WHITE PAPER

# SCALABLE GPS INFRASTRUCTURE: THE BUILDING BLOCKS OF TOMORROW

**BY NATHAN PUGH, TRIMBLE**

As the designers and builders of infrastructure; surveyors, engineers and construction contractors know well the benefits gained from a strong infrastructure. Whether transportation, utilities or communication systems, infrastructure constitutes a society's basic structure, the foundation upon which the growth of a community, state or entire nation depends. Infrastructures are essential for enabling economic productivity: without the nation's transportation system, its interconnected communication network or its powerful utility infrastructure, commerce, growth and development would slow dramatically—and perhaps stop.

But infrastructure doesn't happen overnight. Consider the nation's massive transportation system. Built over several decades, the Interstate Highway system is a good example of infrastructure's scalability—the ability to grow over time as needs increase—and the need for sound urban planning. A powerful network based on smaller interconnecting state roadway systems, the massive Interstate Highway system was discussed and designed as early as the mid-1930s, but not fully approved and started until the mid-1950s. Funded by the Federal-Aid Highway Act of 1956, President Dwight Eisenhower pushed for a national system after being impressed with the strong autobahn network in Germany. The transportation infrastructure was critical to our nation's growth, important, as Eisenhower put it in 1954, to the "unity of a nation…Together, the united forces of our communication and transportation systems are dynamic elements in the very name we bear—United States. Without them, we would be a mere alliance of many separate parts."

Today, similar planning foresight is taking place in states across the nation as private firms, municipalities, and state and federal organizations are providing real-time kinematic (RTK) Global Positioning System (GPS) infrastructure capabilities to their areas. Similar to the national highway system's importance to the nation as a whole, GPS infrastructure can be said to be essential to the growth and development of the surveying community. Here's why.

## GPS INFRASTRUCTURE

For two decades, the tools of GPS have mainly been individual receivers designed for various accuracies and capabilities. Initially, surveyors who used GPS in the early 1980s endured long observation periods in the field and time-intensive postprocessing back in the office. As a result, GPS was really only feasible for establishing control. To gain centimeter-level accuracy positioning in the field, surveyors in 1993 began using RTK GPS technology, which also minimized data postprocessing. For RTK positioning, a reference receiver (station) transmits its raw measurements or observation corrections to a rover receiver via a data communication link, whether radio modem or cell phone. With the introduction of RTK, GPS became a valuable tool for applications other than control work, including topographic mapping, high-accuracy GIS (Geographic Information Systems) and construction stakeout.

The most recent advancement in GPS technology, however, is scalable GPS reference station infrastructure. GPS infrastructure consists of permanent or semi-permanent GPS receivers operating continuously (24/7). Users no longer need to set up a separate base station to achieve RTK positioning; they simply use a GPS rover to connect to the established infrastructure. GPS infrastructure can range from a single reference station to a wide-area Trimble VRS™ (Virtual Reference Station) network; for each option, GPS infrastructure offers several benefits:

- Ubiquitous positioning over a large area
- Common coordinate reference frame
- Reference station security
- Decreased learning curve to achieve precise GPS surveying
- Cost savings for capital improvement projects (government) or larger profit margin on the same type of jobs (private sector)
- Reduced cost for field crews for field setup and equipment costs

**Scalable GPS infrastructure enables users to achieve RTK positioning without setting up a separate base station; they simply use a GPS rover to connect to the established infrastructure.**

The choice of each option depends on requirements and coverage area. Let's look at each.

## SINGLE REFERENCE STATION

The first step in scalable GPS infrastructure is an independently operated community reference station providing data for multiple applications. Private firms, municipalities and larger agencies all find single reference stations a good starting point to gain network RTK benefits. Generally, a single reference station is connected to one computer for a variety of application including:

- Postprocessed file logging for static surveying
- Single-base RTK positioning for precision applications within a 20 km radius
- DGPS corrections for submeter accuracy within a 200 km radius

The prime example of single reference station infrastructures is the National Geodetic Survey (NGS) Cooperative Continuously Operating Reference Station (CORS) network. The Cooperative CORS network consists of single reference stations independently operated by governmental, academic, commercial and private organizations. Through a link on the NGS Web site, users can access the data by contacting the individual station for three-dimensional (3D) positioning activities throughout the U.S. and its territories. CORS sites have to meet established criteria for inclusion in the national database.

## CASE STUDY

Located in Fairfax, VA, BC Consultants invested in RTK GPS equipment several years ago to facilitate meeting requirements to tie all projects into state plane coordinates. “It was either a lot of traversing or GPS,” said BC Consultants president Jim Scanlon, LS, PE. “It was more efficient with GPS.” But the inconvenience of setting up a separate base station—and leaving a surveyor just to guard it—to achieve RTK accuracy made GPS less of an option for many jobs.

So the innovative firm sought ways to improve GPS use, first by switching to a wireless modem communication link, then by setting up a permanent reference station at the Fairfax location. Initially modem to modem in the field, they’ve now advanced to modem to server over the Internet—with the option for CDMA cell coverage in the future.


A Trimble NetRS GPS Receiver operating with GPSBase™ software in BC Consultants office.

The wireless link allows multiple BC surveyors to access the server in the field for centimeter-accuracy within six miles (9.7 km) of the reference station, according to Scanlon. The wireless modem allows access to the signal beyond six miles, but accuracy becomes an issue for the firm, as most of the land development firm's projects require centimeter-level accuracy.

"We're excited and frustrated at the same time," Scanlon said. "With the six-mile circle, we'll use it on all projects within that, but we'd like to get beyond the six miles as well."

BC surveyor Evan Cregger using the Trimble 5700 GPS System as a roving unit to confirm a point during construction. The 5700 receives RTK corrections from an Air-Link Raven CDMA Modem.

That's why BC Consultants is looking to the future, first to add a second station to their Winchester office 50 miles (80 km) away, then to find other locations to fill in the distance and create an infrastructure network.

"Not many people are using GPS for its full potential," said Scanlon. "We're finding our productivity rate is much higher with GPS than conventional: in the right location, it flies. That's why we'd like to use it more."

Because of that, BC Consultants is flying into the future with the first step in scalable GPS infrastructure today.

## MULTIPLE REFERENCE STATIONS CONTROLLED CENTRALLY

The next step in GPS infrastructure is multi-station networks that are controlled at one central site. Analogous to having multiple offices linked together through a wide area network (WAN), these networks cover a larger area. Each station offers single-base RTK positioning but all stations are managed centrally. This level enables an organization with multiple offices to be on a common coordinate reference frame; similar to their IT network, the GPS infrastructure can be controlled using the same architecture as the IT network.

This second infrastructure level expands the geographic territory covered by single reference stations and enables a single administrator to operate an unlimited number of receivers in a network. Cities, counties, states, nations and private firms can establish and control a network of fixed reference stations to provide RTK corrections or postprocessed data for their area of operation.

Quality control is also enhanced at this level. Administrators can monitor the coordinates relative to the other reference stations, holding one fixed and monitoring the base lines. This enables administrators to ensure the network stations aren't moving over time and that coordinates—and thus data quality—are correct.

**CASE STUDY**

With more than 50 offices across North America, Canada's Stantec provides professional design and consulting services in planning, engineering, architecture, surveying, and project management. At its headquarters in Edmonton, Alberta, the Surveys and Geomatics group has set up a network of three GPS reference stations that facilitate RTK GPS positioning at their many local projects. Stantec started with a single semi-permanent station near a large subdivision and interchange in south Edmonton four years ago; it was so successful, they added another station in the city's west end a year later, and in January 2004 a third station at the Stantec office in downtown Edmonton. They also then connected the stations with Trimble's GPSNet™ networking software at that time, using both radio and cell phones to easily transmit and receive data through the Internet. At the end of 2004, Stantec purchased two additional stations—Trimble NetRS® GPS receivers—to expand the network even further.

Stantec network reference station located on the roof of the Stantec head office in Edmonton. The station consists of a Trimble Zephyr Geodetic™ antenna (shown) connected to a Trimble NetRS receiver.

"A network made sense to us as the bulk of our projects are in the network area," said Stantec Associate Kevin MacLeod, P.Eng. "It has resulted in significant gains in productivity. Contractors don't have to wait for us to set up a base station. We're able to respond more quickly to urgent requests and keep everyone happy. We can go anywhere within the network area and immediately start surveying."

The network allows Stantec to manage the system through the Internet from their main office, enabling them to quickly troubleshoot the entire network without having to physically visit each station. The software provides data integrity and quality checks (monitoring each station's satellite tracking, multipath level and the impact of ionospheric effects on the data). They can also monitor usage, which has helped them in project invoicing.

The firm is also looking to expand the network and cover the entire metropolitan area without sacrificing accuracy. Because most of their projects include engineering design work, tight tolerances of 2–3 centimeter vertical accuracy are required. And that means their current stations are within 15 kilometers of each other.

Stantec surveyor Trevor Pasika provides construction staking with the Trimble RTK GPS 5800 survey system on the Anthony Henday Drive road and bridge construction project in Edmonton, Alberta, Canada.

"Right now we're limited to our network boundary," MacLeod said. "With single base line surveying we get the accuracy we need; at greater distance accuracy would be an issue."

But they'd like to expand the distance between stations and still get precision accuracy. For that reason, Stantec is today looking at the third step of GPS infrastructure: Trimble VRS technology.

## FULL ATMOSPHERIC AND SYSTEMATIC ERROR MODELING OVER THE ENTIRE NETWORK

Offering the largest coverage area while minimizing the number of reference stations, the third step in GPS infrastructure is the Trimble VRS network. Including three up to a multitude of stations, Trimble VRS network software processes the entire network simultaneously, offering greater quality control and higher data accuracy at greater distances. Additionally, along with offering scalability in the number of reference stations, network configuration and architecture are also scalable. Trimble VRS networks can run on just one server, or have 10 or more servers running GPS solutions, depending on the redundancy, reliability and processing power required. For example, the Puget Reference Station Network (PRSN) includes 18 stations running on a four-server cluster; system administrators required back-up and rerouting capabilities to ensure system availability in the case of server problems or maintenance and operations downtime.

In the field, the farther users get from a reference station using conventional RTK, the more susceptible they become to reduced accuracy and performance due to ionospheric and tropospheric factors, also called PPM errors. With a Trimble VRS infrastructure, network software provides a fully modeled solution that factors in potential PPM errors. Users connect into the system using a wireless connection; the software acknowledges the users' field positions and allows them to operate as though there is a reference station—a virtual reference station—right next to their rover. As a result, the PPM error is significantly reduced, enabling surveyors to work at long distances from the physical reference stations. Trimble VRS technology thus enables users to achieve RTK precision over much greater distances with fewer base stations. Users can also retrieve stored GPS correction data from a control center via the Internet for postprocessing.

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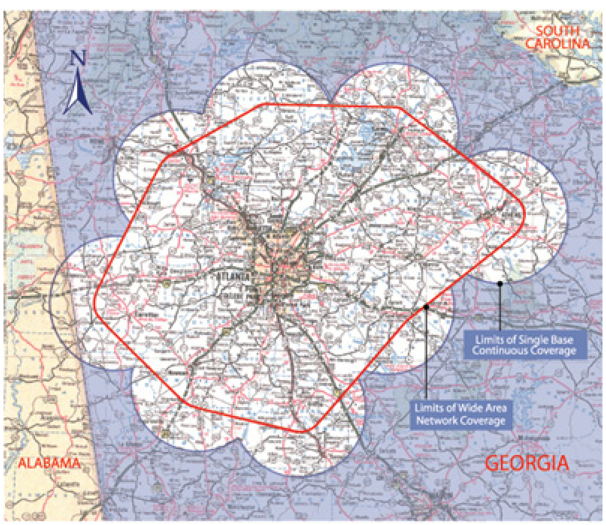
The Trimble VRS solutions enable GPS network administrators to provide RTK corrections through the Internet as well as supply built-in access, authentication, and accounting. This allows GPS network administrators, as well as IT managers, to control who is accessing their system and how often, and where they are in the field. Users then access RTK correction data in the field via a cell phone connected to a GPS rover. And Internet protocol means users don't need to be in radio broadcast range like they do with a conventional RTK radio transmitter. Trimble was the original developer of VRS technology; today, the term VRS is used almost universally for various network configurations.

**CASE STUDY**

Georgia-based Travis Pruitt and Associates 'jumped into' GPS infrastructure in a big way, according to founder and president Travis Pruitt Sr., LS, PE. After evaluating the Trimble VRS network in North Carolina, the engineering and surveying firm set up 10 reference stations over the Atlanta region covering an area of 10,000 square miles for its own use. The innovative firm also started a sister company to manage the new network—eGPS Solutions (www.egps.net)—and started taking subscriptions for the network. All in six months.




The area covered by the eGPS Trimble VRS network. This includes 10 reference stations covering 10,000 square miles in the Atlanta area.

All network stations are tied into the existing NGS monumentation in North Georgia (WGS-84) and eGPS is in the process of bluebooking all stations to NGS specifications. Currently, the network covers close to 20 percent of the state, according to Pruitt; eGPS is in the process of seeking to expand it even further.

The firm has been able to produce field surveys more quickly and with as much as 50 percent less labor cost than was experienced prior to implementing the Trimble VRS system. The system is advantageous on any project that is GPS compatible, including boundary and topographic surveys, photogrammetric control and construction staking. Pruitt also sees the network as valuable for employee retention: "There's a lot of excitement about working with the latest technology," he said.

"Our clients are very busy at this time, so utilizing Trimble VRS we are able to take on many more projects, causing increased revenue" said Pruitt. "That's the reason we went with the network: we've not been able to hire enough people to do the work available to us. With Trimble VRS we have the potential of at least doubling our output."

Travis Pruitt and Associates surveyor Patrick Carey uses the Trimble 5800 RTK GPS survey system to locate features for an ALTA survey within the eGPS Trimble VRS network area.

eGPS, located in Norcross, GA, now has a number of subscribers and is marketing the network throughout the mid-Georgia area. As the network area expands, eGPS is evaluating the possibility of offering a smaller number of stations to individuals at a lesser cost than that of a full network subscription. The firm encourages surveyors to get their GPS receivers “out of storage and into the field!” Users of the Trimble VRS network can enjoy the higher precision, cost savings, and increased profits they were promised when they first bought GPS equipment, according to Lonnie Sears, LS, eGPS president. eGPS expects to have 100 users within 18 months, he said. “We’ve had very positive feedback, particularly from those who have a lot of GPS experience,” said Sears. “Once they see the power of the network and network RTK, they’re true believers.”

***ABOUT THE AUTHOR***

*Nathan Pugh holds a Bachelor of Science in Geomatics Engineering from the University of Calgary. He has worked in the GPS surveying industry for eight years, including roles with Trimble in product management and applications engineering. Nathan is currently Trimble's Americas GPS Infrastructure Manager.*