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Efficient RTK Positioning by Integrating Virtual Reference Stations with WCDMA Network

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Abstract. The most advanced and proven implementation of the networked RTK is the VRS network concept. Its requirement of bi-directional communications is a critical disadvantage as this limits the robustness of the system. High costs and coverage limitations are also associated with the types of technology (i.e. UHF, GSM and GPRS) required for VRS communications. The Virtual Reference Cell (VRC) approach can be used to mitigate the disadvantages of the VRS network. This approach generates corrections for a fixed number of cells that are broadcast to the rovers. The drawback of the VRC system is a lower positioning accuracy due to the use of DGPS corrections instead of RTK. This paper proposes an RTK-VRC system whereby advantages of the VRC are maintained while achieving RTK level accuracy, mitigating high communications costs and supporting kinematic applications. The RTK-VRC system is an integration of the VRS network, to provide RTK positioning, and the WCDMA wireless network, to provide the cell structure and communications. For this system a novel communications link will be implemented using the pilot channel of the WCDMA network to minimise the communications costs. The results of a field experiment that utilises the NR&M VRS network in Australia shows that RTK positioning accuracy is achievable for VRS baselines of up to 2 km. This supports the idea of using the WCDMA cells with the RTK-VRC system.

Keywords: GPS, Network RTK, VRS, WCDMA, VRC

1 Introduction

The use of multiple reference station networks with real time kinematic (RTK) positioning provides a high precision, centimetre level, satellite positioning service that is extremely reliable and accessible (Retscher, 2002, Fotopoulos and Cannon, 2001). This technology has gained wide acceptance in the geodetic, engineering, earthmoving and public works communities. One proven implementation of the networked RTK is the Virtual Reference Station (VRS) network concept. The VRS concept is widely accepted as the most advanced approach for increased spatial separation of reference stations and error modelling (Retscher, 2002). This system calculates network corrections for systematic errors based on real-time data from all reference stations and simulates a local reference station (or VRS) near a

GPS rover station (Vollath et al., 2002, Vollath et al., 2001). Corrections for the VRS are transmitted through a communications link. This approach eliminates the need for actual reference stations on site as VRS data can be generated for any location within the network coverage area. The reduction in systematic errors allows increased spatial separation between the reference stations while increasing the reliability of the system and reducing the initialisation time (Retscher, 2002).

The underlying requirement for any successful RTK operation, including the VRS network, is the ability to communicate timely and reliable reference station corrections to the rover (Liu, 2004). The VRS network requires a bi-directional communication or data link between the rover and the control centre. To create the VRS data for a rover, its approximate location is initially transmitted uplink to the VRS network control centre. The control centre then generates corrections for that approximate location and transmits downlink to the rover. The downlink corrections are updated at a frequency of 1Hz (Landau et al., 2003b). These corrections are then employed with standard RTK GPS algorithms to obtain a precise position fix. For the rover, the data transmitted uplink is independent of the processing of the downlink corrections.

Retscher (2002) and Zhang and Roberts (2003) assert that the requirement of bi-directional communications is a critical disadvantage of the VRS concept. The generation of corrections specific for each rover limits the robustness of the system; especially when there are a large number of rovers (Retscher, 2002, Zhang and Roberts, 2003); (Petrovski et al., 2001). High costs (Zhang and Roberts, 2003) and coverage limitations are also associated with the type of technology required for VRS communications. The communications technology currently being employed are privately owned UHF radio networks, Global System for Mobile Communications (GSM) networks and General Packet Radio Service (GPRS) networks. The communications technology that is used must be carefully selected due to their inherent limitations. The UHF radio network has a limited coverage area and there are large costs associated with spectrum licensing. The GSM network was primarily designed for voice traffic and does not meet the affordability required for VRS network data transmission. GPRS on the other hand, has been introduced recently and is an affordable data transmission alternative to GSM. However for users that require continuous correction updates over long intervals the GPRS technology is still quite costly.

Another disadvantage of the VRS approach is that it poses a problem for kinematic applications with rovers moving over large network areas (Landau et al., 2003a). Distance dependant errors will be present in the solution as the rover moves away from the VRS (Wübbena et al., 2001).

According to Retscher (2002) the limitations associated with system robustness and the bi-directional communications can be mitigated by using the Virtual Reference Cell (VRC) approach. This is similar to the 'gridded corrections' concept discussed by Wanninger (2002). The VRC approach uses the VRS network to estimate correction models for a cell or gridded DGPS service area. Rovers within a particular VRC are assigned corrections associated with that cell. When the rover leaves a VRC it is assigned to another VRC. The tracking of the rover is thus achieved. This approach eliminates the need for bi-directional communications and a broadcast approach is sufficient. The limitation on the number of users is also eliminated as the corrections need to be calculated for only a fixed number of cells. The drawback of this system however, according to Retscher (2002), is a generally lower positioning accuracy than the VRS. This is due to the use of DGPS corrections and algorithms instead of RTK to obtain a position fix. It is also due to distance dependant errors that become more evident for rovers that are further away from the centre of the VRC. In order to achieve RTK level accuracy using the VRC approach, high communications costs will still be incurred.

In this paper an RTK-VRC system is proposed whereby the advantages of the VRC are maintained while achieving RTK level positioning accuracy. The RTK-VRC system will also mitigate the high communication costs and support kinematic applications.

The basis of this new system will be the integration of the VRS network with the Wideband Code Division Multiple Access (WCDMA) wireless network and infrastructure. This involves using the VRS network to provide RTK positioning and the WCDMA network to provide the cell structure and communications. The radius for WCDMA network cells ranges from 500m to 2 km (Norgaard, 2003). This small radius is ideal for the proposed system. The VRS corrections are generated by the VRS network control centre specific for each WCDMA base station within the VRS coverage area. The corrections are then streamed to the WCDMA base station and then communicated to all rovers within the coverage cell.

The communication of corrections to the rover is achieved through a novel approach that uses the Pilot Channel (CPICH) on the physical layer of the WCDMA base station (3GPP-R1, 2003). This approach hides the communication link within the WCDMA network and thus minimises the costs associated with the data transfer. The total coverage of this system is large and only limited by the VRS network coverage and the WCDMA network coverage.

On the user's end, each rover will be attached to a WCDMA wireless device. This device will be able to distinguish between coverage cells and will be used to receive corrections from the WCDMA base station. These corrections are used by the rover in the same manner as the VRS concept to obtain a precise position fix. When the rover moves from one cell to the other, the VRS corrections for the new cell are automatically adopted. This process also supports kinematic applications as the VRS baselines will not be more than the radius of a cell, thus limiting the distance dependant errors.

The objective of this paper is to demonstrate that RTK positioning accuracy is achievable for VRS baselines of up to 2 km. This supports the proposal of using the WCDMA network cell as the VRC. In the following sections background information on the WCDMA technology is presented followed by an outline of the RTK-VRC system. This will be followed by background information and discussion on field tests that were performed using an existing VRS network. These field tests show that RTK level accuracy is achievable with VRS baselines of up to 2 km. The paper then ends with some concluding remarks.

2 WCDMA

Wideband Code Division Multiple Access (WCDMA) is a third generation (3G) wireless communication system. The 3G systems extend the capabilities of the second generation (2G) wireless systems (only voice and low rate data) to include multimedia capabilities with high bit rates and packet data. WCDMA is based on the robust and well proven code division multiple access (CDMA) technology.

The deployment of WCDMA networks is gradually increasing throughout the world. The WCDMA standards have been designed to naturally supersede the aging 2G GSM networks. Consequently, the widespread use of WCDMA in the near future is imminent.

WCDMA uses direct sequence spread spectrum (Rappaport, 2002) on a 5 MHz bandwidth and operates in the frequency division duplex (FDD) mode and the time division duplex (TDD) mode. This paper will focus on the FDD mode. The WCDMA system features are detailed by Karim and Sarraf (2002) and Rappaport (2002). Some of the main features are listed in Table 1.

Table 1 Main Features of the WCDMA FDD Physical Layer

Channel Bandwidth	5 MHz
Chip Rate	3.84 Mcps
Frame Length	10 ms
No. of slots/frame	15
No. of chips/slot	2560 chips (Max 2560 bits)
Uplink Spreading Factor	4 – 256
Downlink Spreading Factor	4 – 512
Channel Rate	7.5 kbps – 960 kbps

The WCDMA system uses a layered protocol architecture at different interface points, each layer performing a set of specific functions (Karim and Sarraf, 2002). The three layers are the physical layer (L1), the data link layer (L2) and the network layer (L3) (3GPP-R1, 2003). The interrelationship between these layers is described by Wesolowski (2002). The purpose of the physical layer is to condition the digital data from higher layers so that it can be transmitted over a mobile radio channel reliably (Karim and Sarraf, 2002). This conditioning implements signal processing functions, channel coding, interleaving, modulation, spreading and synchronisation to user data (or signalling data). The signal conditioning is performed as part of the process of mapping data received from the higher layers through the transport channels to a physical channel.

Some of the specifications of the physical channels such as the chip rate, frame length, time slots per frame and chips per slot are given in Table 1. The types of physical channels available differ between the uplinks and downlinks. These channels are listed in Table 2 and Table 3 respectively. The functions of these channels are described by Karim and Sarraf (2002).

Table 2 Uplink Physical Channels

Dedicated Physical Data Channel	DPDCH
Dedicated Physical Control Channel	DPCCH
Physical Random Access Channel	PRACH
Physical Common Packet Channel	PCPCH

Table 3 Downlink Physical Channels

Dedicated Physical Channel	DPCH
Common Pilot Channel (Primary & Secondary)	CPICH
Common Control Physical Channel	CCPCH
Synchronisation Channel (Primary & Secondary)	SCH
Acquisition Indicator Channel	AIC

The spreading applied to the physical channels consists of two operations in succession – first the channelisation operation followed by the scrambling operation (3GPP-R1, 2001). The channelisation operation transforms every data symbol into a number of chips, increasing the bandwidth of the signal. The scrambling operation then applies a scrambling code to the spread signal. These successive processes spread the signal energy over a large bandwidth (Yang et al., 2000).

The channelisation operation utilises orthogonal channelisation codes. The codes used for WCDMA are variable-length Walsh codes, also known as Orthogonal Variable Spreading Factor (OVSF) codes (Karim and Sarraf, 2002). Orthogonality here implies that different codes, within a family of codes, are mutually orthogonal. The cross-correlation values between these different codes are zero and therefore there is no interference between channels. This concept allows these orthogonal codes to be used as signature codes to distinguish between the signals from different channels or users (Yang et al., 2000). In the uplink the OVSF codes are used to distinguish between channels transmitted by a user. In the downlink these codes are used to distinguish between users within a WCDMA cell.

The scrambling operation utilises pseudonoise (PN) scrambling codes (3GPP-R1, 2001). The aim of the scrambling is to differentiate between cells and thus reduce inter cell interference. WCDMA base stations are each assigned a scrambling code in the cell planning process. WCDMA wireless devices or mobile stations (MS) must know these scrambling codes in order to synchronise and recover data from the WCDMA base station. The scrambling operation and code generation are further described by Wesolowski (2002). The scrambling operation, together with suitable receiver processing is also important for reducing multipath induced distortion.

WCDMA base stations are called Nodes B and perform the physical layer processing (Wesolowski, 2002). The current cell radii range from about 500 m to 2 km (Norgaard, 2003) for micro and macro cells. As the uptake to WCDMA increases, the cell radii will naturally be reduced to handle the increased load. The identifiable nature of the WCDMA cell and its relatively small cell radius makes it well suited to the RTK-VRC system. The ability to differentiate between cells enables MSs to track their movements from one cell to another. This means that if the Nodes B are used to broadcast RTK corrections for the cell, the rovers (that are connected to the MSs) will be able to distinguish between corrections from one Node B to another. The small cell radius implies that the maximum distance between the rover and the Node B will be about 2 km. This will ensure that the inherent distance dependant errors are relatively low for rovers that use the broadcasted RTK corrections.

The primary Common Pilot Channel (CPICH) for the downlink is the basis of the novel communications link for the RTK-VRC system. The primary CPICH is broadcast over the entire cell and is always present. It is currently used for channel estimation. The channel estimate, in conjunction with the Rake receiver (Rappaport, 2002), is used to recover transmitted signals that have been distorted by the multipath phenomenon. The primary CPICH is also transmitted at a higher power level than the other physical channels. The power of the primary CPICH determines the cell coverage area and the capacity of a cell. This is because the handover of the MS from one cell to another is triggered by a measurement of the primary CPICH strength. Increasing or decreasing the power of the primary CPICH makes the cell larger or smaller (Valkealahti et al., 2002). The channelisation code for the primary CPICH is also currently fixed for all Nodes B (3GPP-R1, 2001).

The proposed communications link takes advantage of the fact that there is currently no logic associated with the primary CPICH; as it is not mapped to channels in the higher layers (i.e. L2 and L3). By modifying the layered protocol architecture, broadcast data will be mapped to the primary CPICH. However, in order to continue its use for channel estimation and cell size determination, and at the same time use it to broadcast data a new encoding method will have to be implemented. This will be achieved through the dynamic use of channelisation codes for the primary CPICH. Each of the channelisation codes that are used will be associated with a specific code word and a conversion table will be used to store these associations. The sequence of channelisation codes will then be used to generate a stream of data to the MS. The MS will also need to be modified to be able to process the dynamic channelisation codes. This includes having the correct conversion table. Without the correct conversion table the MS will not be able to correctly decode the data stream. This process will act like an encryption tool for the communications link.

The disadvantage of this method is that the channelisation codes that will be used with the proposed communications link cannot be reused for any other channel. This restriction combined with the fact that there are a fixed number of OVSF codes available, limits the feasibility of such a method. To overcome this limitation, Quasi-Orthogonal Sequences (QOS) will be introduced as additional channelisation codes. QOS are used as a means of increasing the number of physical channels that are available (Yang et al., 2000). These QOSs will be used in conjunction with the OVSF codes.

QOSs are codes that have low cross-correlation with the OVSF codes. The QOSs provide additional capacity at the expense of some channel interference. This constant and minimal interference is generally outweighed by the operational needs of the WCDMA network. According to Jalloul and Shanbhag (2002) the QOS can be generated by applying a mask to the existing family of OVSF codes.

For the proposed communications link the QOSs will be used as the channelisation codes for the primary CPICH. This means that only one QOS will be used at any period. In this manner, the level of channel interference generated from the QOSs will be minimised.

Applying this simple encoding method in conjunction with the implementation of the QOSs allows the novel communications link to be generated. This link requires the Node B and the MS to have the same conversion table to decode the data stream. This communications link is unavailable to MSs that do not have the correct conversion table. The communications link will be capable of broadcasting at a rate of 12 Kbits per second. This bit rate exceeds the required transmission rate for RTK communications of about 9.6 Kbits per second.

3 RTK-VRC

The proposed RTK-VRC system will exploit the cellular infrastructure and primary CPICH of the WCDMA network to provide a satellite positioning system that will be capable of achieving RTK level accuracy. The application of the RTK-VRC system will consist of three main areas – the correction streaming (from the VRS network control centre), the broadcasting of corrections (by the WCDMA base station or Node B) and the receiving of corrections (by the GPS rover station).

Correction data for the RTK-VRC system will be generated based on the location of each WCDMA cell. The correction data will be streamed from the VRS network control centre to the Node B. This streaming will be achieved using the Networked Transport of RTCM via Internet Protocol (NTRIP) technology. This technology is currently available with some VRS networks. The NTRIP technology is discussed by Lenz (2004).

The Node B then encodes the data using the QOSs. These QOSs are used as channelisation codes for the primary CPICH and broadcast to the WCDMA cell. The MSs within this cell are then responsible for receiving this broadcast and decoding it back to a stream of RTK correction data. This stream of data will then be fed to the rover that is attached to the MS. The rover will then use these corrections to help it obtain a precise position fix.

4 Field Experiments using NR&M VRS Network

In order to demonstrate the availability of RTK level positioning for VRS baselines of up to 2 km an experiment was carried out using the VRS network belonging to the Department of Natural Resources and Mines (NR&M). As the accuracy level plays a crucial role in high precision RTK applications the data collected during the experiment focussed on the correction availability and positioning accuracy.

4.1 NR&M VRS Network

The Department of Natural Resources and Mines (NR&M) is responsible for the surveying and geodetic infrastructure within the state of Queensland, Australia. The NR&M is a department of the State Government. It plays a critical role in the stewardship of natural resources. It also manages and allocates the State's land, water, mineral and petroleum resources, and manages native vegetation and the control of pest plants and animals (NRME, 2004).

In 2000 NR&M, in partnership with Trimble Australia and Ultimate Positioning, established a pilot VRS network. The location of the VRS network is shown in Figure 1. The pilot network was designed to investigate the viability of the VRS concept as a future element of the surveying and geodetic infrastructure in Queensland. The goals for the pilot network and the preliminary test results are set out by Higgins (2001). The VRS network is now setup as a production system. The main service provided by the NR&M VRS network is high precision positioning for surveying and earthmoving equipment.

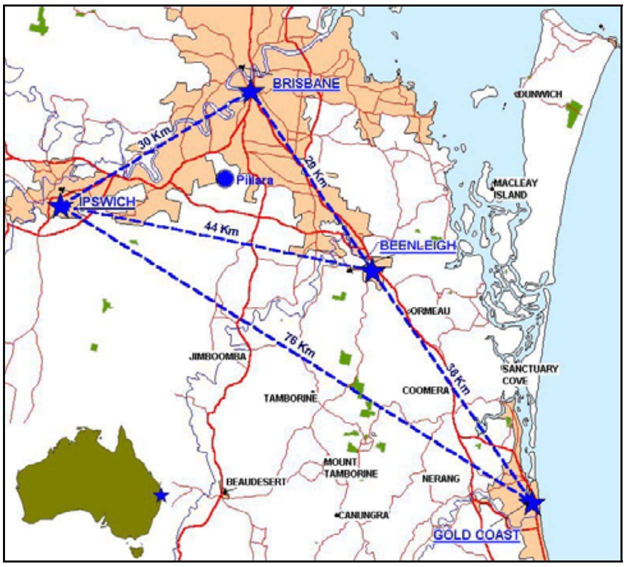

Figure 1 Location of VRS Base Stations

The Gold Coast, Ipswich and Brisbane VRS base stations currently utilise a Trimble 4700 receiver with a choke ring antenna. The Beenleigh VRS base station utilises a Trimble 5700 receiver with a Zephyr Geodetic antenna. The VRS base stations are all linked by a high-speed Wide Area Network (WAN). The VRS network control centre is situated in Brisbane and utilises the Trimble GPSNet VRS software to provide the VRS service. The VRS network is capable of utilising GSM, UHF and GPRS to establish a communication link.

The RTK rover consisted of a Trimble R8 receiver, a Trimble TSCE handheld controller and a standard data enabled GSM mobile phone. The GSM phone was used to establish the communications link between the rover and the VRS control centre.

4.2 Field Experiment

The field experiment was carried out on the 7th of October 2004 commencing at 2:00 pm and concluded at 4:00 pm. The tests were carried out using three markers along Ritchie Road and Gooderham Road in Pillara, Queensland (see Figure 2). Pillara is located at the centre of the VRS network coverage area as shown in Figure 1. The centre of the VRS network is generally the area where the VRS performance is lowest. This means that the worst case scenario was tested. Pillara is a flat semi-urban farming region. The three markers are located in relatively clean multipath environments. The distance from markers A to B is 1.3 km and the distance from markers A to C is 2.0 km. The locations of the surveyed markers are shown in Figure 2. The coordinates of the markers are given in Table 4.

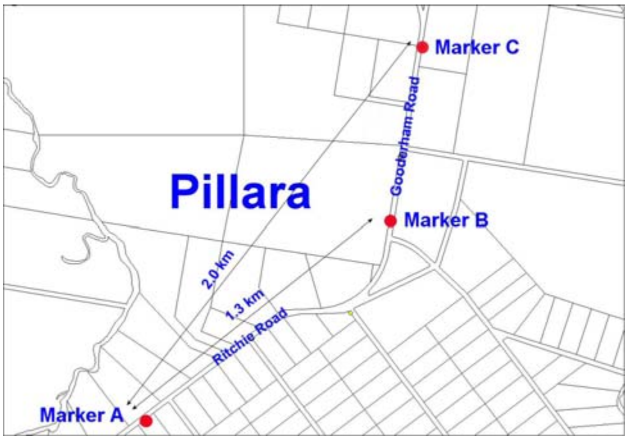

Figure 2 Position of markers along Ritchie Road and Gooderham Road in Pillara

Table 4 Surveyed Markers

Marker	Survey Code	Location (m)		
		Easting	Northing	Height
A	28113	499899.442	6945004.486	34.399
B	Star Picket 1	500938.476	6945844.184	17.377
C	71400	501072.328	6946576.259	13.372

For the first run, the VRS was created at the position of marker A. Then sixty solved position measurements were recorded at a rate of 1 Hz for marker A. Using the same VRS, sixty position measurements were also recorded at markers B and C respectively. This process was repeated twice to establish the repeatability of the recorded results.

The correction availability is an important performance indicator for VRS RTK positioning (Hu et al., 2003). During the time that the measurements were recorded there were at least six satellites with corrections. This is an important threshold for the implementation of RTK positioning (Edwards et al., 1999).

The accuracy and precision of the results was determined by comparing the differences between the three coordinate components of the solved positions and the mean of the positions. The horizontal position scatter plots for the three markers are displayed in

Figure 3, and respectively. The standard deviations for the northing, easting and height component for marker A were 4.7, 3.9 and 14.0 mm respectively. The distribution of deviation from the mean position at marker A for the three runs were graphed and found to follow a Gaussian distribution. This indicates that there were no systematic errors in the recorded data. The position accuracies at a 95% confidence level for the northing, easting and height components were 18.3, 15.4 and 54.9 mm respectively.

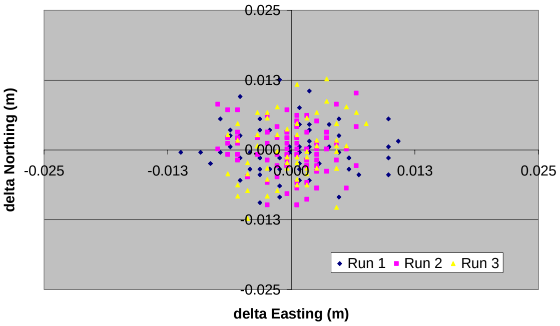

Figure 3 Horizontal Position Plot at Marker A (0 km away from VRS)

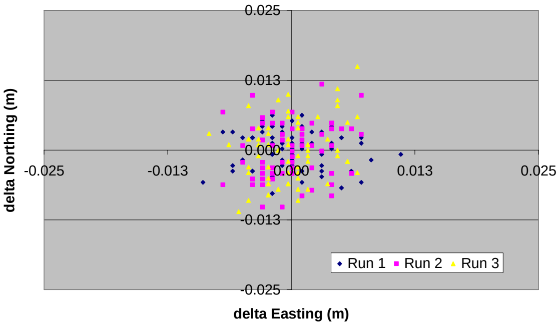

Figure 4 Horizontal Position Plot at Marker B (1.3 km away from VRS)

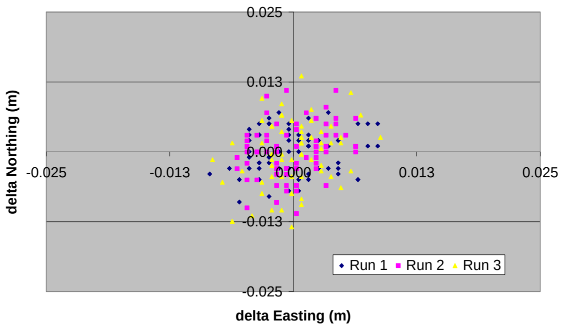

Figure 5 Horizontal Position Plot at Marker C (2.0 km away from VRS)

For marker B the standard deviations for the northing, easting and height components are 4.7, 3.5 and 13.9 mm respectively. The distribution of deviation from the mean position for the three runs were graphed and found to follow a Gaussian distribution. The position accuracies at a 95% confidence level for the northing, easting and height components were 18.5, 13.8 and 54.4 mm respectively.

For marker C the standard deviations for the northing, easting and height component are 5.0, 3.5 and 13.6 mm respectively. The distribution of the deviation from the mean position for the three runs were graphed and found to follow a Gaussian distribution. The position accuracies at a 95% confidence level for the northing, easting and height components were 19.5, 13.6 and 53.3 mm respectively.

A summary of the statistics for the three markers is given in Table 5. The results indicate that the accuracy of the horizontal position for all three markers is generally better than 2 cm and the height accuracy is better than 6 cm. The variation in accuracy between marker A and the other two markers, B and C, is almost negligible. This indicates that for VRS baselines of up to 2 km, RTK level (i.e. centimetre level) accuracy is achievable using the VRS network. This supports the use of the WCDMA base-stations with cell radii of up to 2 km for the RTK-VRC system.

Table 5 Statistical Results for Markers A, B & C in millimetres (where N, E & H are the Northing, Easting and Height)

Marker	Standard Deviation			Confidence Level		
				95%		
	N	E	H	N	E	H
A	4.7	3.9	14.0	18.3	15.4	54.9
B	4.7	3.5	13.9	18.5	13.8	54.4
C	5.0	3.5	13.6	19.5	13.6	53.3

5 Concluding Remarks

This paper provides a basic outline of the RTK-VRC system. The proposed system will integrate the VRS network with the WCDMA network and infrastructure and also mitigate the high communications costs (associated with current VRS systems). This system will provide RTK level (or centimetre level) positioning accuracy.

The field tests have demonstrated that RTK positioning accuracy is achievable for VRS baselines of up to 2 km. This is the typically maximum radius of the WCDMA cell supporting the proposal of using the WCDMA network cell as the VRC.

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