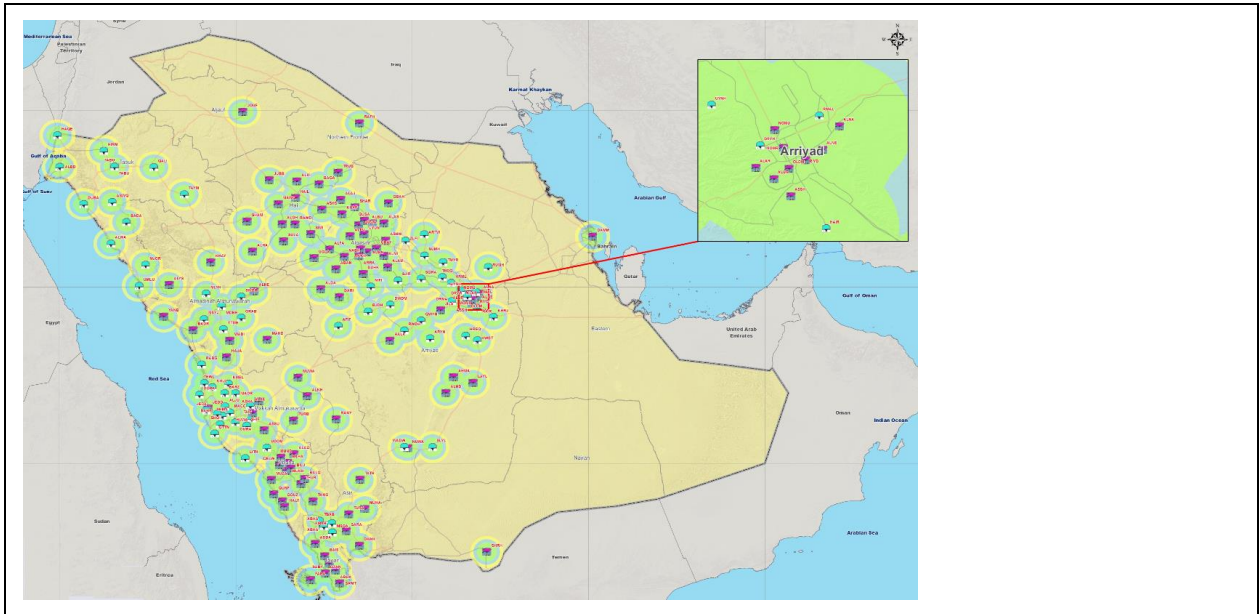


Figure 2.1 MRTN (Phase-1)

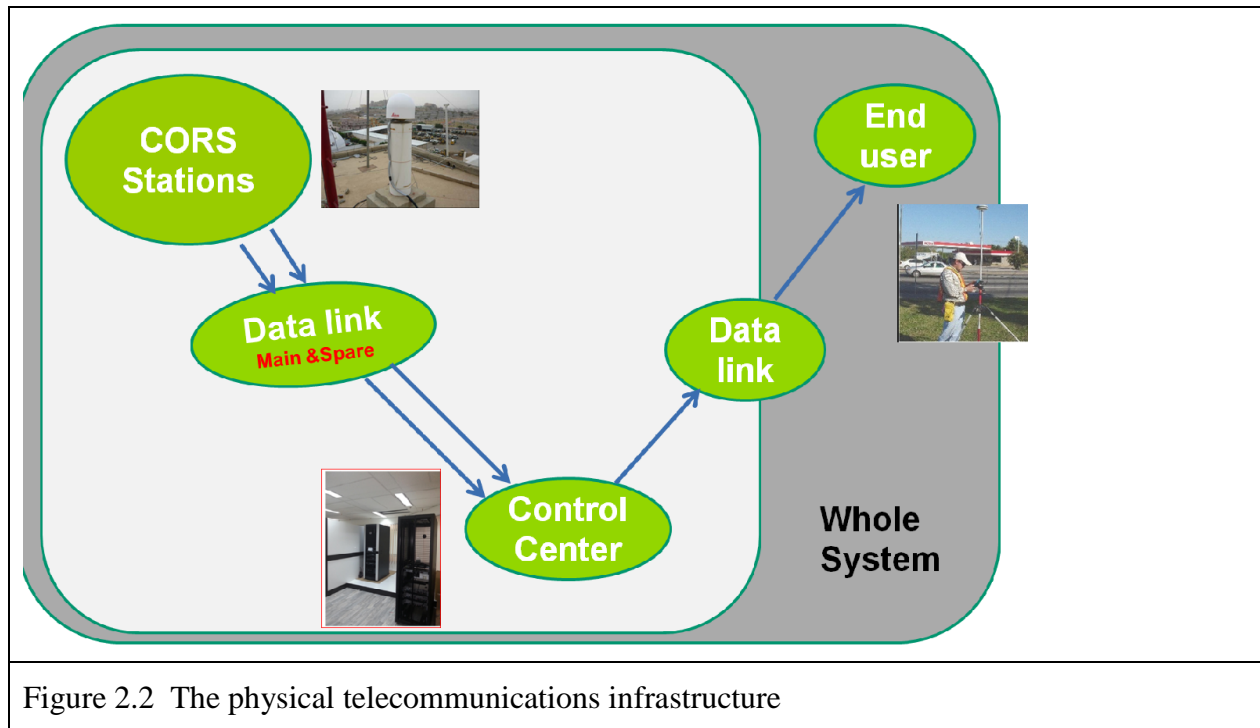


Figure 2.2 The physical telecommunications infrastructure

### 3. REFERENCE STATIONS

All MRTN network stations are located to the major urban areas of Saudi Arabia and monumented on rooftop of building as concrete and iron pillar (Figure 3.1) in order to benefit from the municipalities services. The distances between reference stations are varied in the range of 20-75km.

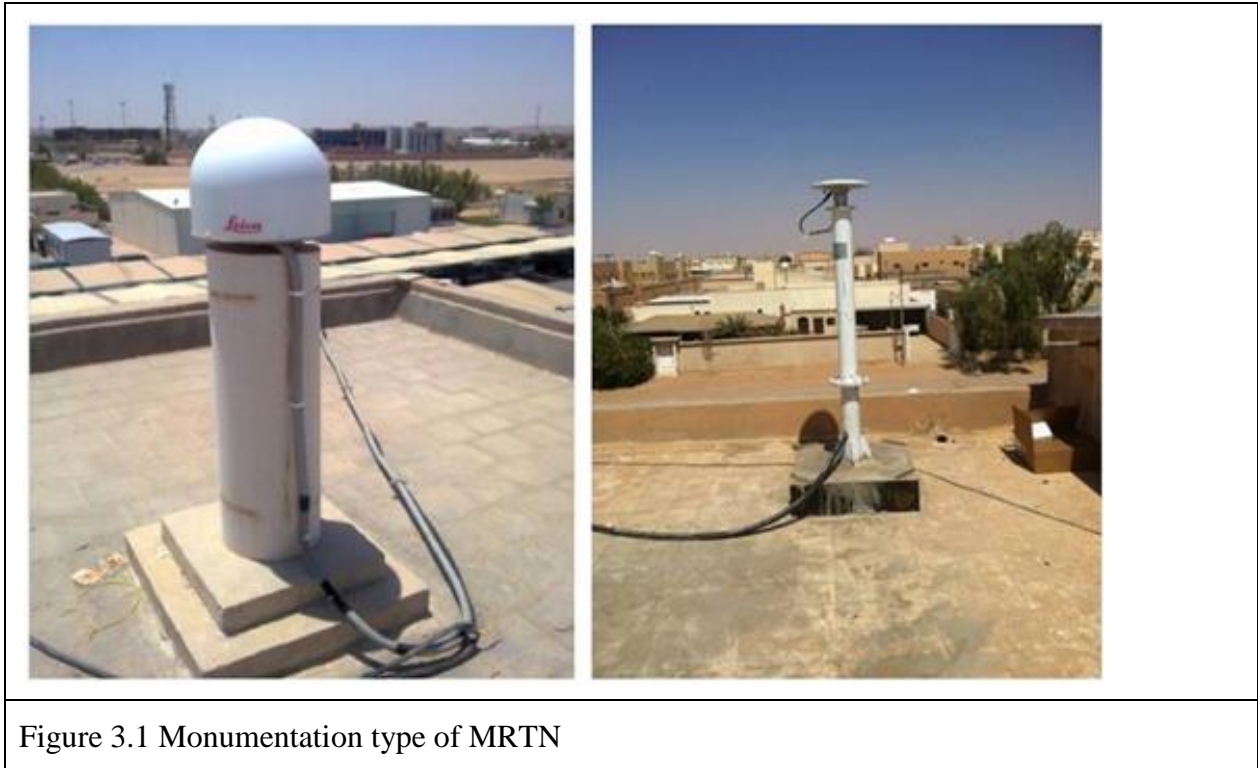


Figure 3.1 Monumentation type of MRTN

Some of the main part of hardware of the Reference Station consists of the following:

- GNSS Receiver
- Geodetic antenna
- Router
- Battery Protector
- Enclosure AC cooling fan
- Lightning protection
- Cabinet/Rack to house the receiver and all accessories.

The system is designed for autonomous operation and is able to run for 48 hours without power.

#### **4. DATA CONTROL CENTER (DCC)**

##### **4.1 Hardware**

The hardware for the DCC configuration is shown in Figure 4.1.

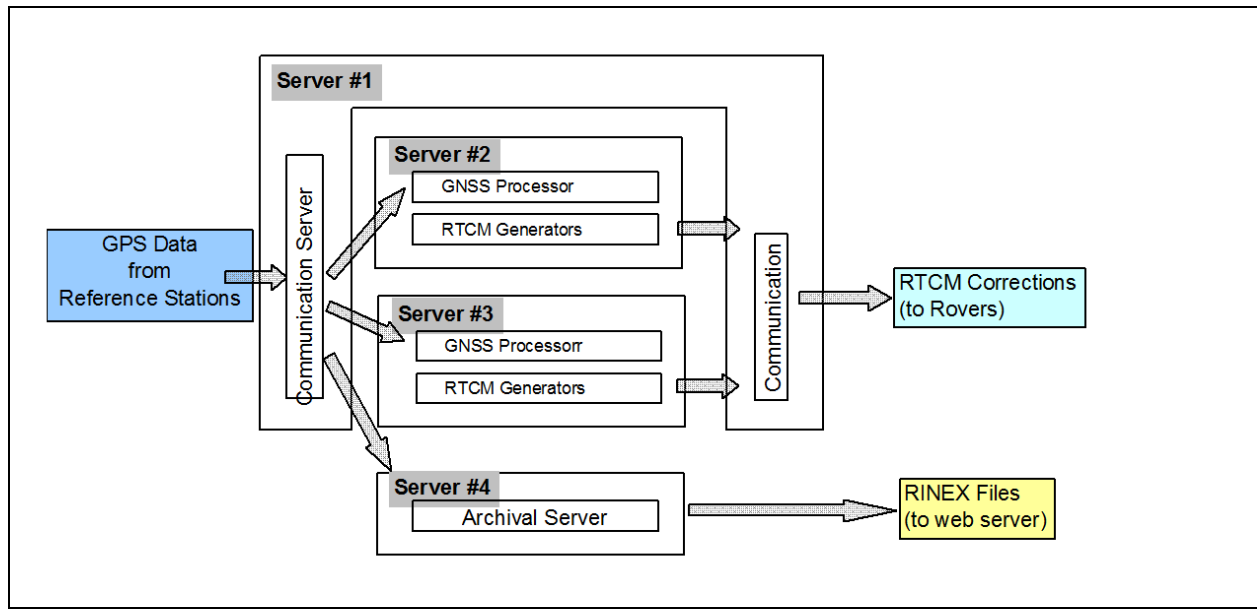


Figure 4.1 DCC Hardware design

The Data Control Centre consists of the following:

- Server racks and rack console,
- Modem/routers/switches
- Firewall,
- UPS (for minimum 48 hours)
- Peripherals for communication with GNSS-CORS stations,

The main activities of DCC consists of :

- Providing communication with GNSS-CORS and rover receivers;
- Getting data from GNSS-CORS receivers;
- Modeling errors;
- Calculating VRS corrections;
- Data screening;
- Creation of virtual data; and
- RTCM output.

## 4.2 Software Systems

The functionality and success of GNSS-CORS depend on the power of Data Control Center Software package. Trimble Pivot (VRS3Net bundle) Software Package has been installed for DCC of MRTN.

The main functionality of the VRS3Net consists of :

- Data collection from the reference stations
- Data storage and processing in the control center
- Transmission of correction data to field users

## 4.3 Virtual Reference Station Connection

### 4.3.1 Reference Station

The Stream server is configured to connect to the reference stations in socket client (TCP/IP connections) mode. This connection will initialize the receiver and start the data stream. It will then setup socket servers that can be connected to by the MRTN servers to receive the streamed data. This connection will initialize the receiver and start the data stream.

### 4.3.2 Remote User

Communication server is configured in socket server mode for the RTK Network module. The remote user will use the registered STC Internet Connection through GSM or GPRS to access the MOMRA Data Control Centre. When a call comes in, the router will authenticate the user before connecting to the system, by using the username and password. If it is in the authorization database, the connection is allowed to proceed, The field user is now connected and following the reception of a GGA NMEA string by the communication server which it will begin sending RTK corrections from a 'virtual base' whose coordinates are based from the field user submitted Global Positioning System Fix Data (GGA) string.



## 5. MRTN SERVICES

### 5.0. VRS Overview

Real time GNSS measurements are becoming an essential part of surveying. During the last decade several real time methods have been introduced. One of the most sophisticated one, Virtual reference station (VRS) is using GNSS CORS network to mitigate typical errors inherent to real time GNSS positioning. VRS uses a technique that calculates corrections for systematic errors (multipath, atmospheric and ephemeris) based on real time data from all reference CORS stations. By modeling these errors from the network data and simulating local reference station with respect to rover position it is possible to diminish the errors inherent to single base RTK measurements and increase the coverage area (Häkli, 2004). A further advantage of the VRS concept is that in the rover receiver standard RTK processing algorithms are employed and no modification of the receiver hardware or software is required (Retscher, 2002).

The basic principles of Virtual Reference Stations (VRS) operation are given in the following overview (Ulrich et al, 2000):

- Data from the reference station (CORS) network is transferred to a data control center.
- The network data is used to compute models of ionospheric, tropospheric and orbit errors.
- The carrier phase ambiguities are fixed for the network baselines.
- The actual errors on the baselines are derived in centimeter accuracy using the fixed carrier phase observations.
- Linear or more sophisticated error models are used to predict the errors at the user location.
- A VRS is created at the user location.
- The VRS data is transmitted to the user in standard formats (RTCM).

This concept is visualized in Figure 5.1. Base station data from CORS stations are used to predict the errors at the Rover location.

The user set-up in the field follows this procedure:

- The field receiver determines the user location with a navigation solution (no reference) or by DGPS (uncorrected data)
- The receiver dials into the data control center via mobile phone and is authenticated. The navigation solution is transferred to the data control center.
- The data control center immediately starts to send Virtual Reference Station data to the field user.

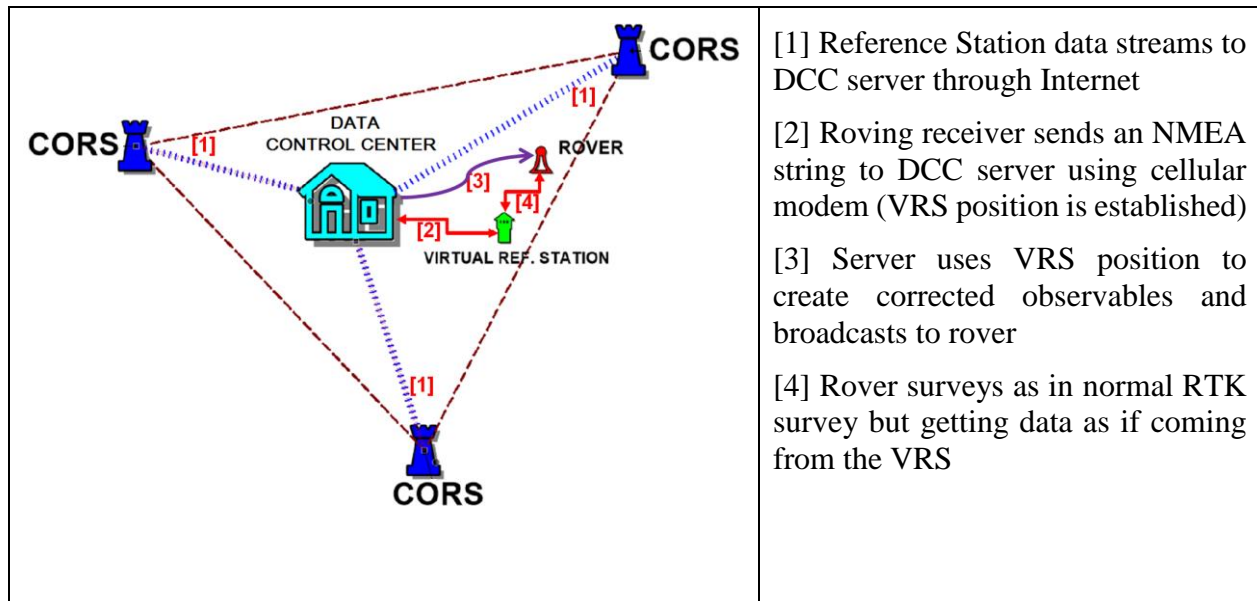


Figure 5.1. Virtual Reference Station Network

### 5.1 VRS Correction

MRTN provides VRS GNSS corrections with an accuracy of 1 to 3 cm horizontally and 3 to 6 cm vertically. Distance dependent errors are considerably minimized, thereby achieving increased accuracy and reliability.

### 5.2 Static Correction Data

MRTN solutions provides data for post-processing of static survey sessions, enabling positioning in the order of millimeter limit. The data is provided on demand in the standardized RINEX format. Information with a data rate of 1-30 seconds is stored indefinitely. Post-processing provides the highest accuracy and is suitable where increased precision is required.

### 5.3 Hardware Requirement

MRTN solutions correction can be applied to any mobile receiver capable of connecting to the communication server of the DCC. Communication server, therefore, is a requirement of the VRS correction service. Presently, there are mobile receivers which have both the capabilities of wireless connection to the data collector. Any single or dual frequency GNSS receiver can be used to collect

data and for static correction data application, post-processing software package is needed to reduce the data to final position that uses standard RINEX files.

## 5.4 Possible Field Applications

MRTN services can be used for various surveying applications ranging from setting up of control to the detailing of project sites; its usage will benefit not only the surveyors, but also many other GNSS users who rely on these utilities to locate their positions. The following are some of the possible field applications of Network RTK services (Hasan et al, 2010):

<ul style="list-style-type: none"><li>▪ Cadastral survey,</li><li>▪ Engineering Survey (i.e Riyadh metro network Project),</li><li>▪ Topographic Survey,</li><li>▪ Boundary Survey,</li><li>▪ Construction Staking,</li></ul>	<ul style="list-style-type: none"><li>▪ Utility Extension Survey,</li><li>▪ Flood Survey Study and Analysis,</li><li>▪ GIS Applications,</li><li>▪ Control surveys for monumentation,</li><li>▪ Mapping survey,</li><li>▪ Aerial Imagery.</li></ul>
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## 6. MRTN TESTING

### 6.1 Case Study for High Accuracy VRS Correction Test

The objective of the High Accuracy VRS Correction test is to compare MTRF observed coordinates with their corresponding published MTRF geodetic values. The test was carried out at the existing MTRF geodetic network. An example of the layout of the network test site is shown in Figure 6.1.

Test site is split to regions based on the administrative regional division of the Kingdom of Saudi Arabia (Figure 6.1). Those are Hail, Qassim, Riyadh, Madinah Al-Munawwarah, Makkah Al-Mukarramah, Asir and Jizan. Existing stations of MOMRA Geodetic Main Network (MGMN) within each region are used as known stations. The Hail and Qassim results only are illustrated in this paper.

### 6.2 Hardware Used

Two rover equipments (Trimble R10) is carried out the measurements during two months. Distances between MGMN and nearest network station varied in the range of 30 km.

### 6.3 Measurement Related Factors

Certain standard rules of RTK measurements taking into consideration during the test phase, such as;

- Minimum five common satellites,
- Maximum GDOP value of 8,
- Make repeated measurements,
- Obstacle-free horizon, etc.

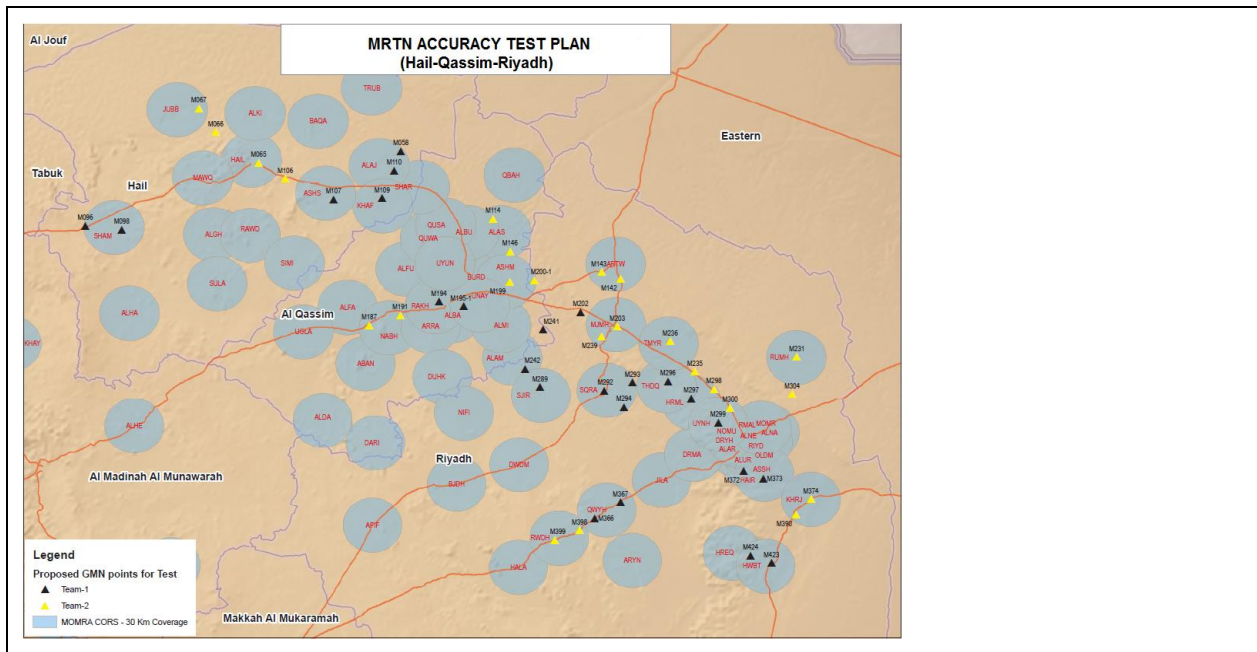


Figure 6.1 MRTN Accuracy Test area

#### 6.3.1. Time to Fix Ambiguity (TTFA)

Time to Fix Ambiguity (TTFA) is limited at first to 10 minutes but after a week it was decreased to 7 minutes. This is limit to stop TTFA and consider it as a failed initialization.

Failed initialization are mainly caused by poor satellite geometry, low amount of satellites or problems with GSM connection and lack of adequate number of network stations. Therefore five minutes could be considered in practice as an adequate limit of starting new initialization. Long initialization time may also reflect bad accuracy (HÄKLI, 2004). User should always be suspicious when initialization takes long time or if there are bad satellite geometry or presence of obstructions.

### **6.3.2. Baseline Length**

The correlation between accuracy and distance to nearest base station and TTFA are studied. Distances varied from 2 to 50 km and total of 100 observations were included in the test. The results shows that the distance to nearest base station seems not to influence on horizontal accuracy at all and only a slight degradation of height accuracy and prolongation of initialization time. This indicates to successful modeling of errors.

### **6.3.3. Rover Position**

The correlation between accuracy and rover position (whether the rover is inside or outside the VRS network) and Time to Fix Ambiguity are studied. In advance this was considered to influence on the accuracy because modeling of errors outside a network requires extrapolation (Häkli, 2004). But the results show that for the accuracy, there is no difference whether the measurements are performed inside or outside the network (10 km further away from the reference station ) where as, for initialization times, correlation is seen when measuring on extrapolation area.

### **6.3.4. Number of Satellites and DOP**

In general increasing number of satellites gives better results because of better satellite geometry and redundant satellites for ambiguity resolving. RTK rover needs at least five common satellites with the base station to resolve the unknown ambiguities with on-the-fly technique. Therefore, during the test the cut-off angle of 10 degrees was used in order to increase the number of visible satellites. The results show that increasing number of satellites decreases the RMS of observations and initialization times get shorter when more satellites are visible.

DOP value describes the distribution of satellites and is important factor while planning the measurements. DOP value multiplied with standard deviation of the measurement gives an estimate of positioning accuracy. Therefore larger DOP value results worse accuracy longer initialization time

### **6.3.5. Number of Epochs**

Adequate number of epochs may have big influence in productivity of VRS measurements We studied whether the amount of epochs have effect on accuracy. Five-epoch observations were chosen based on standard practice used by surveyors and 10 epochs were chosen just to increase the amount of epochs and study whether it has influence on the results. The study was carried out at all the test points during the whole measurement campaign. At every point five-epoch and ten

epoch observations were collected. However from the results we can say that using 10 epochs instead of 5 gives no additional value for the accuracy.

### 6.5.6 High Accuracy VRS Correction Test Results

The final observed coordinates values below (Table 6.1) were the results of the average of the whole set of observations (The coordinates are slightly changed from the real one):

Table 6.1 The final observed coordinates values

No	REGION Name	STATION	MGMN Coordinates			MRTN Measured coordinates			Diff. (m)		
			Northing	Easting	Height	Northing	Easting	Height	DX	DY	DZ
1	QASSIM REGION	M191	915.823	417.811	35.509	915.808	417.793	35.534	0.015	0.018	-0.025
2		M194	193.880	558.439	87.133	193.881	558.444	87.115	-0.001	-0.005	0.018
3		M195-1	249.457	591.726	66.057	249.371	591.744	66.079	0.086	-0.018	-0.022
4		M114	910.804	437.451	75.340	910.781	437.447	75.389	0.023	0.004	-0.049
5		M199	792.691	393.306	28.856	792.702	393.289	28.856	-0.011	0.017	0.000
6		M241	696.615	850.392	87.800	696.639	850.377	87.776	-0.024	0.015	0.024
								RMS <sub>QASSIM</sub>	0.038	0.014	0.027
7	HAIL REGION	M065	112.368	70.993	11.716	112.384	70.984	11.596	-0.016	0.009	0.120
8		M066	372.624	983.663	9.400	372.694	983.676	9.335	-0.070	-0.013	0.065
9		M067	798.994	894.592	87.262	798.955	894.562	87.187	0.039	0.030	0.075
10		M098	257.858	286.800	22.669	257.845	286.798	22.617	0.013	0.002	0.052
11		M096	945.220	953.668	52.630	945.217	953.684	52.581	0.003	-0.016	0.049
12		M106	433.890	482.998	68.270	433.898	483.011	68.280	-0.008	-0.013	-0.010
13		M107	525.995	729.887	92.607	525.980	729.865	92.700	0.015	0.022	-0.093
14		M109	779.740	42.924	33.399	779.729	42.901	33.382	0.011	0.023	0.017
15		M110	492.902	113.358	40.566	492.915	113.350	40.548	-0.013	0.008	0.018
								RMS <sub>HAIL</sub>	0.029	0.017	0.066

The results show that the accuracies in the horizontal and height component were less than 3 cm and 6 cm respectively. It also shows that for areas within 30 km from the network, the accuracies obtained were within the aforementioned levels.

### 6.5.6. Challenges occurred during the study

#### *Surroundings*

Measurements were carried out in Kingdom wide test field where MGMN points were chosen as reference. Each point was measured twice under different satellite geometry. Every time signal is blocked by obstacles a new integer ambiguity for the satellite need to be resolved. This prolongs the initialization time but no big influence on accuracy.

#### *Temporal Variation of Fixed Solution*

Temporal variation of fixed solution is studied. Test was carried out by performing five longer fixed solutions. Duration of the solutions varied from one 10 minutes to 20 minutes and the observations were recorded with frequency of 1 second. The results show that the changes in number of satellites during the period is not affected the accuracy. Instead there is clear correlation between accuracy and PDOP. Therefore measurements during poor satellite geometry should be avoided.

#### *GSM connection*

GSM connection was stuck few times needing a manual reset of GSM modem in computing centre. This may be caused by GSM modems themselves or weak GSM signal.

### ***Missing Satellite Data***

Another subject that caused problems was missing satellite data from distributed correction. This was caused by unsuccessful modeling or resolving of satellite data in computing centre.

### ***Loss of Fixed Solution***

Loss of fixed solution occurred few times causing a need for new initialization. Losses may be caused by obstacles, sudden changes in atmosphere or multipath.

## **8. CONCLUDING REMARKS**

The MRTN infrastructure uses advanced hardware and software to ensure high quality services that is reliable. MRTN supports multi-GNSS constellation tracking with available channels to track additional signals when they are available. Industry standard correction formats ( CMR, RTCM 2.1, RTCM 2.3, RTCM 3.1) are supported with real-time correction streaming of up to 1Hz. Output data formats supported are also industry standards like RINEX v2.10, RINEX v.2.11 and RINEX v3.02.

The system has around two hundred RTK stations with spacing of between 20 to 75 km, forming the network as a first phase that covering the Major cities in The Kingdom. In an effort to give better services to the users like local municipalities, other governments and companies. The MRTN system was expanded and upgraded by including the densifications CORS stations of local municipalities.

High Accuracy VRS Correction test is carried out using MRTN at MOMRA Terrestrial Reference Frame (MTRF) pillars stations to compare MTRF observed coordinates with their corresponding published MTRF geodetic values. At the meantime, some of accuracy performance of the VRS-concept have been tested as well.

The results show that the accuracies in the horizontal and height component were less than 3 cm and 6 cm respectively. It may be said that , MRTN services can be used for various surveying applications such as engineering (i.e Riyadh metro network Project), boundary and cadastral survey. Under this project, services provided are free of charge throughout the country for all clients.

The Virtual Reference Station technique has proven some of its performance in MRTN network as well. The test performed showed improvements of the performance numbers important for the field user, i.e. Baseline length, time to fix and position accuracy. The web portal ([www.momracors.com](http://www.momracors.com)) can be visit, to observe and have brief idea about MRTN.

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## BIOGRAPHICAL NOTES

**ALI ALOMAR** gained his **MSc** in Cadastral from Riyadh, King Saud University. He has more than 10 years experience in GNSS, Geodetic Network and Cadastral Survey. He is now the manager of Cadastral Department at Ministry of Municipality and Rural Affairs (MOMRA). So far, he has published and contributed various papers and presentations at conferences and meetings.

**Ramazan YANAR** gained a PhD in Geodesy from Istanbul, Yildiz Technical University, he has more than 20 years experience in establishment of Geodetic Networks (GNSS CORS/Network, Horizontal, Vertical, Gravity Network), Geodetic surveys (Land, Cadastral, Topographic survey, Precise GNSS Survey) and Computations, Datum Transformation and Geoid Computations. He now works as Geomatics Technologies Consultant in The Ministry of Municipal and Rural Affairs, Riyadh. So far, he has published and contributed various papers and presentations at conferences and meetings. He is member of International Association of Geodesy (IAG) and Room Chamber of Survey and Cadastre Engineers.

**Sami ALBALAWI** gained his **BSc** in Surveying Engineer from Riyadh, King Saud University in 2001. He has more than 17 years experience in Land and Cadastral Survey. He works in Cadastral Department at Ministry of Municipality and Rural Affairs (MOMRA). So far, he has contributed various papers and presentations at conferences and meetings.



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