TRIMBLE XFILL RTK

WHITE PAPER

TRIMBLE SURVEY DIVISION

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ABSTRACT

Trimble xFill™ is a new service that extends RTK positioning for several minutes when the RTK correction stream is not available. Trimble xFill corrections are broadcast by satellite, so they are generally available within covered areas wherever the GNSS constellations are visible. Surveyors with access to the Trimble xFill service will benefit from improved field productivity. This paper describes Trimble xFill and its practical applications.

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INTRODUCTION

This white paper introduces the new Trimble xFill RTK extension service and explores the various aspects of this powerful enhancement to RTK surveying that significantly increases field productivity. During periods of radio outage when the primary correction stream is unavailable to support conventional single-base or Virtual Reference Station (VRS) Network RTK, Trimble xFill provides the technology that enables point measurements to continue for short periods with survey-level precisions. Not only does this eliminate positioning drop-outs, but it may enable a brief excursion into an area masked from the reference radio signal, yet still visible to the GNSS constellations.

To achieve centimeter positioning with GNSS signals, Trimble xFill provides a specialized correction steam broadcast by L-band satellite that is generated using Trimble Real-time eXtended (RTX) technology. Therefore, this paper will provide an overview of the Trimble RTX technology before focusing on the details of Trimble xFill.

TRIMBLE RTX TECHNOLOGY

RTX positioning technology, which was recently developed by Trimble, combines a variety of innovative techniques to provide users with centimeter-level real-time positioning anywhere on or near the earth's surface.

This new positioning technique is based on the generation and delivery of precise satellite corrections (orbit, clocks, and system biases) on a global scale via either L-band satellite links or the Internet. The general infrastructure of the system can be seen in the schematic flowchart in Figure 1.

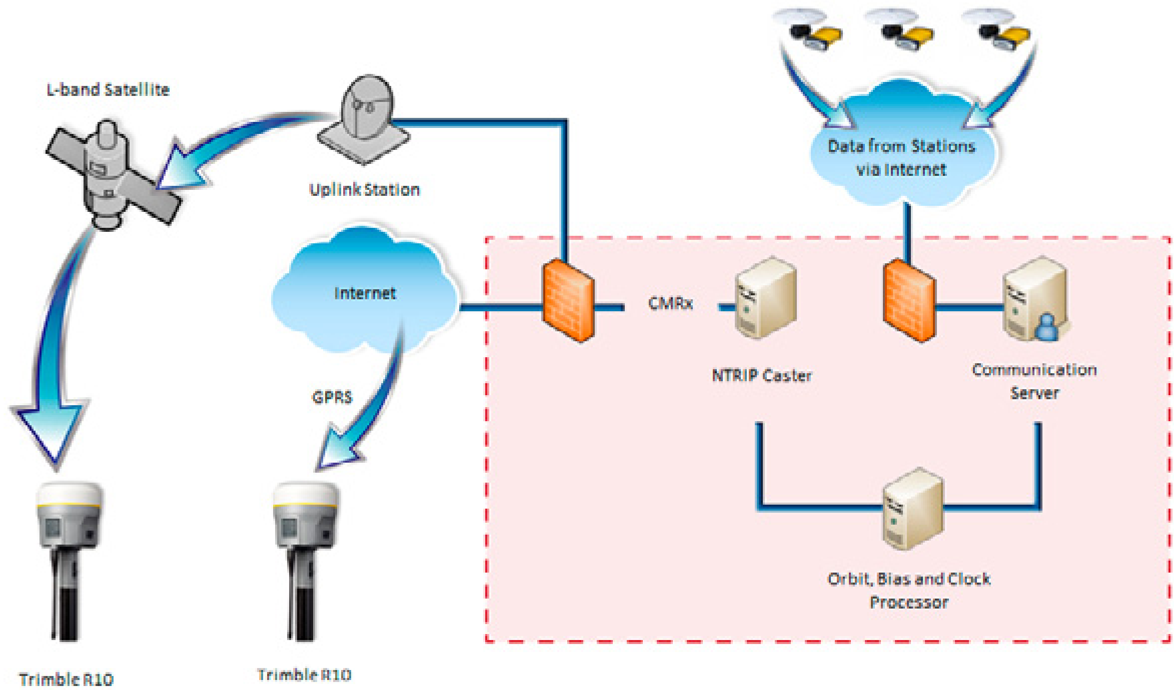

Figure 1. Trimble RTX positioning technology infrastructure

Data from monitoring stations distributed around the globe are collected and transmitted via the Internet to operation centers. The operation centers (encapsulated by the dashed red square in Figure 1) are redundant in order to ensure a very high (~100%) system availability. If there is an operational requirement, the correction stream source can automatically switch between the redundant operation centers and/or processing servers within centers. Inside the operation centers, redundant communication servers are used to relay the network observation data to the data processing servers. These servers host the network processors that produce precise orbit, satellite clock, and models for observation biases valid for any global location.

The precise satellite data generated by the network processors are compressed in messages compliant with the CMRx format, which was developed specifically for compact transmission of satellite information to support RTK positioning, Trimble RTX, and Trimble xFill. The messages are then routed to either a satellite uplink station or made available for Internet access by the users (for example, GPRS cell phones).

The Trimble RTX tracking network currently comprises approximately 100 stations that are distributed across the globe, as shown in Figure 2.

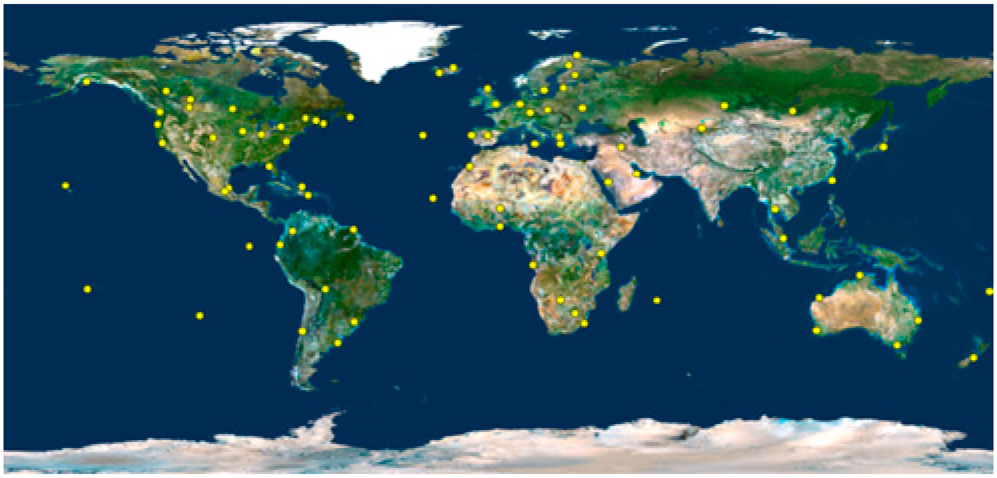

Figure 2. Trimble RTX tracking network distribution

TRIMBLE XFILL: THE CONCEPT

The introduction of Trimble xFill technology allows Trimble R10 receivers performing single-base or VRS RTK surveys to benefit from fundamental aspects of Trimble RTX technology.

Most RTK systems currently rely on radio or cell phone (using the Internet) connections to receive corrections from a reference station. The reference station in this case could be a single physical station, familiar to GNSS surveyors as traditional single-baseline RTK, or a VRS, which generates data derived from a network of receivers. Although the network node spacing typically may be 40 to 70 kilometers, the VRS data "appears" to originate from a virtual position established close to the rover receiver when the survey is started. Figure 3 illustrates these two types of RTK correction streams.

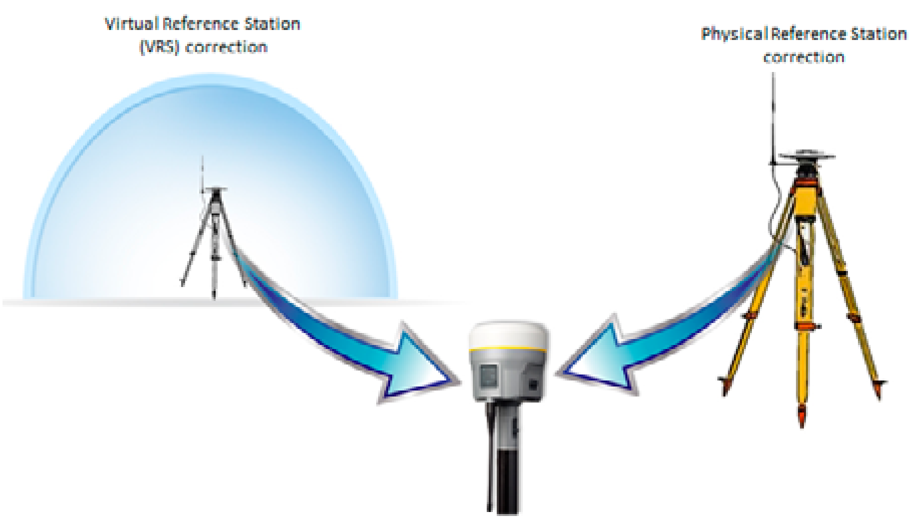

Figure 3. Possible sources of correction for most RTK systems: single physical reference station or VRS

Trimble xFill technology aids standard RTK systems in the event of connection outages with their primary source of corrections: a reference station or a VRS stream. A typical case of radio drop-out is shown in Figure 4, which illustrates radio signal shadowing caused by a building. The signal outage takes place at the rover locations where the building is between the user and the reference station radio transmitter, effectively blocking the signal and causing a suspension of RTK positioning. The same scenario can occur when a VRS user moves to area where a large building or hill blocks communication with the active cellular tower.

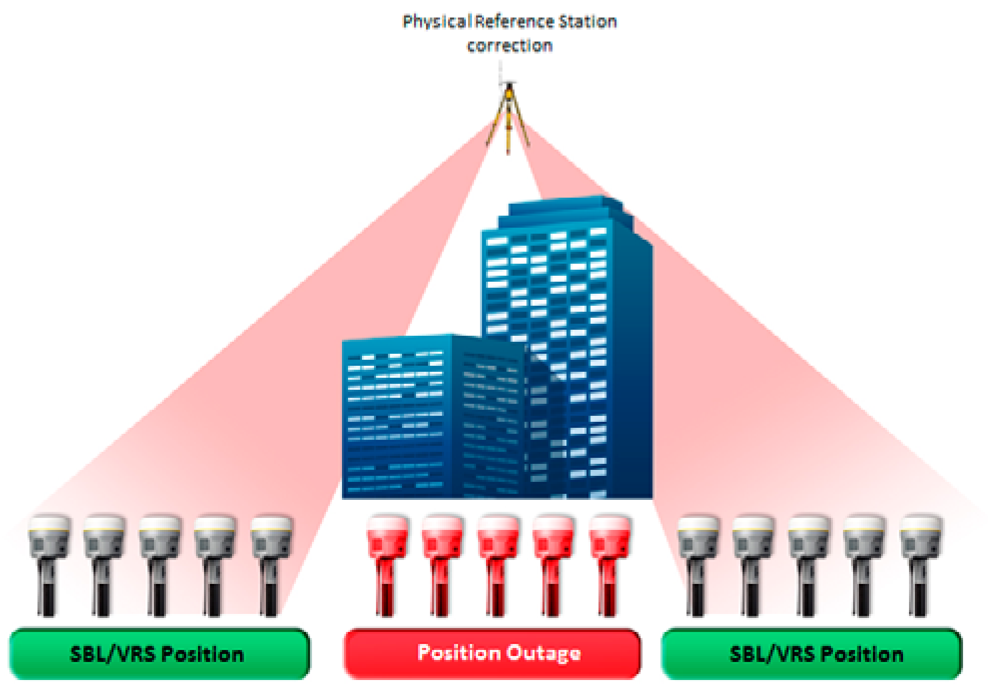

Figure 4. RTK solution outage caused by a building obscuring the RTK radio signal

Trimble RTX technology currently powers stand-alone positioning services for several non-survey applications. Trimble xFill, which is a standard feature with the Trimble R10, is not a stand-alone positioning service but instead uses the RTX infrastructure to augment standard RTK and VRS surveying methods.The multitude of GNSS correction streams now available for Trimble RTK users with the introduction of Trimble xFill is shown in Figure 5.

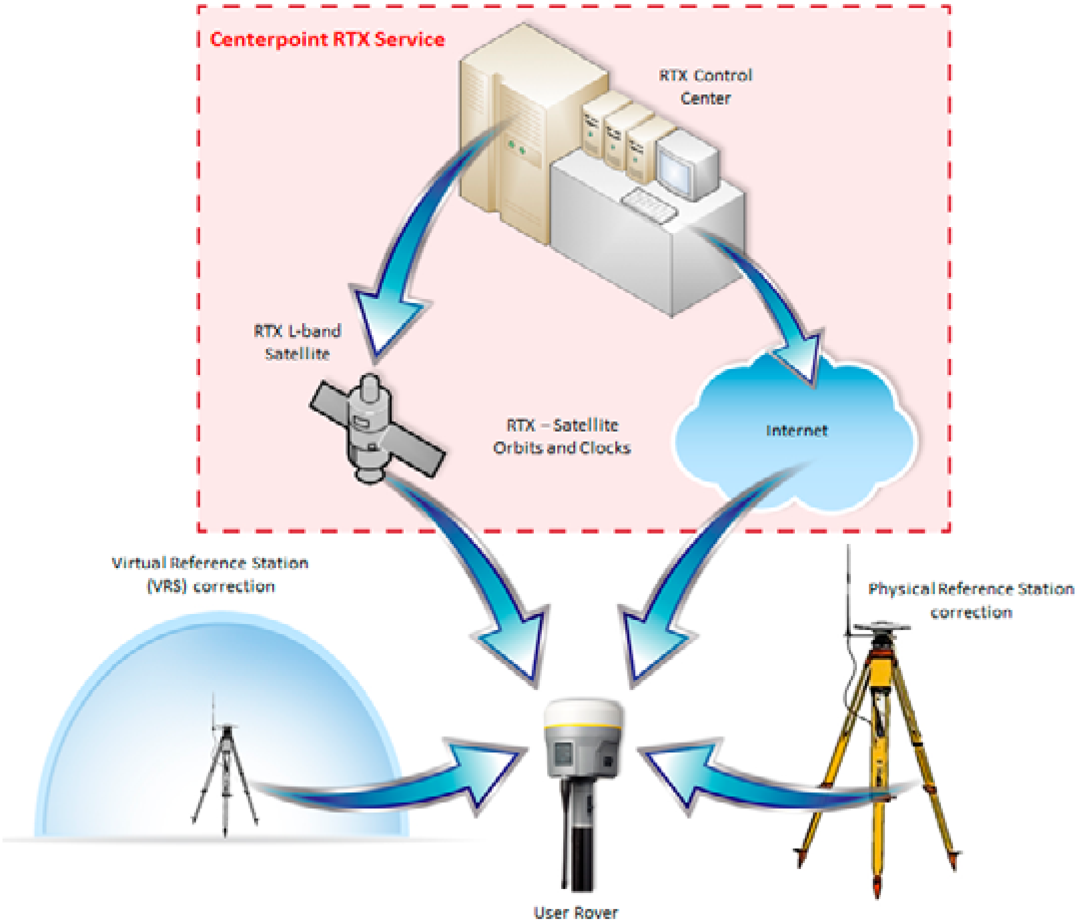

Figure 5. Multitude of GNSS correction streams available for Trimble RTK users enabled with Trimble xFill

In areas of Trimble RTX satellite coverage, the Trimble R10 receiver with Trimble xFill operates with the simultaneous input of single-base or VRS correction streams and the RTX stream. In the event of a correction outage, such as the one illustrated in Figure 4, the Trimble RTX corrections provide the mechanism to maintain high precision RTK positioning based on just the rover GNSS observables. This "fills the gap" caused by the primary correction stream outage (hence the feature name "xFill"). Figure 6 illustrates the expected behavior of a Trimble R10 receiver for this same scenario.

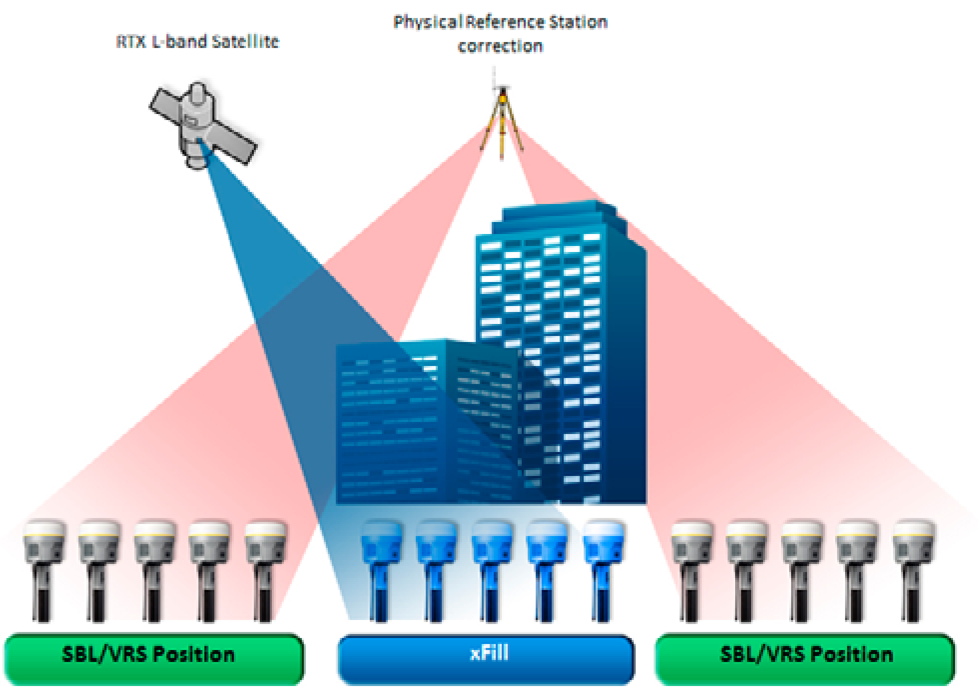

Figure 6. Expected behavior of the R10 receiver using Trimble xFill

As a result of the Trimble RTX corrections being transmitted over an independent link (an L-band satellite beam, rather than the base station radio), they will typically be available when the reference station correction is missing. Terrestrial radio signals are often blocked, leaving a good view of the GNSS satellites and the Trimble xFill L-band beam. The multi-GNSS capabilities of the Trimble R10 further improve the ability to track sufficient satellites for Trimble xFill operation in obscured environments. The receiver is able to continuously provide RTK positions as it crosses the radio shadow area.

The Trimble RTX signal is received continuously by the rover whenever line-of-sight is maintained to the L-band satellite. Therefore, the signal is readily available to seamlessly maintain RTK data processing.

In summary, the Trimble xFill feature allows surveyors using the Trimble R10 to dramatically extend their productivity in areas where the primary correction signal is poor. It does this by maximizing system availability when the Trimble RTX signal is available.

HOW DOES IT WORK?

To understand how Trimble xFill works, it will help to go back and review the principles of differential RTK: namely, the traditional single-base and VRS systems.

When combining reference station and rover GNSS data during GNSS processing, it is assumed that the errors observed at both sites are very similar. These common effects are typically dominated by satellite clock errors, satellite orbit errors, atmospheric effects, and measurement biases. Because these quantities are reasonably consistent between rover and reference, they are mostly cancelled when the two sets of measurements are combined. Any residual errors are typically small enough to allow positioning with relative accuracies at the centimeter level, as illustrated in Figure 7.

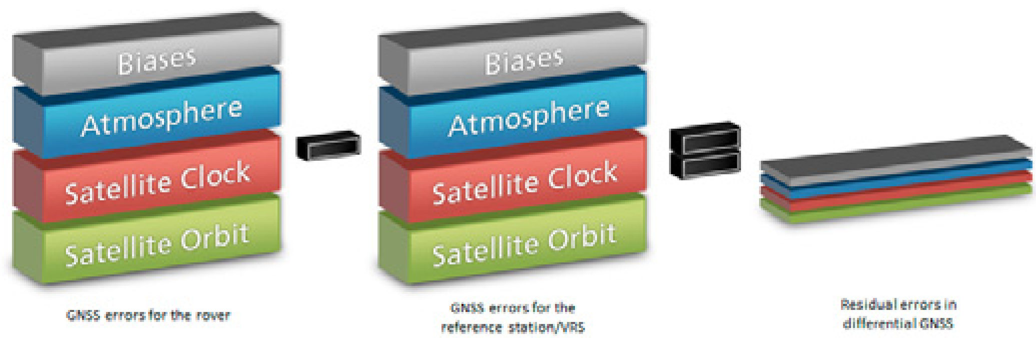

Figure 7. Differential RTK error modeling with single-base or VRS

The Trimble xFill technology is able to produce RTK positions with precision levels similar to traditional differential RTK because it tackles the same source of errors, although using quite a different approach. This is due to the fact that data is available only from the rover once the radio link is suspended. The satellite clock, orbit, and measurement biases that are cancelled via differencing in standard RTK processing are actually modeled and transmitted as part of the Trimble RTX correction stream. These effects then become known quantities and can be properly accounted for when processing the rover measurements. The atmospheric errors are dealt with by algorithms specifically developed for the Trimble RTX system, reducing any residual effects to an acceptable level for high accuracy GNSS positioning applications. As a result, the overall Trimble RTX data processing provides modeling of the residual errors on the satellite observations that are comparable to the ones achieved with differential RTK, as illustrated in Figure 8. Although the various error sources are modeled rather than cancelled against similar errors experienced at the reference receiver, the quality provided by the algorithms in the Trimble RTX processor (shown in Figure 1) is so high, that the final precision of the xFill positions are consistent with the performance of traditional RTK differential processing.

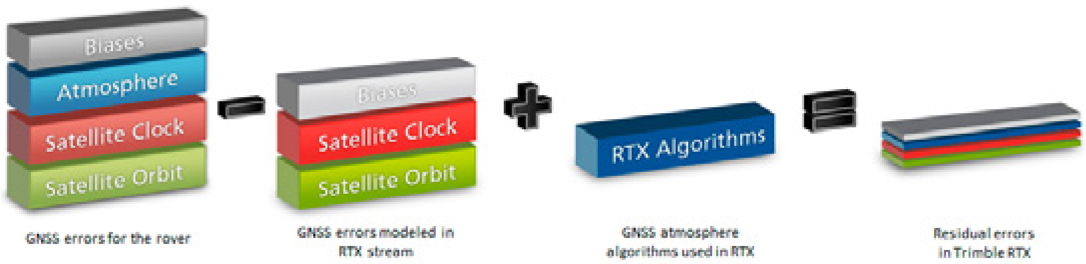

Figure 8. Trimble RTX error modeling

The Trimble RTX L-band stream provides corrections of such high quality that an error modeling approach is commensurate with traditional differential RTK. Therefore, it is possible to use Trimble xFill to sustain RTK operation during a reference data outage without compromising the precision levels required for survey applications, as summarized in Figure 9.

Figure 9. Reference data outage with Trimble xFill

The final residual errors are caused primarily by local effects at the rover, such as the multipath environment. These effects are common between the different correction sources.

PERFORMANCE ASPECTS

One of the most important Trimble xFill benefits is instant availability as soon as the RTK radio signal is lost. There is no delay due to, for example, a short convergence phase similar to the situation when RTK is first started. Trimble xFill is available to sustain RTK operation the same instant that the primary correction stream is lost – seamlessly filling the gaps that would otherwise have occurred. Trimble xFill is available as soon as the first regular RTK position has been reported after the survey start.

Different RTK users operate within different reference frames (coordinate systems). Although all of the Trimble RTX computations and correction stream generation are based on the International Terrestrial Reference Frame of 2008 (ITRF08), Trimble xFill processing provides coordinates that are on the same reference frame as the RTK solution that is being sustained, whether single-base or VRS derived. However, to ensure the best performance, the chosen RTK reference frame should be close to ITRF08 (or WGS84). Further guidance can be found on the R10 datasheet.

In terms of precision performance, Trimble xFill is capable of delivering positioning results with an expected horizontal precision of RTK + 10 mm/minute at a Distance RMS (DRMS) level. (See *Table 1. Trimble xFill characteristics* later in this white paper.)

The actual performance will depend on satellite visibility, geometry, and the local multipath environment at the rover. Once Trimble xFill is active, the error growth is slow and largely linear; it will be represented by an increase in the reported precisions. Therefore, no special field procedure is necessary. If the primary correction source cannot be re-established, when the precision exceeds the user-specified tolerance for the required survey mode (for example, continuous kinematic, topo, or control point), the point will no longer be stored automatically. As soon as primary corrections resume, even for a second, the precisions are effectively "reset" to the level reported prior to switching to Trimble xFill (depending on any change to the satellite visibility). Even very sporadic radio reception could have little impact on the reported RTK precisions. Difficulty may occur only with longer outages. Currently, the Trimble R10 will continue to provide Trimble xFill positioning for up to 5 minutes following RTK outage.

Optimum performance also requires continuous tracking of the GNSS signals, which may not be possible when the signals are obstructed together with the primary correction broadcast. This can occur, for example, when operating very close to buildings. New satellites are always added to the Trimble xFill position solution, and those experiencing tracking interruptions and cycle-slips are introduced back into the solution. However, the temporary loss of GNSS signals can increase the precision growth if the satellite geometry is weakened. This is usually known as an increase in Position Dilution of Precision (PDOP), and it affects all GNSS positioning methods (it is not specific to Trimble xFill). When the number of tracked satellites falls below four, the Trimble xFill solution will terminate until the radio link is re-established and five satellites are visible. (The number may depend on the combination of GNSS satellites tracked when less than five GPS satellites are available.) This is similar to regular RTK, which requires a minimum of four satellites. However, the Trimble HD-GNSS processing engine integrated in the Trimble R10 will ensure a rapid convergence to survey-level precisions once five satellites are visible.

The position error plots in figures 10 and 11 show the actual performance obtained during a Trimble xFill test conducted during development. Each plot comprises exactly 5 minutes of VRS positioning followed by 5 minutes of xFill having disconnected the primary correction stream. These examples illustrate the gradual drift of position characteristic of xFill that is accompanied by an increase in the reported precisions.Note that the current R10 firmware version limits the xFill duration to 5 minutes to accommodate typical survey precision thresholds used with Trimble Access in a variety of field environments.

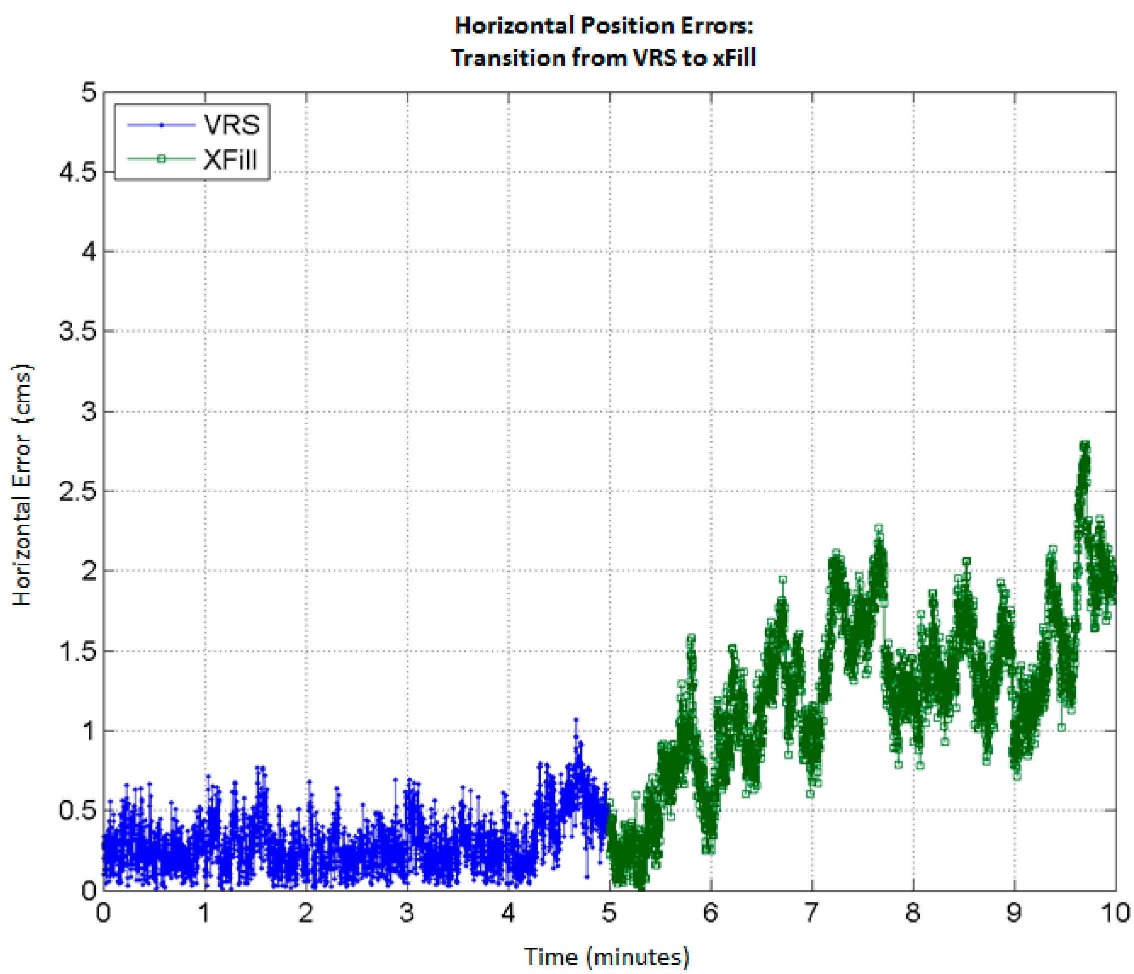

Figure 10. Example of horizontal positioning error during extended Trimble xFill

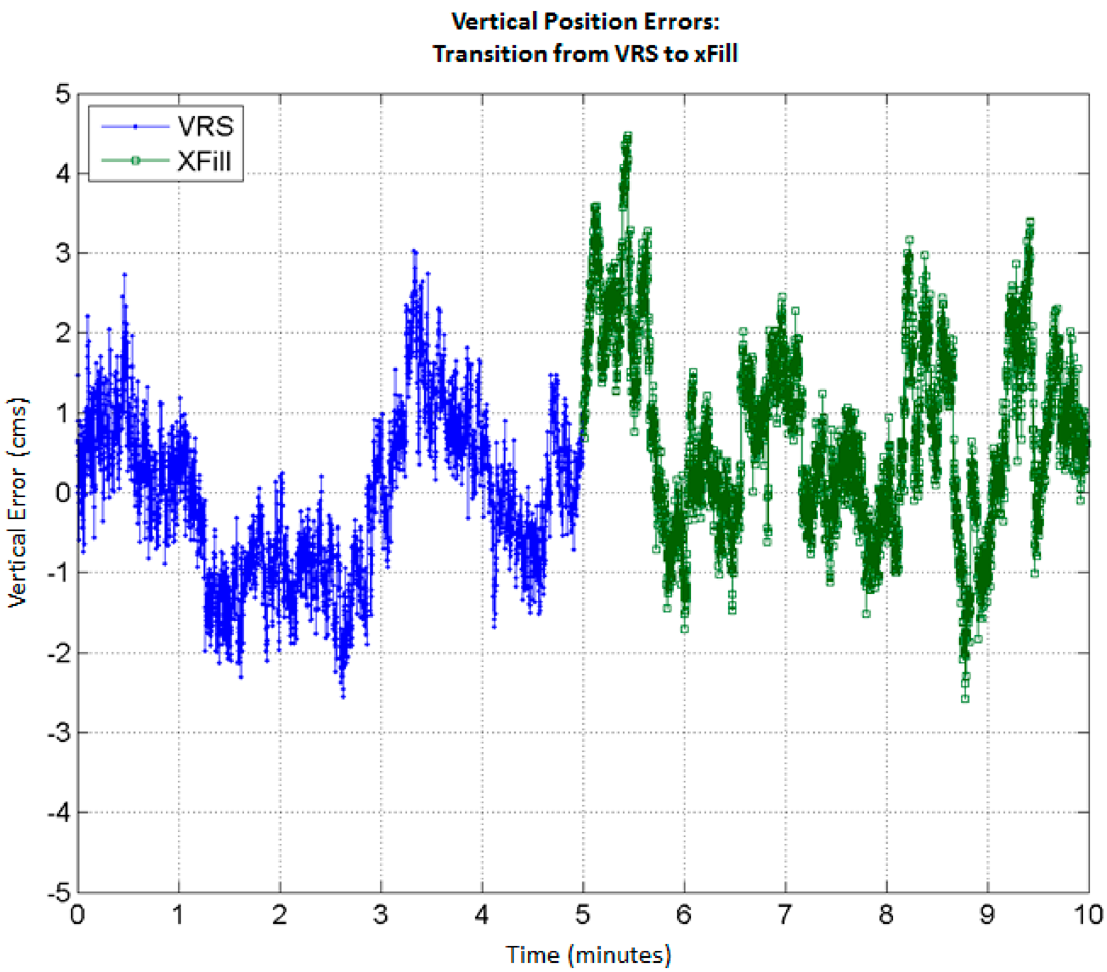

Figure 11. Example of vertical positioning error during extended Trimble xFill

USING TRIMBLE XFILL WITH TRIMBLE ACCESS AND TRIMBLE BUSINESS CENTER

Trimble xFill is applied to RTK surveys with a Trimble R10 receiver and Trimble Access field software. When the RTK correction stream is lost, Trimble Access automatically switches from RTK to Trimble xFill. The transition is immediate and completely seamless to the user. When Trimble xFill is active, Trimble Access displays "xFill" in the status bar along with the estimated precisions, as shown in Figure 12.

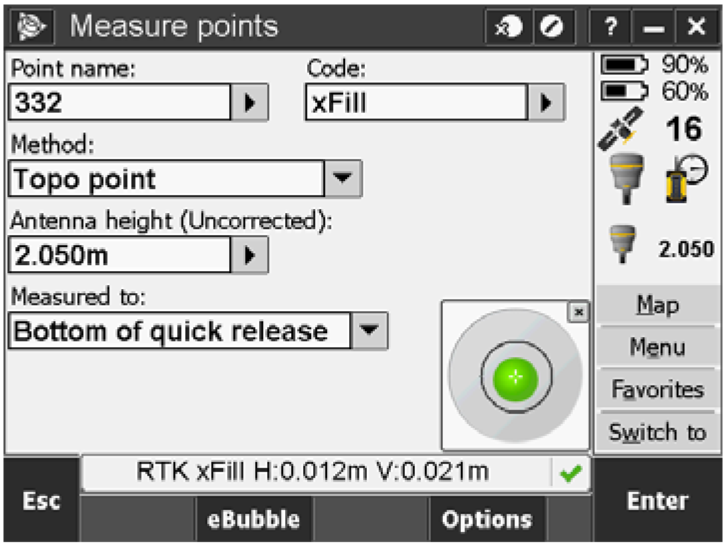

Figure 12. Trimble Access displays "xFill" when Trimble xFill is active

Point measurement is available until the precision values exceed the user-defined tolerances. Once the precisions have exceeded the specified tolerances, Trimble Access switches from displaying a green checkmark to a red "x," which indicates that point measurement is no longer available. At that time, the user needs to restore the RTK correction stream to continue surveying.

Trimble Access stores Trimble xFill observations as RTK vectors. Users can then import these observations into Trimble Business Center office software as shown in Figure 13, where Trimble xFill points can be adjusted relative to the RTK base station or network along with all other RTK points.

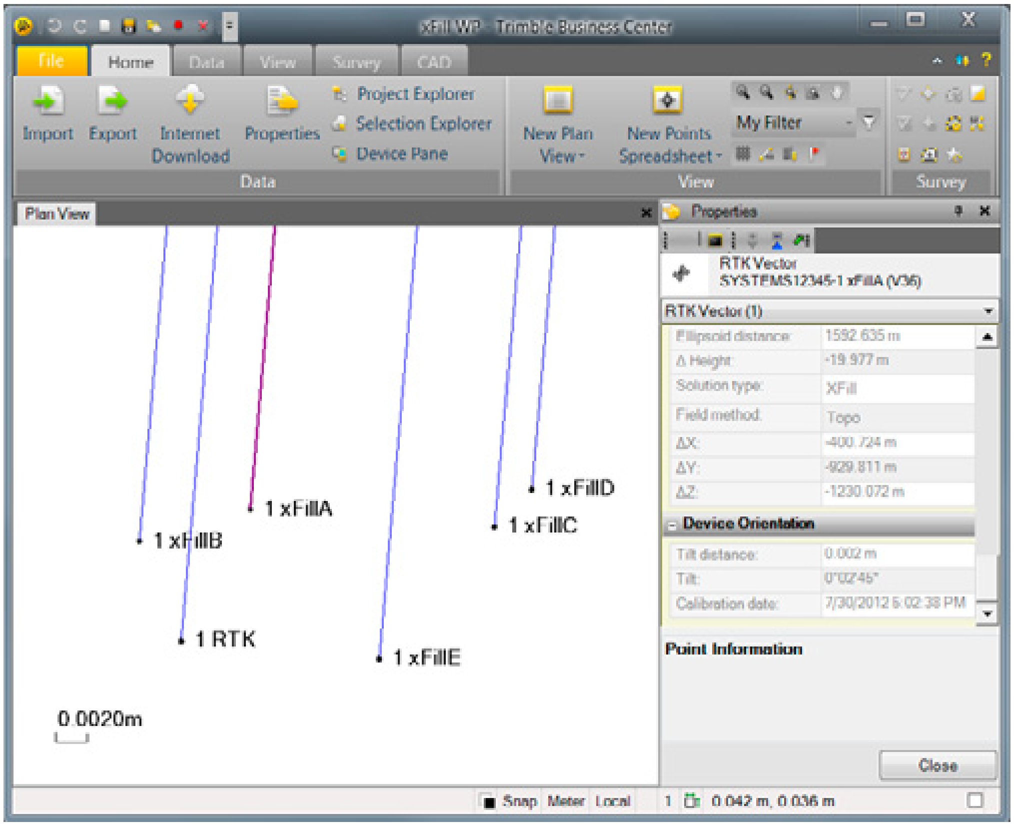

Figure 13. Trimble xFill observations in Trimble Business Center office software

CONCLUSION

Trimble xFill is a new technology developed by Trimble to allow RTK users to benefit from the Trimble RTX L-band satellite service. The traditional methods used by differential RTK processing are enhanced by advanced modeling and estimation of fundamental GNSS errors, such as satellite orbits, clocks, and system biases.

Available for the first time in the Trimble R10 receiver, Trimble xFill is able to deal robustly with radio or Internet connection outages, the primary cause of dropped RTK corrections. Seamless positioning is provided while maintaining survey-level precisions for many minutes. There are no delays when Trimble xFill is automatically activated. Extended Trimble xFill periods are possible for less demanding applications. Sporadic radio reception that can occur in many field environments will no longer have an impact on the field workflow, resulting in less downtime and maximum productivity.

The characteristics of xFill are summarized in Table 1.

Table 1. Trimble xFill characteristics

Trimble xFill Characteristics	
RTK primary correction (single-base, VRS) operation time before Trimble xFill can be deployed	Single measurement at required precision
Convergence time once Trimble xFill is deployed	Zero
Maximum (primary correction) outage time	5 minutes
Typical horizontal precision[1]	RTK[2] + 10 mm/minute RMS
Typical vertical precision[1]	RTK[2] + 20 mm/minute RMS
Reference frame	Same as primary correction RTK
Table Notes: 1. Precisions are dependent on GNSS satellite availability. xFill positioning ends after 5 minutes of radio downtime. 2. RTK refers to the last reported precision before the correction source was lost and xFill started.	