

Evaluation of the Existing CORS Network Infrastructure in Singapore to Meet User Demand

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SUMMARY

The Singapore Land Authority (SLA) has implemented the Singapore Satellite Positioning Reference Network (known as SiReNT) infrastructure, in 2006 to support nation-wide differential GPS positioning. SiReNT is one of the major technical components of Singapore's National Spatial Data Infrastructure (NSDI). It allows homogeneous positioning throughout the country and underpins surveying, mapping, GIS data collection and many other positioning activities. The number of users for SiReNT has tripled in 2008 to more than 100. Since its implementation a total of 128,000 hours of GPS data has been provided through the 3 basic services. The Continuously Operating Reference Station (CORS) infrastructure has been in operation for more than 4 years. It takes advantage of the Trimble GPSNet VRS system at the control centre with the Trimble NetRS receivers that only observe GPS satellites. The advancement of GNSS technology has been enormous in the last 5 years with the introduction of new GPS signals and new satellite systems. Hence, evaluation and assessment of the existing SiReNT infrastructure is necessary to ensure that the infrastructure remains relevant, meet user demand and is able to be support all types of positioning users.

This paper examines and reviews the existing SiReNT system, hardware and software, integration, processes and business plan; recommend necessary upgrading and changes to meet current and future needs of positioning users.

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1. INTRODUCTION

Permanent GNSS reference station infrastructures are being increasingly established by many countries all over the world. It is a global trend that these permanent reference stations are developed in a network environment and operated continuously. These GNSS infrastructure is technically known as the Continuously Operating Reference Station (or in short CORS). Traditionally, the CORS is mainly used to support two main categories of applications - the geodetic and the Differential GPS (DGPS) applications. Nevertheless, the infrastructure is now routinely used to support an increasing number of diverse applications.

The Singapore Land Authority (SLA) implemented the Singapore national permanent GPS reference station network infrastructure in September 2006. The infrastructure known as the Singapore Satellite Positioning Reference Network (or SiReNT in short), is a nation-wide DGPS infrastructure developed to support various DGPS positioning businesses and industries. The primary objective of SiReNT is to support the coordinated cadastral survey system in Singapore. Fundamentally, SiReNT system ensures a homogeneous geographical reference frame for all kinds of land surveying, mapping and positioning activities in Singapore.

Beside surveying and mapping applications, SiReNT is developed as an infrastructure with the fundamental design for the integration with applications that take advantage of DGPS technology. Applications such as vehicle tracking, navigation, deformation monitoring etc. can be developed to leverage on the SiReNT infrastructure.

Currently SiReNT consists of 6 GPS reference stations connected to a Data Control Centre (DCC) which is located at the Singapore Government Data Centre. This is to ensure that we can achieve high system availability and high data integrity. SiReNT adopts leading-edge technology of Network-DGPS both for Real-Time Kinematic (RTK) and Code-based DGPS (CDGPS) techniques. It supports the Network-RTK technique known as the Virtual Reference Station (VRS™) technique.

SiReNT utilised the Trimble GPSNet™ software at the DCC to control and manage the GPS reference stations within the infrastructure network and to generate DGPS corrections. In VRS mode, GPSNet software provides all GPS data interpolated to match the position of the rover, which may be at any location within the reference station network. Matching the rover's position provides a very short baseline, which reduces systematic errors for RTK considerably. See (Vollath, 2000) for information about VRS. Figure 1 show the SiReNT network consists of 6 permanent GPS reference stations.

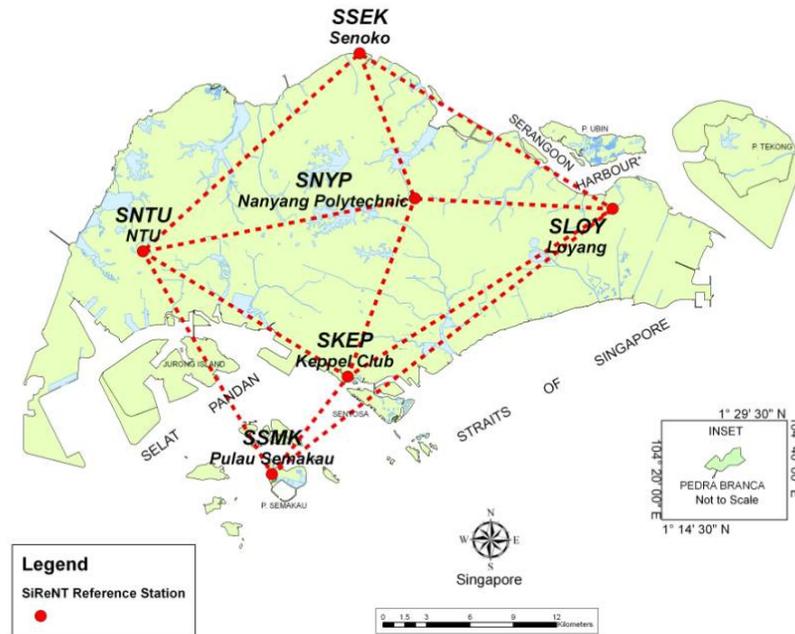


Figure 1: The Singapore Satellite Positioning Reference Network, SiReNT

A few improvements were carried out in the last 4 years since the implementation of SiReNT system. An additional reference station was established in collaboration with the Tropical Marine Science Institute (TMSI) of National University of Singapore (NUS). The station is owned by TMSI and is sharing its data with SiReNT. An integrity monitoring system was also added to the System. Real-time alarm is configured to alert operator of any irregularity within the system. Periodic reports are generated for the integrity monitoring of the network infrastructure.

Today, we have in place a national infrastructure which is operational and meets the basic needs of positioning users. The system is easily accessible by both public and private entities. An effective business plan is adopted to ensure that the signing up process is simple and straight forward. The availability of the system is on average 99.95% computed on a monthly basis.

However, the advancement of technologies (both in GNSS and IT) and the increase demand from diverse applications of DGPS has driven us to examine and review the current system. We also want the infrastructure to stay relevant and be able to meet the current and future demands of geospatial users in government, industry and the community.

This paper examines and reviews the existing SiReNT CORS system implemented in 2006 based on 3 main areas, the technology, the system and the policy governing the system. This review will consider the impact and use of technology; the capacity and effectiveness of the existing system; and the relevance of existing business model and policy to meet the current

and future needs of users. Ultimately, objective of this strategic review will provide us with a basis to decide on the required enhancement to the system and the vision to move forward.

2. APPLICATIONS AND USAGE OF SiReNT

The key objective in the establishment of SiReNT system was to support the Singapore national coordinated cadastre system. SiReNT infrastructure is key component in the new SVY21 cadastral survey system, implemented in August 2004. Under the new survey system, surveyors use the SiReNT reference station data for the establishment of the Integrated Survey Network (ISN) control marks. The ISN control points are used as the survey control in all cadastral survey carried out under the SVY21 system.

In geodetic perspective, SiReNT serves as the national geodetic reference frame (national datum) for surveying and positioning activities. It is regarded as the “Zero” order geodetic control of Singapore which is the reference frame for all mapping, positioning and surveying applications. SiReNT has been widely used in surveying and mapping activities in Singapore and is essential in supporting the NSDI in Singapore.

The need for accurate positioning is not limited to surveying and mapping. Today, a variety of industries are finding a need for accurate positioning i.e.

- Telematics – navigation, tracking, road-pricing etc.;
- Monitoring – deformation monitoring and atmospheric monitoring;
- Satellite remote sensing;
- Geospatial data acquisition to support SDI; and
- Geodetic applications – tectonic plate movement etc.

SiReNT is currently supporting users in the following area of applications:

1. Geodetic and Geodynamics;
2. Surveying and Mapping;
3. Vehicle Tracking and Navigation; and
4. Research.

However, with the SiReNT infrastructure already in place providing agencies with actual scale test bed which has a national coverage and proof-of-concept scheme to facilitate applications development, many agencies have started to adopt Differential GPS positioning in their daily operations as well as building new services utilising the DGPS technology. These agencies have benefited from the SiReNT infrastructure as they are able to prototype their applications before full implementation. Some examples of potential and impending applications suggested by public agencies in Singapore are:

- Satellite-based Electronic Road Pricing (ERP)
- Emergency Response
- National Parks Mapping
- Utilities Asset and Inventory Management

- Container Port Management
- GNSS Aircraft Landing System
- Coastline protection and coastal subsidence monitoring
- Road Inventory Management and Mapping
- Automated Parking Enforcement
- Environmental Mapping

Currently, the SiReNT system is capable of supporting up to 2000 concurrent users, taking into consideration of the capacity of bandwidth and server used in the system. In anticipation of the various impending applications, we need to assess if the current system and infrastructure is in fact able to support these applications. Several factors need to be considered: the number of concurrent users supported, the GNSS system supported, the bandwidth, the data dissemination approach, the correction latency, etc.

The usage of SiReNT has increase over the years. Figure 2 shows the number of transactions for real-time data which include both code-based DGPS and RTK products. In total, 56400 real-time transactions were recorded since October 2006. We have seen the increase of 370% for the full year of 2010 as compared to 2008. In 2009, SiReNT recorded a higher than normal transactions of about 20000. This is due to a mapping project carried out by one customer. The number of transaction recorded for the first 2 months of this year already surplus the total transactions of 2008. We will see a record high of real-time usage this year as a few new telematics users have started to use the system. Each login connection to the system is recorded as a transaction. This is a good measure of the usage of the system.

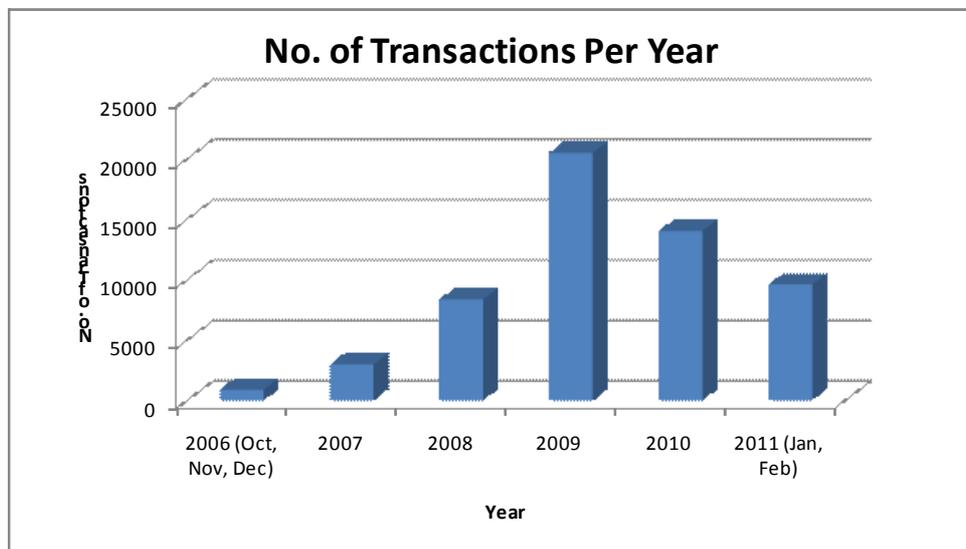


Figure 2: No. of Real-time Transactions of SiReNT

Figure 3 shows the total usage of SiReNT data (in hour) and the number of users over the last

5 years. A total of 128,000 hour of GPS data has been consumed since the implementation of the system. The usage has been increasing overall over the last five years in conjunction with a general increase in the number of users. With initiatives in new customer segments upcoming, it is projected that the next 5 years will see a continued increase in both these statistics.

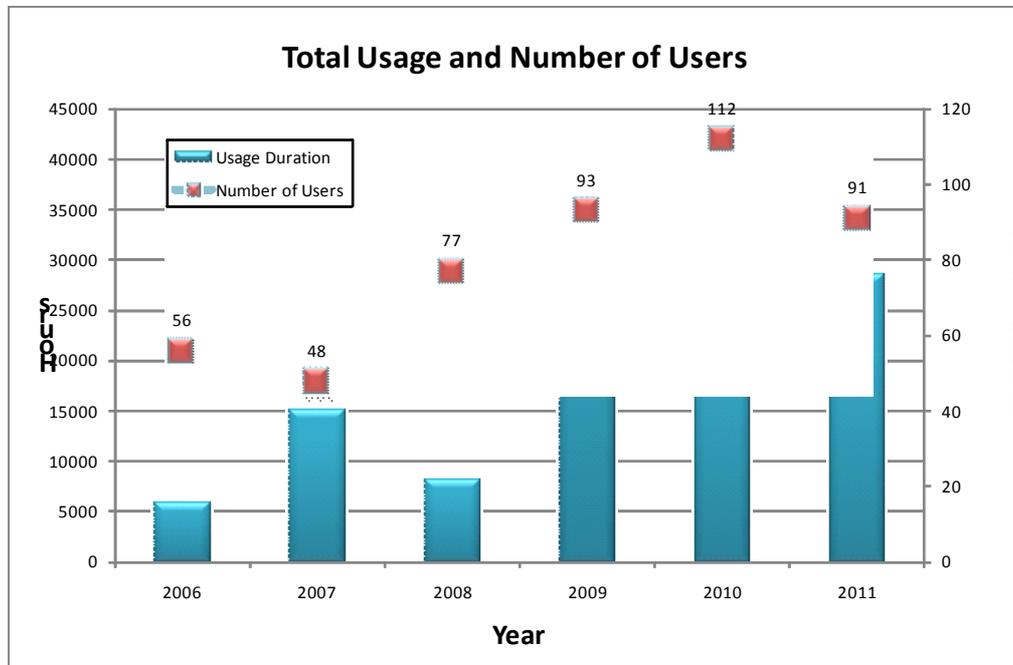


Figure 3: Total usage and the number of users of SiReNT from 2006 to 2011

Figure 4 below shows the number of monthly transactions based on different RTK mount points of the NTRIP (Networked Transport of RTCM via Internet Protocol) server. SIRENT-RTK which is the mount point streaming Network RTK correction recorded the highest transaction over the years. The statistic shows that the usage of Network-RTK is higher than the single-based RTK. This information enables us to understand the users' preference.

We are expecting exponential increase of users in the next 5 years. Transaction is expected to grow in tandem with the growth in the number of new users as potential customers in various segments are beginning to realise the need for high accuracy GPS positioning and tracking to enhance their workflow or to achieve their objectives. From analysing the current system and its operation, it helps us to strategically plan for enhancement of the system to meet users needs.

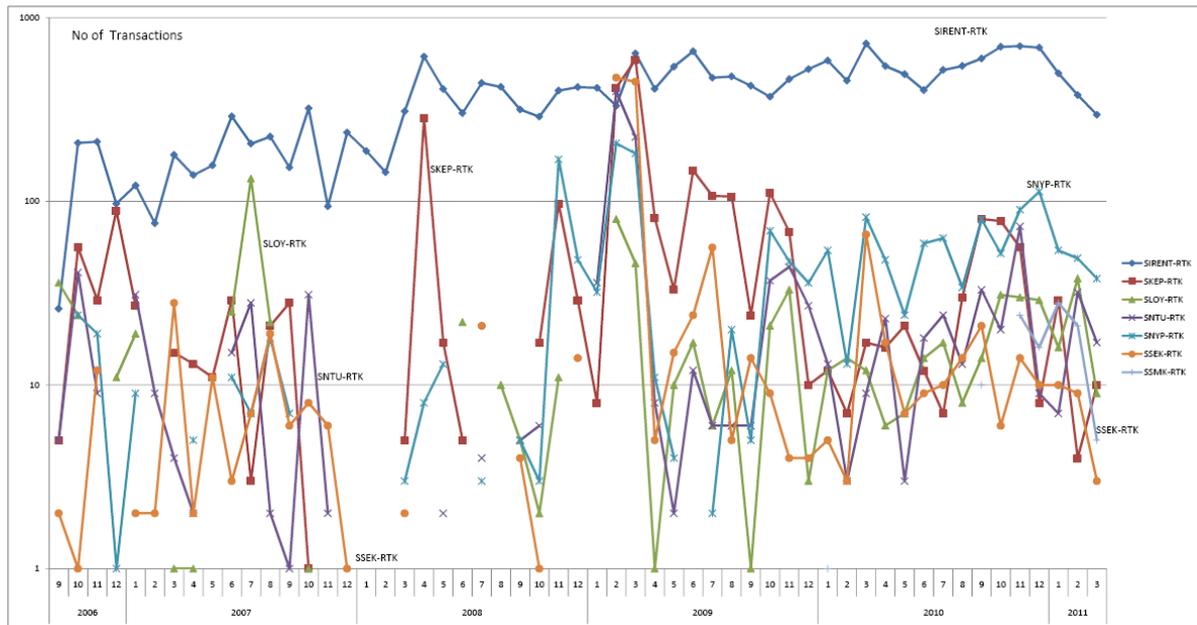


Figure 4: Number of monthly transaction based on the different RTK mount points available via NTRIP

3. REVIEW OF THE SYSTEM

Since the establishment of SiReNT system, SLA has been pro-active in assessing areas in which we can improve on to keep the infrastructure relevant and up-to-date. Communication with stakeholders and consultation with industry experts and academics enable us to formulate effective and efficient system management processes. However, with this being the 5th year of SiReNT’s operation, there is a need to embark on a complete and comprehensive SiReNT system assessment. The evaluation and assessment of SiReNT is carried out base on the following 3 major areas:

1. Technology
2. System
3. Policy and Business

3.1 Technology

Currently, 5 of the 6 CORS in SiReNT support only NAVSTAR GPS. The 6th station which was incorporated into SiReNT later supports both GPS and GLONASS. The advancement of GNSS technology has been enormous in the last 5 years with the introduction of new GPS signals, increase in the GLONASS satellites and new satellite systems such as Galileo. There are currently 27 GLONASS satellites in orbit with 23 in operation status. The additional visibility of GLONASS satellites is especially important to overcome tough urban canyon and garden city environment in Singapore. It is also important to understand the global and local

GNSS receiver market trend as well as the users' choice of equipment. Most of the survey grade GNSS receivers available today are already GPS+GLONASS. Hence, it would be prudent to consider upgrading all the SiReNT CORS to support both GPS and GLONASS.

The addition of GLONASS capability can significantly improve (about 10 percent improvements observed) the number of position solutions with redundancy available in the urban canyon. With increasing GLONASS satellite availability, the benefits of using GLONASS will even be greater. Figure 5 below shows the increase visibility of satellites if GLONASS is tracked. The cut-off angle is set at 20 degree to simulate the urban environment.

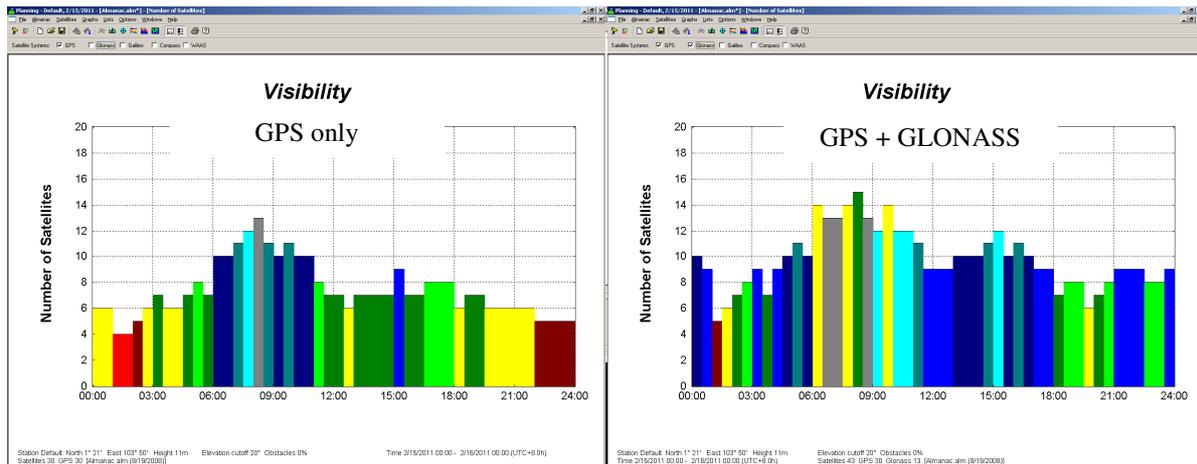


Figure 5: GPS only compared to GPS+GLONASS visibility for 20 degree cut-off angle in Singapore

Besides the GNSS technology, there is a need to review the communication link between the reference station and the control centre. The main consideration is to choose a communication link that presents very little or no downtime and yet able to provide the bandwidth for the streaming of SiReNT data. A potential increase in the SiReNT data streams will be taken into consideration. In addition, redundancy in the communication link will be considered with the possibility of using two different types of communication links for the entire infrastructure.

3.2 System

SiReNT is a real-time system that operates continuously 24 by 7 automatically with minimum human interventions. The system heavily involved the usage of GNSS Technology, Information Technology and Communication Technology. Besides that the system also depends on good management and maintenance procedures to ensure high availability and reliability. The 4 major components of SiReNT CORS system are:

- GNSS hardware and equipment;
- GNSS software and database;
- Reference station infrastructure; and

- Communication system.

Figure 6 shows the system configuration at the SiReNT Control Centre. The review will focus on the need to improve on system availability, system redundancy and integrity monitoring.

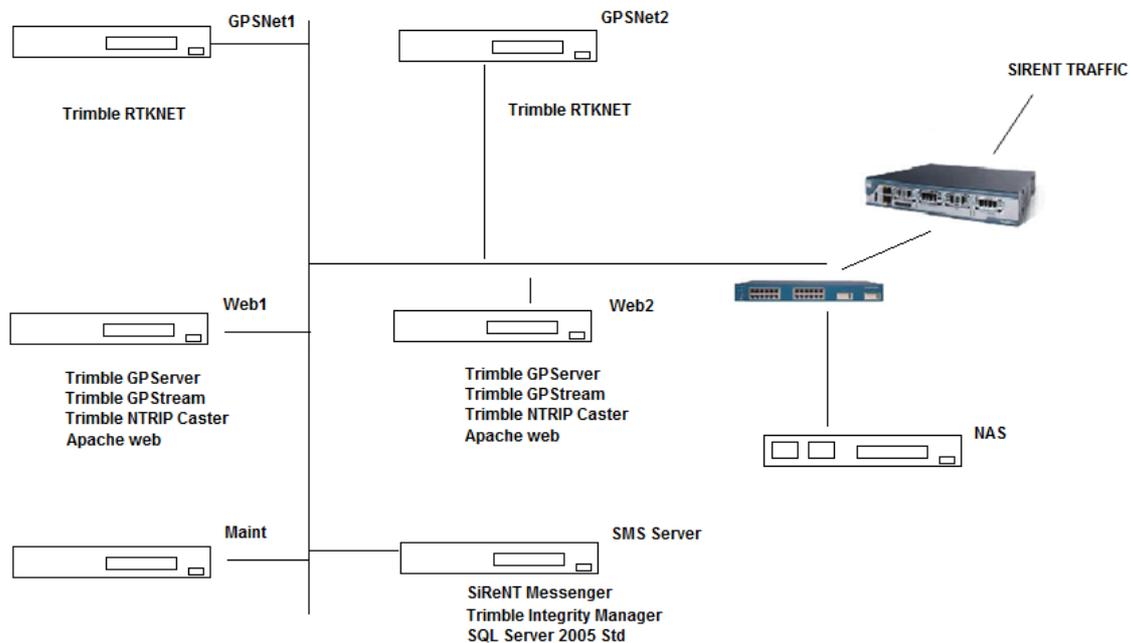


Figure 6: SiReNT control centre configuration

Currently, the integrity monitoring is carried out based on the analysis of the GPS data from the 6 reference station. In order to improve the integrity monitoring, we need to consider setting up independent remote monitoring station. A remote monitoring system can be implemented to assist in the monitoring of SiReNT and provide relevant information to users on availability, reliability and system accuracy.

By plotting the approximate location recorded by the Network RTK or Network DGPS users, we are able to see the growth and the concentration of SiReNT users. Figure 7 shows the concentration of SiReNT Network RTK users over 4 years from 2007 to 2010. We can see that there was a steady growth of SiReNT usage year-on-year and the users have expanded from main land to the outer islands. This analysis will help in the determination of new CORS sites location.

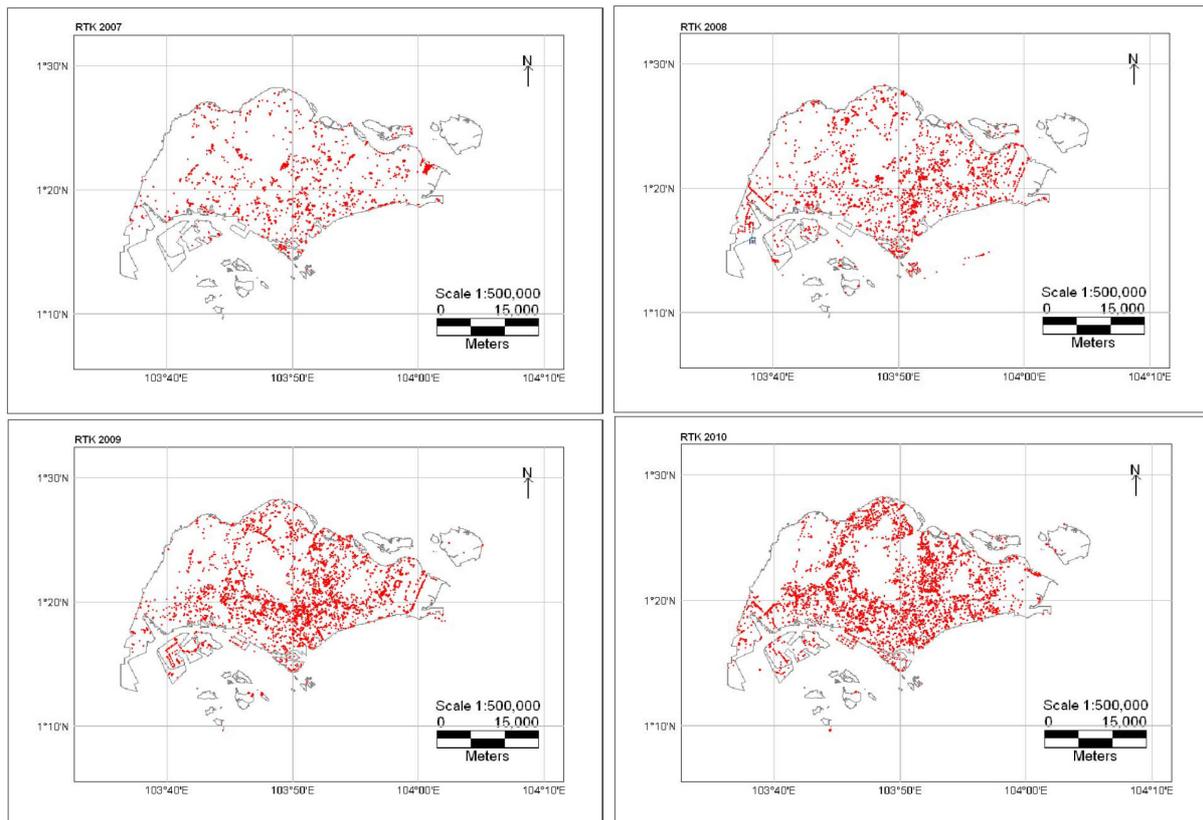


Figure 7: Concentration of SiReNT Network RTK users from 2007 to 2010

The system evaluation and assessment should further break down to include the following components and areas:

1. Hardware
2. Software
3. CORS site location (including tendency agreements)
4. Data Flow
5. Network Connectivity
6. Power Management
7. Housing of the Equipment (Protection)
8. System Performance which is a factor of System Redundancy and Availability
9. System Integrity and Reliability
10. Periodic Maintenance Plan

3.3 Business and Policy

SiReNT provides basic standard services primarily to cater for the general applications in surveying and mapping. It offers the following 3 standard services:

- Post-processing (PP) service;
- Real-time Kinematic (RTK) service (include both conventional single-base RTK and Network RTK services); and
- Real-time Code Differential GPS (DGPS) service (include both conventional single-base DGPS and Network DGPS services).

The real-time services of SiReNT are provided via NTRIP mount-points and the post-process services are provided through SiReNT website where RINEX files can be generated on demand. A subscriber can subscribe to any of the 3 services or all of them depending on their needs. Each subscriber will have to register an account with SiReNT and the charging is on monthly basis. The fundamental charging principle of SiReNT is based on the amount of data used and is computed based on the time period. However, the real-time code DGPS service is provided based on annual fee with unlimited usage. The SiReNT website and the online services provided have been very reliable, consistent and simple to use. The user interface was designed to cater for is particularly was

SiReNT is designed to be able to support diverse applications in Singapore. In order to promote the usage of high accuracy DGPS applications in sectors outside surveying and mapping, the SiReNT Proof-of-Concept (POC) scheme was introduced. The scheme allows and supports developers in the development of DGPS system in telematics, tracking and monitoring applications. SiReNT focus on enabling public agencies in Singapore with the capability of Differential GPS. The SiReNT team collaborates with GPS equipment vendors and distributors to ensure that equipment available in the market are compatible with SiReNT. The vendors are encouraged to carry out equipment test using SiReNT DGPS and provide documentations for their successful connection to SiReNT. The SiReNT team proactively engage in stakeholders:

- Government agencies, private sectors & end users;
- System integrators;
- Equipments vendors & manufacturers; and
- Research / Universities.

Going forward, in order to stay relevant and to be able to support wider applications, reviews are needed in:

- Business model;
- Type of Services;
- Promotion Scheme; and
- Terms and conditions.

4. CONCLUDING REMARKS

SiReNT played an important role in the building of National Spatial Data Infrastructure (NSDI) and provided the most needed satellite positioning services in Singapore for the past 5 years. The next decade will see many changes in the GNSS technology. These changes are critical and required in the improvement of CORS infrastructure. It is expected that many new users will demand for high satellite availability, high system reliability and availability and flexible data dissemination technique.

The L2C and L5 signals that are part of GPS modernization will provide users with opportunities for more robust satellite tracking. The additional signals also demonstrate a commitment by the US Department of Defense to support the many civilian GPS users worldwide. The Russian GLONASS system has a renewed commitment by the Russian government; with additional satellites provide beneficial augmentation to GPS in difficult environments.

Hence, GNSS CORS like SiReNT needs to constantly evolve and keep up with the development of GNSS and relevant technologies in the industry in order to function effectively and efficiently as a positioning, tracking and monitoring infrastructure. SiReNT needs to be administered under the best policy and a robust business plan to be put in place to meet the needs of users with great demand for positioning, tracking and monitoring accuracy.

We hope that with a comprehensive review and evaluation of the current system, we will be able to put up a strategic plan to improve the national CORS network and build a robust system to meet users' need in the next 5 to 10 years. The enhanced system should meet user expectations, should be flexible to accommodate continuous improvements in positioning accuracy as well as provide easy and reliable access to all applications require to take advantage of DGPS.

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BIOGRAPHICAL NOTES

Victor Khoo is a Senior Principal Surveyor with the Land Survey Division of Singapore Land Authority (SLA). He received his Ph.D. and Master of Engineering from the Nanyang Technological University (NTU), Singapore and his Bachelor degree in Land Surveying from the University Technology of Malaysia (UTM). Victor is a Registered Surveyor; a professional surveyor registered under the purview of Singapore's Land Surveyors Act. He works in diverse geospatial related subjects that encompass the collection, management and dissemination of geospatial data. His specific areas of interest include Differential GPS, Cadastral Surveying and Spatial Data Infrastructure.

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