eRTK: A New Generation of Solutions for Centimeter-Accurate Wide-Area Real-Time Positioning

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Trimble

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Abstract

In 1993, Trimble released the world's first centimeter-accurate, Real-Time Kinematic (RTK) surveying system. Since its release, this technological innovation has been embraced by thousands of surveyors and engineers worldwide because of its accuracy and productivity. It has changed the world of surveying forever.

Trimble has developed a new RTK technology, termed eRTK, that further enhances GPS surveying. A highly flexible choice of infrastructure and communications media, coupled with the eRTK rover technology provides a unique new range of solutions for wide area RTK coverage which can be easily customized to meet exact and specific user requirements. Because eRTK infrastructures can be scaled and upgraded, users can acquire systems that meet their specific size requirements today, and expand or upgrade in the future.

Figure 1. Conventional RTK

The most common configuration for a Real-Time Kinematic surveying system consists of a GPS reference station, a GPS rover, and a UHF or VHF radio link between the two. Typically, a surveyor establishes the reference station and radio link in the area of the survey.

Previous technologies limited the baseline length to 10 km (6¼ miles) yielding an RTK coverage area restricted to approximately 300 km sq (115 sq miles).

eRTK is the next generation of RTK positioning solutions. It is the product of new, advanced technology, and combines innovations in GPS infrastructure, wireless telecommunications, and GPS processing methods. Trimble eRTK provides users of the new Trimble™ 5700 advanced GPS/WAAS receiver with wider-area, high-performance RTK surveying.

Introduction

Trimble released the first commercial Real-Time Kinematic (RTK) positioning system in 1993. Since its inception, RTK technology has been used across a broad spectrum of applications.

Many enhancements have been made to RTK technology over the past seven years. Most notably On-The-Fly (OTF) initialization that provides automatic progression to centimeter-level precision irrespective of user motion. Other enhancements to receiver and RTK technology include multipath suppression, improved signal tracking, all-on-a-pole hardware (such as the 4800), and 20 Hz positioning with minimal latency. Enhancements to communication links and antenna design have complemented system performance. However, existing RTK systems have been limited in terms of their operating range. Most systems specify that a rover can only work within 10 km of the reference (base) station.

The latest product offering from Trimble is the Trimble 5700 GPS receiver. It is equipped with eRTK technology. Rather than being limited to a 10 km range, eRTK has flexible options for extending operation from city-wide, to county and even state or national coverage.

This white paper presents eRTK and documents the expected performance of each mode.

Scalable Infrastructures

Roving Trimble 5700 GPS receivers equipped with the new eRTK technology can be used with a variety of GPS reference station infrastructures, including the following:

- Conventional RTK or RTCM reference stations
- eRTK single base
- eRTK multi-base
- eRTK with a virtual reference station (VRS™)

A single base system easily expands into a multi-base system, which can then expand into a VRS system. As users' needs change and expand, so can the system.

eRTK systems can operate over a far greater area than conventional RTK. VRS solutions cover a virtually limitless area, and can be scaled to cover a city, county, state, or even an entire country.

Figure 2 shows the relative coverage areas for six different infrastructures, based on typical configurations.

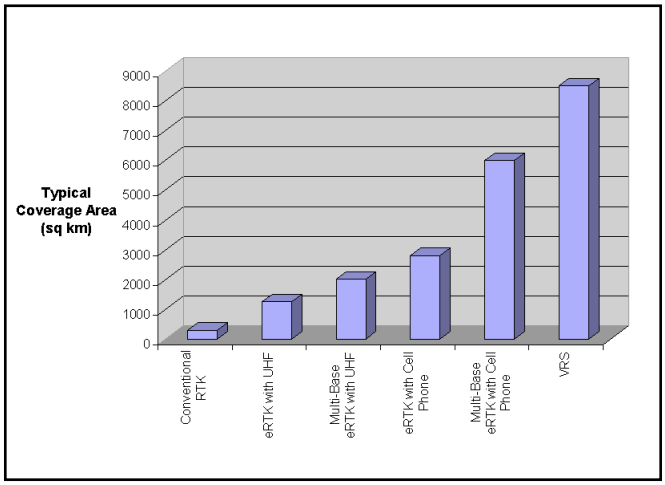

Figure 2. Relative Coverage Areas of Six Typical RTK Infrastructure Configurations

Wide-area capability means that eRTK reference stations can be significantly further apart than those with conventional solutions, so fewer reference stations are required for a survey area.

Figure 3 compares typical reference station spacing for three RTK modes.

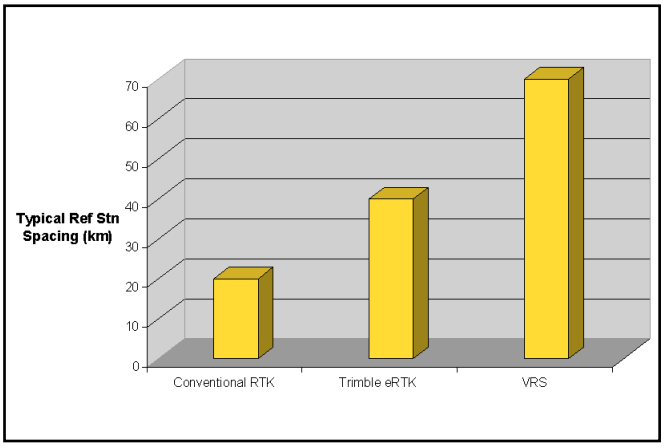

Figure 3. Comparison of Typical Reference Station Spacing

Single Base eRTK: Up to Four Times the Coverage Area of Conventional RTK

Single base conventional RTK is typically limited to a coverage area of approximately 300 sq km (115 sq miles) due to a combination of factors, which includes the following:

- The inability of the RTK processor at the rover to initialize (resolve integer ambiguities) over wider areas and at longer ranges from the base.
- The inability of the RTK engine at the rover to retain accuracy over wider areas and at longer ranges from the base.
- Limitations in traditional communications link technologies between base and rover.

The new Trimble eRTK technology combines technological advances in GPS signal processing, real-time GPS data processing, and wireless telecommunications. The result is a range of solutions for wide-area RTK operation.

Errors caused by the de-correlation and spatial variation of ionospheric effects between base and rover limits the range of conventional RTK. eRTK technology uses adaptive dual-frequency processing to maximize its use of all L1 and L2 code and carrier phase observations in the real-time solution. This allows initialization to occur even under varying ionospheric conditions.

The new Trimble Maxwell 4 Application Specific Integrated Circuit (ASIC) gives very low-noise L1 and L2 measurements. When these measurements are combined with the adaptive dual-frequency eRTK model, the quoted RMS accuracy specifications of 1 cm + 1 ppm horizontal and 2 cm + 2 ppm vertical are maintained even at long ranges.

With the GPS Total Station® 5700 system, users can choose from telecommunications methods that give wide-area eRTK coverage. Common methods include high-power, high-performance Trimble UHF telemetry links, and wireless telecommunications infrastructures such as GSM or CDMA cellphones, Cellular Digital Packet Data (CDPD) modems, or other wireless data devices.

To provide wide area coverage with a conventional UHF data link, the highly sensitive Trimble 5700 internal rover radio, combined with a TRIMMARK 3, 25 W base station transmitter, can achieve a line-of-sight range of 15 km (8 miles) with proper set-up techniques.

Figure 4 shows the Trimble 5700 GPS receiver.

The Trimble 5700 GPS receiver with internal radio option includes an internal, purpose-built radio modem developed by Trimble.

This internal radio has enhanced sensitivity for extended eRTK range, and works with a variety of antenna options.

For shorter ranges (up to 3 km) a short whip antenna can connect directly to the receiver on the pole or belt.

For longer ranges, the eRTK pole antenna or a backpack whip antenna can be used. Combined with multiple repeaters, ranges of 20 km or more from a single base station can be achieved.

Figure 4. The Trimble 5700 GPS Receiver

The TRIMMARK 3 and TRIMTALK 450S radios can use up to two repeaters, enabling the coverage area to be extended significantly beyond the range of a single transmitter located at the reference station site—without the need to use more than a single radio channel or frequency. This results in a total potential range of 25 km (14 miles) when using a 25 W TRIMMARK 3 base and two repeaters. Repeaters can also be deployed to extend the coverage area more generally, or to improve radio penetration in environments with many obstructions.

Figure 5. The Range Pole Antenna

Even without the use of repeaters, the Trimble eRTK UHF range pole antenna, as shown in Figure 5, maximizes the effective coverage area from a TRIMMARK or TRIMTALK base station transmitter.

For maximum range, this lightweight, high-gain antenna is mounted high on the pole. It outperforms ordinary whip antennas in range while avoiding potential interference which could degrade positional accuracy.

The eRTK range pole antenna has a greater range because of its high gain and position high above the ground. It receives base station transmissions at longer ranges than smaller, rubber whip antennas mounted lower on the pole.

The eRTK range pole antenna has greater accuracy because it is specifically designed not to interfere electrically with the GPS antenna. A whip antenna located above the GPS antenna, and in its line of sight to the satellites, interferes with the antenna phase center. This causes errors and loss of accuracy in the RTK positions.

Figure 6 shows the positioning of both antennas.

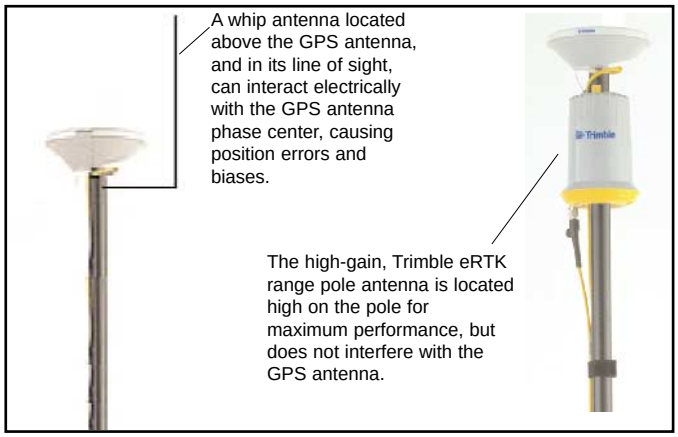

Figure 6. The Whip Antenna versus the Range Pole Antenna

Where digital cellphone coverage is available (for example, GSM, CDMA), cellular modems can transfer data from base to rover in real time. Even analog cellular infrastructures can be used if CDPD service is available. CDPD technology uses spare bandwidth on the analog cellular telecommunications networks to send packets of digital data.

With single base eRTK, the rover dials into the cellphone located at the base station, which starts sending continuous data to the rover via the cellular network. The RTK rover can then conduct eRTK positioning from a single reference station in an area of more than 1000 sq km.

For more information on using cellphones with Trimble GPS receivers, see the Trimble document “Using Cell Phones and CDPD Modems for eRTK”.

Figure 7 shows the use of a cellphone with eRTK.

Figure 7. A Cellphone Used with eRTK

Successful tests of single base eRTK initialization and positional accuracy have been conducted at ranges greater than 40 km from a base station. However, the recommended coverage area to expect for single base Trimble eRTK is approximately 1250 sq km, depending on the communications medium used and local conditions. This is a radius of approximately 20 km from the base, below which the optimum performance is achieved in terms of accuracy, initialization time, and reliability. Although the Trimble eRTK solution maintains the 1 cm + 1 ppm horizontal and 2 cm + 2 ppm vertical specification even for longer ranges, as the distance from the reference station increases beyond 20 km, the part-per-million error starts to become significant. Therefore, maximum accuracy is achieved at ranges of 20 km and less.

1250 sq km is approximately four times greater than the coverage of a conventional RTK base station, making eRTK a much more efficient solution—as each eRTK reference station covers a much greater area.

Multi-Base eRTK: Efficient Use of Radio Frequencies and Very Wide-Area RTK

Multi-base eRTK is useful when a chain of RTK reference stations needs to cover a wide area or long corridor of interest, for example, a large linear engineering project. It can also maximize use of a single radio channel that is used by a number of independent users in a locality.

With ever-increasing demands on a limited radio frequency spectrum, many users of UHF radio links for GPS face the problem of a crowded radio spectrum and consequential difficulty in obtaining the right to use a specific frequency or channel. Multiple users of a single frequency within an area can also lead to problems of interference and jamming.

Trimble multi-base eRTK technology maximizes use of a single radio channel by using the highly compressed Trimble CMR+ data format and the inclusion of a delay in the transmission of that message.

For RTK work, the base station typically broadcasts raw measurement data once every second. When using the Trimble Compact Measurement Record Plus (CMR+) data standard, with a Trimmark 3 base station radio, all necessary data can be transmitted in less than one-third of a second.

When not using repeaters, this means that only one-third of each second is actually used to transmit data. Thus, the potential exists to use each channel three times more than it is currently used under conventional RTK operation.

Trimble Multi-Base eRTK makes up to three times the use of a single channel by having some base stations delay their transmission of the CMR+ message—effectively splitting each second into three unique slots. This way, up to three base stations with overlapping coverage areas can each be assigned one of these slots, providing a unique transmit opportunity to each base station within every second. This means that the coverage areas of the radios can overlap, but they will not interfere with each other. Yet, each station transmits once per second as usual.

When using the Trimmark 3 25 W base radio with a line-of-sight range of up to 15 km (8 miles), reference station networks with station-to-station spacing of up to 30 km can be installed. When used in conjunction with Trimble 5700 rovers that are equipped with wide area eRTK dual-frequency technology, a single radio channel can support three reference stations and cover an area of more than 2000 sq km (800 sq miles).

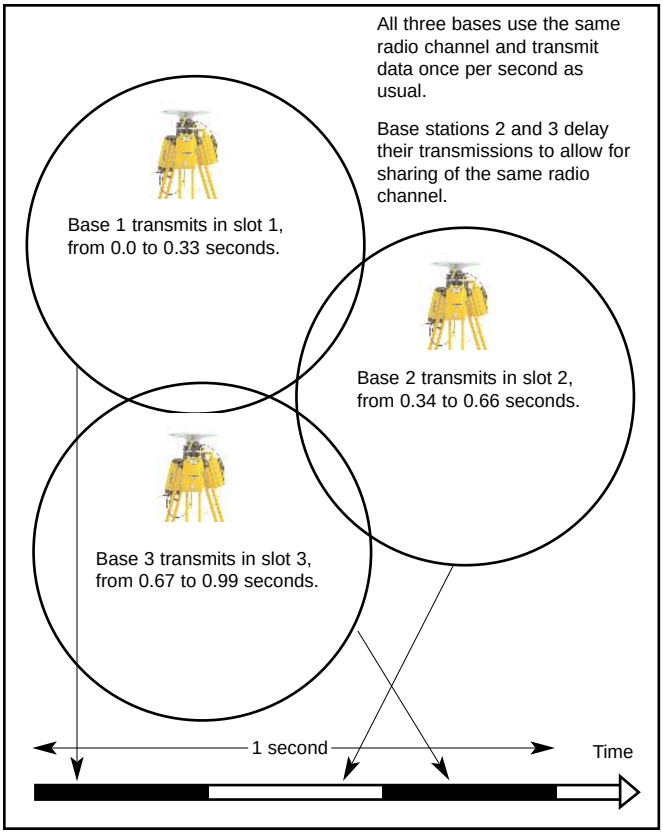

Figure 8. Trimble eRTK multi-base operation enables base station radios with overlapping coverage areas to use a single frequency without causing interference to one another. This technology works by delaying the transmission of certain base stations—effectively dividing each second into slots. Each GPS base station in the chain is assigned one of these slots, so that each station takes a turn within each second to send its data.

In the areas where coverage overlaps exist, another advantage of Trimble multi-base eRTK is that fixes can be made from more than one base station. For example, users can position a point from one base station, using eRTK surveying, then select a different base station without having to change the radio channel. They can then re-initialize on-the-fly using the second reference station, and immediately compare each result.

Trimble multi-base eRTK can utilize the Trimble 5700 GPS eRTK receiver's ability to use alternative wireless communications to VHF or UHF radios, including cellphones or other wireless modems. Each reference station in the chain has a different telephone number, and the user dials into the selected base station to carry out eRTK real-time accurate surveying.

With a reference station spacing of 40 km, three eRTK reference stations using cellphones can cover four times the area of three conventional RTK reference stations. For example, an area of 3750 sq km (1500 sq miles) would require 12 conventional RTK reference stations. The same area with Trimble multi-base eRTK using cellphones only requires three stations. This reduces the GPS infrastructure cost by 75%.

eRTK with Virtual Reference Station (VRS) Technology

For wide-area, eRTK coverage requirements of more than 3750 sq km, virtual reference station (VRS) networks are ideal.

Figure 9 shows how VRS technology works.

To initialize VRS positioning, the eRTK rover dials into the network and supplies its approximate location. The VRS network generates a set of virtual measurements similar to that which would be observed by an actual reference station located at the user's position, hence the term virtual reference station.

Because VRS uses all of the stations in the triangle, the accuracy is not degraded due to range as much as with conventional RTK. Also, the initialization times required for wide-area RTK are shorter too. This means that VRS reference stations can be up to 70 km apart, and users can perform RTK surveys with accuracy and initialization performance similar to that experienced within a very short range of a conventional RTK reference station.

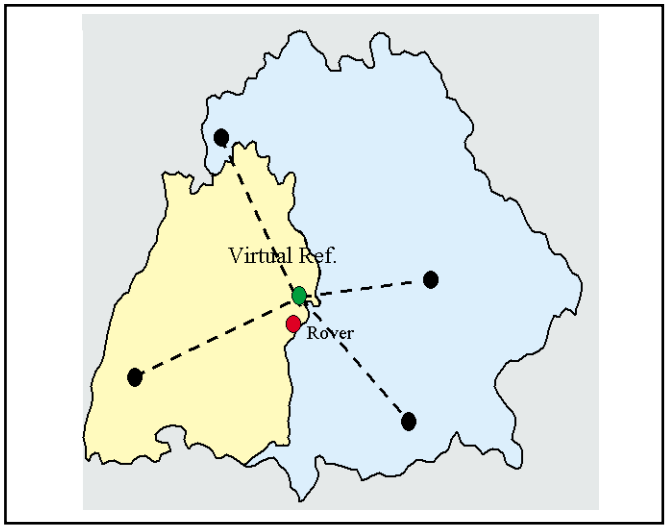

Figure 9. VRS Technology

VRS networks can cover a city, a county, or even an entire country with very high-accuracy, high-speed, real-time positioning. VRS technology goes far beyond a simple, long baseline solution derived from a single reference station.

The network of reference stations is divided into triangles formed between any three adjacent reference stations. For the area covered by each of these triangles, the data from all three reference stations is used to measure and monitor the varying error sources, such as atmospheric conditions and satellite orbital errors.

This enables the system to produce a set of measurements similar to that which would be observed by a physical reference station if it were located at some chosen location anywhere within the triangle.

The graphs overleaf show the results of a VRS performance trial, with the user located 32 km from the nearest reference station in the network. The trial was conducted over 90 consecutive hours, with new initializations occurring approximately every 30 seconds.

The results show that the achieved precision is approximately 1 cm horizontal and 2 cm vertical. Thus, the part-per-million (ppm) error that is normally encountered at 30 km from a base station is almost eliminated from the VRS solution, and the performance is similar to that achieved with conventional RTK at a distance of only 1 or 2 km from the reference station.

Additional advantages of using the VRS are that the positions are always established in a common coordinate system, and the VRS system is able to provide continuous integrity monitoring. Both of these further improve position reliability.

VRS Performance Test.
Point 32 km from the nearest reference station. 90 hour continuous trial.

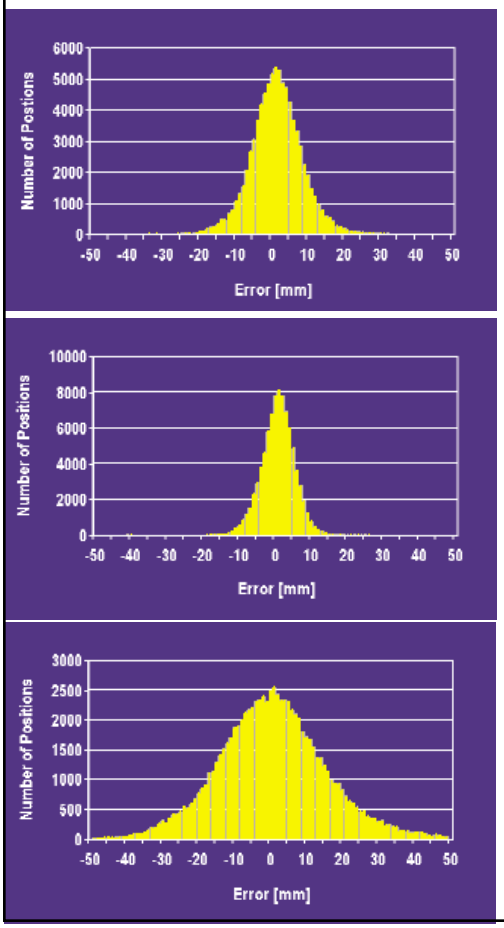

Figure 10. Results of VRS Performance Trial

Conclusion: Trimble eRTK Solutions for Maximum Efficiency and a Fast Return on Investment

Table 1 overleaf compares the typical effective coverage areas of a range of infrastructure and wireless communication configurations. The results show the increased efficiency of Trimble eRTK surveying.

Trimble eRTK infrastructures have a choice of single base, multi-base, and VRS networks-all of which can be easily upgraded and expanded both now and in the future. As a result, they are the natural choice for those seeking a total solution for the provision of wide-area RTK.

An equally natural choice for the roving surveyor is the new, eRTK-equipped, GPS Total Station 5700 system, which is a total solution from Trimble that is packed with technological innovations and new features that enhance productivity.

Visit our website at www.trimble.com to learn more about our advanced GPS infrastructure options and leading total surveying solutions.

Infrastructure Type	Number of Bases	Wireless Communication Method	eRTK Coverage Area up to:	Number of Stations per 1000 sq km	Coverage increase per station over conventional RTK	Notes
Conventional RTK	1	UHF / VHF radio link	300 sq km	3	N/A	
eRTK Single Base	1	UHF / VHF radio with repeater option, or Cellphone, GSM, CDMA, or CDPD Modem	1250 sq km	0.8	Up to 275%	Subject to radio line-of-sight or cellular coverage
eRTK Multi-Base	2 or more	UHF / VHF with up to 3 over-lapping bases on the same channel	2000 sq km (3 bases at 30 km c/c)	1.5	100%	Requires eRTK rover antenna and subject to terrain
eRTK Multi-Base	2 or more	Cellphone, GSM, CDMA, CDPD modem	3750 sq km (3 bases at 40 km c/c)	0.8	up to 275%	Requires cellular coverage
Virtual Reference Station with eRTK rover	3 or more	Cellphone, GSM, CDMA, CDPD modem	8500 sq km (6 bases at 70 km c/c)	0.7	325%	Fastest and most reliable eRTK at rover

Table 1. Comparison of GPS Infrastructure and Wireless Communication Alternatives

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