Overview
of
SmartNet Reference Station Network
for
RTK Positioning and Rinex Data Services

by

Henri B. Ayers
Leica Geosystems Ltd.

Presented at the 10th Annual GEOIDE Scientific Conference
Precise Point Positioning Workshop Session
Niagara Falls, Ontario, Canada

May 27, 2008

Overview of SmartNet Reference Station Network

Contents:

- *General Network and Sub-Net Station Layouts*
- *Montreal, Ottawa and Southern Ontario Clusters*
- *Master-Auxiliary Concept (MAC) RTK Positioning Process*
- *Dispersive and Non-Dispersive MAC RTK Network Corrections*
- *Status of Common Level Ambiguity Resolution from Clusters*
- *Auto Cell MAC Network RTK Solution Examples*
- *RTK User Product Selection and Access*
- *Summary and Conclusion*

SmartNet Reference Station General Layout as of May 2008

- when it has to be right

Leica Geosystems

Notes:

SmartNet Reference Stations Network consists of over 45, as of May 2008, GNSS Stations spread between Nova Scotia and Southern Ontario providing live RTK Positioning Data services via the Internet and 1-second Rinex data from a FTP Download Site.

Atlantic Reference Station Layout as of May 2008

- when it has to be right

Leica Geosystems

Notes:

Atlantic Reference Stations consist of 5, as of May 2008, Reference Stations spaced by about a few 100 kilometres providing Single Site RTK Positioning Data services via the Internet and 1-second Rinex data from FTP site.

The Atlantic Reference Stations coordinates are based on CSRS as computed from CACS and CBN Control Points in the area via Network Adjustment of several independent baseline vector solutions between stations.

Montreal Reference Station Layout as of May 2008

- when it has to be right

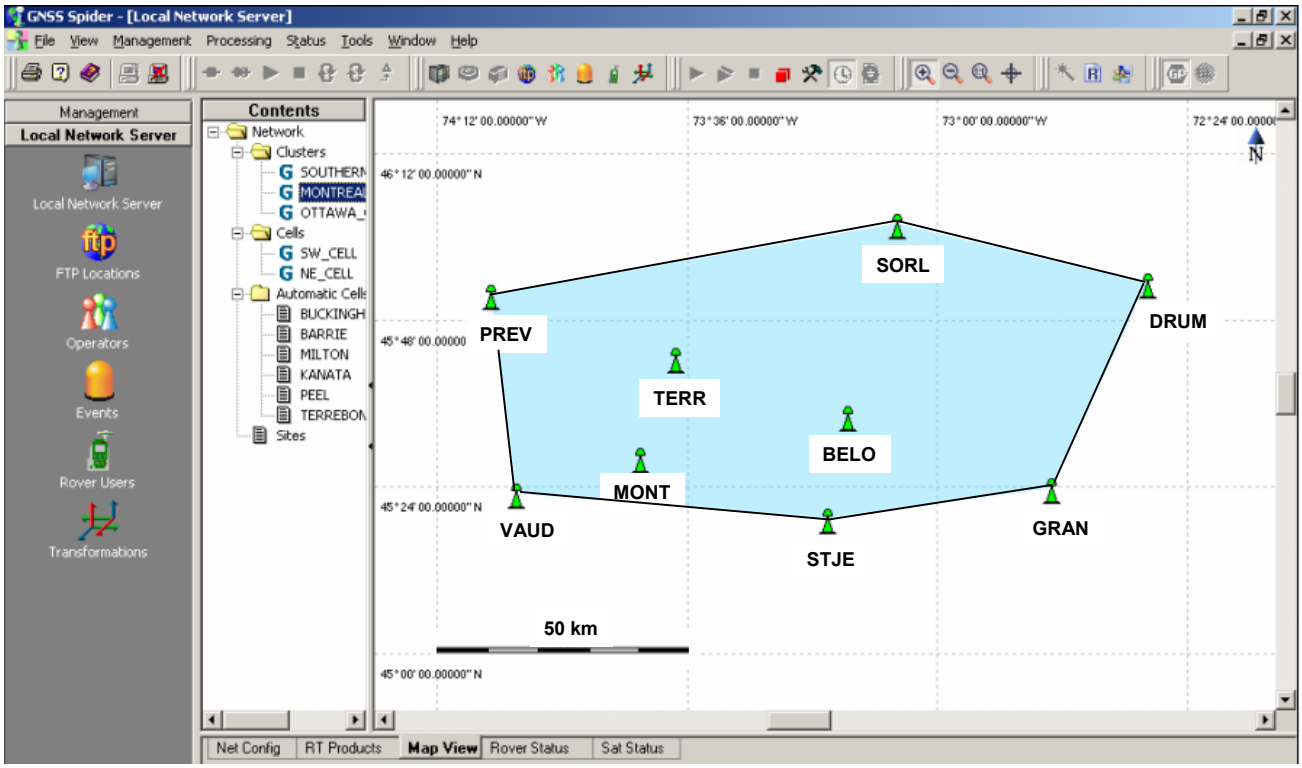
Leica Geosystems

Notes:

Montreal Reference Stations consist of 9, as of May 2008, Reference Stations spaced by about 50 to 70 kilometres providing Single Site and Network RTK Positioning Data services via the Internet and 1-second Rinex data from FTP site.

The Montreal Reference Stations coordinates are based on CSRS as computed from CACS and CBN Control Points in the area via Network Adjustment of several independent baseline vector solutions between stations.

Montreal Network Cluster Layout as of May 2008



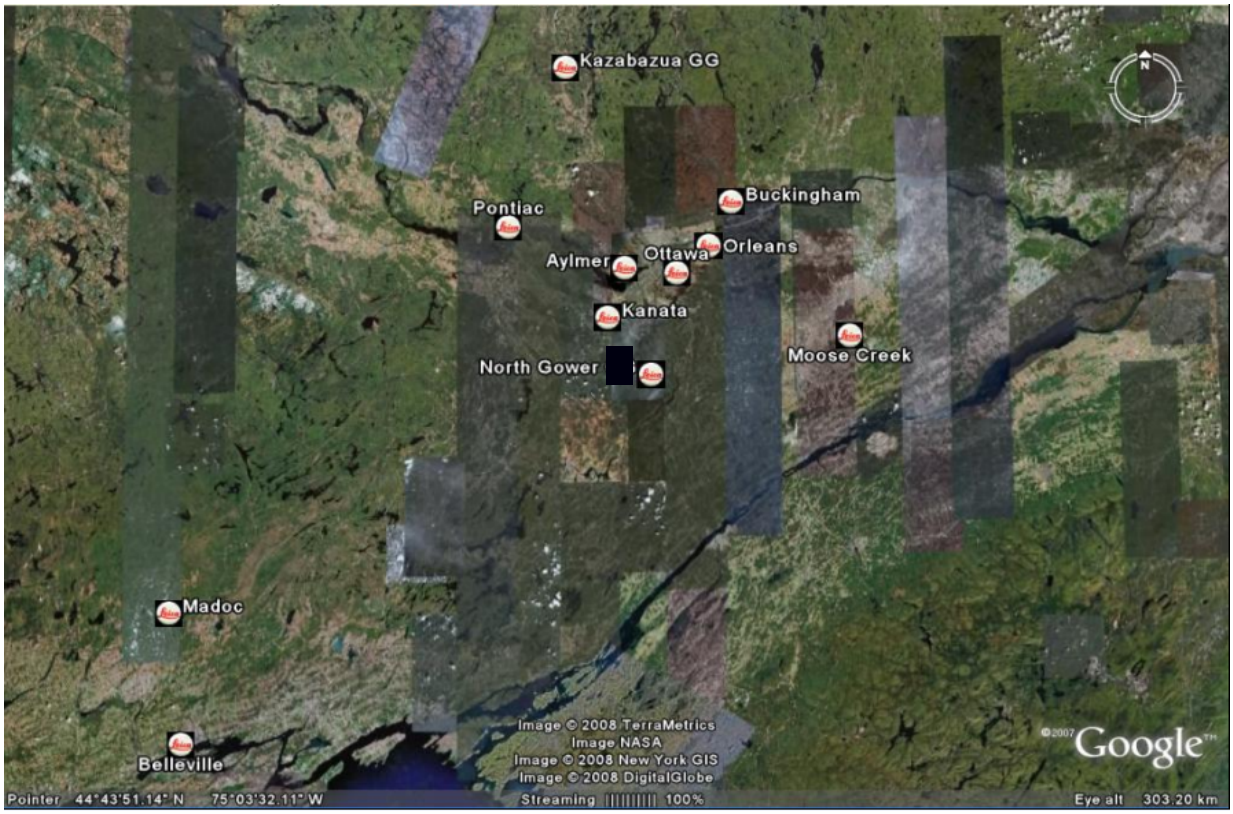
Notes:

The Montreal Network Cluster consist of 9, as of May 2008, Reference Stations forming a rectangular shape of about 100 km by 50 km which are processed together to determine Common Level Site, Satellite and Frequency Phase Integer Ambiguities for Ionospheric and Tropospheric Network RTK space based corrections.

The Montreal Cluster provides different Network RTK Message types based on the Master-Auxiliary Concept (MAC) from automatically created Cells.

Each Cell is a subset of Cluster Stations surrounding the RTK Rover location and is automatically redefined as the RTK Rover moves in the Cluster area.

Ottawa/Gatineau Reference Station Layout as of May 2008



- when it has to be right

Leica Geosystems

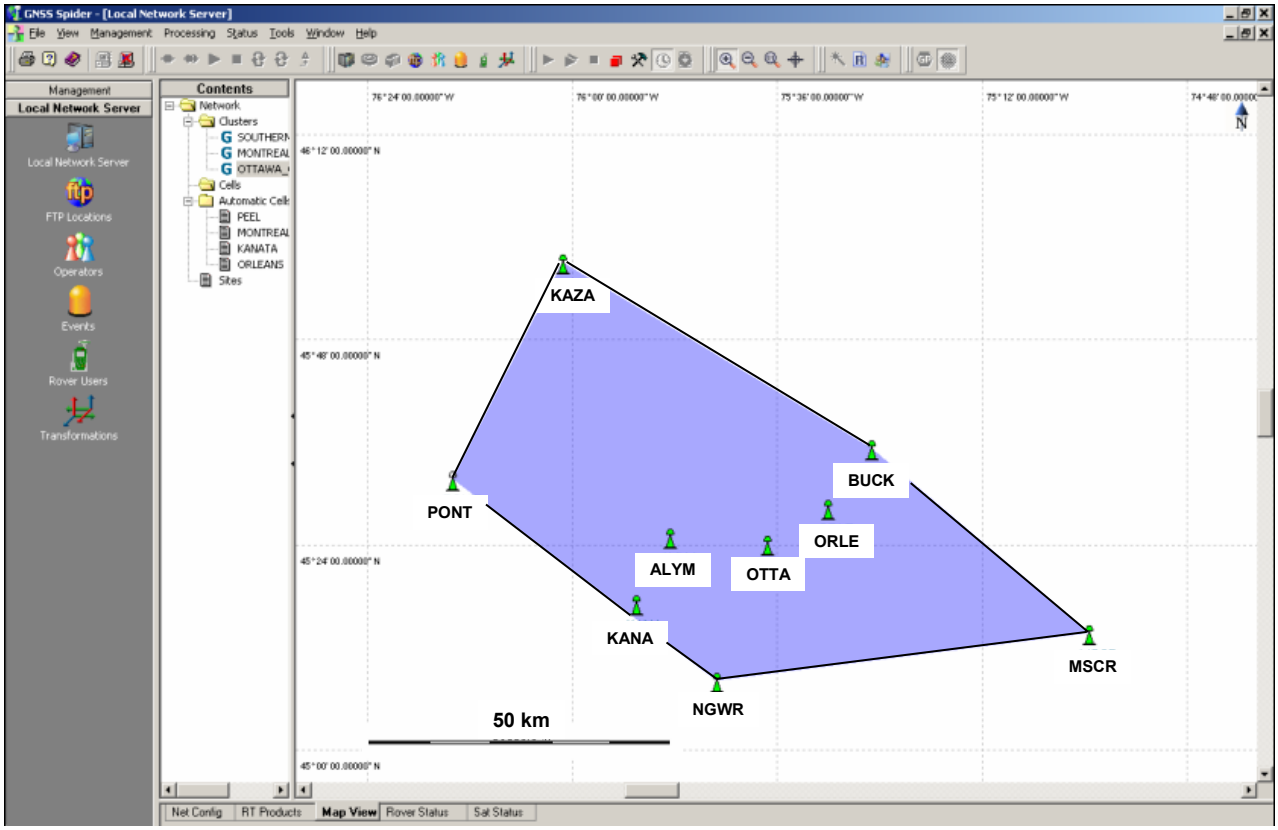
Notes:

Ottawa/Gatineau Reference Stations consist of 9, as of May 2008, Reference Stations spaced by about 50 to 70 kilometres providing Single Site and Network RTK Positioning Data services via the Internet and 1-second Rinex data from FTP site.

Ottawa/Gatineau Reference Stations coordinates are based on CSRS as computed from CACS and CBN Control Points in the area via Network Adjustment of several independent baseline vector solutions between stations.

Other Reference Stations in Eastern Ontario are providing Single Site RTK Positioning Data services via the Internet and 1-second Rinex data from FTP site.

Ottawa/Gatineau Network Cluster Layout as of May 2008



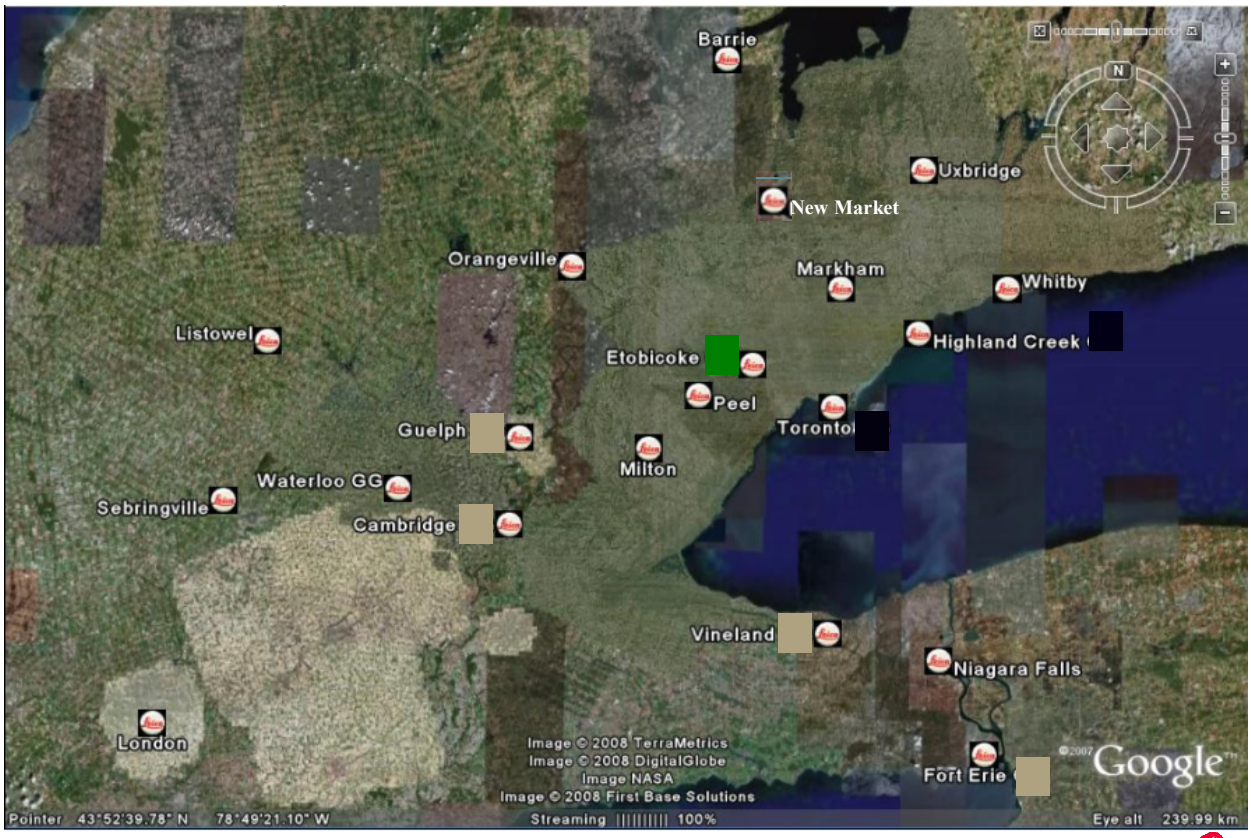
Notes:

The Ottawa/Gatineau Network Cluster consist of 9, as of May 2008, Reference Stations forming a trapezoid shape of about 150 km by 50 km which are processed together to determine Common Level Site, Satellite and Frequency Phase Integer Ambiguities for Ionospheric and Tropospheric Network RTK space based corrections.

The Ottawa/Gatineau Cluster provides different Network RTK Message types based on the Master-Auxiliary Concept (MAC) from automatically created Cells.

Each Cell is a subset of Cluster Stations surrounding the RTK Rover location and is automatically redefined as the RTK Rover moves in the Cluster area.

Southern Ontario Reference Station Layout as of May 2008



- when it has to be right

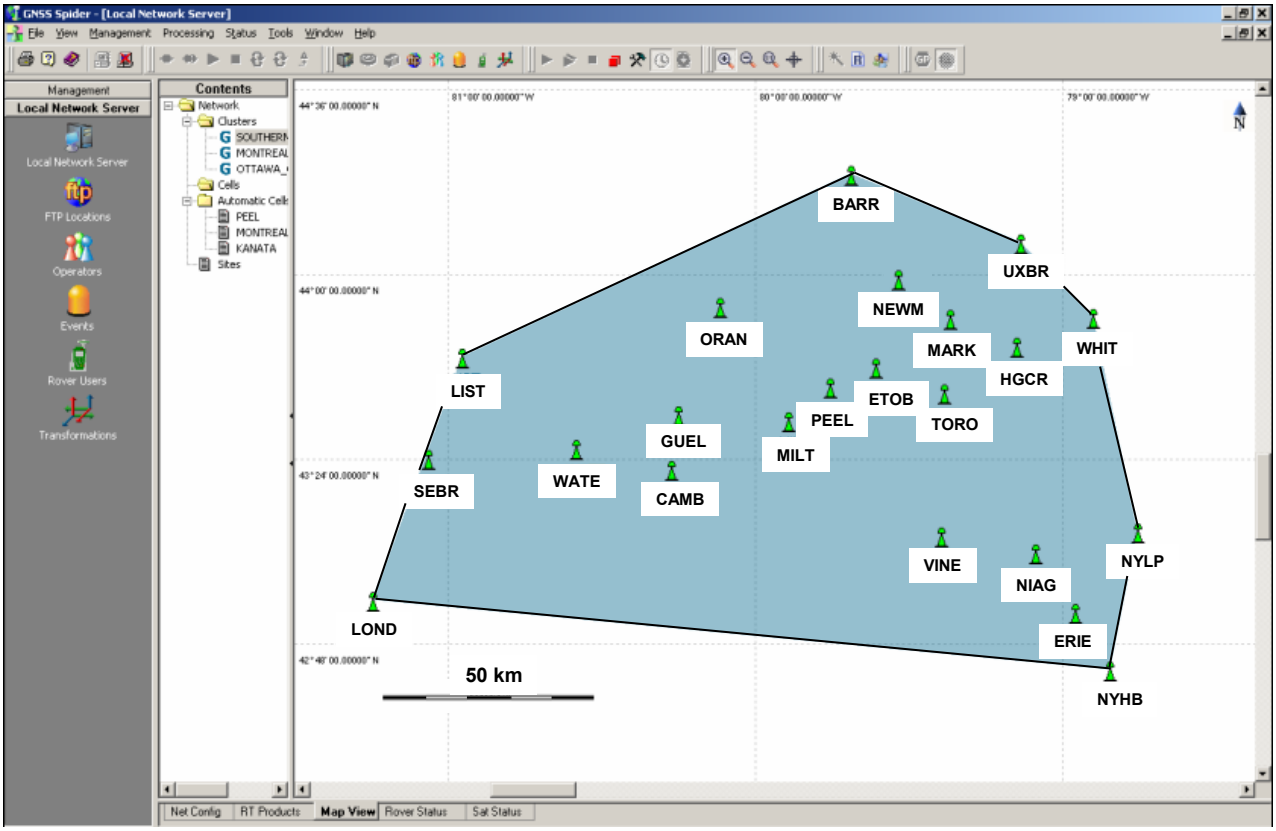
Leica Geosystems

Notes:

Southern Ontario Reference Stations consist of over 20, as of May 2008, Reference Stations spaced by about 50 to 70 kilometres providing Single Site and Network RTK Positioning Data services via the Internet and 1-second Rinex data from FTP site.

Southern Ontario Reference Stations coordinates are based on CSRS as computed from CACS and CBN Control Points in the area via Network Adjustment of several independent baseline vector solutions between stations.

Southern Ontario Network Cluster Layout as of May 2008



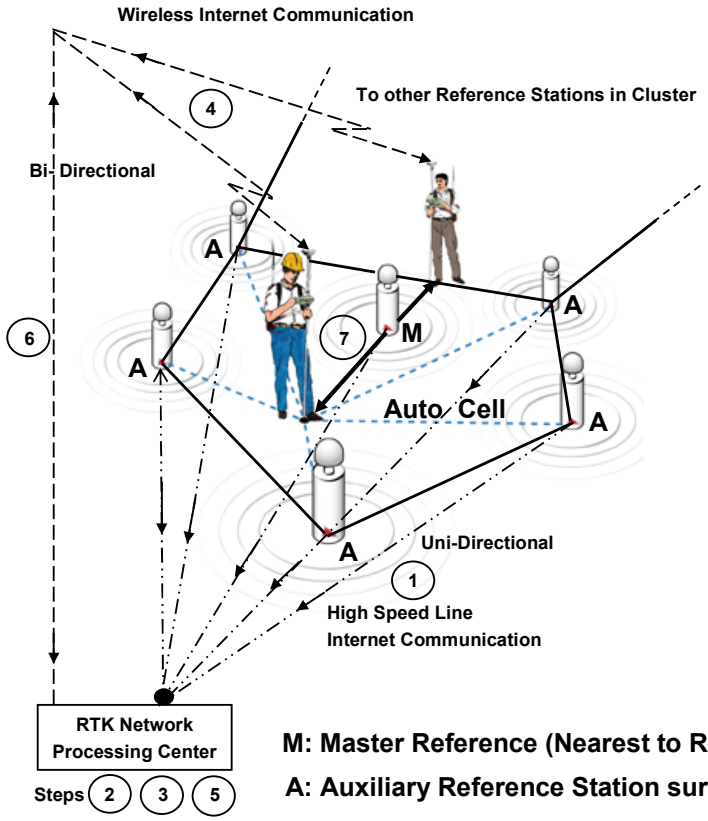
Notes:

The Southern Ontario Network Cluster consist of 22, as of May 2008, Reference Stations forming a dome shape of about 200 km by 150 km which are processed together to determine Common Level Site, Satellite and Frequency Phase Integer Ambiguities for Ionospheric and Tropospheric Network RTK space based corrections.

The Southern Ontario Cluster provides different Network RTK Message types based on the Master-Auxiliary Concept (MAC) from automatically created Cells.

Each Cell is a subset of Cluster Stations surrounding the RTK Rover location and is automatically redefined as the RTK Rover moves in the Cluster area.

Master-Auxiliary Concept (MAC) RTK Positioning



Data Processing Steps

1. **Reference Station Data Gathering**
2. **Common Level Ambiguity Determination and Clock Correction from Cluster Stations**
3. **Dispersive and Non-Dispersive Single Difference Phase Corrections**
4. **Connection Authentication and Selection of RTK Message Types**
5. **Assignment of Nearest (Master) and Surrounding (Auxiliary) Reference Stations in Auto Cell**
6. **Transmission of RTK Network RTCM V3.1 (MAC) Messages**
7. **RTK Network Rover Positioning in the Field from Nearest Reference Station in Auto Cell**

M: Master Reference (Nearest to Rover) Station in Auto Cell

A: Auxiliary Reference Station surrounding Rover in Auto Cell

- when it has to be right

Leica Geosystems

Notes:

The Master-Auxiliary Concept (MAC) RTK Positioning Process consists of obtaining raw measurements from all stations within a Network Cluster to determine and maintain Common Level Site, Satellite and Frequency Ambiguities with Receiver Clock corrections from Single Difference Phase measurements.

Upon the reception of Rover positions, Cells are automatically created and updated by forming Single Difference Phase corrections from a Master (nearest to Rover position) and a few Auxiliary stations (surrounding Rover position) to provide raw measurements from the Master Site with Dispersive and Non-Dispersive Single Difference Phase corrections for Network RTK positioning.

MAC Network Corrections from Reference Stations

- **Dispersive (Ionospheric Single Difference) Corrections**

$$\delta\Delta\Phi^{j\ \ disp}_{km,1} = \frac{f_2^{\,2}}{f_2^{\,2} - f_1^{\,2}}\,\delta\Delta\Phi^{j}_{km,1} - \frac{f_2^{\,2}}{f_2^{\,2} - f_1^{\,2}}\,\delta\Delta\Phi^{j}_{km,2}$$

- **Non-Dispersive (Tropospheric Single Difference) Corrections**

$$\delta\Delta\Phi^{j\ non\text{-}disp}_{km,1} = \frac{f_1^{\,2}}{f_1^{\,2} - f_2^{\,2}}\,\delta\Delta\Phi^{j}_{km,1} - \frac{f_2^{\,2}}{f_1^{\,2} - f_2^{\,2}}\,\delta\Delta\Phi^{j}_{km,2}$$

for Delta Single Difference (L1 Frequency case) :

$$\delta\Delta\Phi^{j}_{km,1} = \Delta s^{j}_{km}(t) - \Delta\Phi^{j}_{km,1}(t) + c\cdot\Delta dt_{km,1} + \frac{c}{f_1}\cdot\Delta N^{j}_{km,1}$$

based on Single Difference (L1 Frequency case) :

$$\Delta\Phi^{j}_{km,1}(t) = \Delta s^{j}_{km} + \Delta\delta r^{j}_{km}(t) + c\cdot\Delta dt_{km,1} + \Delta T^{j}_{km}(t) - \frac{\Delta I^{j}_{km}(t)}{f_1^{\,2}} + \frac{c}{f_1}\cdot\Delta N^{j}_{km,1} + \Delta\varepsilon_1$$

Where:

m = Master Station

k = Auxiliary Station k = 1, 2, 3, …

f1 = L1 Frequency

f2 = L2 Frequency

j = "j-th" Satellite

i = "i-th" Frequency (1, 2)

- when it has to be right

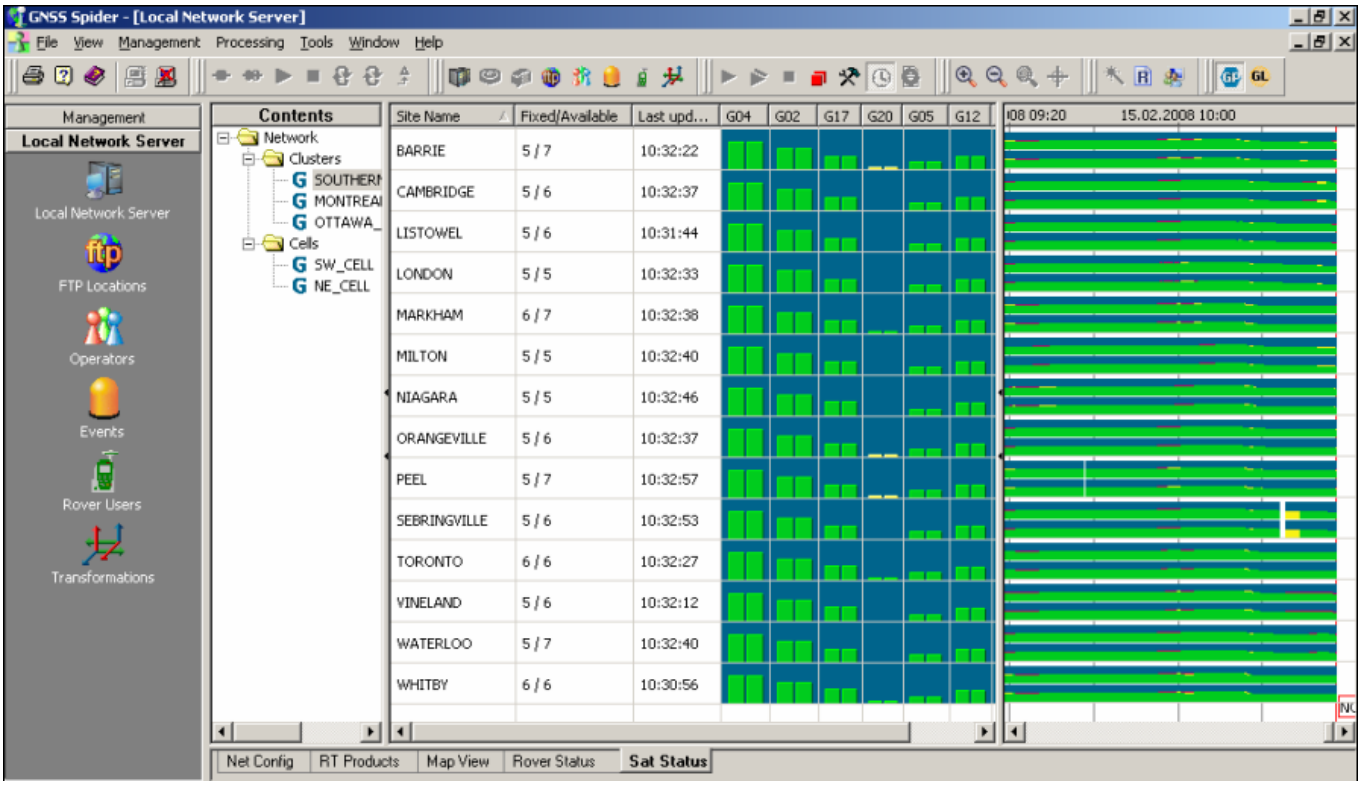
Leica Geosystems

Notes:

RTK Network corrections consist of Delta Single Difference Ionospheric (Dispersive) and Tropospheric (Non-Dispersive) corrections factorized with respect to their frequencies. These corrections are derived from Delta Single Difference Phase between Auxiliary " k " and Master " m " Reference Sites for the " j-th" Satellite on the "i-th" Frequency (L1 or L2) based on raw Single Difference Phase measurements corrected for Common Level Network Ambiguities, Across Receiver Clock Offset and Geometric Delta Receiver-Satellite Range.

The Ionospheric and Tropospheric corrections are being updated and sent to the different Cells Network RTK Messages at every 5 seconds to maintain a high degree of reliability in the changes of those corrections over time.

RTK Network Cluster Common Level Ambiguity Status

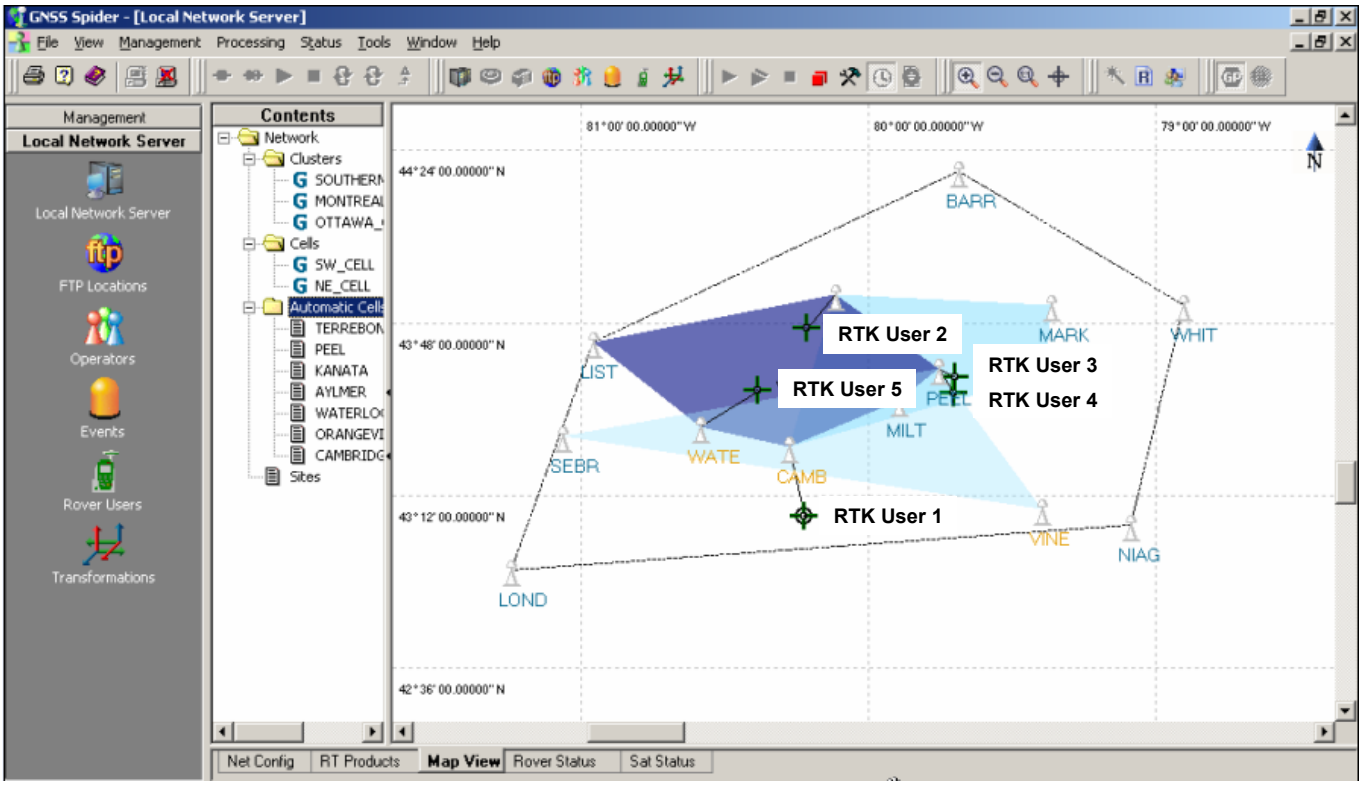


Notes:

The Status of Common Level Ambiguities from all Sites forming a Network Cluster is continuously reported to confirm the correctness of Satellite and Frequency Measurement data at each site in order to provide consistent RTK Network corrections.

Fixing and maintaining fixed the Common Level of Ambiguities to their Integer values for Stations forming a Network Cluster requires that Site coordinates be precise to better than 2 cm relative between themselves and better than 2 decimetres absolute with respect to a Geocentric Datum (CSRS) to properly handle Precise Orbit predicted in real-time via the Internet.

Examples of Auto Cell Network RTK Solutions



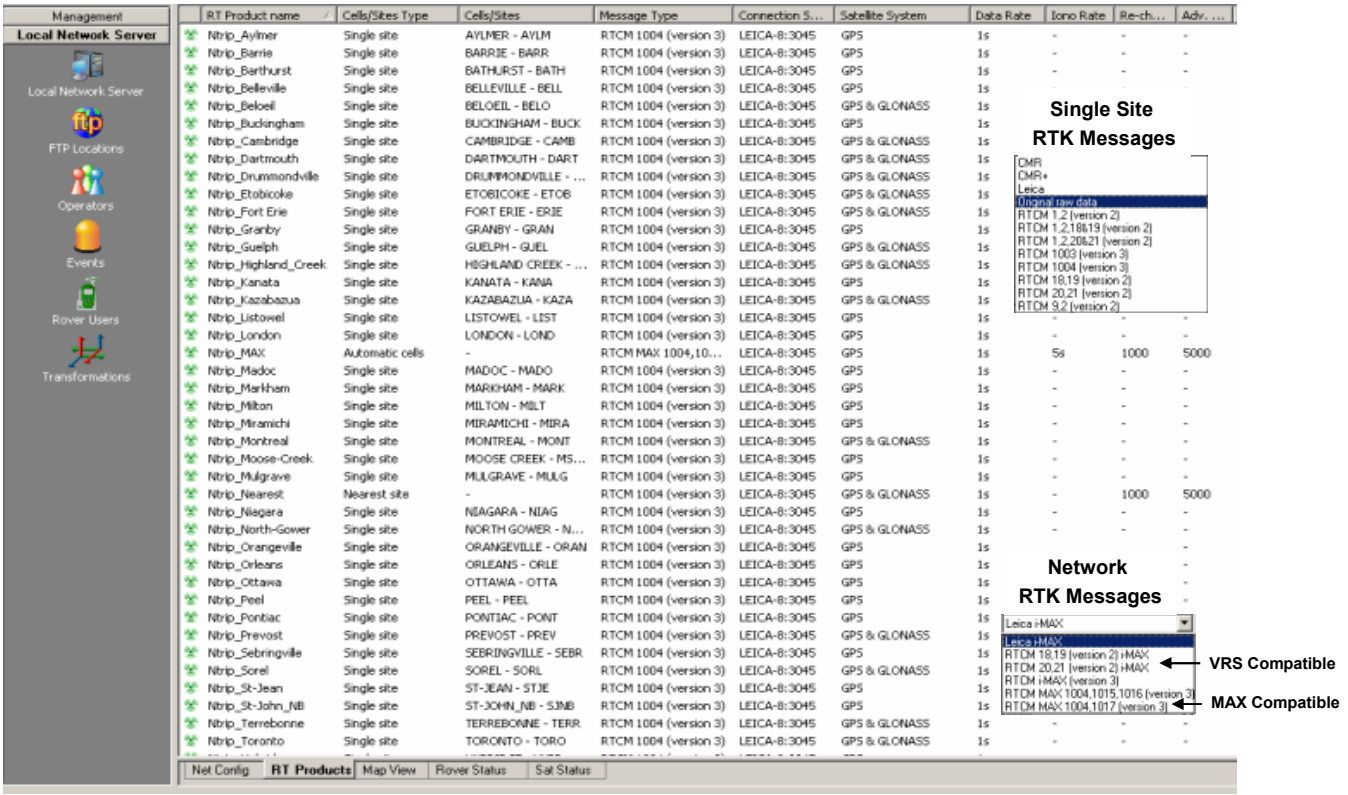
Notes:

Different Cells are created when Rovers access MAC RTK Network Auto Cell Messages to provide Raw Measurements from the Nearest Station with Dispersive and Non-Dispersive Corrections from the Auxiliary Stations surrounding their location.

Each Rover receives its own MAC RTK Network Cell message, uses Raw Measurements from the Nearest Site and interpolates the Ionospheric and Tropospheric Single Difference Phase corrections from the Auxiliary Stations surrounding its location. The MAC RTK Network Cell messages are automatically updated while Rovers are changing locations within a Cluster as well as from different Clusters.

When Rover location is outside of a Cell and/or Cluster, the system still provides RTK Data from the Nearest Site.

SmartNet RTK Product and Message Types



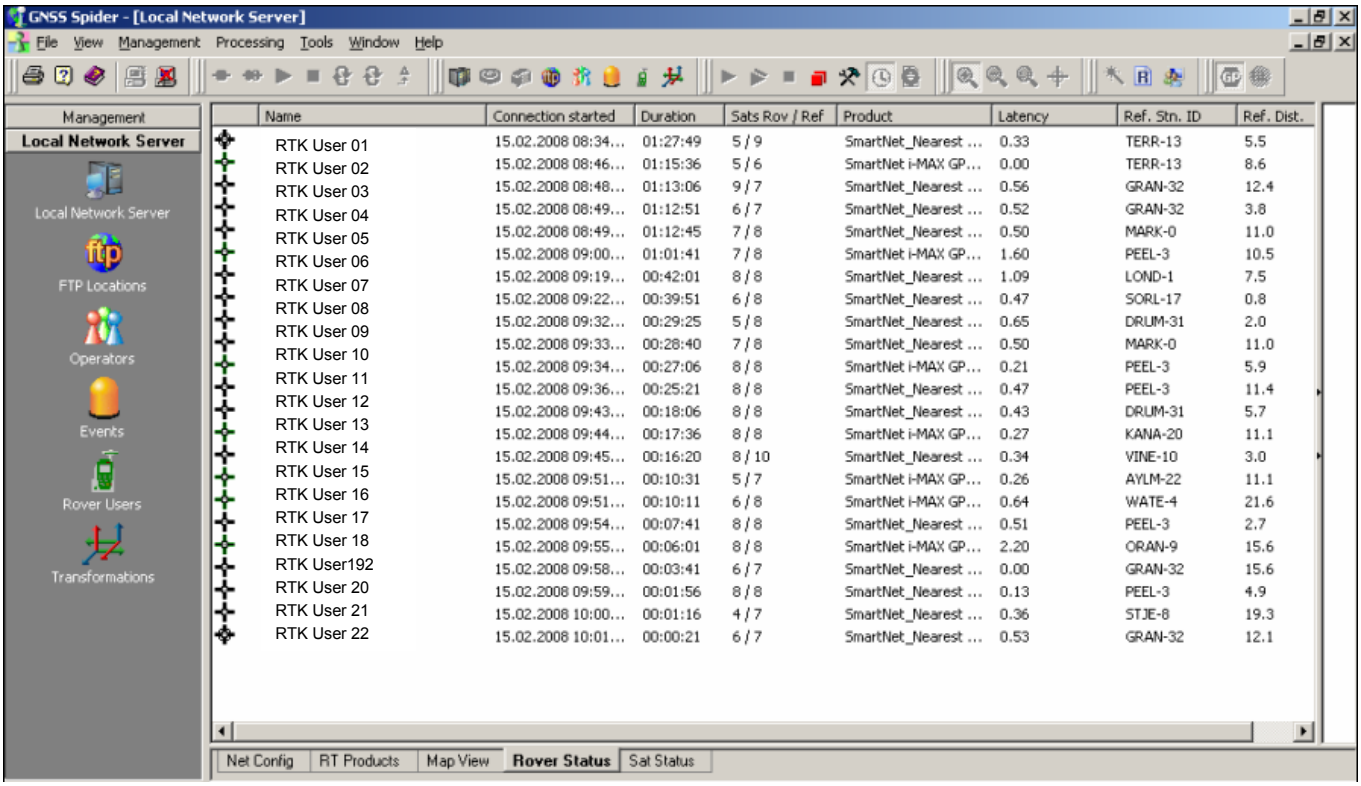
Notes:

Different RTK Message Types are instantaneously available to several Users simultaneously connected to SmartNet via the Internet.

All Single Site and RTK Network messages are related to the Reference Station Antenna Reference Plane (ARP) to provide a common base to RTK Rovers using different Antenna Types than the ones used in SmartNet avoiding incorrect L1 and L2 Phase Center handling in RTK Positioning solutions.

Different Single Site RTK Message Formats for Leica, CMR , CMR+, RTCM Versions 2 and 3 as well as different Network RTK Message Formats for Leica i-MAX, RTCM Versions 2 and 3 i-MAX, simulating VRS message formats, and Leica MAX RTCM V3.1 are automatically provided to accommodate different RTK Rover equipments and models.

SmartNet Real-Time User Connection Status



Notes:

Several RTK Users can be simultaneously connected to either the same or different Stations for different Single Site RTK Message types as well as to different MAC Auto Cell RTK Network Message types specific to their location and movement within the different Network Clusters.

The Spider Network Server application monitors the Number of Satellites available from the Nearest Site and Rover location , RTK Rover Position Status (Navigated, Code Differential or RTK Fixed Ambiguity solutions), Distance from the Nearest Site and the Position Latency of all Rovers simultaneous connected to the SmartNet Network.

Summary and Conclusion about SmartNet

- ***SmartNet Reference Network consists of GNSS Reference Stations spread between Nova Scotia and Southern Ontario providing live RTK Positioning Services over the Internet.***
- ***It also provides 1-second Rinex Data to support KOF and Static Post-Processing solutions in areas of intermittent or poor Cellular Coverage.***
- ***Three different Clusters provide Auto Cell RTK Network Solutions based on RTCM V3.1 Master-Auxiliary Concept (MAC) in the Montreal, Ottawa and Southern Ontario Regions.***
- ***Different RTK Message Types in various formats are instantaneously available to several RTK Users simultaneously connected to the Network via the Internet.***
- ***Field Survey Results reveal that Long Term Positioning Precision (Repeatability) of RTK Network MAC solutions are typically a few centimeters under adequate observing conditions with an overall positioning latency of less than half second.***
- ***The Precision of RTK solutions are also consistent with the Reference Network Frame.***
- ***Future Plans include the installation of more Reference Stations along major Highways for Wireless Network access together with Full GPS and GLONASS Single Site and Network RTK Positioning Services to provide better control in local infrastructure positioning needs.***

References:

F. Takak, W. Lienhart (2008) SmartRTK: A Novel Method of Processing Standardized RTCM Network RTK Information for High Precision Positioning . Proceedings of ENC GNSS 2008, Toulouse, France, April 22 – 25.

Euler, H-J, R. Keenan, S. Seeger, O. Zeltzer, F. Takak, B.E. Zebhauser, (2004) Improvements of Positioning Performance Using Standardized RTCM Network RTK Messages. Proceedings of ION NTM, San Diego, CA, January 26 – 28, 2004

Radio Technical Commission For Maritime Services (RTCM) (2007), RTCM Standard 10403.1 for Differential GNSS Services – Version 3 - with Amendment 1. RTCM Paper 177-2006-SC104-STD Developed by RTCM Special Committee No.104, amended May 21, 2007