Making GNSS-RTK Services Pay

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SUMMARY

The authors are regularly fielding questions by (potential and current) GNSS permanent receiver network operators on ways to recoup investment and on how this network infrastructure could be turned into a profitable business. One approach is to try to find a core of users who are prepared to pay for the GNSS-RTK services. But this is only feasible if the number of users and the fees charged are sufficient to generate a reasonable return-on-investment. On the other hand, there are those who advocate that there is no need to recoup investment, that the installed GNSS infrastructure should be seen as public infrastructure such as roads. The downside of this is the quality need not be assured as it is a service provided "as is". Both operating models also assume that the user or consumer of such GNSS-RTK services operates top-of-the-line GNSS receivers, typically dual-frequency receivers with sophisticated carrier phase-based RTK software installed on the units. These tend to be the most expensive GNSS products currently on the market.

This paper investigates options for new business models. One of these is based on the Client-Server model. What if instead of broadcasting RTK/RTCM corrections and placing the onus of obtaining a final solution on the user and his equipment, advantage was taken of the existing network system infrastructure to compute the user's coordinates for them? Final (position) solutions for all (logged) users would 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. After all, there exist already a number of web-based services for the generation of coordinates via the post-processing of data submitted by the user. *Why not extend this functionality to real-time processing?*

Currently providers of GNSS corrections have no control over the quality of the results computed by the user. This makes it difficult for them to justify charging for their services. Compounding the problem, providers of GNSS hardware typically implement their own proprietary algorithms to compute an RTK-derived position. Overall this situation leaves GNSS-RTK service providers in a weakened position to charge for their services, since they do not have any control over the quality of the solutions generated in the field using their data! With the trend towards lower cost GNSS equipment, it is clear that putting the computational effort on the server side will justify more easily the charging of users for a value-added product.

Furthermore, the service provider need not even own or operate the GNSS receiver network. There may be different networks; some sparse and some dense; some offering free data, some

charging for raw data access; some offering full service (i.e. coordinate computation), some providing nothing more than raw data streams. The GNSS-RTK service provider may therefore access the appropriate sets of raw data for a customer from whichever network is prepared to provide it (free or fee-based), effectively acting as a GNSS data broker. Then this data is processed, together with the customer's data, at the RTK Server and passed back to the customer as quality assured coordinate results. This paper describes the concepts and possible business models that may underpin such a service model. Some case studies from around the world will be discussed.

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1. BACKGROUND

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 of professional GNSS users in many areas of surveying and mapping. Examples of applications are survey control work, engineering surveying, machine guidance/navigation, acquisition of data for GIS applications, cadastral surveys, determination of ground control points for photogrammetric work, monitoring of engineering structures, mapping of utility corridors and assets, etc. In fact, the number of applications benefiting from the establishment of permanent networks seems to be growing daily. The widespread use of GNSS Real-Time Kinematic (RTK) and Differential GNSS (DGPS)[2] techniques has encouraged geodetic government agencies to look for ways to use networks of permanent GNSS reference receivers to support ever expanding non-geodetic real-time applications of high accuracy positioning for surveying, engineering, precision agriculture, etc. But first let us review how such receiver networks came to be established by government agencies in the first place.

1.1 National Geodetic GPS Networks

GPS in the 1980s (outside of the military) was almost exclusively used for geodetic control surveys. "GPS geodesy" was in fact 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 apart (being the average distance between first order geodetic control groundmarks). However, GPS was also proving itself to be an effective space geodesy technique for measuring crustal motion due to tectonic and other geophysical phenomena, and progressively the distances between GPS receivers increased to hundreds and then thousands of kilometres, while simultaneously the relative accuracies went up – hence ensuring cm-level relative accuracy within GPS receiver networks, even as inter-

[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.

[2] The authors distinguish 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 DGPS being the metre-level real-time techniques based on pseudo-range data.

receiver distances grew significantly. GPS is now the premier tool for modern geodesy, and relative accuracies at the 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 geodetic effects – effectively ushering in the era of 4-dimensional geodesy), (b) realising "modernised" geocentric geodetic datums at the national level, and (c) the densification of geodetic control networks using GPS techniques.

However, as GPS became an indispensible geodetic technology, government agencies looked for ways to replace traditional geodetic networks initially with groundmarks surveyed using GPS technology, and then increasingly with networks of permanent GPS reference stations. 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 permanent GPS 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 maintenance task is very cost efficient). Another is that the national geodetic datum can be propagated to all other GPS surveys using reference network data. Almost without exception the first permanent GPS receiver networks were established by geodetic/surveying agencies.

1.2 Hierarchy of Permanent GPS Networks

It is important to acknowledge the "über-network" of reference stations of the International GNSS Service (IGS, 2006). Hundreds of globally distributed GPS receivers have been operating on a continuous basis for over ten years. The data they have collected have been used in progressive realisations of the geocentric International Terrestrial Reference Frame (ITRF) – the latest of which is ITRF2005 (ITRF2005, 2006). Many countries have over the last decade or so redefined their national datums to be "compatible" with an ITRF reference frame, by typically linking primary stations and/or groundmarks to the ITRF via the nearest IGS reference stations. 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 national 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 over time, as in Japan, USA, New Zealand, Indonesia, etc.

Even countries that do not directly experience the crustal deformation arising from tectonic plate motion/collision that challenges a national datum's internal integrity, consider permanent GPS receiver networks (e.g. established by the national geodetic agency) as *infrastructure* to support national and international geodetic studies. However, 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 permanent receiver networks was justified on "geodetic grounds", national networks were similar to IGS stations. That is, although operated on a 24/7 basis, the data was only periodically downloaded from each receiver into (typically) ASCII files in RINEX format, and were transmitted daily to an archive or data centre. From there the data was available to users for post-processing.

Archived RINEX[3] files from both IGS stations and national GPS reference networks were (and still are) accessed by any user via the Internet. All IGS data has been, and continues to be, available at no cost. Although some GPS receiver network operators charged fees for their RINEX files, the trend is to increasingly make such data available for free. (Although high rate data at 1Hz tends to be considered "special" data and can attract a charge.) If users were: (a) satisfied with post-processed coordinate results (i.e. they did not want real-time coordinates), and (b) were fortunate to be carrying out a GPS survey or positioning task "close" to a reference station[4], then users could benefit from such data in two ways:

- Download data from the nearest GPS reference station(s), for the time period of their own survey, and then process this data together with their own receiver-collected data, using their own software (which could be "commercial" or "scientific"[5]).
- Rather than the user managing all the data files and doing their own data processing, there are several free "web engines" that can accept data upload by a user, combine it with nearby IGS station data, and carry out the processing for them (examples, AUSPOS, 2006; OPUS, 2006; SCOUT, 2006).

Note that no distinction is made between data sourced from an IGS station, or from any other GPS receiver network. The data is provided in "receiver-independent" format (RINEX). 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). Nevertheless it is sometimes useful to consider the hierarchy of permanent GPS reference stations: (1) *Tier 1* being the IGS stations, (2) *Tier 2* the primary national geodetic network (e.g. the Australian Regional GPS Network), and (3) *Tier 3* the state 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/networks.

[3] RINEX: Receiver Independent Exchange Format.
[4] The definition of "close" in the case of cm-level accuracy applications depends on the GPS technique and operational mode used (Rizos, 2002), ranging from no more than ten kms for 'rapid-static' or 'on-the-fly' carrier phase-based techniques using "commercial" software, to perhaps hundreds of kilometres if "scientific" software is instead used.
[5] The distinction accepted here is: "commercial" software is generally that provided by the GPS manufacturer (though it can be 3rd party sourced) 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; while "scientific" software such as the Bernese, GAMIT or Gipsy packages have a sophisticated data modelling capability and process data from many stations, up to thousands of kilometres apart, resulting in relative accuracies of down to a few ppb.

That national GPS receiver networks can satisfy GPS 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, and the National Geodetic Survey in the U.S.). For other states or agencies in Australia or North America, however, state-established Tier 3 networks are rarely justifiable on "geodetic grounds", and hence supporting professional (surveyors, engineers, etc.) users 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 The Era of 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[6] increased to such a degree that private survey companies could invest in the receiver equipment (Lachapelle et al, 2002; Rizos, 2002). At first surveyors 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 GPS 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, not the least of which were: (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 was:

- A GPS-RTK system was the most expensive of all GPS technologies.
- Reference receivers were set up on an ad hoc basis, only for the duration of the survey.
- Proprietary formats and protocols proliferated.
- Communication links were point-to-point, not broadcast (in contrast to DGPS services).
- No sharing of reference receiver data 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, state or even nation (so that reference-rover distances could be kept to under ten kms in order to ensure rapid OTF-AR).

[6] "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 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.

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

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

The greatest impact on GPS receiver infrastructure was that network-based techniques enabled cm-accuracy positioning with reference receiver spacing of between 50-100kms, even in real-time (Rizos & Han, 2003). Such less-dense reference station 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 topic of research that includes: (a) next generation GNSS (the integrated constellation of modernized GPS, revitalised Glonass, and the planned Galileo satellites; Rizos, 2006), (b) multi-frequency GNSS (Feng & Rizos, 2005), (c) different implementations of network-RTK (VRS, FKP, etc., Rizos & Han, 2003), (d) 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.

In this new era of real-time data streaming, the number of reference stations contributing GPS data over the Internet grows daily. The IGS and some national geodetic GPS reference stations provide their data streams for free (e.g. Geoscience Australia, National Resources Canada). Other government and private GPS networks may charge fees. *The ‘marketplace’ for GPS data is therefore increasingly confusing*. Even choosing which sets of data to use in a network-RTK solution is not a trivial issue, hence it not surprising that the first generation network-RTK systems are, for the most part, proprietary – all reference receiver hardware and the RTK Server software that computes the ‘corrections’ being provided by one manufacturer. Many network-RTK systems have been established around the world. **But could such networks generate enough fees to justify their startup and running costs?**

A clue to a possible second generation network-RTK architecture can be found when considering the recent implementation of the RTCM 3.0 network corrections standard format by Leica Geosystems in its GNSS SpiderNET software (Cranenbroeck, 2004). In this implementation the RTK Server receives a request for a *sub*set of reference receiver data around the location of the user. This procedure involves the user sending their approximate location to the RTK Server, where data from a surrounding set of GPS reference stations is processed to extract information on the spatially correlated biases. These are then used to remove the dispersive and non-dispersive biases from the *nearest* reference station data to provide the rover with the ability to generate a fast, long-range RTK solution, obviating the need for a sophisticated algorithm in the receiver unit to handle this processing. This is therefore a customised service for a user, for which a premium fee could be charged. *In addition, this implementation requires a bi-directional communications link between the rover and RTK Server*.

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 stations are being converted so as to provide real-time data streams. This data is available for free, over the Internet, to any interested party. (Note, however, that the IGS does not 'own' any GPS stations, these are operated by national geodetic agencies, geoscientific research organisations or academic institutions.) Nevertheless, 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. So there are a number of questions, including: **Free GPS-RTK or fee-based GPS-RTK? Free single-base RTK and fee-based network-RTK?**

2.1 Can the Costs Associated with GPS-RTK Networks be Recovered?

The government entities and organisations that are now providing free real-time data streams typically justify the costs of implementing GPS networks by citing the approach of "preventable costs", similar to the strategy used to finance the establishment of classical geodetic 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 local industry lower than the alternative (i.e., having no geodetic infrastructure). *This approach also encourages network standardisation and avoids the appearance of a patchwork of private, ad hoc networks for project-specific purposes*.

The net result of these free, but limited, services (they may only support single-base RTK 'out of the receiver' – no network-RTK Server being needed) has been to give the user the impression that the distribution of differential GPS corrections should remain free of charge, and that the cost of establishing and maintaining the networks, and providing services, should be borne by the network operators. This observation is supported by the marked decrease in the number of paying customers for DGPS correction services since the U.S. presidential decision to turn off Selective Availability in 2000.

Even today, many agencies are facing an uphill battle in trying to convince potential users to subscribe to their real-time GPS services. The primary reason is the disproportionate (heavy) 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 dominant GPS network receiver operators, are notoriously *bad* 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 generated using the basic GPS network infrastructure. **But is there a market large enough to turn a profit for the service provider?**

2.2 Should GPS Manufacturers Invest in Permanent Networks?

Given the prevailing attitude, GPS companies working in the cm-level accuracy market such as Leica Geosystems must find ways to justify investment of substantial resources in R&D to improve next generation services built on, for example, network-RTK concepts (Cranenbroeck, 2004). **Should investment be in the rover/user equipment only? Or additionally in the RTK Server/Network management software? Should the latter be sold to customers (as would a GPS field unit)? Or should GPS reference networks be established on the grounds that they will encourage the growth in sales of rover/user GPS receivers (and hence the network establishment and running expenses are absorbed by the GPS sales agent or manufacturer as a cost of "developing the market" in rover receivers)?**

There are also alternative business models based on mobile telephony. It may be useful to compare the present situation with that of cellular phone service providers several years ago. These companies are now seeing healthy profits from the various levels of wireless service they offer. However, when the products were first introduced to the public the companies gambled on what services would lure customers, so as to offset a complex and costly mobile telephony infrastructure. The costs of handsets are in fact largely subsidised by the telecommunications service providers because they generate revenue from the customer services not from handset sales. Evidence that these investments paid off can be found in the rapid increase in the number of users over the years and the attraction of new service offerings being rolled out on a regular basis. These services are indeed new applications that users are willing to pay for. **What lessons are there for next generation GNSS-RTK service providers who also want to become profitable?**

In summary, there are at least two business models for permanent GNSS reference stations based on some form of "subsidy" for the establishment of GNSS-RTK reference station infrastructure:

- To drive an increase in the sales of rover receivers, generally supported by very low service fees. *This scenario would be best if the aim is to market high-value dual-(or triple-)frequency GNSS receivers (or devices which have GPS as substantial components as in the case of Leica's SmartStation).*
- To drive an increase in revenue from 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.*

2.3 Towards a New Information Broadcast Service Based on Permanent GNSS Networks

What if service providers[7] wish to control or/and tailor the quality of services based on the type of products their networks provide? They may also committed 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 (or state lands agency) is to offer a complete integrated datum-consistent solution that possibly includes geoidal height correction.

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 user to calibrate their system on existing 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' to ITRF92 at epoch 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 these frames) to grow to almost one metre! **Surely taking essentially a 'do-nothing' approach means that the national geodetic agency has eschewed its responsibility for providing the fundamental geodetic infrastructure to support surveying, mapping, and other uses of the Spatial Data Infrastructure?**

The subject of increased data integrity is also creating considerable interest among GNSS network operators and/or service providers. **What if they could provide a service that overcame the problems that users routinely encounter in processing their own data?** A reliable GNSS-RTK service providing high quality and high fidelity solutions could generate significant revenue because of the 'value-added' nature of such high integrity services. **How many of the current GNSS-RTK network operators do not appropriately charge for their data/services only because they cannot guarantee continuous and reliable positioning?** The "geodetic legacy" of permanent GNSS networks means that many of the network operators have surveying and geodesy backgrounds, and few of them have the IT specialists, and even the resources, to maintain a reliable service. (This shortcoming is often compounded by a lack of marketing and promotional effort.)

2.4 Some Further Comments…

GNSS-RTK network operators are increasingly looking to improvements in technology performance, for example by allowing users to survey longer baselines with a high (and

[7] The owner of the physical GNSS reference network infrastructure need not be the entity offering GNSS-RTK (and any other) service. Here 'service provider' refers to the agency, company or organisation that markets the data service generated using the network infrastructure.

reliable) accuracy. However few of them are designing their infrastructure with an appropriate cost-benefit analysis that would allow them to compare the expected cost of implementing a system with the expected benefits that will result from providing the new correction/data product. (Such an analysis could indicate whether or not a project would be financially viable, and when the operator could expect an actual financial return on his initial investment.)

For example, in many cases, there is a tendency to want to deploy a dense and large network systematically covering the complete service area regardless of existing or potential surveying activity. Second generation of GNSS-RTK Network/Server software like the Leica GNSS SpiderNET Software allows a much more flexible and scalable approach. That is, a GNSS-RTK network can be established today by phasing the whole project, adding reference stations as needed.

However, the apparent difficulty in turning such high-tech infrastructure into profitable businesses may also be due to the fact that the actual network operators have a direct relationship with their users. For managing such a GNSS-RTK service the network operator should contract a service provider with good experience in developing new services and is capable of implementing a charging mechanism. But those new business operators will want to have the technology able to support new business models.

3. TOWARDS NEW BUSINESS MODELS FOR GNSS-RTK SERVICES

3.1 Client-Server Approach

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 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. After all, there exist already a number of web-based services for the generation of coordinates via the post-processing of data submitted by the user (section 1.2). What is proposed as one business model is to extend this capability to real-time processing. Currently, providers of GNSS corrections have no control over the quality of the results computed by the user, and as already suggested this makes it difficult for them to justify charging for their services. Compounding the problem, GNSS hardware manufacturers typically implement proprietary algorithms to compute an RTK-derived position. Overall this situation leaves GNSS-RTK service providers in a weakened position to charge for their services since they do not have any control over the quality of the solutions generated in the field using their data.

A "Client-Server" approach reverses the data flow in conventional RTK by requiring the user/rover to transmit their data to a control centre – sometimes also referred to as *"reverse RTK"* (see Figure 1). This facility can select the optimal combination of stations to, for example, apply network corrections, and compute the best possible position solution before returning the result to the user. By having the computation on the server side, the IGS rapid orbit could be used to improve the quality of the solution over and above that which could be possible with conventional rover RTK. The advantages of such an approach are clearly evident. Service providers can exercise control over the generated products and, as a result, place a commercial value on the service.

Furthermore, the typical user is released from the obligation of learning 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 ("legal minefields") of traceability and integrity looming on the horizon for positioning services, such 'total quality assured coordinate services' look increasingly attractive.

Needless to say that in this case the computing facility can derive easily the local coordinates, even corrected by using a geoid model. A much more sophisticated approach can therefore be implemented for transformations (horizontal or vertical) using, e.g., grid corrections, and updated at any time. See Figure 2. An added benefit to this approach is the decreased burden placed on the rover units by removing the need for field calculations, thus encouraging the development of a new generation of less costly rover hardware operating only in a network context (such as in the mobilephone business model analogy – section 2.2).

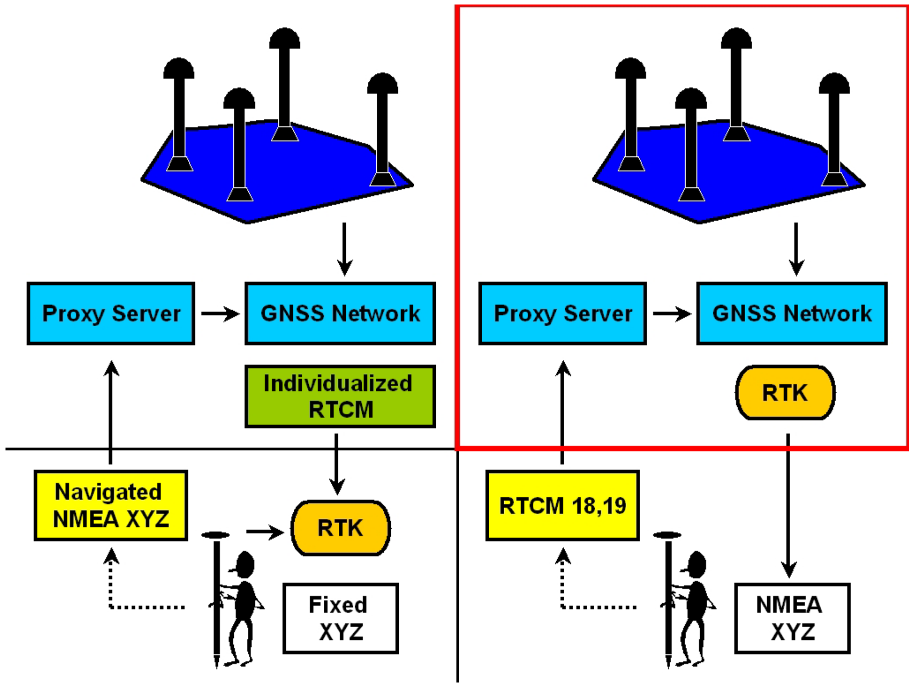

Figure 1. Standard GNSS-RTK (left), reverse (client-server) GNSS-RTK (right).

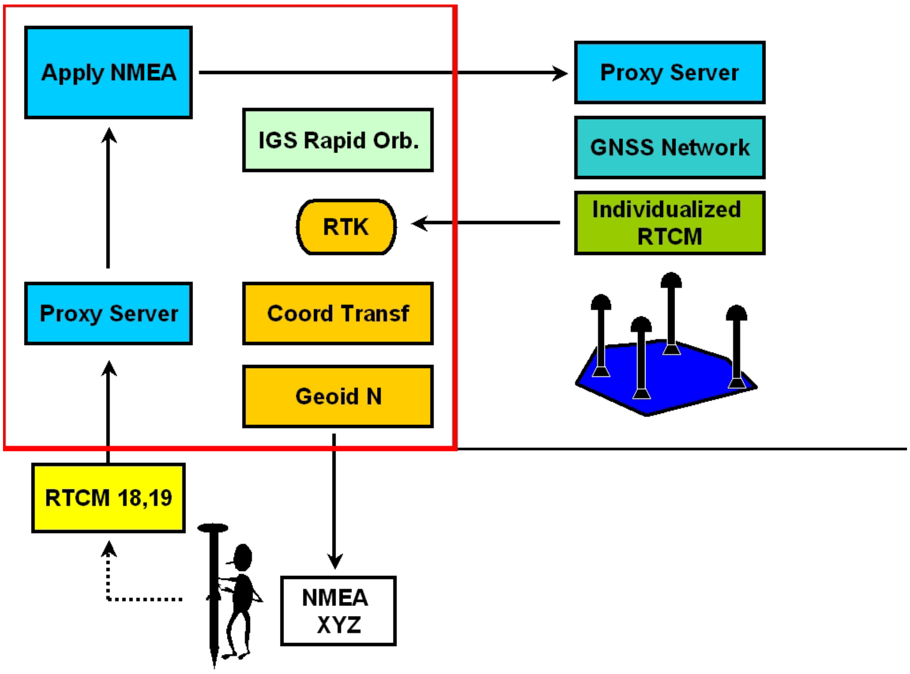

Figure 2. Sophisticated client-server GNSS-RTK model implemented transformations.

3.2 The GNSS-RTK Service Broker

In fact the "Client-Server" approach doesn't need to be implemented in an existing GNSS-RTK Network software solution. It can be independent. Examples are the SmartNet proposal in the U.K. where Leica Geosystems is gathering the raw data from the OS-UK network and processes independently of other RTK services the raw data to derive new products such as MAX and I-MAX. Nippon GPS Solution in Japan is doing the same using data from the GSI (Geographical Survey Institute) GEONET network. For example a *service broker* could check which GNSS-RTK services are available around the user and then arrange for the user's position to be computed by accessing one (or more) service provider's or network operator's VRS, FKP or I-MAX data stream. The user's position could be computed using different models and then a 'majority voting' process applied to deliver a more reliable solution (Figure 3). On the other hand, the rover/user can be charged if they wants a "multi-solution". In some cases there may not be a Network-RTK service available, then a DGPS solution can be provided based on a sparse network of stations; perhaps a free marine beacon-based service or even a fee service such as Omnistar's.

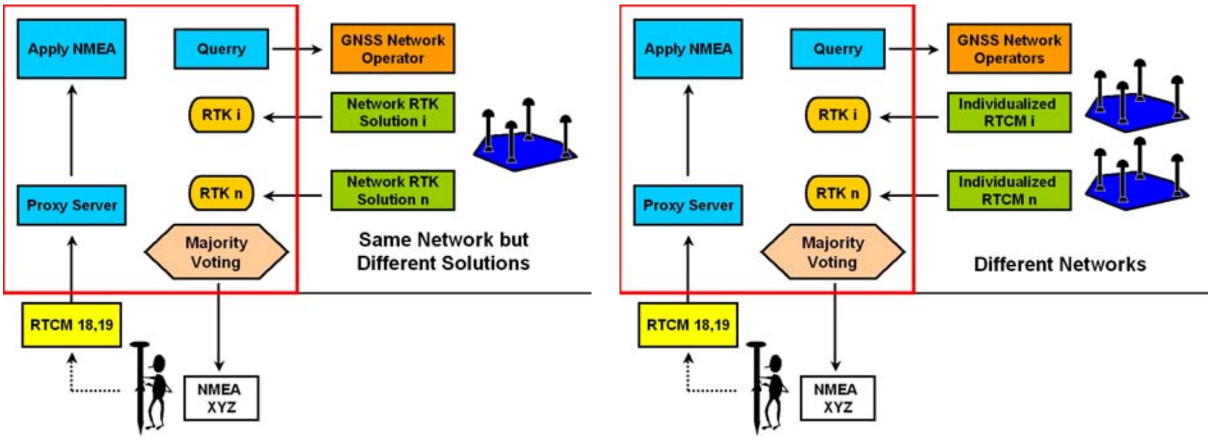

Figure 3. Concept of a GNSS service broker, accessing different DGPS services (left) or networks (right).

Such a proposed GNSS-RTK *service broker* would establish commercial agreements with existing GNSS Network service providers, much like the wireless operators today to enable mobilephone 'roaming'. One could imagine that RTK Servers would be installed anywhere in the world, in some dedicated data centre with mirroring and backup. This suggests the concept of 'ubiquitous computing' where the user has only a tablet PC with wireless Internet link, but benefits by using software and any hard disk space located in a data centre. **Perhaps such a new service could be called "Ubiquitous RTK" (URTK)?** Another interesting development is that any kind of user that can stream out of his/her receiver 'box' the raw data can request an accurate position – a car navigation system, a handheld GPS receiver for GIS, a monitoring GNSS receiver. With the advent of techniques like Precise Point Positioning, and the availability of products/data from the real-time global IGS network, such services could provide even more coverage.

But what will be the *profile* of this new class of operators? It's relatively easy to see that the wireless data service operators, and even the telecommunication carriers themselves, are ideal candidates. A traditional GNSS network operator like a lands or mapping agency could become a business partner in such ventures, and will may more easily receive a return on their investment (so as to maintain and expand their network). However the telecommunications/telematics world is aggressively chasing the LBS, A-GPS and other positioning service markets. They are not yet interested in providing accurate positioning services – *however accuracy is addictive!*

4. CASE STUDIES

4.1 An Innovative Surveying Operation…

Let's imagine that a surveyor is arriving in a country to conduct a survey. When he[8] lands at the airport he will power up the GNSS equipment and will 'log onto' his service broker. He

[8] It can of course be a she!

knows that some networks have been setup in the vicinity. He will select the accuracy he needs to travel to the area where he will have to organise his survey. The accuracy needed is few metres, and he will automatically be charged for the DGPS service. When he arrives at the site, he will change his accuracy criteria to (say) 5cm with a confidence level of 99%, and select the local datum in which he wants the coordinates. When he leaves the site with all the points coordinated he will terminate the 'transaction'. Automatically all the coordinate information (and perhaps point attributes) he has collected will be forwarded immediately to his office via his service broker. *Job is done*.

4.2 An Innovative Monitoring Operation…

Some drivers that have crossed a bridge have felt some unusual movements and have raised the alarm to the highway authority. Immediately a set of GNSS receivers are placed at critical locations and commence operating. 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 perhaps smoothed with a sliding window post-processing solution as well, 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 at the headquarters of the highway authority.

4.3 An Innovative Urban GIS Operation…

A GIS database must be updated to reflect the positions of new buildings. The GIS operator has selected an accuracy of (say) 50cm with a confidence level of 95%, and the maximum number of satellites. Fortunately he has a GPS+Glonass receiver and the service broker will select the appropriate network/service provider to compute the positions. For some points the multipath effects are so challenging that instead of getting a coordinate the user receives a message saying to come back to that point within a precise time window, when the disturbance is predicted to be less. At other locations he will receive a message that the coordinates of his location is unavailable for security reasons. He has been fined automatically. *Bad day!*

5. 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 became a useful surveying/mapping tool. Applications in non-traditional applications are increasing.

- At first specialist users established their own reference station(s), but over time real-time services were offered by the the GNSS receiver 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 subsiding 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. The client pays for a reliable service.
- Variations of this basic model can be developed by studying how mobile telephony business is conducted. For example using data/service ‘brokers’.
- The concept of a service broker is an innovative new model for supporting a range of value-added services, not only ‘standard’ GNSS-RTK.

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