Wang, Charles and Feng, Yanming and Higgins, Matthew and Looi, Mark (2009) ***Communication infrastructure study for precise positioning services in regional Queensland***. In: Proceedings of International Global Navigation Satellite Systems Society Symposium, 1-3 December 2009, Holiday Inn Hotel, Gold Coast, Queensland.

International Global Navigation Satellite Systems Society
IGNSS Symposium 2009

Holiday Inn Surfers Paradise, Qld, Australia
1 – 3 December, 2009

Communication Infrastructure Study for Precise Positioning Services in Regional Queensland

Charles Wang
Queensland University of Technology, Australia
+61 7 3138 1963, cc.wang@qut.edu.au

Yanming Feng
Queensland University of Technology, Australia
+61 7 3138 1926, y.feng@qut.edu.au

Matt Higgins
Department of Environment and Resource Management
+61 7 3896 3754, Matt.Higgins@derm.qld.gov.au

Mark Looi
Queensland University of Technology, Australia
+61 7 3138 5114, m.looi@qut.edu.au

ABSTRACT

Providing precise positioning services in regional areas to support agriculture, mining, and construction sectors depends on the availability of ground continuously operating GNSS reference stations and communications linking these stations to central computers and users. With the support of CRC for Spatial Information, a more comprehensive review has been completed recently to examine various wired and wireless communication links available for precise positioning services, in particular in the Queensland regional areas. The study covers a wide range of communication technologies that are currently available, including fixed, mobile wireless, and Geo-stationary and or low earth orbiting satellites. These technologies are compared in terms of bandwidth, typical latency, reliability, coverage, and costs. Additionally, some tests were also conducted to determine the performances of different systems in the real environment. Finally, based on user application requirements, the paper discusses the suitability of different communication links.

KEYWORDS: Precise Positioning, Communication, RTK, Regional QLD

1. INTRODUCTION

In recent years, Global Navigation Satellite Systems (GNSS) based Precise Positioning (PP) services have been rapidly developed and established around the Globe. Such services are capable of providing centimetre level positioning accuracy through the Real-Time Kinematic (RTK) technique where GNSS measurement corrections derived from continuously operating reference stations (CORS) (such as ionospheric, tropospheric, and orbit errors) are provided to user receivers over a communication link. User groups from surveying, agriculture, mining, utilities, and construction sectors can benefit from these services. For instance, in open cut mining, precise GNSS is used for a variety of tasks including surveying, grading, dozing, drilling, collision avoidance and fleet management; productivity increases are as much as 30% by adopting GNSS (Higgins, 2008). In civil engineering, machine guidance is delivering significant increases in productivity and improved on-site safety. Using GNSS machine guidance and other innovative techniques the Port of Brisbane Motorway was completed six months ahead of schedule, 30% reduction in time required, with a 10% reduction in total project costs, 10% reduction in traffic management costs and 40% reduction in lost time injuries (Higgins, 2008). GNSS machine control in the form of auto-steer is widely used in the grain, cotton, sugar and horticultural sectors of Queensland agriculture. Using auto-steer for control traffic farming can reduce input costs of fuel, seed, fertilizer, herbicide and time by 10-20%. An estimated 15% of grain growers in Australia use GNSS for machine guidance and 9% for auto-steer, However, start up costs and lack of CORS Infrastructure are seen as major impediments to further uptake of the machine guidance approach (Higgins, 2008).

The CRCSI-funded research project "Delivering Precise Positioning Services in Regional Areas" has been undertaken by the authors since mid-2007. The research aims to address the technical and business issues that currently constrain GPS-based local area RTK PP services, so as to operate in future across larger coverage areas, and therefore support services for agriculture, mining, utilities, construction industries, and other users, across the whole of Queensland. Feng et al (2009) has given an overview for the GNSS technical aspects of project research findings, such as an overall technical framework proposed to transition the current RTK services to future larger scale coverage; data processing algorithms appropriate for triple-frequency GNSS signals; a server-based RTK software structure and suggested optimal deployment scheme for reference stations across a larger-scale network. This lengthy paper reviews the wired communication infrastructure and wireless communication systems available in regional QLD and investigates the most suitable communications solution for precise positioning services. Firstly, section 2 outlines the basic RTK architecture and operation for single station and network approach, as well as the data transmission bandwidth requirement for enabling PP services. Section 3 provides a summary of the user market segments and their requirements on the PP service. Section 4 presents the communication survey which detailed the most commonly available communication options in the market for wired, mobile carrier, and satellite services, including some technological details, theoretical performances, and coverage for each of the data communication options are presented. Section 6 provides the field test setup and results for three selected communication options which demonstrates the performances of these in real environment. Finally, section 7 presents the suitability of each communication options for enabling the PP service in regional area.

2. RTK ARCHITECTURE

The basic architecture of a RTK system comprises three components: reference stations (in a permanent known fixed location), processing facility and rover receivers or users. In its simplest form developed in the mid-1990s, a RTK system operates in the single station configuration where only reference station and rover receivers are involved. Satellite observations were gathered by the reference station and transmitted to the rover receiver in either raw measurement or as correction message via some form of data communication link, usually radio. However, a significant drawback of this approach is that the maximum base-rover distance should not exceed 20 km in order to maintain rapid and reliable carrier phase ambiguity resolution (Wanninger, 2004; Rizos and Han, 2003).

The system architecture has later been extended to the network-based approaches to overcome the baseline distance limitation. In the network RTK mode, satellite observations are gathered by the multiple reference stations and transferred to a network process centre on the secondly basis. Differential correction messages are generated based on these observations and delivered to rover receivers for centimetre level positioning. The distance-dependent biases, such as effects of ionosphere and troposphere, can be interpolated between reference stations, thus effectively controlling the growth of distance-dependent errors. As a result, the inter-reference station distance can be extended to 70km to 90km, depending on the capability of the network-based ambiguity resolution software used (Feng and Rizos, 2009).

The bandwidth requirement for data transmission between the network processing centre and the rover receiver is greatly dependent on the network RTK architecture, the data format, and the number of visible satellites. In the typical single-base scenario where there is 1 reference station with dual frequency code and carrier phase raw measurements for 12 satellites, the early RTCM v2.3 format requires approximately 4.5 Kbps, whereas the newer RTCM v3.1 format requires only 1.8 Kbps. For the network approach, multiples of RTCM data streams are required from reference stations to the network processing centre and thus the minimum required bandwidth would be 6 Kbps (RTCM v3.1) or 13.5 Kbps (RTCM v2.3) if typically 3 reference stations form the network. Additionally for delivering correction message to the rover, it can be achieved with either the Virtual Reference Station (VRS) approach or the Master-Auxiliary approach (Euler, 2006). For the VRS approach, the demand on the communication bandwidth is the same as for the single station mode (2 Kbps ~ 4.5 Kbps), whereas the Master-Auxiliary approach requires a RTCM v3.1 message which consists of raw carrier phase information of the master reference station as well as correction differences for surrounding reference stations. The required data stream is approximately 3 Kbps for a typical 12 visible satellites and 7 to 9 reference stations involved (Euler, 2006).

Apart from the bandwidth requirement, several other technical aspects of the communication network, such as coverage and reliability, need to be considered. The latency of the communication link could impact on the accuracy of the PP service, for instance 2 seconds required for cm level of accuracy (Liu, 2004). Other economical aspects such as setup cost, ongoing maintenance cost, and additional charges may also need to take into consideration.

3. USER REQUIREMENTS

As one of the CRCSI project deliverables, Positioning One Consulting conducted an investigation to identify potential user markets and their requirements on the RTK PP services (Position One Consulting, 2008) in four major user markets: agriculture, civil engineering construction, spatial/surveying, and mining. Other applications (such as navigation and scientific research) do exist, however the number is insignificant compared to the four major markets. Additionally, seven parameters were evaluated as part of user requirements which includes: accuracy, initialization, repeatability, availability, integrity, timeliness, and continuity and reliability. While some of these parameters have been met with current RTK systems, three of these parameters are of concerns to this project, including:

Accuracy required of the service, ranging from 10cm to 1cm.
Timeliness of the service delivery, ranging from 10 seconds to 0.05 second (20 Hz).
Continuity and Reliability of the service: ranging from 95% to 99.9%.

Based on the user needs analysis report by Position One Consulting, the PP service requirements from different user market segments are summarised in Table 1. The criteria used for evaluating performance parameters are shown in Table 2. It is clear that the timeliness requirements for some of the high accuracy applications are challenging for the existing communications.

		Accuracy	Timeliness	Reliability
Agriculture		Low ~ Moderate	Moderate	Moderate
Construction		Moderate ~ High	Moderate ~ High	High
Mining		Moderate ~ High	Moderate	High
Spatial		Moderate ~ High	Low/Moderate	Low ~ Moderate
Others	**Port**	Moderate ~ High	Moderate	Moderate ~ High
	Navigation	Low ~ Moderate	Moderate ~ High	Moderate
	Emergency	Low ~ Moderate	Low ~ Moderate	Moderate ~ High

Table 1: Market Requirements for Precise Positioning Services

	Low	Moderate	High
Accuracy	10 cm	5 cm	1 cm
Timeliness	10 seconds	1 seconds	0.05 seconds (20Hz)
Reliability	95%	99.5%	99.9%

Table 2: Performance Evaluation Criteria for Precise Positioning Services

4. COMMUNICATION SURVEY

A detailed survey for communication infrastructure options in Queensland that can enable data communication between three RTK components (reference station, network processing centre, and rover receiver) is conducted. Regardless of single-base and network-based RTK architectures, two separate communication links are required for the system to function: the link between the reference stations and a network processing centre (unless physically at the same location), and the link between the roving receiver and the network processing centre.

In additional to the availability of each communication options, the performance and quality of data communication networks are analysed with respect to three fundamental characteristics: bandwidth, latency (delay), and reliability. Each of these has effects on the RTK PP service performance.

Bandwidth: Bandwidth is defined as the rate of data transfer, measured in bits per second (bps). It has to be sufficient to carry and transport data between the reference station, the network processing centre, and the rover receivers. Typically, the bandwidth required depends on the data format used and on the number of visible satellites. With the adopted standard of RTCM message format, version 2.3 requires 4800 bps for dual-frequency code and carrier-phase observations of 12 satellites, where version 3.1 requires only 1800 bps for the same information content. The required bandwidth for other proprietary data message formats varies between different manufacturers and different format versions.

Latency: It is to be noted that for RTK PP services, the performance of RTK system could be significantly affected by latency of the correction messages, typically seconds or more between the network processing centre and a rover receiver. Additionally, low communication latency between the reference stations and the network processing centre is required. For example, GPSnet specified a maximum latency of 0.5 seconds for data from the source GPS receiver of a reference station to arrive at the network processing centre for processing (Miller, 2006).

Reliability: Reliability in data communication networks is an important issue, but has been less addressed in the past. Studies have identified that the existing Internet core was not designed to provide any level of guaranteed quality of service (QoS), instead operating on a best-effort basis (SIFT, 2007). Thus, applications with critical communication requirements should provide adequate planning steps to mitigate potential risks with sufficient redundancy in network links and supporting infrastructures.

4.1 Wired Data Communication

Wired infrastructure implies that a physical communications link (typically twisted pair wire, coaxial cable, or fibre optic cable) is used to provide the means for data transmission. Such links are capable of carrying data at a wide range of speed, depending on the particular technology in use. Although many wired communication technologies have been developed and in use, the general characteristics of these are:

- Network fixed in a specific location;
- Service availability is restricted to locations where cables are running;
- Reliable data transmission; and
- Wide range of available bandwidths and traffic limits.

Of all different wired technologies, Digital Subscriber Line (DSL) is a relative new technology that has gained popularity and adoption of such service is rapidly growing. Data communication is carried out on existing twisted pair telephone lines and the achievable speed is greatly dependent on the distance from telephone exchanges and also different standards in use. Figure 1 shows the achievable speed of ADSL, ADSL2, and ADSL2+ with respect to the distance away to the exchange. The figure shows that the speed of all three technologies dramatically decreases to around 6 Mbps when approximately 3.3 km away from the exchange. Also it is widely suggested that the maximum distance from the exchange is around 6km.

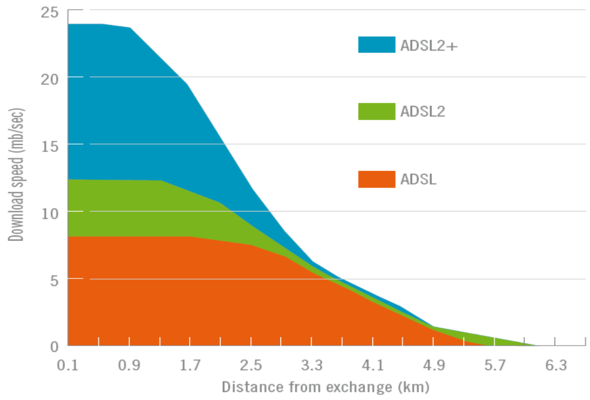

Figure 1: Speed Comparison for DSL Technologies (DCITA, 2006)

Apart from the ADSL, ADSL2 and ADSL2+ standards, other DSL technologies exist including: ADSL2+M which doubled the upload speed of ADSL2+; SHDSL provides symmetric connection of speeds up to 5.69 Mbps, and VDSL and VDSL2 are developed to enable asymmetric connection at much higher download speed of 100 Mbps and 200 Mbps respectively. A summary of DSL technologies is outlined in Table 3.

Name	**Standard**	**Downstream Speed**	**Upstream Speed**
ADSL	ANSI T1.413-1998 Issue 2	8 Mbit/s	1.0 Mbit/s
ADSL2	ITU G.992.3/4	12 Mbit/s	1.0 Mbit/s
ADSL2+	ITU G.992.5	24 Mbit/s	1.0 Mbit/s
ADSL2+M	ITU G.992.5 Annex M	24 Mbit/s	2.0 Mbit/s
SHDSL	ITU G.991.2	5.69 Mbit/s	5.69 Mbit/s
VDSL	ITU G993.1	100 Mbit/s	5 Mbit/s
VDSL2	ITU G993.2	200 Mbit/s	64 Mbit/s

Table 3. Types of DSL Technologies

The number of ADSL and ADSL2+ exchanges in Queensland is rapidly growing. Table 4 shows a comparison of the number of ADSL and ADSL2+ enabled exchange for June 2008 and June 2009. It is noted that while Telstra is the main service provider, other players (such as Optus, iiNet, TPG, Internode) have their own ADSL network equipment (technically referred to as DSLAMs – Digital Subscriber Line Access Multiplexers) located in the Telstra exchanges. Such providers are able to make use of the Telstra fixed wired network to provide ADSL services. Additionally, the distribution of these ADSL/ADSL2+ enabled exchanges are shown in Figure 2.

	As of June, 08	**As of June,09**
Telstra (ADSL)	429	1709
Telstra (ADSL2+)	~ 250	403
Optus	82	82
Chime (iiNet)	43	49
TPG	62	63
Primus	28	36
Agile	10	12
EFTel	19	26
OnTheNet	8	8

Table 4. Number of ADSL/ADSL2+ enabled exchange in Queensland

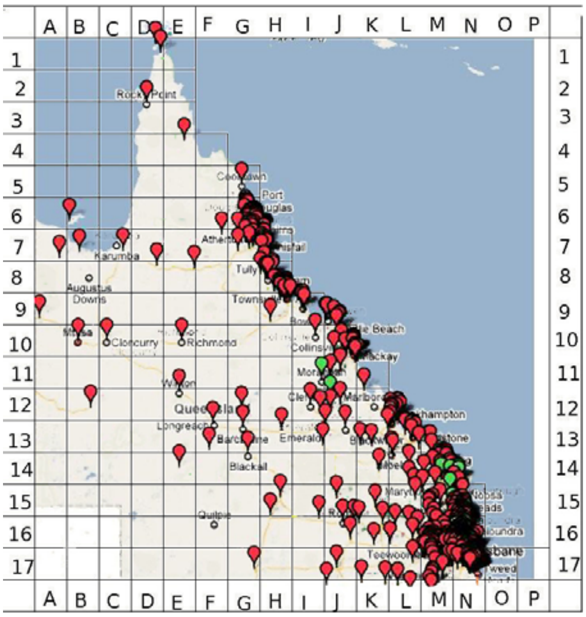

Figure 2. Distribution of ADSL/ADSL2+ enabled telephone exchanges

In addition to the DSL technologies, fibre optic connection has emerged and is growing rapidly as the wired data communication for the future. There are two common fibre optic technologies existing in the market: Fibre-to-the-Node (FTTN) and Fibre-to-the-Premises (FTTP). FTTN extends fibre cable from the telephone exchange to a cabinet on the street. The remaining “last-mile” connection to premises is done with a copper network. On the other hand, FTTP extends fibre cable all the way the home or business (DCITA, 2006).

Currently, the Australian government has proposed to build a national FTTP network that will reach 90% of the population with an estimated cost of AUD$43 billion over 8 years. The network will connect 90% of homes, schools, and workplace with speeds of up to 100 Mbps, while other places will be provided with 12 Mbps through wireless or satellite technology. While it’s in the development stage, it would replace ADSL/ADSL2+ once completed.

4.2 Wireless Data Communication

Another category of data transmission is by using electromagnetic waves propagating through space at a specified frequency band. Terrestrial microwave transmission, mobile carrier services, wireless systems (IEEE 802.11 and IEEE 802.16), and satellites are examples of wireless communication technology. Networks using such technologies permit communications to occur with users who are moving around and not necessarily at a fixed location. Some characteristics of wireless networks are:

- Support for user mobility; user can move anywhere inside the coverage.
- Coverage and quality of performance is dependent on many environmental factors, including topology, interference, physical obstructions to line of sight (LoS), as well as technical considerations including frequency of radio signal, output power of transmitters, type of antenna
- Quality of network performance (bandwidth, latency, and reliability) is typically poorer than wired solutions

Of all different wireless technologies, mobile carrier services and satellite services are the two main communication options for providing PP services in regional Queensland. Technologies such as radio, WiFi, and WiMax, either provide limited service coverage or still in development stage. Thus, only mobile carrier services and satellite services are considered.

4.3 Mobile Carrier Service

In general, mobile technologies are divided into three generations, with 2.5G and 3.5G providing additional network enhancements to 2G and 3G respectively. Currently, mobile communications services are now in 2.5G phase transmit with rapid migration to 3G and 3.5G. The 3G mobile networks focus on the provision of various services: voice, data, and multimedia. Figure 3 shows the history of mobile carrier services development.

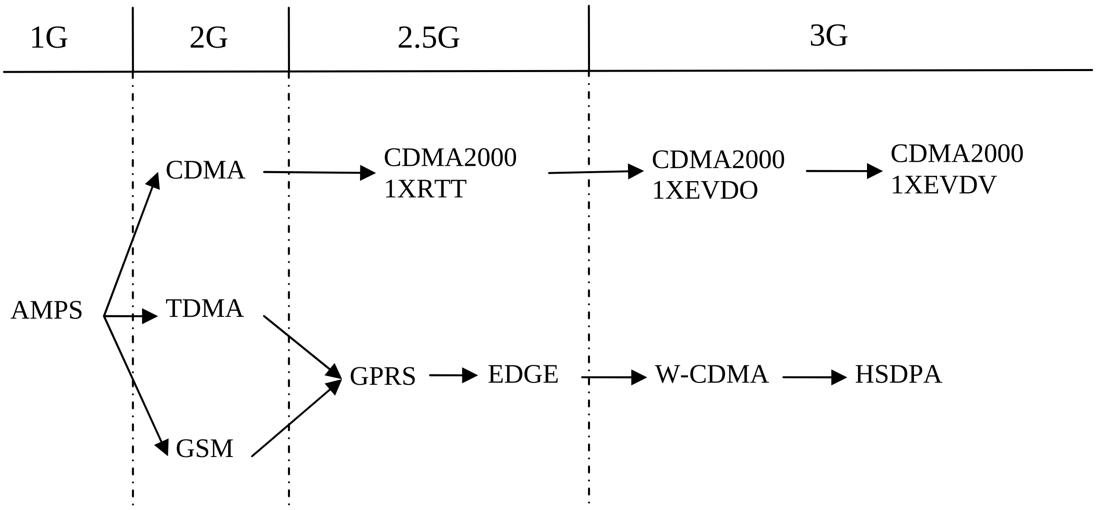

Figure 3. Mobile Carrier Services Development History

Several different protocols have been developed and implemented on the mobile carrier networks. For the 2G network, GPRS and the enhanced GPRS (EDGE) offer packet switching data communication with speeds of up to 114 Kbps, whereas GSM offers circuit switched data communication with speeds of up to 9.6 Kbps. On the other hand, 3G network supports High Speed Packet Access (HSPA) data communication with HSDPA standard to provide improved downlink speeds and HSUPA standard to enhance the upload speeds. HSDPA provides speeds of up to 14.4 Mbps (downlink) and 384 Kbps (uplink) and HSUPA provides improved upload speeds of up to 5.76 Mbps. Additionally, an enhanced HSPA (HSPA+) is under development and will boost the speed up to 42 Mbps. A summary of the data communication is tabulated in Table 5.

Technology		**Maximum Downlink**	**Maximum Uplink**
GSM (CSD)		9.6 Kbps	9.6 Kbps
GPRS		80 Kbps	20 Kbps
EDGE		236.8 Kbps	59.2 Kbps
HSPA	HSDPA	14.4 Mbps	384 Kbps
	HSUPA	14.4 Mbps	5.76 Mbps
HSPA+		42 Mbps	22 Mbps

Table 5: Summary of Mobile Data Communication Services

There are two major types of mobile networks in Australia, those based on 2G (GSM), (operating at 900 MHz and 1800 MHz) and those based on 3G (operating at 850 MHz, 900 MHz, or 2100 MHz). While there are currently many more GSM users than 3G users, it is expected that this will reverse over the next few years (ACMA, 2007). There was also an existing CDMA network, which was shut down on May 2008. All these mobile networks are capable of carrying data services at varying speeds.

Telstra has the most extensive mobile networks in Australia, operating three parallel mobile networks, a GSM network running at dual frequencies of 900 MHz and 1800 MHz, a 3G network running at 2100 MHz and a 3G network (marketed as NextG) running at 850 MHz. Telstra's GSM network provides coverage primarily in populated areas along the Queensland coast, as well as following the major inland highways to major towns. The NextG network has a significantly wider coverage area, with coverage reaching much further inland and reaching up into some of the remote communities in Far North Queensland. Telstra's 3G network is only available in a limited geographic region in Brisbane and Gold Coast.

Apart from Telstra, Optus has the second largest mobile service network. It operates a GSM network, running at dual radio frequencies of 900 MHz and 1800 MHz, as well as a 3G network, operating at 900 MHz and 2100 MHz which is shared with Vodafone. The Optus GSM network has some, but limited regional coverage, while the Optus/Vodafone 3G network is restricted to metropolitan areas only. Additionally, other mobile carrier services, such as Vodafone, 3 or Virgin, also have their own mobile network as well as shared networks between Telstra and Optus.

Telstra coverage maps for the GSM and NextG networks in Queensland are shown below in Figure 4 (left). The combined coverage for all mobile carrier services are shown in Figure 4 (right). It can be seen that the majority of services are concentrated along the coast line and there is still a large proportion of area that is not covered in regional/rural areas, in particular in the middle, up north and east end of Queensland region.

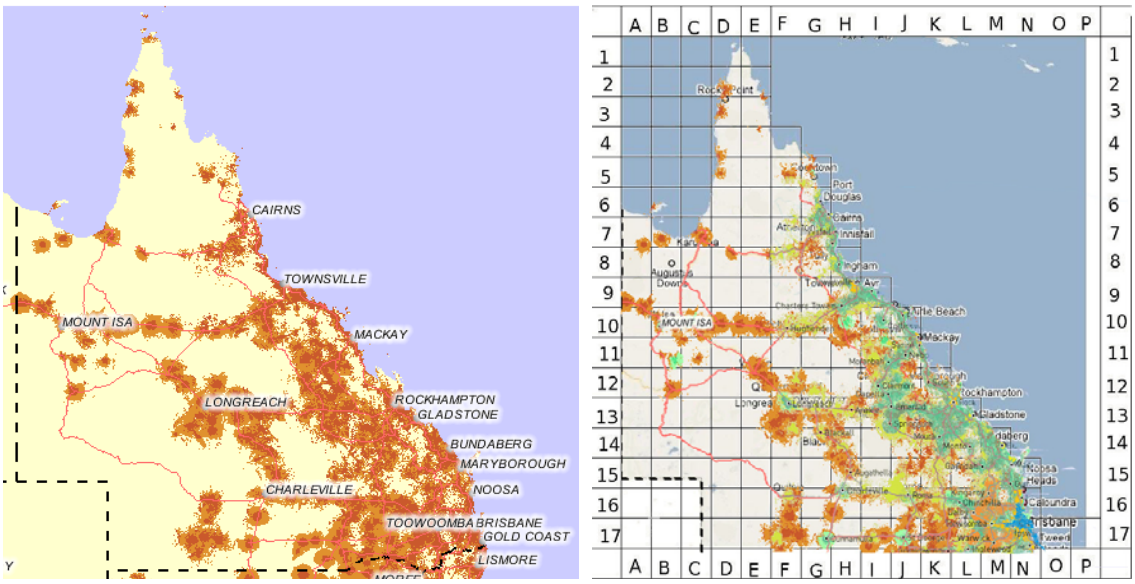

Figure 4. Mobile coverage in Queensland for NextG network (left) and combined coverage for all mobile carrier networks (right)

The key technical parameters of the relevant Telstra mobile networks and Optus network are summarized in Table 6. Additionally, the network coverage and approximate monthly access fee and excess charges are provided.

	Telstra GSM	Telstra 3G	Telstra NextG	Optus GSM	Optus single band 3G	Optus dual band 3G
Radio Frequency	900 MHz 1800 MHz	2100 MHz	850 MHz	900 MHz 1800 MHz	2100 MHz	2100/900 MHz
GPRS	Yes	Yes	Yes	Yes	Yes	Yes
EDGE	Yes	No	No	No	No	No
HSDPA	No	14.4 Mbps	14.4 Mbps	No	3.6 Mbps	7.2 Mbps
Max. base station coverage	35 km	30 km	Claimed 200 km	35 km	30 km	30km
coverage of population in Australia	96%	Capital cities only	98%	96%	80%	96%
Monthly access fees (2GB)	$45-$110	$45-$110	$45-$110	$5-$15	$5-$15	$5-$15
Typical excess data charges	15c to $1 per MB	15c to $1 per MB	15c to $1 per MB	$0.35-$0.5 per MB	$0.35-$0.5 per MB	$0.35-$0.5 per MB

Table 6. Summary of mobile data services for various Telstra and Optus networks

4.4 Satellite Services

Communication satellites may be classified into Geostationary Earth orbit (GEO), Medium - Earth-orbit (MEO), or Low-Earth-orbit (LEO). Geostationary satellites orbit at around 36,000 km above the Earth's surface, at the same angular speed that Earth rotates, and therefore appear to be stationary above a fixed location on Earth. MEO communication satellites are usually positioned between 5000 and 15,000 km above Earth and take approximately 6-8 hours to circle the Earth. LEO satellites are located much closer to the Earth, at an altitude of below 2000km.

Each of these satellite constellations is capable of providing communication services, but with different system configurations and user equipments. With non-geostationary satellites (such as MEO and LEO), a constellation of multiple satellites is required to maintain continuous service coverage for users in a particular region. The lower the satellite altitude, the more satellites are required to maintain continuous communication services. For GEO satellites, because of the higher orbits, the power requirement of satellite receivers using such a satellite is noticeably higher than of receivers using MEO or LEO satellites due to the much further distance the signal needs to travel from the receiver to the satellite. Additionally, geostationary satellites only tend to provide services to a limited geographic area, as opposed to the generally broader service area of low earth orbit satellite constellations. Table 7 summarises the pros and cons that affect mobile GNSS positioning services.

Satellite orbit	Advantages	Disadvantages
LEO	Low latency (20-40milliseconds) Low power High-speed communications (500kps or higher, depending application Antenna doesn’t need to point in the direction of the satellite	Very high orbit speed Tens to hundreds of satellites to cover the entire Earth Small footprint

MEO	Medium latency (50-150 milliseconds) Larger footprint Slower orbital speed	Higher-latency than LEO Higher power than LEO
GEO	Large footprint, 3 to cover entire Earth Very high speed used for broadcasting	Very high latency (250 milliseconds), not efficient for two-way IP communication High-power The receiver antenna have to point in the direction of the satellite

Table 7. Comparison of GEO, MEO and LEO satellite technologies (Olenewa and Ciampa, 2007)

In the Australian region, available satellite communications systems include those provided by the following companies:

GEO : Inmarsat Plc, IP Star, NewSat, and SingTel Optus Pty Ltd

LEO constellations: Globalstar Australia Pty Ltd and Iridium Satellite LLC

Inmarsat Plc (“I nmarsat”)

The primary data service offered by Inmarsat satellites in Australia is the Broadband Global Area Network (BGAN). It is a packet switched IP network with a maximum bandwidth of 492 kbps which uses the Inmarsat-4 satellites. A new Inmarsat-4 satellite was launched in 2008 which provides the full service coverage for Australia region. The coverage of Inmarsat service in February 2009 is shown in Figure 5.

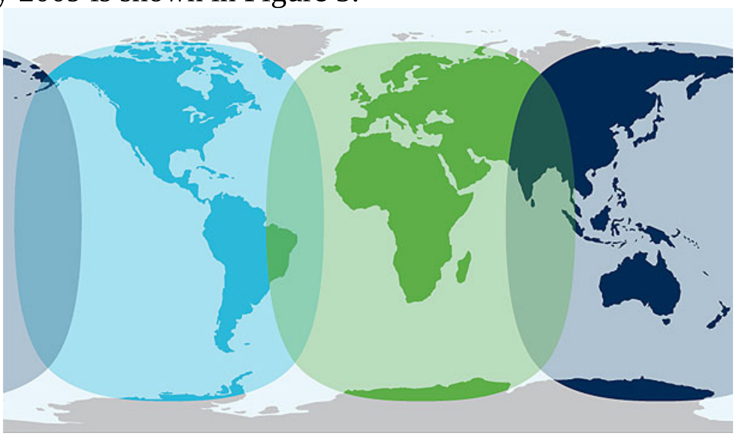

Figure 5. Inmarsat BGAN Coverage as of February 2009

IPStar Australia Pty Ltd

The IPStar Broadband Satellite System provides a large scale bandwidth platform with network configured on Gateway STAR topology where a user terminal receives and transmits signals from/to a Beam which connects with a gateway. The gateway then connects to other networks such as the Internet backbone, telephone network, or other IPStar Gateways. It provides full coverage services to Australia with Ku and Ka Band, where both shaped and spot Ku Beams are used. The shaped Ku Beam provides coverage to all regions of Australia, while multiple narrowly focused spot beams of the Ku Band are used to maximize the available frequency for transmission and thus increase the available bandwidth. The service coverage for Australia and New Zealand region is shown in Figure 6. Currently, IPStar provides satellite communication services through a number of ISPs; including Westnet, ACTIV8me, Skymesh, Westvic broadband, Aussie Broadband, Broadband Wireless.

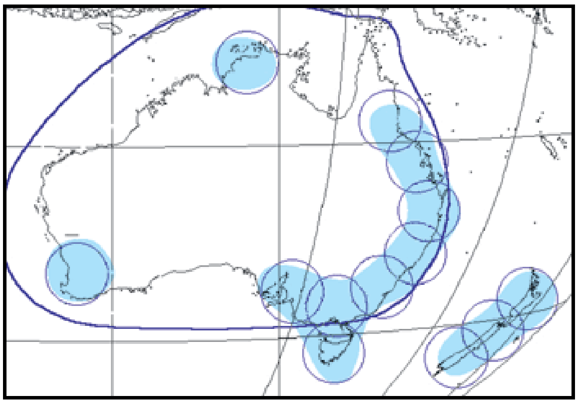

Figure 6. IPStar Coverage for Australian and New Zealand Region

NewSat

NewSat is a satellite service provider which carries its services on numerous existing satellites and operates a number of teleports. Two teleports in Adelaide and Perth provide linkage with 11 existing satellites with 23 antennas in both C band and Ku band. Additionally, it plans to raise an estimated $400 million to build a new geostationary satellite and launch it in late 2009. The new satellite will provide 100% Australia coverage and provide an affordable service through the use of Ka band. The access plan offered by NewSat is shown in the following table:

Singtel Optus Pty Ltd ("Optus")

Optus currently has 5 satellites operating (which they refer to as A3, B1, B3, C1, D1) and providing voice, data and television services throughout Australia, with 2 more (which they refer to as D2, D3) scheduled to be operational within 2 years. The A series satellites were launched in the 1980s, and the B series satellites in the early 1990s. The launch of the C series satellite was in the early 2000s, and the current generation of D series satellites commenced operation in 2005. The coverage of the Optus D1 satellite is shown in Figure 7 where it can be seen that full service is available for Australia with enhanced signals in capital and major cities.

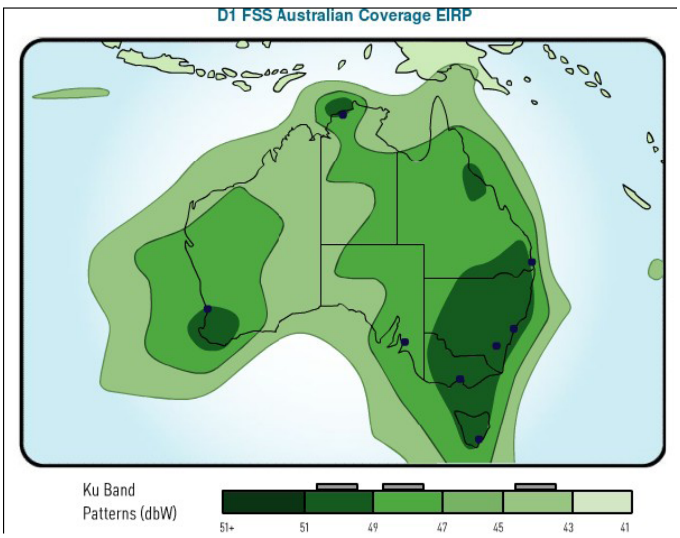

Figure 7: Optus D1 Satellite Coverage, http://www.optus.com.au

Table 8 shows the cost for typical GEO satellite communication services with IPStar, NewSat, and Optus, as of July 2009. It can be seen that the monthly cost is very similar across three service provider, ranging from $40 to $65 for 1GB of data allowance and $65 to $150 for 3GB of data depends on the speed of connection.

	Monthly Allowance				
Westnet Satellite Service Plan (through IPStar)					
Speed	500MB	1GB	3GB	5GB	
512/256	$30	$40	$65	N/A	
1000/512	N/A	$65	$110	$150	
NewSat Satellite Service Plan					
Speed	500MB	1.5GB	2.5GB	5GB	10GB
256/64	$39.50	N/A	N/A	N/A	N/A
512/128	N/A	$59.50	$79.50	N/A	N/A
1024/256	N/A	N/A	N/A	$189.50	$249.50
Optus Satellite Service Plan					
Speed	1GB	2GB	3GB	5GB	10GB
256/64	$40	N/A	N/A	N/A	N/A
512/128	$50	$58	$66	$98	$180
1000/128	$60	$83	$106	$158	$288
1000/256	$75	$113	$151	$227	$417

Table 8: Typical GEO-based Satellite Communication Services Cost for IPStar, NewSat, and Optus, as of July 2009

Globalstar Australia Pty Ltd ("Globalstar")
Globalstar operates a LEO satellite constellation comprising 40 satellites which provides Australia-wide coverage. The two-way voice and data service (Deplux) is capable of providing Circuit Switched Data ("CSD") or packet data, each with a 9.6 Kbps throughput. However, due to degraded satellite S-band antenna amplifier, the duplex data service is at present not available 24 hours a day. Based on the coverage tool on Globalstar's website, the service availability is currently around 60% to 70%. The service is expected to improve with 8 spare satellites to be activated. However, the fully operational service is not expected until the next generation constellation (Globalstar 2.0) is available for which the schedule initial launch is in the second half of 2009.

Iridium Satellite LLC ("Iridium")
Iridium is a network of 66 operational LEO satellites (with several spare satellites) providing a complete service coverage of the world. The satellite services are offered to customers through various reseller companies, such as Telstra and AST Australia. The Iridium service includes a CSD service with a maximum speed of 2.4 kbps.

Both LEO satellite services have shortcomings when comes to enabling PP services for regional Queensland. Globalstar is battling with their service availability and thus not able to provide continuous service when needed. On the other hand, Iridium can only provide low CSD service of up to 2.4kbps which is not enough for real-time correction message transmission. Furthermore, the lack of packet data service and time-based service charges make Iridium unsuitable for PP services.

5. COMMUNICATION LINK TEST AND RESULTS

Based on the communication survey presented in the previous section, three of the most suitable communication networks were selected and tested in field trials to determine the real environment performances, these include: wired service (ADSL2+), mobile carrier service (Telstra NextG), and GEO satellite service (MedSat). The equipment used for each service is as follows:

The ADSL2+ service is provided by TPG and is capable of speed up to 24Mbps.

The NextG service is connected through Telstra NextG AirCard 880U modem which is a USB third generation (3G) wireless modem that supports HSDPA (up to 7.2 Mbps download) and HSUPA (up to 2Mbps upload).

The GEO satellite service tested is a portable satellite system provided through Kansat with speeds of 1Mbps download and 128 kbps upload. The portable satellite Internet system consisted of a 1m antenna with 1 watt BUC, HN7740 Broadband satellite modem and a light Tripod mount.

Several network performance tests were conducted using a computer network tool "PING" command. It works by sending Internet Control Message Protocol (ICMP) packets to the target host and listening for the replies. It measures the round trip time and records any packet losses. For this experiment, Google server (www.google.com [66.102.11.104]) was chosen as the target host with varied ICMP packet sizes from 32 bytes to 1024 bytes. Results are shown in Table 9.

In general, it can be seen that ADSL2+ offers the best performance in terms of both reliability with 0 pack loss as well as the lowest average latency of less than 50ms for all different ICMP packet sizes tested. In the case of a mobile wireless carrier service, Telstra NextG results in only very few packet losses (less than 0.5%) and is not of concern when comes to providing PP services. The latency of between 150ms to200ms (300ms to 400ms round trip delay) won't have any problems delivering correction messages for most PP services where the timeliness requirement is no less than 1 second delay as shown in Table 1. However, it might have problems dealing with construction or high-speed navigation applications where timeliness is as high as 0.05 seconds (20 Hz). Finally the GEO satellite services results show the worst network performance with packet losses reaching up to 6% and latency of up to 2 seconds. The performance limited the use of GEO-based satellite communication system for non mission critical applications where no wired or mobile wireless solutions are available.

		Size of the ICMP packets sent in the ping request					
		32 bytes	**64 bytes**	**128 bytes**	**256 bytes**	**512 bytes**	**1024 bytes**
ADSL2+	**Tx Packet**	900	900	900	900	900	900
	Packet Loss	0	0	0	0	0	0
	Av. Latency	33ms	34ms	33ms	36ms	35ms	42ms
Telstra NextG	**Tx Packet**	900	900	900	900	900	900
	Packet Loss	0	0	1	1	1	3
	Av. Latency	294ms	300ms	318ms	353ms	369ms	404ms
Satellite	**Tx Packet**	900	900	900	900	900	900
	Packet Loss	9 (1%)	18 (2%)	11 (1%)	22 (2%)	25 (2%)	51 (6%)
	Av. Latency	976ms	1025ms	1161ms	1414ms	1795ms	1984ms

Table 9. Performances summary for ADSL2+, Telstra NextG, and Satellite services

The latency results with respect to the ICMP packet size provide an overall estimate of the network performance. The short packets (such as 32 ~ 64 bytes) are usually used to stress the network device. Medium size packets (such as 256 ~ 512 bytes) are considered to be the "average" Internet traffic packet size, and the long packets (such as 1024 bytes) are way too long to stress a network. Note that for the majority of Internet traffic uses the TCP protocol involves a mix of very long and very short packet lengths.

Figures 8, 9 and 10 show a more detailed latency results against the ICMP packet size. Again, the ADLS2+ service has the best performance with latency fluctuating mostly between 30ms to 100ms for all ICMP packet sizes. The NextG service is slightly worse than the ADSL2+ results, where latency is between 300ms and 500ms with occasional outliers with latencies of up to 1.5 seconds. Finally, Figure 10 shows the most fluctuation of latency results for the portable satellite service, as well as degraded latency performance with increasing ICMP packet size. It indicated that there is hardly a guarantee on the latency performance using satellite communication.

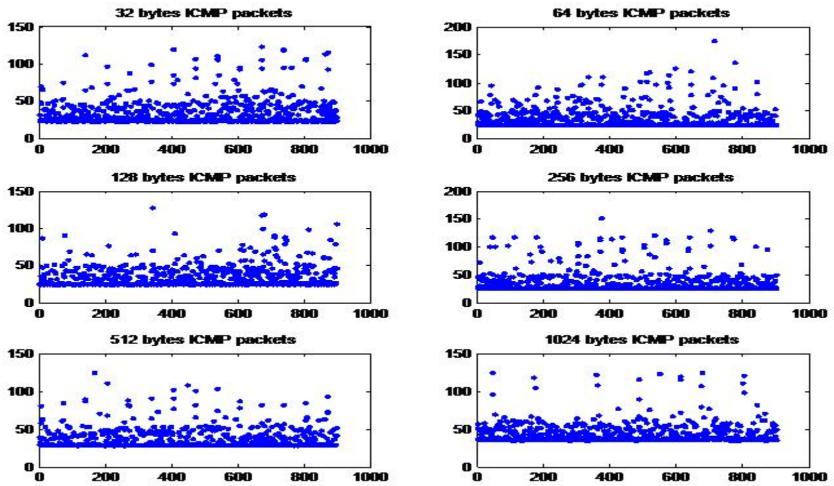

Figure 8. Network latency for ADSL2+ service for different ICMP packet sizes

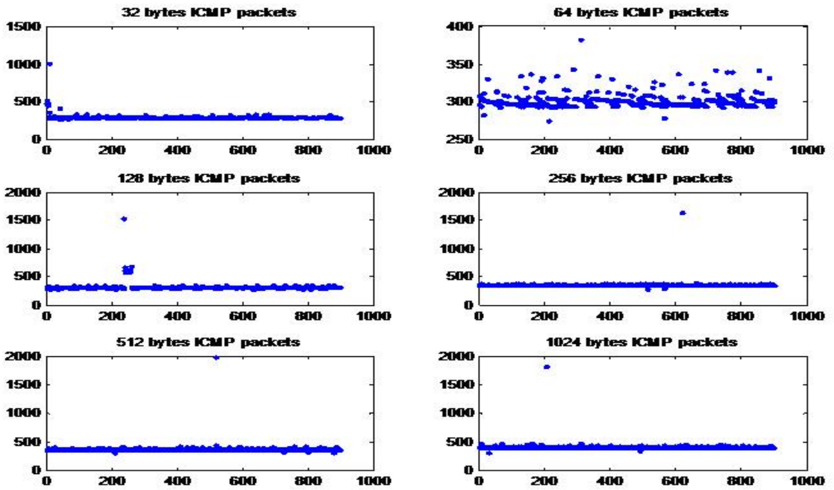

Figure 9. Network latency for Telstra NextG service for different ICMP packet sizes

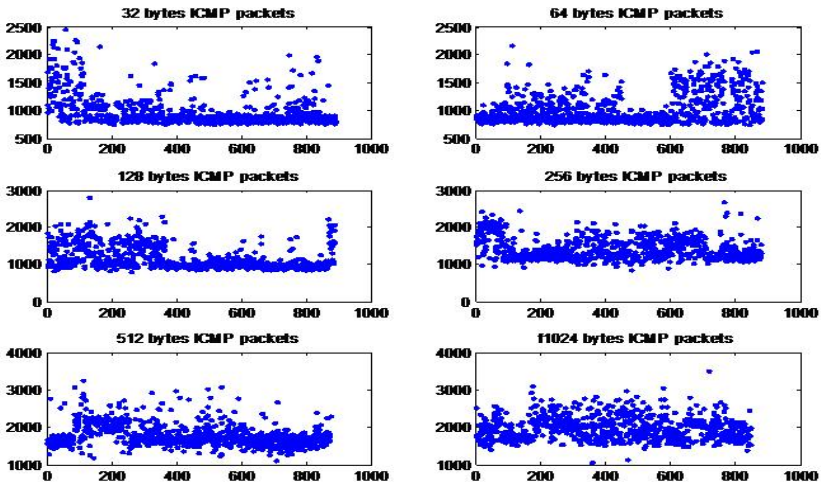

Figure 10. Network latency for satellite service for different ICMP packet sizes

6. COMMUNICATION OPTION FOR PRECISE POSITIONING SERVICES: DISUCSSION AND RECOMMENDATION

Overall, there are three commonly available communication infrastructures in Queensland that are suitable for enabling Network RTK PP services: wired telephone infrastructure with DSL technologies, mobile carrier infrastructure with 3G/HSPA technologies, and geostationary satellites with broadband connection. The characteristics of these three communication infrastructures with respect to three aspects, technical (bandwidth and latency), service (reliability and coverage), and economics (setup and ongoing maintenance cost), are summarized and shown in Table 10.

In general, both the wired and the satellite services require fixed on premise equipment with physical connection to telephone sockets or satellite dishes, whereas the mobile wireless offers mobile solutions such as handheld devices (mobile phones, PDAs) and thus suitable for mobile users. In terms of the bandwidth, all three communication solutions provide more than an adequate level of data throughput, in the order of few Mbps. The latency of all three is generally lower than 1 second, with the lowest being the wired connection in the order of 15ms. However, there is no guarantee for the latency level and variation is largely dependent on network conditions, in particular for satellite solutions. As to the network reliability, field test results show that wired and mobile wireless solutions are much more reliable than the MEDSAT satellite connection with packet loss rates of 0%, 0.5% and less than 5% for wired, mobile wireless and satellite solution respectively. However, it has to be noted that data communication services on the mobile carrier networks are offered on the best-effort basis, thus the result might be degraded during the peak voice traffic period.

		Wired (DSL)	Mobile wireless (3G/HSDPA)	Satellite (Geostationary)
Max Bandwidth	Downlink	8 ~ 24 Mbps	14 Mbps	2 Mbps
	Uplink	1 ~ 2 Mbps	1.92 Mbps	1 Mbps
Latency		30ms	300ms	1000ms
Reliability (packet received rate)		100%	> 99.5%	> 95%
Coverage	% of the population	90 ~ 96%	99%	100%
	% of the area	-	-	100%
Cost	Setup	A$200	A$200	A$2000
	Monthly Ongoing	$50 - $150	$50- $150	$50- $150

Table 10. Characteristics of Commonly Available Communication Infrastructures in Queensland

The coverage of the communication options can be expressed in terms of percentage of population and percentage of the total area. Of the three options, only the satellite provided the full-state wide coverage service (hence 100% of the population), whereas the wired and wireless are available to 90~96% and 99% of the population respectively. Finally, the initial cost (equipments and installation) of the satellite is significantly higher than the other two. However, once the connection has been setup, the ongoing monthly service fee of all three options varies between $50 to $150, depending on the data allowance and the connection speed.

The three major components of the RTK system, reference station, network processing centre, and rover receivers, have different requirements on communication needs. Thus it is necessary to determine the most suitable and feasible communication option for each of them.

6.1 Reference Station

As the reference station provides measurements for correction generation, high availability and reliability of the link from the reference station to the network processing centre is required to ensure that the PP service is not disrupted by a point failure in the communication link. The bandwidth requirements on the link are less significant as a reference station typically sends its observed positioning data once per second, with approximately 2 Kb to 5 Kb of data sent per second of transmission. As to the latency requirements, it is required for the information to arrive at the network processing centre as soon as possible (500ms is specified for the GPSnet network).

As the reference stations are in fixed locations and distributed approximately 70km apart from each other, they are mostly likely to be located in local town centre where wired communication infrastructure is available with DSL technologies. Together with the advantage of having the lowest latency and highest level of reliability, DLS services should be considered as the primary means of communication links for reference station. Additionally, as the reference station is an essential part in providing PP services, it is also recommended to have a redundant communication link to prevent point failure.

6.2 Network Processing Centre

The network processing centre is the most critical component of the RTK PP system as it has to gather measurements from the reference stations and generate corrections for the users. One to several network processing centres may be required depending on the number of the reference stations and the users. Typically, one network processing centre is responsible for a number of reference stations, ranging from 10 to no more than 100. With the RTCM format at 2 Kbps (version 3.x) and 4.5 Kbps (version 2.3), the total incoming (downlink) bandwidth required by the network processing centre may be as high as 200 ~ 450 Kbps. Additionally, the network processing centre has to generate and deliver correction messages to users in RTCM format. Thus, with a typical estimate of 10 to 100 concurrent users, the outgoing (uplink) bandwidth required by the network processing centre is in the order of 200 ~ 450 kbps. Furthermore, in choosing the communication link for network processing centres, the reliability of the link must be of the highest standard. Any disrupts or failures in the link will have impacts on the overall precise positioning services. Low latency in the communication is also necessary for the network processing centre to ensure the correction message can be delivered to the rover receiver with no more than 1 second delay.

Communication requirements for the network processing centre can be satisfied with the wired infrastructures, such as DSL or FTTN, that are very likely to be available in metropolitan areas where processing centres will be located. Additionally, for risk mitigation of the communication link, dual/triple redundant links utilizing wired, wireless, or satellite should be used. Finally, careful network design and planning is required to enhance the communication link reliability and hence the service reliability.

6.3 User Rover Receiver

The rover receivers require a two way communication link to the network processing centre such that they can send the approximate position to the network processing centre which returns a correction message (2 kbps to 5 kbps). The nature of this link is significantly different from the link between the reference stations and the network processing centre in that the roving receiver is typically not in a fixed location. Thus, it requires a highly mobile communication service with high availability and service coverage.

Currently, only the mobile wireless service is capable of offering mobile communication connection for the user rover receiver. In order to address the PP services delivery issue when mobile wireless service is not available, hybrid communication devices using a mix of wired and wireless local area network are proposed. The hybrid communication solution has been implemented in Victoria with GPSnet using VSAT connection and radio to rebroadcast the solution. This approach can be further extended using other wireless technologies, such as Wi-Fi for local service coverage of up to a few hundred metres, or WiMax for coverage of up to tens of kilometres.

Unlike the reference station and network processing centre, the requirement for a user rover is dependent on the user markets as shown in Table 1. Each of the applications has their own requirement on accuracy, timeliness, and reliability of the PP services which affects the choice of communication links. A list of user market needs and the suitable communication options are shown in Table 11 below.

		Accuracy	Timeliness	Reliability	Communication Solutions
Agriculture		Low/Moderate	Moderate	Moderate	Mobile wireless / Hybrid combinations
Construction		Moderate/High	Moderate/High	High	Dual redundant Fixed DSL Hybrid + Mobile wireless
Mining		Moderate/High	Moderate	High	Dual redundant Fixed DSL Hybrid + Mobile wireless
Spatial		Moderate/High	Low/Moderate	Low/Moderate	Mobile wireless / Portable Satellite
Others	**Port**	Moderate/High	Moderate	Moderate/High	Dural redundant Fixed DSL Hybrid + Mobile wireless
	Navigation	Low/Moderate	Moderate/High	Moderate	Mobile wireless
	Emergency	Low/Moderate	Low/Moderate	Moderate	Mobile wireless / Portable Satellite

Table 11. User Market Needs and Communication Options

Agriculture is one of the fastest growing markets in utilizing the RTK precise positioning services. In general, the service is used for control traffic farming and auto-steer machine guidance at low moving speeds which require low/moderate accuracy (2cm to 10cm), moderate timeliness (1 Hz), and moderate reliability (99.5%). When the wireless services (based on mobile carrier networks) are available within the operating zone, it is the most appropriate solution for agriculture uses. It offers the mobility as well as the low operating cost that most agriculture users care the most. They hybrid combination using either DSL technology or satellite can be used as an alternative to the wireless connection.

Civil engineering construction is another major user market for the precise positioning services. It requires moderate to very high accuracy (5cm to 1cm) depending on specific tasks, moderate to high timeliness (1Hz to 20Hz), and very high reliability rate (99.9%). With some activities requiring very high vertical accuracy, the latency of the communication link has to kept as low as possible. Also dual redundant communication links have to be in place to prevent point failures and hence achieve the required reliability rate. The most appropriate communication option for engineering construction users has to be dual redundant connections utilizing wireless and Fixed DSL hybrid combination. Although it requires additional network configurations and additional costs, it provides the high reliability level as well as the mobility that no other independent network can otherwise offer.

The timeliness requirement (1Hz to 20Hz) raises two issues when choosing the suitable communication link. First of all, in designing the hybrid combination (wired + wireless), the satellite connection should be avoided, or be the least preferred option. This is due to the fact that the satellite connection has the highest latency of all three options. It is very possible that latency will exceed 1 second from time to time, depending on the network traffic and environmental factors, and thus not meet the minimum requirement of 1Hz (which is 1 second). The second issue is that if the correction packet is required to be updated at 20Hz for some activities (which translates to a maximum of 50ms of latency allowance), there is no existing communication solution that can guarantee the service. One of the solutions is that correction packets delivered at 1Hz updating rate, while interpolation/extrapolation algorithms are in place to provide intermediate position solutions.

The PP service requirements for the mining users are very similar to that of the engineering construction: moderate/high accuracy (5cm to 1cm), moderate timeliness (1Hz), and high reliability (99.9%). Thus, it is recommended to employ dual redundant communication links consisted of wireless and hybrid combination. Again, satellite connection is not recommended as part of the hybrid combination connection due to its higher latency.

In general, spatial users are either stationary or in low kinematic mode which require relatively high accuracy; but low to moderate timeliness and reliability. Considering the main activities performed (e.g., road mapping and cadastral surveying), a mobile wireless communication service is very likely to be available and thus would be considered an appropriate communication choice for such activities. Otherwise, the hybrid combination (based on a portable satellite connection and wireless LAN) can be used in rural areas where mobile wireless services are not available.

Although classified as niche markets, precise positioning services are used in the areas of ports, navigation, and emergency services. For port users, most activities are performed within a defined region (dredging, cargo handling and quantity surveying) requiring moderate to high accuracy, moderate timeliness, and moderate to high reliability level. For such applications, dual redundant communication connections (similar to the construction and mining users) should be utilized for ensuring connectivity and reliability. Loss of communication will have a severe impact on the business operation and thus the risk of such an event should be minimized.

For navigation users, precise positioning is often used in traffic management for vessels, land vehicles, and aircraft. The operating zones for such activities are very wide areas and require low/moderate accuracy, moderate/high timeliness, and moderate reliability. Additionally, communication links must be of high mobility due to the nature of such uses. Currently, the existing mobile wireless networks are the only communication option that meets the requirements of navigation users. However, the coverage is limited and may not be available when required. Improvements to the service coverage or a new communication option may be required to fully fulfil the requirements.

Lastly the emergency users utilize the precise positioning services for activities such as forensic surveys (e.g., traffic accidents) and fire front mapping. The nature of such activities is very similar to spatial users and so the recommended communication link options are similar. The mobile wireless network services should be sufficient to provide the correction packets for emergency users. The hybrid combination utilizing portable satellite connections and wireless LAN can be used as an alternative.

7. CONCLUSION

This paper has outlined the availability of data communication services for supporting the establishment of Precise Positioning Services in regional Queensland. The underlying technologies, network performances, and the cost of each of the services were investigated and presented. Three widely available communication services have been identified as the potential enablers for delivering PP services: wired DSL connection through existing telephone line, mobile wireless through 3G mobile carrier networks, and GEO based satellite connection. Each of these three options has its advantages and disadvantages in terms of network performance (bandwidth, latency, and reliability), mobility and service coverage.

Field tests and results were then presented for three of the identified communication options to determine their performance in a real environment. Results have shown that there is a trade-off between the network performance and mobility and service coverage. While the wired solution offers the best network performance results, it is worse in terms of mobility and service coverage. On the other hand, the satellite service provides 100% coverage, but with worse network performance. The mobile wireless solution offers the best mobility and a good balance between the network performance and service coverage.

Finally, this paper discussed the requirements and potential communication solutions for the reference stations, the network processing centre, as well as rover receivers with respect to different market segments. The study has shown that there is no total solution for the problem. The choice of a communication service will vary depending on the service requirements as well as for different market segment. For areas where no mobile wireless service is required but not available, a hybrid connection with a mix of fixed connection (DSL or satellite) and wireless LAN (e.g., Wifi) can be used with a coverage of up to few kilometres.

It is hoped that this paper has provided a generalized communication needs requirements for establishing PP services in regional areas, as well as provided a guideline for choosing the most suitable communication solutions.

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