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Sensors

Advances in DGPS Systems

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ABSTRACT

During recent years there have been two important advances in wide area Wide Area Differential GPS (WADGPS) systems:

- *Wide area network carrier phase services.*
  These services utilise the dual frequency carrier phase of the GPS signal and have sub-decimetre level position accuracy. The carrier phase measurement accuracy is sub-centimetre, and the phase is far less susceptible to multi-path than the code.

- *Orbit/Clock services.*
  This concept utilises reference stations with a worldwide spread to calculate the orbit and the clock value of each GPS satellite more accurately than the broadcast GPS ephemeris. Orbit and clock corrections to the broadcast ephemeris are then transmitted to user. These corrections are valid worldwide and the distance from the nearest reference stations to the user does not affect performance. Typically orbit/clock user equipment make dual frequency carrier phase measurements as well, achieving decimetre level accuracy.

The paper describes characteristics of phase-based systems versus code-based systems and characteristics of orbit/clock solutions versus traditional network based systems. Position results for different systems under different conditions are presented.

Fugro’s long-term strategy is to maintain two independent services for customers that require a high degree of redundancy and reliability of their Differential GPS (DGPS) position system. One such application is Dynamic Positioning (DP) offshore, where two independent DGPS services are used extensively. The paper describes how Fugro will maintain the independence of the two main services: the orbit/clock carrier phase service and the network carrier phase service.

INTRODUCTION

Fugro launched a decimeter level service in 2001 [Ørpen, et al., 2002] providing extremely high accuracy over large regions. This differential service is based on a network of reference stations and has been extended further to cover most of the world, see figure 1. Since the service was introduced, a lot of experience has been gained concerning performance under different conditions.

Orbit/clock services have been fielded during the same period to provide truly worldwide coverage to the decimeter level. Fugro is cooperating with NASAs JPL (Jet Propulsion Laboratory) to provide such a service based on NASAs network of reference stations, see figure 2.This ensures independence of the two main Fugro services.

PHASE BASED SERVICES

The carrier phase based systems utilize the carrier phase of the GPS signal to the full extent. The carrier phase has a wavelength of about 20 cm, while the C/A code chip length is about 300 m (see figure 3). The measurement accuracy of the code is < 0.5 m; while the measurement accuracy of the phase < 1 cm.

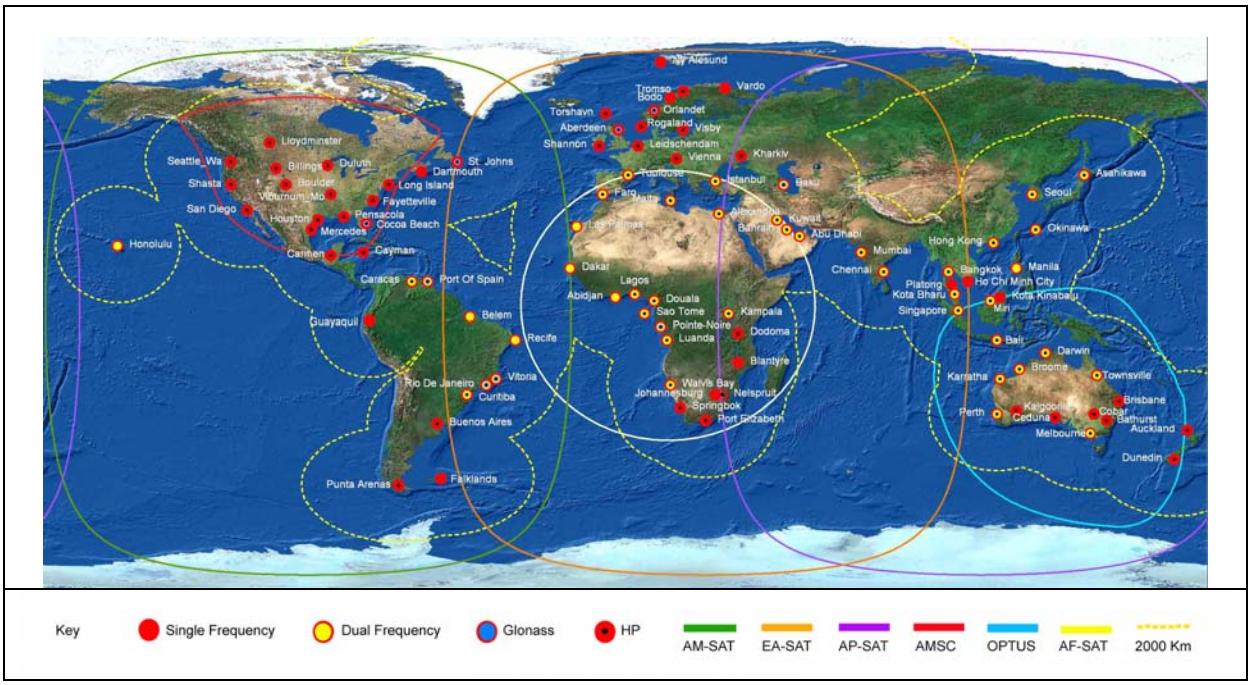

Figure 1: World Wide Fugro DGPS Coverage.

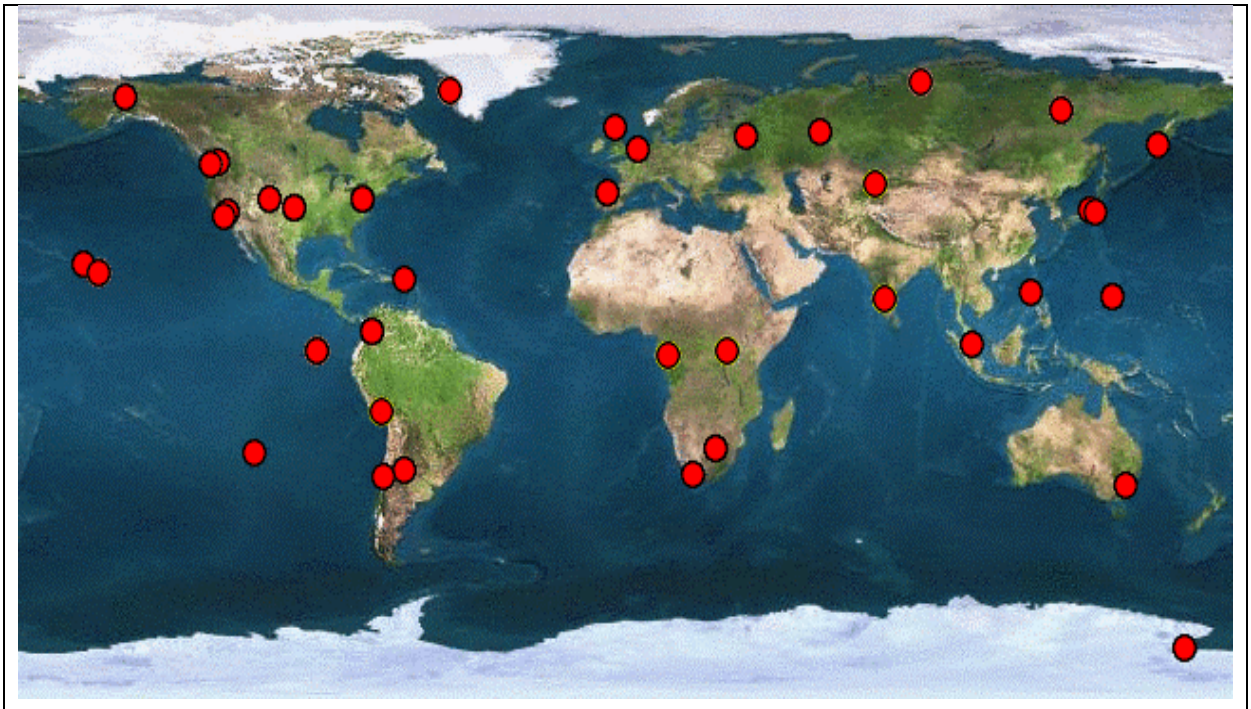

Figure 2: NASA/JPL Network.

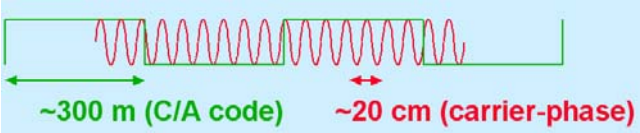

Figure 3: Code and carrier on the GPS signal (not to scale, there are 1540 carrier cycles in one code chip)

The disadvantage of using the carrier phase is that it takes the user equipment some time to reach full accuracy, as there is an ambiguity in terms of what carrier cycle the GPS receiver is tracking to each satellite. This ambiguity must be determined before the carrier phase can be used as a range measurement in the position calculation. The time needed to determine the ambiguities depends on the number of satellites tracked, their geometry, the level of multi-path and the accuracy of the differential corrections.

One of the great advantages of using the carrier phase measurements is that it is less susceptible to multi-path errors. Further, the carrier phase based decimetre level systems perform better during ionospheric scintillations periods (typical for equatorial regions). The scintillations can be so strong that the GPS receiver looses track on the GPS signal. The magnitude of range errors caused by scintillations is generally significantly less for the carrier-phase measurements than for the code measurements. Thus, carrier phase based systems will generally provide a much more stable position during scintillations.

Characteristics of carrier phase based services:
- Carrier-phase measurements
- Dual-frequency ionosphere correction
- Estimation of tropospheric delay
- DGPS network solution or orbit/clock solution
- Less susceptible to multi-path and other code tracking errors

An example of the improved performance of decimetre level phase based systems is shown in figure 4. The data is collected on Transocean's drill ship Discoverer Seven Seas while at harbour in Rio de Janeiro in Brazil. Due to practical limitations the antenna was placed low on the vessel, and was shadowed by the derrick (figure 5). In figure 4 the two upper curves show the variations in the easting and northing using the Fugro HP (High Performance) network carrier phase decimetre service. Actual movements of the drillship are reflected, specifically in northing. The lower two plots are using the same GPS antenna and GPS receiver, but position is calculated using the C/A code and the Fugro dual frequency code based DGPS service. It is seen, specifically towards the end of the two-hour period (due to GPS satellites dropping in and out of the solution because of shadowing), that there are a lot of jumps in the position measurement (errors up to 8 m) in the code-based solution while the phase-based solution is not noticeably affected.

An example of improved tracking during ionospheric scintillations is given in figure 6 and 7. The data is from Fugro's monitoring site in Macae in Brazil and shows large jumps (10 m and more) in the code-based solution (figure 6), while the phase-based solution is unaffected (figure 7, the plot shows a straight line as it is decimetre errors on a 9 m scale). In Brazil the scintillations can be so severe that the number of satellites drops below the required number to generate a solution, this will of cause affect both code based and phase based systems.

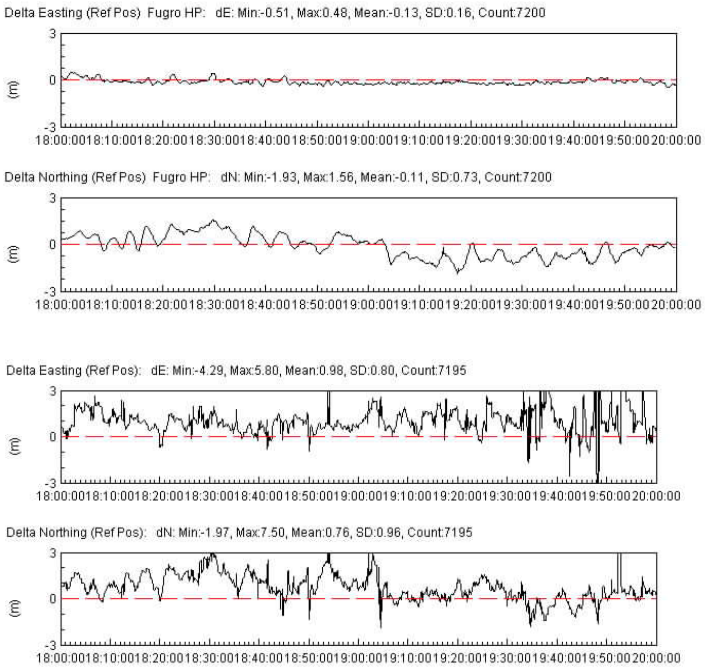

Figure 4: An example of the improved performance of Decimetre level phase based systems is seen in the difference in errors in Easting and Northing with HP (top) and VBS (bottom). The drillship was at harbour as reflected in the regular movement in HP Northing error.

Figure 5: Transocean’s drillship Discoverer Seven Seas. Picture is taken from GPS antenna towards the derrick.

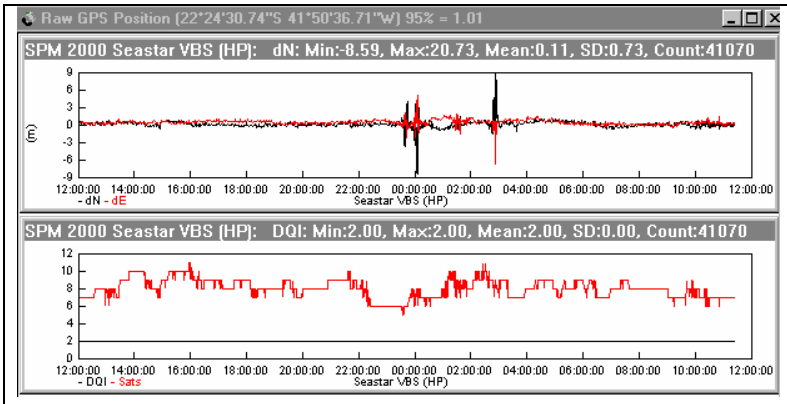

Figure 6: Code based iono free solution, north and east error (top) and number of satellites tracked (bottom) in Macae Brazil 12:00 UTC 30 September 2003 to 1200 UTC 1 October 2003. Between 23:00 and 03:00 scintillations result in the GPS receiver loosing lock on some satellites.

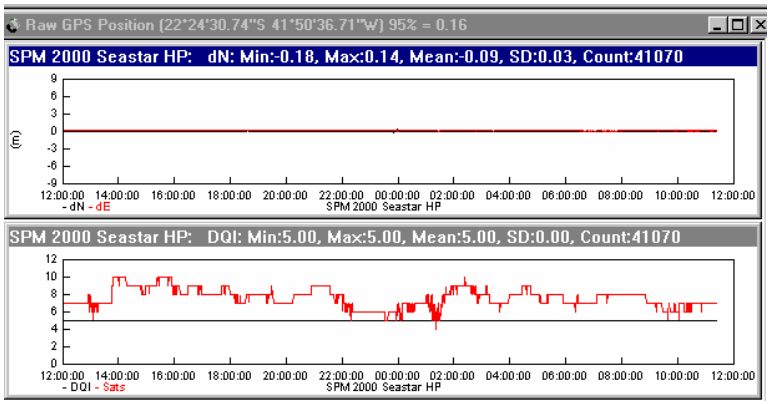

Figure 7: Phase based iono free solution, north and east error (top) and number of satellites tracked (bottom) in Macae Brazil 12:00 UTC 30 September 2003 to 1200 UTC 1 October 2003. Between 23:00 and 03:00 scintillations result in the GPS receiver loosing lock on some satellites.

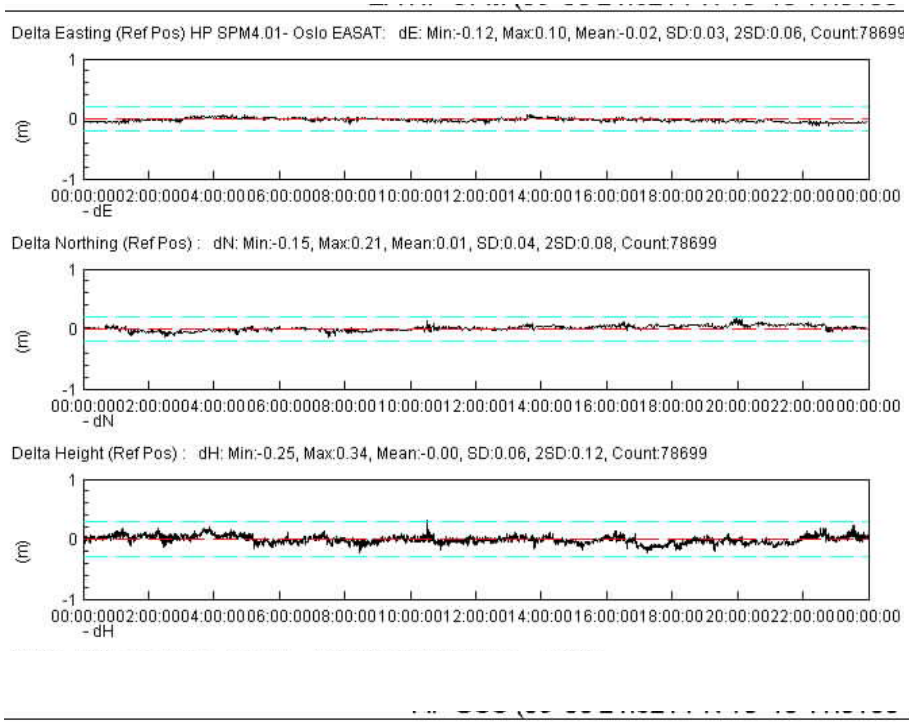

Figure 8: Phase based DGPS network solution, north, east and height error in Oslo, Norway 00:00 to 24:00 UTC 12 April2004.

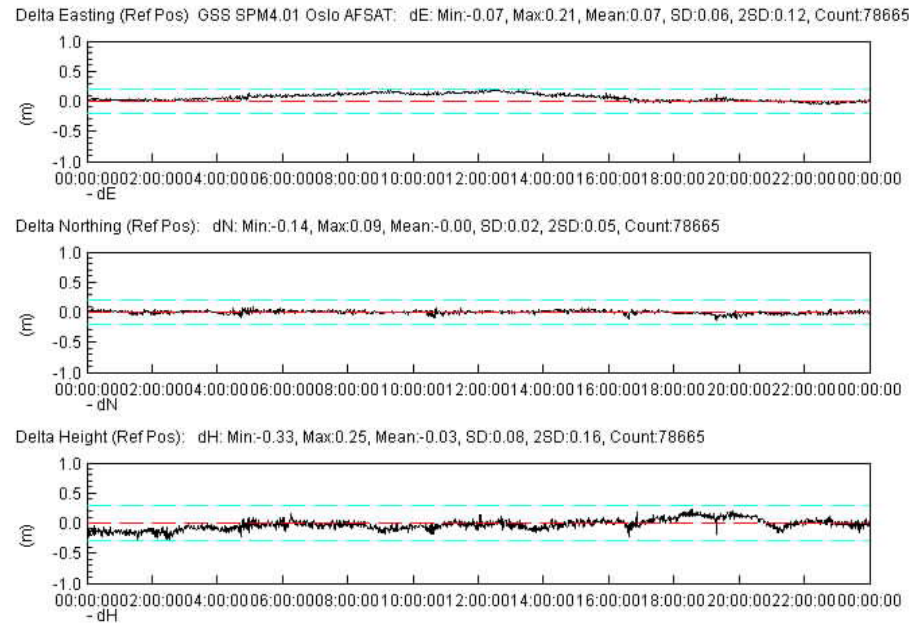

Figure 9: Phase based Orbit/Clock solution, north, east and height error in Oslo, Norway 00:00 to 24:00 UTC 12 April 2004.

ORBIT/CLOCK SERVICES.

The orbit/clock concept utilises reference stations with a worldwide spread to calculate the orbit and the clock value of each GPS satellite. The resulting orbit and clock corrections are transmitted to the user. The user software applies these corrections to the broadcast GPS ephemeris. When the corrections have been applied the ambiguity determination and position calculation is similar to methods used for network carrier phase solutions.

The orbit/clock corrections are valid worldwide and the accuracy is dependent on the overall geometry of the reference station network, rather than the position of the user with respect to the reference stations. Orbit/clock services also typically use dual frequency carrier phase in the mobile, providing decimetre level position accuracy.

Figure 8 and 9 show monitoring plots from Oslo, Norway, for a wide area carrier phase network solution (~10 cm 95% horizontal error) and an orbit/clock solution (~20 cm 95% horizontal error) respectively. Figure 10 shows a summary of the accuracy for the 11 day period 4 through 14 April 2004.

MAINTAINING INTEGRITY THROUGH SERVICES INDEPENDENCE

Fugro operates a number of services with different accuracy levels today. In the future the main services will be a wide area network carrier phase service and an orbit/clock carrier phase service. These will be configured to maintain full independence. This includes maintaining independence of reference stations used in each solution, Network Control Centres (NCCs) or hubs through which the data is routed and uplink sites, (no common point of failure, see figure 11). The two services will be available on High Power Broadcast and Low Power Broadcast (independent satellites), and data on one broadcast will be copied on the other broadcast.

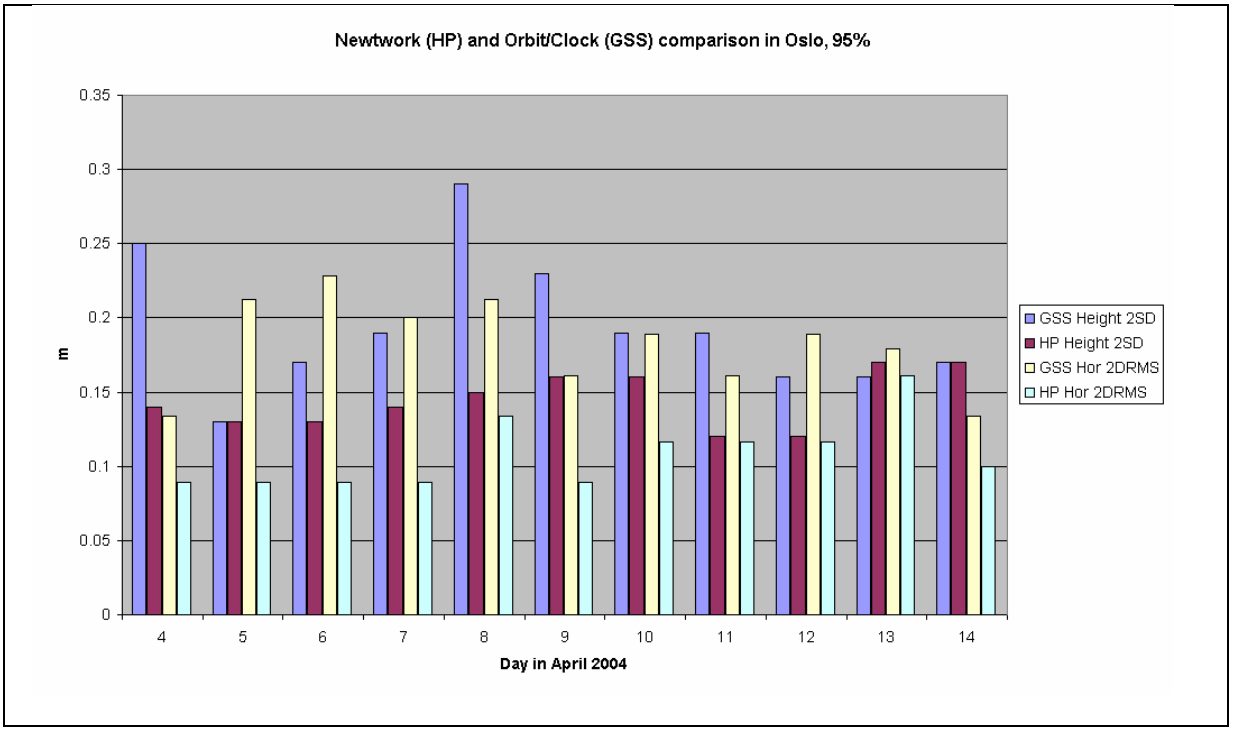

Figure 10: Summary of horizontal and height accuracy (95%), April 4-14 2004, in Oslo, Norway

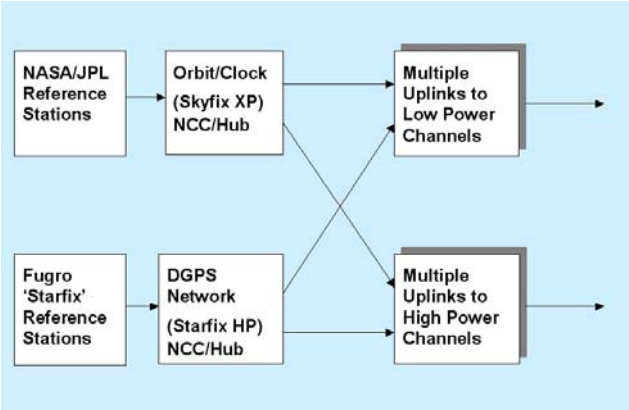

Figure 11: Independent DGPS network and orbit/clock Services

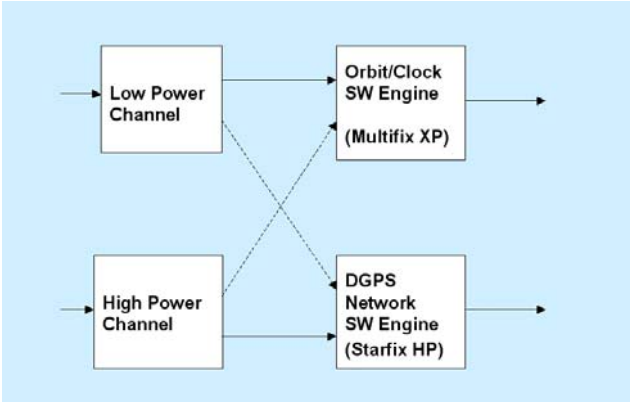

Figure 12: Possible mobile setup, retaining independence. Dotted lines used for maximum availability.

The availability of all data on all broadcasts will make it possible to configure a mobile in two distinct ways (see figure 12):

1. *Configuration for maximum independence*:
   This configuration uses the orbit/clock solution from the Low Power Broadcast and the network carrier phase solution from the High Power broadcast or vice versa. Different and independently developed mobile software packages can be used for the two broadcasts. This setup will have the lowest risk of a failure/error that influences both solutions. A typical application for this configuration is Dynamic Positioning where it is important to have two independent solutions for safety reasons.

2. *Configuration for maximum availability:*
   This configuration uses one (or two) mobile setups, feeding data from the two broadcasts channels into each mobile setup. This assures availability of a position even if one broadcast is unavailable.

SUMMARY

Fugro wide area network carrier phase service can provide position accuracies at the sub-decimetre level, and the orbit /clock service is only slightly less accurate. The two approaches provide independent solutions, using dual-frequency carrier phase measurements to obtain the significantly improved accuracy over traditional DGPS.

Results from the field demonstrate that the carrier phase solution is less susceptible to satellite blockage and poor geometry than a traditional code based solution.

Furthermore, operational experience in Brazil shows superior performance for a carrier phase solution compared to a code based solution during ionospheric scintillations.

Fugro offers completely independent wide area network carrier phase and orbit/clock services in order to provide full redundancy to for instance Dynamic Positioning applications. For other user groups, to which maximum availability is the main concern, both services can be combined.

REFERENCES

Ørpen O., Melgård T. E., Łapucha D., Barker R. Ott L., Visser H, *Experiences with a Decimetre-Level Real-time Carrier Based Positioning System at ranges of over 500kms.* GNSS 2002, Copenhagen, May 30, 2002.