Alternatives to Current GPS-RTK Services & Some Implications for CORS Infrastructure and Operations

Chris Rizos

School of Surveying & Spatial Information Systems

University of New South Wales, Sydney 2052, Australia

Abstract

This paper reviews the establishment of GPS continuously operating reference stations (CORS) by government agencies and research institutes over the last two decades. The justification for the establishment of CORS networks was initially in support of geodesy and other geoscientific applications, at the global and regional level. However, increasingly GPS CORS network operators have sought ways of making their network infrastructure the basis of a profitable business. This has arisen with the introduction of real-time centimetre-level accuracy services, carrier phase-based modes of operation generally referred to as GPS-RTK (Real-Time Kinematic). One approach is to try to recruit a core group of users who are prepared to pay for the GPS-RTK services. But this is only feasible if the number of users, and the fees that are charged, are sufficient to generate a reasonable return-on-investment (ROI). This ROI (or at the very least "cost-recovery") is important for many network operators in order that they may provide for the maintenance and upgrade of the CORS infrastructure. On the other hand, there are those who advocate that there is no need to recoup CORS investment, that the installed GPS receivers should be seen as public infrastructure, in a similar manner to roads, bridges, etc. This paper discusses some new business and operational models for GPS-RTK services. These include models for the establishment and operation of CORS infrastructure, service provision, business cases, and options for value-added services beyond the standard GPS-RTK service. One concept is based on a "client-server" model. Currently GPS-RTK service providers have no control over the quality of the results computed by users. This makes it difficult for them to justify charging for their services. What if instead of broadcasting RTK corrections and placing the onus of obtaining a final solution on the user and his equipment, the user's coordinates are determined by the service provider? Putting the computational effort on the server side will justify more easily the charging of users for a value-added product: an accurate and quality assured position in the local reference frame. This paper describes the client-server concept as well as possible business models that may underpin such a service model. These models include some derived from mobile telephony and service/hospitality businesses. Furthermore, with the projected proliferation of independent, competitive GPS-RTK services, the concept of a GPS data/service "broker" is worth exploring.

1. BACKGROUND TO CORS NETWORKS

It is well recognised today that a reference network comprised of permanent stations operating Global Navigation Satellite System[1] (GNSS) receivers on a continuous basis provides the fundamental infrastructure required to meet the needs not only of geodesy and the geosciences, but also of professional GPS users in areas of surveying, mapping and navigation. These high accuracy applications can only be satisfied through the use of the carrier phase-based, *differential* GPS technique, whereby the "reference" or "base" receiver is located at a station whose coordinates are known in a geocentric datum or reference frame (Rizos 2002). Furthermore, the widespread use of the GPS Real-Time Kinematic (RTK)

[1] The umbrella term for all satellite-based navigation systems including their regional augmentations, and generally refers to the current and modernized GPS, the revitalised Glonass, and the planned Galileo systems. The interchange of the terms 'GPS' and 'GNSS' in the text should not confuse readers, as currently GPS is the only fully operational GNSS.

technique has encouraged government geodetic and/or land survey agencies to look for ways to use GPS reference receivers to support ever expanding non-geodetic, *real-time* applications of high accuracy positioning for engineering, machine guidance, precision agriculture, etc.

1.1 National Geodetic GPS Networks

GPS in the 1980s was almost exclusively used for geodetic control surveys. "GPS geodesy" could claim to be the first civilian application of the U.S. Department of Defense's Global Positioning System. It was also the first example of a civilian innovation the use of integrated carrier phase measurements for the determination of position parameters to a relative accuracy of about 1 part per million (*ppm* – equivalent to 1cm relative position error between two GPS receivers 10km apart). The inter-receiver distances were at first several tens of kilometres, being the average distance between first order geodetic control groundmarks. The task was to establish new geodetic groundmarks using differential carrier phase-based GPS techniques. However, at about this time GPS was also proving itself to be an effective *space geodesy* technique for measuring crustal motion and for establishing the global reference frame. Hence progressively the distances between GPS receivers increased to hundreds and then thousands of kilometres, while simultaneously the relative accuracies increased, ensuring cm-level relative accuracy within GPS receiver networks even as inter-receiver distances grew significantly. GPS is now the premier tool for modern geodesy, and relative accuracies at the few parts per billion (*ppb*) level are routinely achieved (IGS 2006). These GPS geodetic stations inevitably became permanent reference stations for: (a) the monitoring of the station motion itself (due to horizontal and vertical crustal motion), (b) realising or defining "modernised" geocentric geodetic datums at the national level, and (c) the densification of the geodetic control (groundmark) networks using GPS techniques.

However, as GPS was becaming an indispensible geodetic tool, government agencies looked for ways to replace traditional geodetic control networks initially with groundmarks surveyed using GPS technology, and then increasingly with networks of CORS receivers. This trend from groundmarks surveyed using carrier phase-based GPS techniques – commencing in the 1980s – to today's networks of GPS receivers supporting high accuracy positioning, anytime and increasingly in real-time, has been generally justified on the basis of improved efficiency. For example, one of the reasons cited by government agencies for replacing "passive" networks of groundmarks with "active" networks of CORS receivers is the lowered maintenance of the network (there are typically far less GPS stations than groundmarks – and even if they need to be re-established using the permanent GPS receiver network, such a re-survey task is very cost efficient). Another is that the national geodetic datum can be propagated to all other GPS surveys using reference network data.

1.2 Hierarchy of Permanent GPS Networks

It is important to acknowledge the significant contribution of the "super-network" of reference stations of the International GNSS Service (IGS 2006). Several hundred globally distributed GPS receivers (some with Glonass tracking capability) operate on a continuous basis, many for over ten years, contributing data to analysis centres[2] and other users. Typically IGS stations are hundreds to perhaps a thousand kilometres or more apart. The satellite (carrier phase) tracking data they have collected have been used in progressive *realisations* of the geocentric International Terrestrial Reference System, known as the International Terrestrial Reference Frame (ITRF) (ITRF2005 2006). Many countries have redefined their national datums to be "compatible" with an ITRF reference frame, by typically linking primary stations and/or first order geodetic control groundmarks to the ITRF via differential carrier phase-based GPS surveys, using the nearest IGS reference stations as the fixed known datum points. These national datums are geocentric, and as far as most users are concerned they are equivalent to the GPS datum WGS84. Many countries have also established "active" primary/geodetic networks of GPS reference stations to monitor the *stability* and *integrity* of their datums. This is particularly the case for countries located on or near tectonic plate boundaries that cause their datum (or to be more correct, the realisation of their datum in the form of 3D coordinates of groundmarks and reference stations) to undergo deformation (or coordinate *change*) with time.

Even countries that do not directly experience widespread crustal deformation that challenges a national datum's internal integrity consider permanent GPS receiver networks to be *infrastructure* that supports national (and international) geodetic and geoscientific studies. However, the inter-receiver spacing was rarely less than a hundred kilometres, and often it was much more. (There are exceptions such as Japan's GEONET, where the inter-receiver distance averages about 30kms.) Furthermore, all such infrastructure until relatively recently did not have a real-time data transfer or processing capability. In the 1990s, when the establishment of such CORS networks was justified on geodetic grounds, national networks were similar to IGS stations. That is, although operated on a "24/7" basis, the data were only periodically downloaded from each receiver as (typically) ASCII files in the Receiver Independent Exchange (RINEX) format, and transferred daily to an archive or data centre. From there the data were available to users for post-processing. The station monumentation was typically of the very stable, concrete pillar variety.

Archived RINEX files from both IGS stations and national GPS reference networks were (and still are) accessed by users via the Internet. All IGS data have been, and continues to be, available at no cost. Although some GPS receiver network operators charge fees for their RINEX files, the trend is to increasingly make such data available for free. If users were: (a) satisfied with post-processed results (i.e. they did not want coordinates in real-time), and (b) were fortunate to be carrying out a GPS survey or positioning task "close" to a CORS[3], then users could benefit from such data in two ways:

---

[2] IGS station tracking data is used to compute a wide variety of geodetic-quality products, including precise GPS and Glonass satellite orbits and clock parameters, tropospheric and ionospheric model parameters, as well as accurate station coordinates to support a wide range of geodetic and geoscientific applications (IGS, 2006).

[3] A more precise definition of "close" in the case of cm-level accuracy applications depends on the GPS technique and operational mode that is used (Rizos, 2002), ranging from no more than ten or so kms for 'rapid-static' or 'on-the-fly' carrier phase-based techniques using off-the-shelf "commercial" software, to perhaps a few hundred kilometres if "scientific" software is used.

1. Download data from the nearest GPS CORS, for the time period of their own survey, and then process this data together with their receiver measured data using their own software (which could be of the "commercial" or "scientific" variety[4]).
2. Alternatively, rather than managing all the data files and doing their own data processing, there are several free "web engines" that accept data uploaded by a user, combine it with nearby IGS station data, and carry out the data processing for them (examples include AUSPOS 2006; OPUS 2006; SCOUT 2006).

Both modes provide the user with significant savings, as they can obtain high relative accuracy coordinate results without the need to operate their own reference station(s). Note that no distinction is made between data sourced from an IGS station, or from any other GPS receiver network. Nevertheless it is sometimes useful to consider the hierarchy of permanent GPS reference stations: (1) *Tier 1* being the IGS stations possibly augmented by high quality stations from regional networks such as the EUREF Permanent Network, the Plate Boundary Observatory, etc., (2) *Tier 2* the primary national geodetic networks, and (3) *Tier 3* the state (or secondary) and private GPS networks. For some applications the source of the GPS data is irrelevant. However, other applications seeking the highest accuracy and/or integrity may only use data from Tier 1, and perhaps Tier 2, stations or networks.

That national GPS receiver networks could also satisfy surveying applications came to be viewed as an important justification for the provision of *geodetic infrastructure* in its own right. Note, this can be considered an *extra* benefit of a Tier 2 permanent network operated by a national geodetic agency (the primary justification always being that the network allows the national geodetic framework to be "monitored", as in the case of Geoscience Australia, National Resources Canada, the U.S. National Geodetic Survey, and similar organisations in many other countries). For other states or agencies in Australia, Europe or North America, however, state-established Tier 3 networks are rarely justifiable solely on "geodetic grounds", and hence supporting professional (surveyors, engineers, etc.) users and critical industries (agriculture, mining, etc.) so that they can carry out high accuracy GPS surveys with greater efficiency may be the *sole* justification. *But how to justify the use of permanent GPS station infrastructure for the provision of real-time cm-level accuracy services?*

1.3 Real-Time GPS Networks

With the advent of GPS-RTK techniques in the early 1990s, carrier phase-based GPS technology finally could be seriously considered a *surveying tool*. Productivity[5] increased to such a degree that private survey companies could

[4] The distinction here is: "commercial" software is generally that provided by the GPS manufacturer (though it can be sourced from 3rd parties) and intended to give few centimetre-level accuracy over inter-receiver distances of up to a several tens of kilometres, i.e. relative accuracies of a few ppm; whereas "scientific" software such as the Bernese, GAMIT or Gipsy packages have a sophisticated data modelling capability and process data from many stations, up to a thousand or more kilometres apart, resulting in relative coordinate accuracies down to a few ppb.

[5] "Productivity" can be measured in many ways, but essentially refers to the number of points that could be coordinated in a day, with minimum constraints on operations. This

invest in the receiver equipment (Lachapelle et al. 2002; Rizos 2002). At first users operated their own reference stations and the radio links used to transmit reference receiver data to the user or rover unit. In this way full control was exercised over the positioning system, and the rover unit provided an immediate coordinate for time-critical applications such as engineering construction, detail surveys, precision agriculture, etc. However, to ensure high productivity GPS-RTK (i.e. rapid 'on-the-fly' ambiguity resolution – OTF-AR) there were many constraints, including: (a) that all GPS receivers (reference and rover) must have dual-frequency tracking capability, and (b) the inter-receiver distance should be less than ten or so kilometres. These are significant constraints and the impact has been:

- The GPS-RTK system was the most expensive of all GPS technologies.
- Reference GPS receivers were set up on an *ad hoc* basis, only for the duration of the survey task.
- Proprietary formats and protocols proliferated.
- Communication links were point-to-point, not *broadcast* (in contrast to DGPS[6] services).
- Typically UHF links were used, with associated user frequency allocation and cross-interference problems amongst several users sharing the same UHF frequency band.
- Limited sharing of reference GPS receiver data with other users was possible.

The most serious implication was that it was difficult for any agency or private organisation to justify the establishment of a network of GPS reference stations with inter-receiver spacing of the order of 20km covering an entire region (so that reference-rover distances could be kept to under ten kms in order to ensure rapid OTF-AR).

This mode of 'single-base' RTK was enhanced, from the late-1990s, by the so-called 'network-RTK' approach, where the spatially correlated atmospheric and satellite orbit errors could be better mitigated using *several* continuously operating GPS reference stations surrounding the rover receiver. Rizos et al. (1999, 2000) identified some advantages of network-RTK over single-base RTK, including:

- Rapid static and kinematic GPS techniques could be used over baselines many tens of kilometres in length.
- Instantaneous (i.e. single-epoch) OTF-AR algorithms could be used for GPS positioning, at the same time ensuring high accuracy, availability and reliability for critical applications.
- Rapid static positioning was possible using lower-cost, single-frequency GPS receivers, even over baselines tens of kilometres in length.

However, the greatest impact on GPS receiver infrastructure was that network-based techniques enabled cm-accuracy positioning with less dense reference

---

required rapid ambiguity resolution (AR), or at the very least the use of techniques such as 'stop-and-go' that did not need frequent AR.

[6] The authors distinguishes between the two types of "relative positioning" techniques in the following manner: GPS-RTK refers to cm-level accuracy techniques based on the processing of double-differenced carrier phase measurements in real-time; and Differential GPS (DGPS) being the metre-level real-time techniques based on pseudo-range data (Lachapelle et al. 2002).

receiver spacing - of the order of 50-100kms - even in real-time (Rizos & Han 2003). Such CORS spacing could now be considered feasible as *surveying infrastructure*, and by the late 1990s and early 2000s many government and private network operators became interested in the *economics* of network-RTK.

Network-based GPS techniques remains an active area of research, with topics that include: (a) next generation GNSS (Rizos 2006), (b) multi-frequency GNSS (Feng & Rizos 2005), (c) different implementations of network-RTK (VRS, FKP, etc.; Rizos & Han 2003), (d) RTK/RTCM standards, e.g. NTRIP TCP/IP communications protocols, (e) improvements in data streaming over the Internet (reliable long-range, wireless data transfer via either TCP/IP or UDP/IP), and (f) recent developments in real-time data streaming from IGS stations.

2. COMMERCIALISING GPS-RTK NETWORKS & SERVICES

As a result of the "geodetic legacy" referred to above, the majority of permanent GPS networks have been, and will continue to be for some time to come, initiatives primarily from (national and state) government agencies. As already mentioned, a large number of IGS and EUREF Permanent Network (EPN) stations are expected to be upgraded so as to provide real-time data streams. This data is available for free, broadcast over the Internet, to any user[7]. More than 200 real-time CORS networks are estimated to exist (Schrock 2006), and perhaps increasing in number by about 10% per annum. However, many national and state government GPS reference networks are hesitant to offer such data for free, believing that a business could be built on transmitting RTK/RTCM correction data to subscribers of a real-time service. *The 'marketplace' for GPS data will therefore become increasingly confusing.*

2.1 Who Will Establish & Maintain CORS- Networks in an Era of Commercial Services?

The government agencies and organisations that are now (or soon will be) providing free real-time data streams typically justify the costs of implementing CORS networks by citing the principle of "preventable costs", similar to the strategy used to finance the establishment of classical geodetic groundmark networks decades earlier. The return on the original investment is not measured in terms of revenue earned, but justified as a means of keeping the costs borne by the community lower than the alternative (i.e., having no geodetic infrastructure). *This approach also encourages network standardisation and avoids the establishment of a patchwork of private, ad hoc networks for project-specific purposes*.

If extended to real-time operations the net result of these free, but limited, services (they may only support single-base RTK "out of the receiver"[8]) would be to give

[7] Note, however, that the IGSas an organisation does not own any GNSS stations – it merely coordinates the generation of geodetic-quality products from the GNSS tracking data. The reference receivers are operated by national geodetic agencies, geoscientific research organisations and academic institutions.

[8] Many survey-grade, dual-frequency GPS receivers are capable of outputting RTK/RTCM messages out of one of their I/O ports. This port can be connected to an

the user the impression that the free distribution of GPS-RTK corrections is the only business model available, and that the cost of establishing and maintaining the networks and services should be borne by the network operators (and ultimately the state or nation's tax payers). In fact many government agencies are currently facing an uphill battle in trying to convince potential users to subscribe to their real-time GPS services. The primary reason is the disproportionate cost for the offered services when borne by a limited number of customers, typically the land surveyors who require high accuracy positioning on a day-to-day basis. Furthermore, government agencies, the most common GPS network operators, rarely are successful at running commercial ventures. One option is for the government agency to license their data to a private service provider, who is then responsible for the marketing of data or services generated using the GPS CORS network infrastructure. (see below). *But is there a market large enough to turn a profit for the service provider and sufficient income to maintain or upgrade the CORS infrastructure?* Before an attempt is made to address this question, a brief (and far from exhaustive) review of some models for the establishment of CORS infrastructure is presented.

Model 1: Institutional CORS Infrastructure, No Commercial Services

A government agency or institution can justify the *establishment* and *maintenance* of a CORS network on the basis of a "public good" requirement such as monitoring crustal deformation, as in Japan by the Geographical Survey Institute (GSI 2006), and parts of the U.S. as in the case of the Plate Boundary Observatory (PBO 2006). The U.S. cooperative state CORS network coordinated by the national Geodetic Survey (NGS 2006) and the E.U.'s EUREF Permanent Network (EPN, 2006) are also other examples. The CORS operators do not in general provide commercial RTK services, though they may license the raw data to private service providers (as in the case of GSI). The EPN does not even bother with licensing, providing their data streams for free.

Model 2: Government CORS Infrastructure, Operates Commercial Services

A government agency can justify the *establishment* of a CORS network partially on the basis of improving internal (survey/geodesy) operations, but seeks to also operate a commercial RTK service, as in Germany where the different state CORS networks are coordinated into a single Satellite Positioning Service (SAPOS 2006).

Model 3: Government CORS Infrastructure, Licences Data to Private Sector

A government agency establishes a CORS network, but *licenses* the raw CORS data (or the RTK messages) to one or more private service provider(s) who undertake to market the services derived from the CORS data. In some cases the SP agreement may call for the establishment of additional CORS sites and/or the upgrade of CORS hardware over time. For example, this is the model adopted by the U.K.'s Ordnance Survey (2006), who have licensed the CORS data to Leica Geosystems and Trimble. Leica has undertaken to install more than 40 additional GNSS CORS receivers (capable of GPS and Glonass satellite tracking).

Internet IP address, and the messages to support single-base RTK can be provided to users with almost no effort.

Model 4: Cooperative Privately-Owned CORS Infrastructure, Commercial Services

A consortium of private companies may setup their own CORS network and market RTK services. A federation of licensed surveyors have established a CORS-RTK network across the whole of France (TERIA 2005). In local areas this is happening in other parts of the world as well.

Model 5: Privately-Owned CORS Infrastructure, Commercial Services

This is the standard private sector model - own and operate the CORS infrastructure, develop and implement a business plan that gives an adequate return-on-investment through the sale of RTK services. This model assumes the company belongs to the "spatial industry" (surveying, engineering, mapping, etc.). However, there is no reason why a company that does not have positioning/surveying/mapping as a core activity should not also enter the business of CORS-RTK services. An example is the CORS sites operated by the Italian telecommunications company Telespazio Spa.

2.2 Are There Alternative Business Models That Could Justify Investment in Permanent Networks by Private Industry?

GPS manufacturers (or at least their agents) have an important role to play in how future CORS networks evolve in different countries and regions, by educating prospective CORS operators of different financing options and operational models. Nowadays there are business models based on other industries that could be investigated, such as those based on mobile telephony and the service or hospitality industries. For example, the costs of handsets are largely subsidised by a telecommunications service provider because they generate revenue from the customer services, not from handset sales. On the other hand, in the case of what we might call the "Starbucks" model, access to services could be provided free (or at a very low cost) in order to encourage customers to purchase goods or other services from them. For example, many shops and hotels now offer free Internet connectivity via WiFi access points. This attracts customers to their businesses.

Hence there are at least two business models for CORS services that could be identified in other service industries:

1. To drive an increase in the sales of rover GNSS receivers, generally supported by very low (or zero) CORS-RTK service fees. *This scenario would be best if the aim is to market high-value GNSS receivers.*
2. To drive an increase in revenue from CORS-RTK service fees, generally encouraged by very low (even free) rover receiver hardware. *This would be the preferred scenario if the rover hardware were of the low-cost variety, such as current single-frequency systems*.

GNSS manufacturers (or their agents), if they were to adopt the first model, would be expected to partner with current CORS (government or private) operators to *subsidise* a GPS-RTK service, so as to encourage customers to purchase GPS-RTK enabled hardware. If there are no CORS networks in a city (or at a location where there is a potential demand for GPS-RTK services), they may even establish their own CORS networks (section 2.1).

It is not clear whether the second model would find favour with GPS manufacturers at the present time, as it would require their business model to be based on encouraging a mass market in carrier phase-capable instrumentation by *reducing receiver hardware costs*. However, with the launch of more GPS IIR-M satellites (broadcasting the civilian L2C signal) and GPS IIF (broadcasting in addition a third L5 signal) in the coming years (Rizos 2006), there is likely to be increased competition for multi-frequency GNSS receivers from many different manufacturers (including from China), which may drive down the cost of user hardware. Future GNSS receivers may therefore become relatively low-cost "commodity" items.

2.3 New Non-Global Broadcast Services Based on CORS Networks

Service providers may commit to providing GNSS network solutions in the appropriate reference system (local or national datum), as often the very justification of permanent GNSS networks by the national geodetic agency is to offer a complete integrated datum-consistent solution to users of CORS data. This may include geoidal height correction to convert GPS-derived ellipsoidal height to orthometric or levelled heights.

Some argue that any datum transformation algorithms that may be required could be integrated into the rover units, and that a certain level of control can be achieved by forcing the users to calibrate their systems on existing ground control points. This is exactly the situation with the recent decision by Omnistar to provide only correction data that ensures coordinate results are obtained in the ITRF datum, not in a locally-realised geocentric datum. For example, the Geocentric Datum of Australia (GDA94 2006) was "frozen"[9] to ITRF92 at the epoch year 1994, and since that time the tectonic plate motion of the Australian continent has resulted in the divergence between the GDA94 and WGS84/ITRF2005 datums (and the groundmark or permanent GPS station coordinates that realise or define these frames) to grow to almost one metre! In Europe, ETRS89 (EUREF 2006) is a datum that is based on tectonic motion that was "frozen" at the epoch year 1989. There are many other examples around the world of geocentric datums realised by coordinates that are *not* in the ITRF2005/WGS84 datum. Hence a commercial service may provide RTK corrections consistent with the local geodetic datum. (This would require the coordinates of the CORS receivers to be maintained in the local datum.) *Surely taking essentially a "do-nothing" approach means that a national geodetic agency has eschewed its responsibility for providing the fundamental geodetic infrastructure to support surveying, mapping, and other users of the Spatial Data Infrastructure?*

The subject of increased data integrity is also creating considerable interest among GPS network operators and service providers. What if they could provide a service that overcame the problems that users routinely encounter in processing their own data? A reliable GPS-RTK service providing high quality solutions could be the basis of a sustainable CORS business because of the value-added nature of such high integrity services could justify premium charges.

---

[9] In a sense that the coordinates are assumed fixed in a geocentric global reference frame, even as the ground stations and receivers move due to tectonic motion. This implies that the axes of the reference frame *move* (as opposed to the ITRF, which is maintained "fixed" by allowing the coordinates of all groundmarks and CORS to change with time).

3. TOWARDS NEW MODELS FOR GNSS-RTK SERVICES

3.1 Client-Server Model

What if, instead of broadcasting corrections or data and placing the onus of obtaining a final solution on users and their equipment, advantage is taken of the existing GPS network infrastructure to compute their coordinates in the required reference system? Final (position) solutions for all real-time (logged) users could be simply computed as a by-product of the continuous network processes – all the time satisfying the quality and integrity criteria implemented at the network administrator level. Note that improved accuracy and reliability of the user coordinates can be expected if GPS data is processed in the *network mode*, rather than as individual baselines as is the case for standard RTK-type techniques[10]. In addition, precise ultra-rapid IGS ephemerides can be used in the network computations instead of the braodcast ephemeris. After all, there exist already a number of web-based services for the generation of coordinates via the post-processing of data submitted to a server by the client user *in combination with some IGS data* (section 1.2)[11]. What is suggested as one business model is therefore to extend this capability to real-time data processing. (Although post-processing service could also be considered.)

A client-server approach reverses the data flow in conventional RTK by requiring the user to transmit their data to a control centre – sometimes also referred to as *"reverse RTK"* or *"remote RTK"* or *"inverted RTK"* (see Figure 1). Note that there is still the need for two-way communications between the client (field user) and server (computer centre). The server software can select the optimal combination of CORS, and compute the best possible position solution before returning the result to the field user. The user then receives not just raw coordinates, but a value-added product. Service providers can now exercise control over the generated products and, as a result, place a true commercial value on the service.

In addition, the user does not have to learn complicated GNSS surveying techniques or software. Safeguards, and thus integrity, can also be easily implemented into such a service. For example, if the number of satellites is too low, the geometry is unfavourable, or the multipath effects too detrimental, a message can be sent back to the user warning them that the provided solution is not optimal and that it may not meet their specifications. With the critical processes of *legal traceability* and integrity looming on the horizon for positioning services, such a *total quality assured coordinate service* may become increasingly attractive. This is a role that a GNSS *service broker* may play (section 3.2). For example, Nippon GPS Solution has implemented an inverted RTK service in Japan (Kanzaki 2006), and is marketing their service by promoting the quality assurance aspects of server-based RTK processing.

---

[10] In the network mode all GPS data (from all reference stations and all user/rover receivers) are processed together, taking into account the full variance-covariance information contained within a simultaneously tracking network of receivers.

[11] Although data from several nearby IGS stations are used, only one user data file is added to this 'mini-network'.

For some applications, such as the tracking of buoys or other platforms, and structural or crustal deformation monitoring, the coordinates need not be transmitted back to the field receiver unit(s). Hence there is only one-way data communications. The computed coordinates can then be subject to further processing by a specialist service, e.g. time series analysis of a continuous stream of 3D coordinates. This is also a role that a GNSS *service broker* may play (section 3.2). Such a service is similar to vehicle fleet management telematics services.

Furthermore the computing facility can easily compute local coordinates, even corrected by using a geoid model. A more sophisticated approach can therefore be implemented for coordinate transformations (horizontal or vertical) using, e.g. grid corrections for geoid heights or horizontal offsets, and updated at any time (see Figure 2). An added benefit to this approach is the decreased burden placed on the rover receivers by removing the need for field calculations, thus encouraging the development of a new generation of less expensive rover hardware operating only in a network context (such as suggested in the mobilephone business model – section 2.2). (There is of course an increased burden on the RTK Server, but that could be addressed with more computing resources.)

3.2 The GNSS Service Broker

In fact the client-server approach doesn't need to even be implemented in an existing GNSS-RTK network software solution. It can be independent. Examples are the SmartNet in the U.K. where Leica Geosystems is gathering the raw GNSS measurement data from the Ordnance Survey network and processes independently of other RTK services the raw data to derive new GNSS-RTK products such as MAX and I-MAX corrections (Cranenbroeck 2004). Nippon GPS Solution in Japan is doing the same using data from the GSI (Geographical Survey Institute 2006) GEONET network (Kanzaki 2006). This is a trend that we may expect to continue as more and more sources of real-time raw GNSS tracking data become freely available – though there must still be a business model in place to underpin the CORS infrastructure (section 2.1).

The *service broker* need not operate a CORS network, nor even operate a sophisticated network processing facilty, but could check which GNSS-RTK services are available in the vicinity of the user and then arrange for the user receiver's coordinates to be computed by: (a) accessing one (or more) service provider's VRS, FKP or I-MAX data stream, or (b) submitting the user's data to a service that did the actual coordinate computation. Furthermore, the user's position could be computed using different models or services and then an 'optimal combination' or 'majority voting' process applied to deliver a more reliable solution (Figure 3). In some cases there may not be a RTK service available, in which case a DGPS solution can be provided based on a sparse network of stations; perhaps a free marine beacon-based service or even a fee-based service such as Omnistar's. In fact the user may not always require cm-level accuracy, so why should a user subscribe to different services (offering different levels of accuracy)? By using a single GNSS service broker, a "customer" is shielded from such complexity.

Hence such a service broker may be viewed as an "aggregator" of services and, for example, could establish commercial agreements with existing GNSS-RTK service providers, much like the telecommunications service providers today enable mobilephone "roaming" across different countries. In fact there may be GNSS-RTK service providers who do not even operate their own CORS network infrastructure. They simply access free data streams from the IGS (and other CORS operators) and generate RTK corrections where and when they are requested by users directly, or by service brokers working on behalf of users.

In summary, the GNSS service broker:

- Operates as an interface between user and different GNSS service providers (varying accuracy, geographic spread, etc.), as well as value-added services (that enhance the value of the raw coordinates).
- The service need not be restricted to point coordination, but could include polyline or polygon surveying.
- Need not be a GNSS service provider.
- Seeks to find the best 'deal' for the user.
- Facilitates 'global roaming'.
- Manages coordinate generation via new services such as reverse-RTK (e.g. as in typical fleet management tracking / telematics services).
- Provides quality assured and specialist services (if needed).

3.3 Some Scenarios

An Innovative Surveying Operation

Let's imagine that a surveyor is arriving in a country or region to conduct a survey. When he (or she) lands at the airport they will power up their GNSS equipment and 'log on' to their service broker. The surveyor will select the accuracy he/she needs to travel to the area where the survey will be undertaken. The accuracy needed is a few metres, and he/she will automatically be charged for the DGPS service. When he/she arrives at the site, the surveyor will change their accuracy criteria to (say) 5cm with a confidence level of 99%, and select the local datum for the coordinates. When the surveyor leaves the site with all the points coordinated the "transaction" will be concluded. Automatically all the coordinate data (and perhaps point attributes and any other information) the surveyor has collected will be forwarded immediately to their office via the service broker.

An Innovative Monitoring Operation

A bridge is exhibiting some unusual movements and drivers have raised the alarm to the highway authority. The highway authority commissions a service provider to deploy a set of GNSS receivers at critical locations and commence operations. The premium "mission critical" service with best accuracy and reliability is selected by the service broker. Automatically these receivers are identified and located by the appropriate network/service provider and their positions computed in real-time, and the results forwarded to an analysis centre that is responsible for the frequency domain analysis (another value-added service). The coordinates have been transformed into the local bridge axis system for better visualisation by engineers of the highway authority.

4. CONCLUDING REMARKS

The following summary comments can be made:

- Permanent GPS networks are a "geodetic legacy" that has been established over the last ten or so years. However these were not initially intended to support real-time positioning applications.
- With the development of RTK techniques (single-base or network-based), cm-level GPS positioning has become an important surveying/mapping tool.
- At first specialist users established their own reference station(s), but over time real-time services have started to be offered by GNSS network operators. However most of these services are not run on a sustainable business basis.
- New business models are needed if service providers are to generate the revenue necessary for infrastructure maintenance and upgrade. Some may involve subsidising the network infrastructure to sell more user hardware. Others may involve subsidising the user equipment with a view to selling more RTK services.
- One set of models are based on the "client-server" architecture, where the Client (the roving user) streams raw GNSS data back to a Server (a computing centre), where the coordinate computation is carried out in a "reverse RTK" mode of operation. The client pays for a reliable service.
- Variations of this basic model can be developed by studying how mobile telephony (and other service industries) business is conducted. For example using data/service brokers to provide the optimum solution for a user based on their requirements and the available DGPS/RTK services in the area of operation.
- The concept of a "service broker" is an innovative new model for supporting a range of value-added services to GNSS users, not only "standard" GNSS-RTK. These include integrity services, time series analysis, database update, and many more.

ACKNOWLEDGEMENTS

This paper is based on "Making GNSS-RTK Services Pay" by C. Rizos & J. van Cranenbroeck, presented at the FIG Congress, Munich, Germany, 8-13 October 2006. The author would like to thank Joel for his many stimulating discussions, and for drawing the figures presented in this paper. Special thanks also to Masayuki Kanzaki and Gorou Yamamoto of Nippon GPS Solutions. Nippon GPS Solutions – a member of the Hitachi Zorzen Group, Tokyo Japan – is the company who has developed and implemented the "Client-Server" concept using the GSI GEONET as the GPS network backbone infrastructure.

REFERENCES

AUSPOS (2006) Australian online GPS processing service, see http://www.ga.gov.au/bin/gps.pl, accessed 15 October 2006.

Cranenbroeck, J. van (2004) GPS network services for supporting surveying tasks, *GIS Development*, see http://www.gisdevelopment.net/technology/survey/mi04150.htm, accessed 18 November 2006.

EUREF (2006) European Terrestrial Reference System 89, see http://www.euref-iag.net, accessed 18 November 2006.

EUREF Permanent Network (2006) EUREF-IP Pilot Project, see http://www.epncb.oma.be/_organisation/projects/euref_IP/index.php, accessed 9 December 2006.

Feng, Y., & Rizos, C. (2005) Three carrier approaches for future global, regional and local GNSS positioning services: Concepts and performance perspectives. *18th Int. Tech. Meeting of the Satellite Division of the U.S. Institute of Navigation,* Long Beach, California, 13-16 September, 2277-2287.
GDA94 (2006) Geocentric Datum of Australia 1994, see http://www.ga.gov.au/geodesy/datums/gda.jsp, accessed 15 October 2006.
GSI (2006) Geographical Survey Institute home page, see http://www.gsi.go.jp/ENGLISH/, accessed 18 November 2006.
IGS (2006) International GNSS Service, see http://igscb.jpl.nasa.gov, accessed 15 October 2006.
ITRF2005 (2006) International Terrestrial Reference Frame 2005, see http://itrf.ensg.ign.fr/ITRF_solutions/2005/ITRF2005.php, accessed 15 October 2006.
Kanzaki, M. (2006) Inverted RTK system and its applications in Japan. *12th IAIN Congress & 2006 Int. Symp. on GPS/GNSS*, Jeju, Korea, 18-20 October, 455-458.
Lachapelle, G., Ryan, S., & Rizos, C. (2002) Servicing the GPS user. Chapter 14 in *Manual of Geospatial Science and Technology*, J. Bossler, J. Jenson, R. McMaster & C. Rizos (eds.), Taylor & Francis Inc., ISBN 0-7484-0924-6, 201-215.
Ordnance Survey (2006) GPS OS Net, see http://www.ordnancesurvey.co.uk/oswebsite/gps/, accessed 18 November 2006.
OPUS (2006) U.S. National Geodetic Survey's online processing user service, http://www.ngs.noaa.gov/OPUS/, accessed 15 October 2006.
PBO (2006) UNAVCO's Plate Boundary Observatory, see http://pboweb.unavco.org/, access 18 November 2006.
NGS (2006) U.S. National Geodetic Survey, CORS network, see http://www.ngs.noaa.gov/CORS/, accessed 18 November 2006.
Rizos, C. (2002) Making sense of the GPS techniques. Chapter 11 in *Manual of Geospatial Science and Technology*, J. Bossler, J. Jenson, R. McMaster & C. Rizos (eds.), Taylor & Francis Inc., ISBN 0-7484-0924-6, 146-161.
Rizos, C. (2006) New GNSS developments and their impact on the geospatial industry. *GIS Development Asia-Pacific*, 10(6), 34-36.
Rizos, C., & Han, S. (2003) Reference station network based RTK systems - Concepts & progress. *Wuhan University Journal of Nature Sciences*, 8(2B), 566-574.
Rizos, C., Satirapod, C., Chen, H.Y., & Han, S. (1999) GPS with multiple reference stations: surveying scenarios in metropolitan areas. *40th Aust. & 6th S.E.Asian Surveyors Congress*, Fremantle, Australia, 30 October - 5 November, 37-49.
Rizos, C., Han, S., Ge, L., Chen, H.Y., Hatanaka, Y., & Abe, K. (2000) Low-cost densification of permanent GPS networks for natural hazard mitigation: First tests on GSI's Geonet network. *Earth, Planets & Space*, 52(10), 867-871.
SAPOS (2006) Germany's Satellite Positioning Service, see http://www.sapos.de/, accessed 18 November 2006.
Schrock, G.M. (2006) On-grid goal: Seeking support for high-precision networks. *GPS World*, 17(10), 34-40.
SCOUT (2006) Scripp's coordinate update tool, see http://csrc.ucsd.edu/cgi-bin/SCOUT.cgi, accessed 15 October 2006.
TERIA (2005) Users can locate themselves on the ground in real time, *GEOinformatics*, see, http://www.geoinformatics.com/asp/default.asp?t=article&newsid=1968, accessed 19 November 2006.

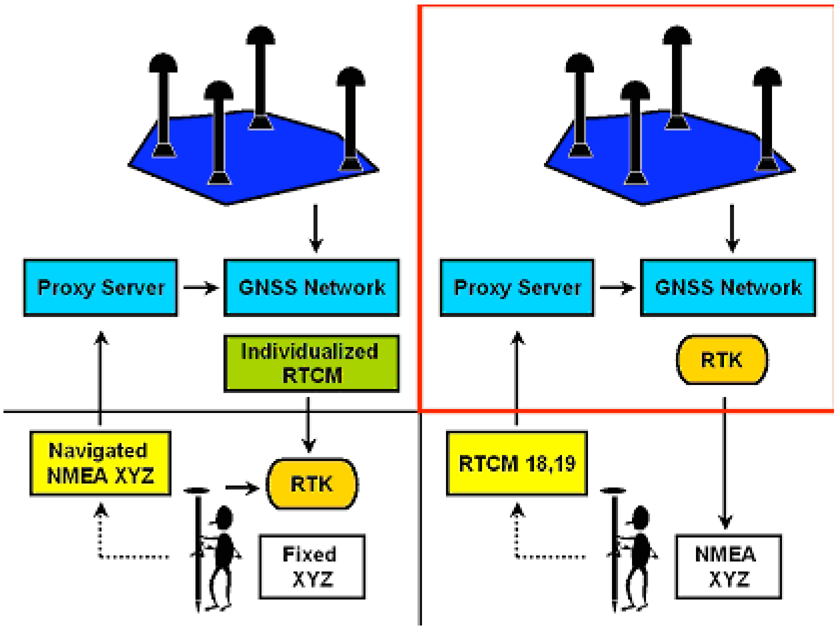

Figure 1. Standard GNSS-RTK (left), reverse (client-server) GNSS-RTK (right).

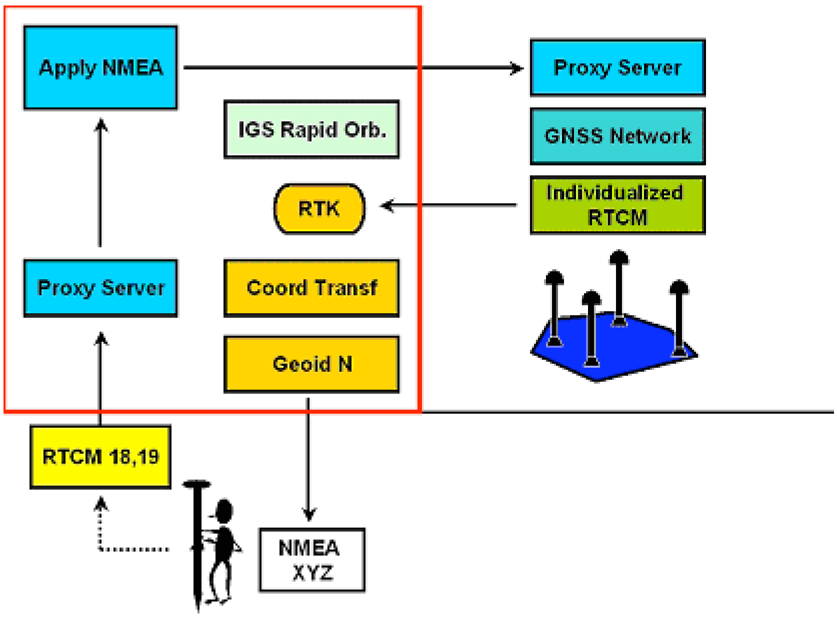

Figure 2. Client-server GNSS-RTK model implementing value-added transformations.

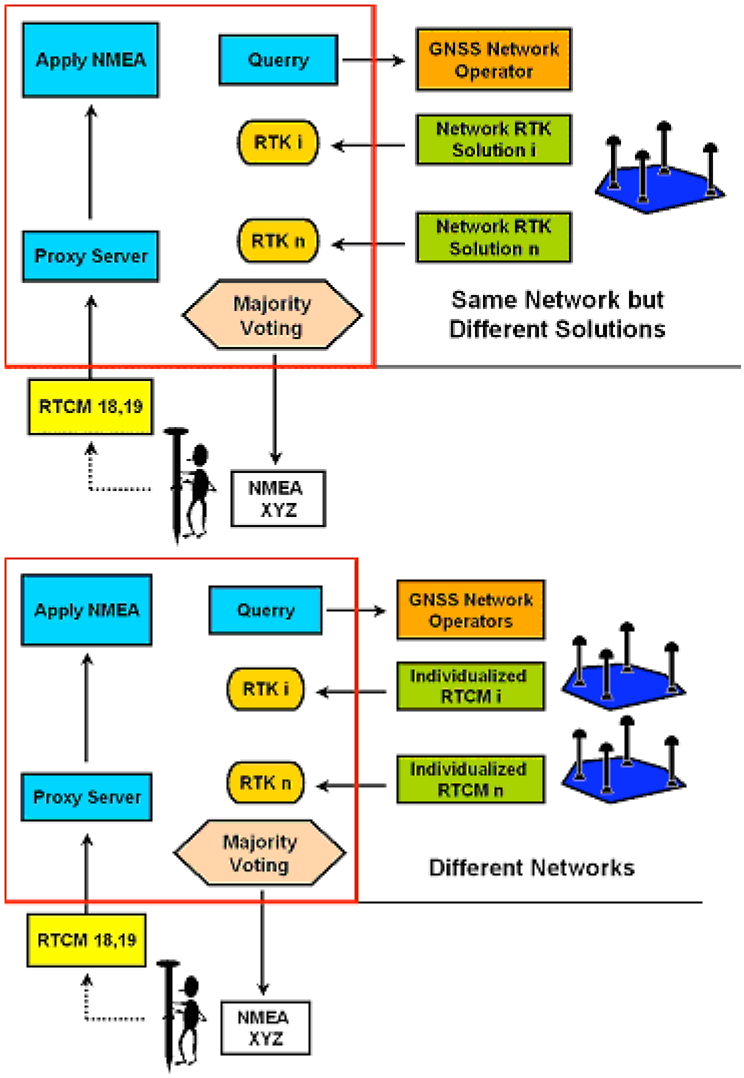

Figure 3. Concept of a GNSS service broker, accessing different DGPS services (top) or CORS networks (bottom).