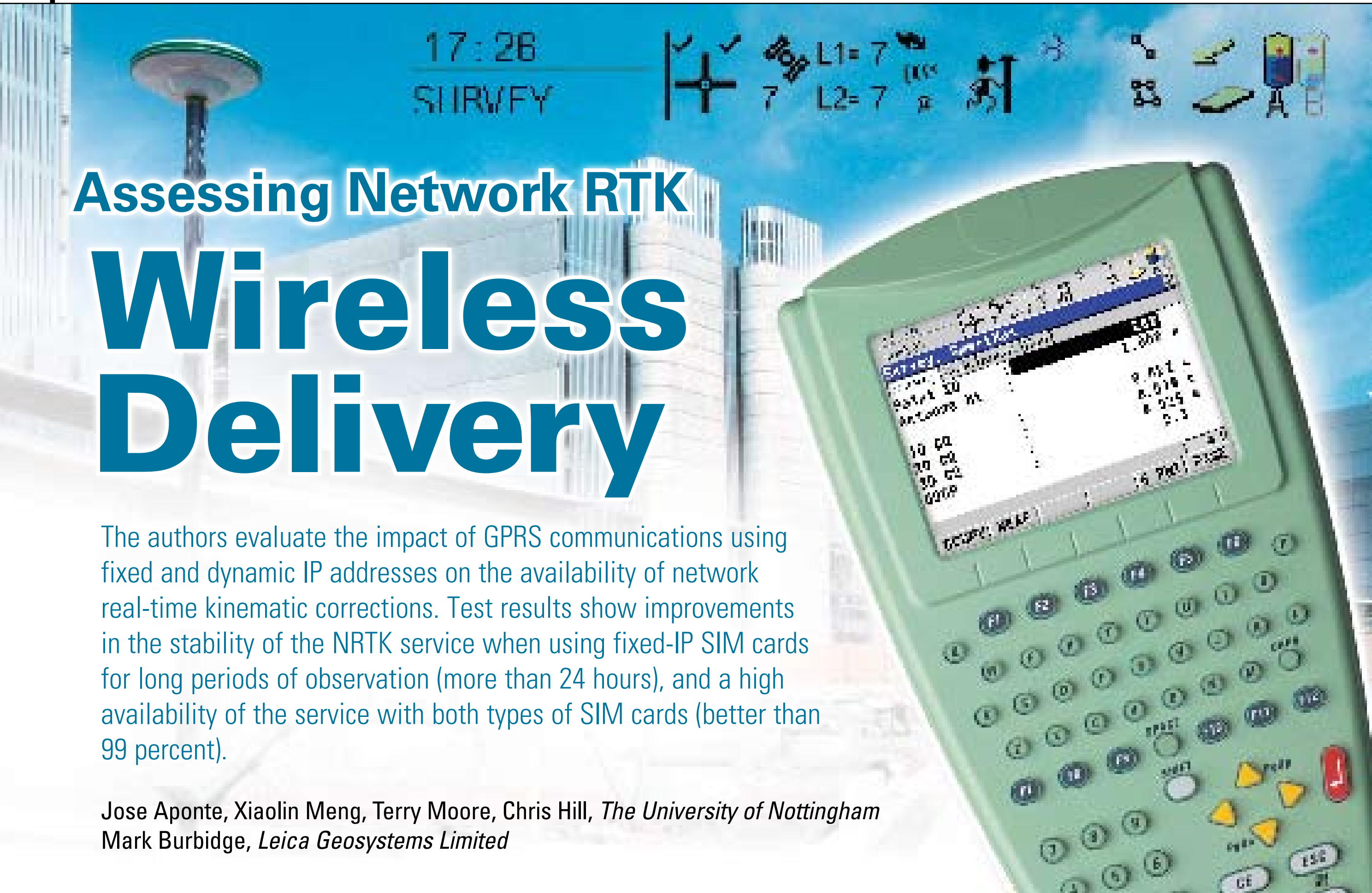

Assessing Network RTK Wireless Delivery

The authors evaluate the impact of GPRS communications using fixed and dynamic IP addresses on the availability of network real-time kinematic corrections. Test results show improvements in the stability of the NRTK service when using fixed-IP SIM cards for long periods of observation (more than 24 hours), and a high availability of the service with both types of SIM cards (better than 99 percent).

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Wireless communications employed in a network real-time kinematic (NRTK) GNSS system to deliver network corrections to roving users play a vital role in achieving good positioning performance. The communication link must ensure high flexibility and availability to satisfy the requirement of centimetric positioning accuracy and mobility that NRTK can offer. Since the advent of General Packet Radio Service (GPRS) communication technology, it has been used as the best option to deliver the NRTK corrections to users and therefore it directly impacts the availability and general performance of the NRTK service.

In the past, commercial mobile phone network companies did not offer specialized "data only" transmission services through GPRS. Therefore, normal mobile phone Subscriber Identity Module (SIM) cards for voice and data had to be used for the transmission of the NRTK corrections. A SIM card is a component, usually in the form of a miniature smart-card that is theoretically tamper-proof and is used to associate a mobile subscriber with a mobile network subscription. The SIM holds the subscriber's unique MSISDN along with secret information such as a private encryption key and encryption/digital signature algorithms. Most SIMs also contain non-volatile storage for network and device management, contact lists, text messages sent and received, logos, and in some cases even small Java programs. The use of these cards was degrading the availability of the NRTK service by interrupting the communications between the network control center and users after long periods of connection, and also when priority was given to voice calls. The increase in the demand of services such as mobile Internet and machine-to-machine (M2M) data transmission using GPRS has seen the wide use of new SIM cards with fixed or dynamic IP addresses that are specially designed for data-transmission purposes through GPRS.

Network-based RTK GPS positioning can appropriately solve performance problems caused by distance-dependent errors such as satellites' orbit and atmospheric biases that were experienced with conventional single-reference-based RTK positioning. Such errors and biases can cause a phenomenon called spatial decorrelation of errors, which requires that a rover receiver performing RTK must be located at distances no greater than about 20 kilometers from a reference station in order to achieve centimetric positioning accuracy. However, NRTK uses the raw GPS observations gathered from a network of continuously operating reference stations (CORS) to create proper models that can mitigate most of the distance-dependent errors acting within an area covered by the CORS. NRTK accuracy is as good as or even better than that achieved with conventional RTK GPS positioning. Further, separations between the rovers from the nearest reference station can be extended to 50 kilometers or even more, giving users much improved positioning flexibility and reducing infrastructure costs.

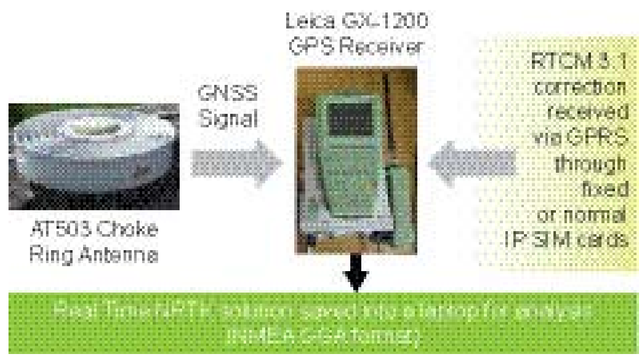
Currently, several commercial NRTK services operate around the world, and more comprehensive networks will be established to address some urgent environmental and geo-hazard problems. In Great Britain, for instance, Leica Geosystems in partnership with Ordnance Survey GB has offered an NRTK service to its clients since 2006; the service is called SmartNet and subscribers can carry out positioning to centimetric accuracy with only one rover receiver.

Wireless communications using Global System for Mobile communications (GSM)/GPRS links between a network control center and rover users play a vital role in ensuring high flexibility, mobility and availability when delivering the network corrections. Although SmartNet is mainly designed to work under the master auxiliary concept (MAC) especially suitable for one-way communication links (broadcast), like many other NRTK service providers, and in order to guarantee full service coverage, SmartNet takes advantage of mobile-phone networks already operating across Britain to deliver its Radio Technical Commission for Maritime Services (RTCM) corrections. These network corrections are normally delivered via GSM/GPRS mobile communications under the Networked Transport of RTCM via Internet Protocol (NTRIP). Therefore, SmartNet users can employ any mobile phone network with a good coverage of the geographic area where they are working.

Well-developed mobile phone networks cover most of Great Britain, offering users a variety of voice and data services. As in most parts of the world, these networks were initially designed for the transmission of voice, but due to the growing demand of services such as M2M communications and more recently mobile Internet, they have also implemented data-transmission support. Even though the requirements of voice and data transmission differ greatly, both services are supported by the same platform and are generally included under the same mobile-phone contracts. Therefore, SIM cards that are normally used by the NRTK services' subscribers in Britain are the same as those employed by common mobile-phone users.

Past tests carried out by the authors reveal some availability problems in the SmartNet NRTK service, mainly caused by instability in the wireless data link. The availability of NRTK corrections was about 88 percent, with the wireless connections being dropped after two or three hours of continuous activity. The voice and data SIM cards used during these tests are believed to be the main cause of these instability problems when interrupting the GPRS connection after a long period of connection to the mobile-phone network. Since these are conventional SIM cards, they use dynamic IP addresses, and the interruption could therefore be caused when they renew their IP addresses or also when they prioritize voice traffic across the mobile phone network.

▲ **FIGURE 1** SmartNet CORS as of August 15, 2007



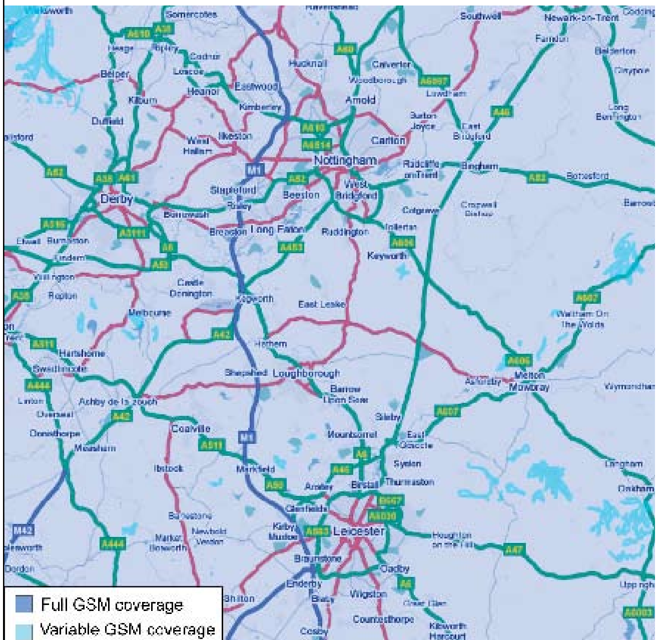
▲ **FIGURE 2** Equipment configuration for the tests

Leica Geosystems UK is trying to implement the use of a new kind of data-only fixed-IP SIM card that should contribute to the solution of the instability problems in the wireless links currently used by its customers. These static-IP SIM cards are the latest solution of mobile-phone network providers to the increased demand on M2M wireless data transfer services under GSM/GPRS protocols.

Leica provided the Institute of Engineering Surveying and Space Geodesy (IESSG) at the University of Nottingham with one of these SIM cards for a trial. We here report the results of tests carried out with the new fixed-IP SIM cards. Several static tests were designed to investigate the impact of the available voice-and-data and data-only commercial GSM/GPRS services on the availability and general performance of SmartNet.

SmartNet

SmartNet comprises about 150 CORS distributed fairly evenly in the whole country as shown in **FIGURE 1**. Since July 2007, Leica Geosystems has also offered the SmartNet service to Ireland and Northern Ireland. Although the



▲ **FIGURE 3** Wireless coverage map of the study area

Test	SIM Card	Obs. Method	Cut Off Angle	Obs. Rate (Hz)
TS1	Fixed IP	Static	10	1
TS2	Fixed IP	Static	10	1
TS3	Fixed IP	Static	10	1
TS4	Fixed IP	Static	10	1
TS5	Normal IP	Static	10	1
TS6	Normal IP	Static	10	1

▲ **TABLE 1** Configuration of the performed tests including type of SIM card, observation method, and parameters for cut-off angle and observation rate in Hz

	UTC Start Time		UTC Finish Time		Duration
Test	Date	Time	Date	Time	hh:mm:ss
TS1	22/02/12	9:15:00	23/02/12	17:31:59	32:17:00
TS2	29/02/12	9:28:00	01/03/12	17:05:59	31:38:00
TS3	01/03/12	17:45:00	04/03/12	2:17:59	56:33:00
TS4	07/08/12	9:46:00	08/08/12	9:45:59	24:00:00
TS5	21/05/12	16:55:00	22/05/12	10:56:59	18:02:00
TS6	30/05/12	12:00:00	31/05/12	12:01:59	24:02:00

▲ **TABLE 2** Start and finish UTC time for each test including duration.

majority of CORS are owned by OSGB, known as OSNet, 23 CORS are managed and owned by Ordnance Survey Ireland and Ordnance Survey Northern Ireland, and 20 CORS are owned by Leica. All sites in Ireland are GPS-and-GLONASS, with OSGB currently upgrading OSNet to GPS, GLONASS, and Galileo-ready receivers/antennas (around 40 so far).

Receivers at the CORS collect raw GNSS data from the satellites and pass them through dedicated communication lines or the Internet to a network control center (CC). At the CC a software suite called GPS Spider processses the observations and produces the NRTK corrections as per the MAC technique, the most recently developed NRTK GPS technique.

Once the NRTK corrections have been produced, they are broadcast to the service's subscribers via GPRS under the NTRIP standard or via GSM without the need of any particular protocol.

Although, as mentioned before, GSM can certainly be used to deliver the NRTK corrections, SmartNet subscribers more frequently use GPRS due to its significant advantages. GPRS uses the IP data transmission protocol allowing easy Internet connection. Additionally, its data transmission rate is faster than that of GSM, and its users can stay connected to the GPRS network all the time while being only charged based on the quantity of the data transferred, rather than the elapsed connection time, as is the case of GSM.

NTRIP, the RTCM standard for efficient NRTK corrections transmission, is equally effective at permitting wireless Internet access through mobile-IP networks such as GPRS. Therefore, the use of GPRS and NTRIP as the combined wireless technology to transmit NRTK corrections to end users should guarantee the high flexibility, mobility, and availability that are needed when performing NRTK.

Testing Methodology

Several recent static tests evaluated the availability of the NRTK service that SmartNet could offer when using two dif-

Test	Possible Epochs	Actual Epochs	Availability (%)
TS1	116220	115420	99.31
TS2	113880	113051	99.27
TS3	203580	202589	99.51
TS4	86400	85735	99.23
TS5	64920	64769	99.77
TS6	86520	85654	99.00

▲ **TABLE 3** Availability of SmartNet including number of possible NRTK epochs and actual epochs in which a NRTK solution was actually achieved

Test	Lost Lock	Navigated	DGPS	Availability
TS1	0.00	0.00	0.69	99.31
TS2	0.01	0.17	0.55	99.27
TS3	0.00	0.13	0.36	99.51
TS4	0.00	0.16	0.61	99.23
TS5	0.02	0.09	0.12	99.77
TS6	0.00	0.75	0.25	99.00

▲ **TABLE 4** Detailed percentage of observations performed under different solution types (navigate, DGPS, and so on) during tests including availability of NRTK observations

ferent types of SIM cards to transmit the RTCM corrections. As shown in **TABLE 1**, the new fixed-IP SIM card was employed during tests TS1, TS2, TS3, and TS4, whereas tests TS5 and TS6 used the normal voice-and-data SIM. **FIGURE 2** shows equipment configuration used in the tests, and **FIGURE 3** a wireless coverage map for the study area.

All tests used the facility within the IESSG building with a geodetic antenna on the roof of the building and a dual-frequency geodetic GPS receiver that can accept NRTK corrections from SmartNet via a GPRS wireless modem; the receiver was also connected to a laptop logging real-time positioning solutions via NMEA GGA sentence. The receivers and the GPRS data link were, during most tests, placed indoors in the Geodesy Lab of the IESSG. This lab presents good mobile phone coverage and therefore no GPRS communications problems were experienced due to the data link being indoors.

Fixed-IP SIM card tests TS1, TS2, TS3, and TS4 lasted for at least 24 hours, with TS3 running for as much as 56 hours continuously. Tests TS5 and TS6, using the normal dynamic-IP SIM card, were designed to last for 24 hours; however, the GPRS connection during TS5 stopped at about 18 hours. **TABLE 2** shows detailed observation dates, times, and durations.

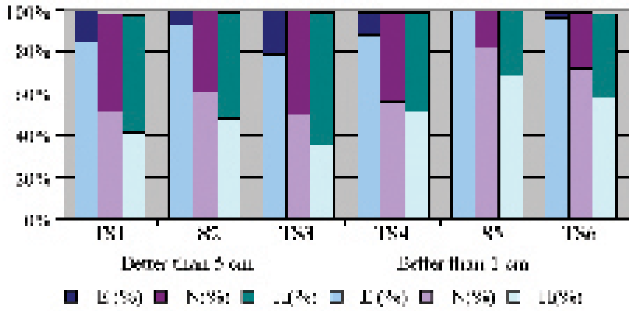
Link Impact on Availability

The resolution of the integer ambiguities in any NRTK survey can be affected by many factors, such as the presence of high multipath, low number of satellites in view, and lack or interruption of the correction message feeds. Considering that the IESSG test facility is a good location for GNSS observations with very low multipath and clear open skies, it was the reception of the RTCM corrections that could directly affect the proper resolution of the integer ambiguities during the tests.

Therefore, we considered availability of the SmartNet service as the percentage of observations in which a NRTK solution (integer ambiguities resolved) was achieved during each test.

When a NRTK solution is not possible but there is still a network correction message available, the SmartNet solution switches to DGPS. The presence of a DGPS solution, however, is not an indication that new NRTK corrections messages are still being received, because the rover receiver used during these tests can keep the last correction message received in its internal memory, allowing a DGPS solution to be performed for as long as 60 seconds after the data communication link is lost. This is another clear reason to use the number of observations with NRTK solution as the availability of the service and therefore the availability of the NRTK correction message.

TABLE 3 summarizes the availability during the tests. Availability of the NRTK service during fixed-IP SIM card tests was always greater than 99.23 percent. At the same time, normal IP SIM card tests (TS5 and TS6) also showed high availability, greater than 99 percent. The highest availability was obtained



▲ **FIGURE 4** Percentage of the observations with accuracy better than 5 centimeters (deep colors as the background) and 1 centimeter (bright colors at the front).

during TS5 (99.77 percent); however, it is important to point out that this test was initially planned to last for 24 hours, but the GPRS connection stopped after 18 hours of continuous use. The lowest availability level was observed during TS6 (99 percent), which used the voice-and-data SIM card.

TABLE 4 shows the detailed availability results. Aside from the NRTK epochs, some of the observations resulted in DGPS solutions that did not indicate that the NRTK corrections were being received.

In general, it is evident that even when using the normal IP SIM card, the availability of the service is still very high (greater than 99 percent), in contrast with the results of 85 percent obtained in the past tests mentioned at the beginning of the article. However, the new fixed-IP SIM card demonstrated more stability when performing long periods of continuous observation.

Impact of Availability on Accuracy

The availability of the NRTK solution is a vital index for the good performance of the SmartNet service. The accuracy and precision of the observations directly depend on whether the solution obtained is NRTK or not. Past tests demonstrated that SmartNet can achieve accuracy generally better than 5 centimeters.

Therefore, is the availability of this high accuracy similar to the availability of the NRTK solution shown above? To answer this question, we evaluated the availability of the accuracy as the percentage of NRTK observations with accuracy better than 5 centimeters. We also calculated the percentage of observations with accuracy better than 1 centimeter. A summary of the availability of the accuracy results appears in **FIGURE 4**, in the order of East (ΔE), North (ΔN) and Height (ΔH).

Observation accuracy was better than 5 centimeters over 97.50 percent of the time in all three coordinate components. At the same time, the Easting coordinate has a higher accuracy than the Northing and Height components, with at least 80 percent of the observations being better than 1 centimeter accuracy. It is then quite possible to say that, under similar testing conditions, SmartNet can achieve accuracy better than 5 centimeters when an NRTK solution is performed.

Issues for North America

As these tests took place in the European wireless environment, we now address a few comments on these issues relative to cellular phone service in the United States, which is provided on a state-by-state basis.

There are many different U.S. network carriers, who provide a mix of CDMA and GSM. Typically, CDMA has a better overall coverage, especially in rural areas. The top U.S. carriers are Verizon, Alltel, Sprint, USCellular, and AT&T. GSM-based carriers are AT&T (formerly Cingular) and T-Mobile. They have concentrated their efforts in larger cities, especially with respect to their data services, but one can find them everywhere.

Network RTK correction providers willing to offer their services in a particular area would need to research the coverage of the network providers. For example, in the Southeast, Verizon and Alltel are the best networks, and they use CDMA. Other areas are AT&T or T-Mobile — GSM.

In Iowa, USCellular, Verizon, T-Mobile, Alltel, and AT&T are used to do the network acceptance testing in case one of them didn't work for a particular area but the others did. Unfortunately, the coverage maps on each of the providers' websites are pretty marketing images and don't really reflect the actual coverage. One normally doesn't know until actually out in the field trying the service.

As a best practice, customers should choose their cellular provider based on who has the best coverage in the areas where they are primarily going to be working. In the United States, the most commonly used devices employ CDMA services. Although GSM is available, for some reason people have migrated to the CDMA versions. Contracts are usually bought as unlimited connectivity, costing about $60 a month.

CDMA is the only service used in Canada, where GSM has not taken off at all. Although available, almost 100 percent of NRTK GPS positioning customers prefer CDMA. In addition to the provider/coverage/technology problems, which phones may or may not work for each provider also must be considered. Technical representatives of each provider should help with the list of phones that would have unlimited data service, Bluetooth, dial-up networking, or tethering; however, just because it can get to the Internet is not a guarantee it will let the instrument bond and connect properly. Therefore, not only the selection of the proper cellphone carrier but also of the hardware to be used plays an important role in the provision of a reliable NRTK correction service in the United States.

One of the biggest recent changes is the use of data-relay systems or bridges. For example, the Intuicom bridge is a device that has a cellular modem in it and a regular radio. The devices have a Linux brain that can log in to a network and start communication. They also have an option of an L1 GPS receiver to start a position. This type of device works great when you have several units operating in a small area or if you need to extend to an area where mobile communications are not available. This is a kind of last-mile idea.

Question: Are data-only SIM card subscriptions widely enough available among wireless providers that the data/voice conflicts are not an issue?

Applications such as accessing financial portfolios via mobile phones or online, remote managing of ATMs, tracking vehicles and cash in transit, capturing meter readings and monitoring energy consumption, setting up highly effective and reliable surveillance and alarm systems, and accepting and authorizing credit and debit card payments on the move have notably increased the demand of wireless data transmission services for M2M communications. Emerging M2M technology such as the wireless logic SIM cards tested in this research now exists for applications that require critical mobile data such as the operations mentioned above and the RTCM message transmissions.

Further, new M2M companies have seen a gap in the market to supply data-reliant SIM cards on private Access Point Names (APN), to enable fully managed wireless data solutions. Main mobile phone operators such as Vodafone and Orange, which cover about 99 percent of the UK territory, now have business sections dedicated to the M2M services.

Question: Does the same data/voice issue exist in wireless networks utilizing CDMA?

The most common data transfer technology CDMA has to offer is the EVDO technology, allowing for a maximum download speed of about 2 Mbps (about 700 kbps in practice), which is similar to what a DSL line has to offer. Most importantly, CDMA 1X EVDO (3G) is the newest data-only service for CDMA; it offers high-speed data access of up to 3.1 Mbps (Rev A).

GSM, on the other hand, offers EDGE, allowing for a maximum download speed of 384 kbps (around 140 kbps in practice). More technologies are being developed on top of EDGE such as UMTS (3G) and the newest HSPA (3.5G) which supports downlink speeds of 1.8, 3.6, 7.2 and 14.4 Mbps, therefore opening the path to the so-called mobile Internet.

Although as initially conceptualized CDMA could offer faster data download than GSM, with the advent of the new technologies such as CDMA 1X EVDO and HSPA, both cellular networks will be able to offer high-speed and reliable data-only transfers that will benefit NRTK correction providers and users.

Research at the University of Nottingham shows promising results in the use of HSPA technology for the transmission of RTCM corrections, which is affected only by the reduced coverage of the service.

Conclusion

A preliminary analysis of the impact that commercial GPRS communications have over the availability and general performance of a NRTK GNSS service shows that in ideal conditions (low multipath environment and clear sky view), the availability of the NRTK service SmartNet directly depends on the proper reception of the network correction messages. During all the tests, the service showed a very high availability of more than 99 percent, which therefore also indicates the high availability of the GPRS transmission.

Fixed-IP SIM cards that are specially designed for data transmission only proved more stable than normal voice-and-data SIM cards. The former allowed continuous connections for more than 24 hours without dropping communication, whilst, in one case, data transmission was stopped after 18 hours when using the normal dynamic-IP SIM card.

We also found high availability of the accuracy, with more than 97.50 percent of the observations presenting accuracy better than 5 centimeters. Therefore, it is clear that the accuracy of SmartNet service directly depends on the availability of the NRTK solutions.

We are currenntly analyzing other topics such as the impact of the completeness and the age of the NRTK message over the NRTK service, as well as the use of new mobile communication technologies such as 3G for transmission of network messages.

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Manufacturers

Tests used **Leica** (*www.leica-geosystems.com*) *AT503* antenna, Leica *GX-1200* dual-frequency geodetic GPS receiver as a rover, network RTK corrections generated from Leica *Spider* software system, and GPRS service by **Vodafone** (*www.vodafone.com*) and **Wireless Logic** (*www.wireless-logic.com*).