STUDY ON GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS) GROUND INFRASTRUCTURES IN MALAYSIA

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Abstract: There are currently two Global Navigation Satellite System (GNSS) core systems namely Global Positioning System (GPS) and GLObal NAvigation Satellite System (GLONASS). The GALILEO is expected to be up by 2008. The dependency on these space-based technology for navigation, positioning and timing is on the increase globally, and it is expected to be 'the' vital system worldwide in future. The present service of GPS has encouraged the acceptance and integration of the technology into peaceful civil, commercial, and scientific applications worldwide. Presently, users in most developing countries are accessing to the system on their own through services provided by the core system service provider, or augmentation systems provided by commercial companies. Issues such as integrity, accuracy, availability, and continuity are not adequately addressed. Lacking of these requirements may lead to occurrence of catastrophes such as ship collisions, landing failures, and etc. To ensure GNSS services to be more reliable and efficient, many developed nations such even the United States of America (USA), Europe and Japan are working on in establishing appropriate augmentation infrastructures for their local users. This paper reviews the current GNSS infrastructures that are available in marine, land and aviation sectors locally with global development in mind.

1.0 INTRODUCTION

Global Navigation Satellite System (GNSS) is the generic name for the global satellite-based navigation systems and their augmentations. In other words, the United States' Global Positioning System (GPS), the Russian's GLObal NAvigation Satellite System (GLONASS), the future European's GALILEO and the use of certain augmentations are all 'GNSS'.

The first generation of GNSS**,** known as GNSS-1, as defined by the International Civil Aviation Organization (ICAO)/GNSS Panel, include the basic GPS and GLONASS constellations and any system augmentation needed to achieve the level of performance suitable for civil aviation application. The development of several Satellite-based Augmentation Systems (SBAS) such as the Wide Area Augmentation System (WAAS) of the USA, the European Geostationary Navigation Overlay System (EGNOS), and the Japanese Multi-transport Satellite Based Augmentation System (MSAS), and others are parts of the development of GNSS-1.Meanwhile, the second generation of GNSS is called GNSS-2. It is independent of GPS or GLONASS but interoperable with the two systems. From the European context, the future Galileo can be considered as GNSS-2 (Verman, 2002, Vermeij, et al, 1999).

The reliance on the GNSS especially GPS at the moment for navigation, positioning and timing is already vital. In the future, it is enhanced by the improvement of GLONASS service and the operation of Galileo. Doubtfully, civilian users in developing countries including in Malaysia are accessing to the systems independently with their own risks due to unavailable of rules and guidance regarding the services prepared by the authoritative bodies in the concerned country (Subari and Kadir, 2001). GNSS signal subjects to several natural and man-made phenomenon such as atmospheric effects, interferences , blockage, malicious threats and deliberate disruption.(Abousalem, et al, 2000). Indeed, the users must have understood that the GNSS core service alone can lead to safety, economic, and environmental risk due to signal disruption. It is important therefore the transportation planners, the operators and the GPS users themselves should prepare the possibility of GNSS signal disruption (Carroll J.V, 2003; Mosley, 2001).

Performance of a GNSS can be measured based on four parameters, namely accuracy, integrity, continuity, and availability. A*ccuracy* is a measure of how close the navigation solution provided by the system is to the user's true location and velocity. *Integrity* is the ability of a system to provide timely warnings to users when the system should not be used for navigation. Specifically, a navigation system is required to deliver a warning (i.e. an alarm) of any malfunction (as a result of a set alarm limit being exceeded) to users within a given period of time (i.e. time to alarm) and with a given probability (integrity risk).

Meanwhile, *Continuity* is the ability of the total system to perform its function without interruption during an intended period of operation (POP). The risk is the measure of system reliability. Furthermore, *Availabilty* is the percentage of time during which the service is available for use taking account all the outages whatever their origins. Normally, the service is available if accuracy, integrity and continuity requirements are satisfied.(Ochieng, 2002, FRP, 1999).

This paper reviews the current GNSS infrastructures that are available in land, marine and aviation sectors locally with the global development in mind

2.0 GNSS CORE SERVICES: A Review

The GNSS core services comprised of the United States' Global Positioning System (GPS), the Russian's GLObal NAvigation Satellite System (GLONASS), and the coming European Union's GALILEO.

2.1 GLOBAL POSITIONING SYSTEM (GPS)

Technical description of GPS can be referred in several literatures such as Hofmann-Wellenhof, et al (2001), Misra and Enge (2001). Basically, GPS offers two kind of services: **Precise Positioning Service (PPS) and Standard Positioning Services (SPS)**. The PPS is only limited to the United States (U.S.) forces, U.S.'s allied military, certain

U.S. government agencies, and to selected civil users by the U.S. government. The PPS signal can only be accessed through special type of receivers that are equipped with cryptographic facilities. Table 1 summarizes the PPS predictable accuracy. It appears that the PPS service provide both horizontal and vertical accuracies are below than 30 meters, i.e. approximately one second of arc, and timing accuracy is about 200 nano-second. These level of accuracies will be sufficient for most navigation applications.

Table 1: The PPS Predictable Accuracy

Parameter	Accuracy
Horizontal	**22 meter**
Vertical	**27.7meter**
Time (UTC)	**200-nanosecond**

(Source: Misra and Enge, 1999; Misra, 1999)

Unlike PPS, **Standard Positioning Service (SPS)** can be accessed by all civil users worldwide without charge or restrictions using receivers that are obtainable in the open market. The United States Department of Defence (USDoD) has initially degraded the SPS accuracy by the use of Selective Availability (SA). Responding to the request of U.S GPS civil users, the U.S. Government then terminated the SA on May 2nd., 2000. Without SA, the remaining major errors in single point positioning are the atmospheric effects (i.e. ionosphere and troposphere), receiver multipath, and external interferences. The SPS Predictable Accuracy of a single point measurement is approximately as in Table 2:

Table 2: The SPS Predictable Accuracy

Parameter	Accuracy with SA	Accuracy (without SA)
Horizontal	**100 meter**	**36 meter**
Vertical	**156 meter**	**77 meter**
Time (UTC)	**340 nanosecond**	**Not Available**

(source: Misra and Enge, 1999)

It appears that with the termination of SA, both horizontal and vertical accuracies have been improved approximately 30% and 50% respectively.The improvement of timing accuracy is not available, but it is expected likely to be better. Under modernization program, a new civil code (C/A- code) on the L2 frequency will be introduced (Block IIR satellites). The availability of two civil codes (i.e. C/A code on both L1 and L2 frequencies) allows users with a stand alone GPS receiver to correct for the effect of the ionosphere. A third civil signal, L5 (1176.45 MHz) will be available in 2005 (Block IIF satellites). This third frequency is robust and has high power level, wide broadcast bandwidth (a minimum of 20 MHz) and higher chipping rate (10.23 MHz). This signal characteristic will improve accuracy of positioning especially under noisy and multipath conditions. It is expected to improve the accuracy of autonomous GPS positioning and also Real Time Kinematic (RTK) positioning where integer ambiguity can be solved instantaneously. The modernization process will also include the study of next generation Block III satellites, which will carry GPS into the year 2030. (Karner and Caswell, 2001),

2.2 GLObal NAvigation Satellite System (GLONASS)

The GLONASS standard service is provided to civil users with limited constellations. The GLONASS standard accuracy performance (95%) as in Table 3:

Table 3: The GLONASS standard accuracy performance

Parameter	Accuracy (95%)
Horizontal	**20 meter**
Vertical	**30 meter**
Time (UTC)	**0.7 microsecond**

(Source: Polyschuk and Kulik, 2001)

Comparing with the GPS accuracy, the GLONAS positioning accuracies appear to be better. The problem with the GLONASS is the limitation of services. However, a GLONASS modernization program that was approved by the Russian Government in August, 2001 will hopefully benefit civil users worldwide. The modernisation phase includes the deployment of GLONASS-M satellites with extended lifetime to 7 years (total 11 satellites) from 2003 to 2006.

The **first** civil signal at L1 will be moved to the international conventional frequency band (1593 – 1610.5 MHz) and the **second** civil signal will be implemented at L2 frequency band (1238 – 1253.5 MHz). New generation of satellites called GLONASS-K which will transmit the **third** civil signal at L3 frequency band (1190.5 – 1212 MHz) will be launched in the year 2006. When in full constellation by 2010, GLONASS will have 24 satellites transmitting two civil signals. There will be 27 GLONASS-K satellites by 2012. and the third civil signal will be available after the year. At that time, it is expected positional accuracies are in the range of 5 to 7 meters at 95% probability level.
(Polyschuk and Kulik, 2001)

2.3 GALILEO

GALILEO is the first civil global stand-alone satellite positioning and navigation system under the control of European public authorities and to be operated by a private entity. The development of GALILEO involves three stages, namely Development and In-orbit Validation (2002-2005), Deployment (2006-2007), and Commercial Operations (from 2008). Combined use of GALILEO and GPS standard positioning service will result in a 95% availability of satellite signals in an urban environment which at present if relying on GPS only gives 55% availability (Onidi, 2002).

3.0 GNSS AUGMENTATION SYSTEMS

GNSS augmentation is the technique used to augment the 'raw' signals from GNSS core satellites. This is to ensure accuracy , availability, continuity and integrity of the navigation system. Presently, GNSS augmentation systems are being developed to be for specified applications, either for marine, land or aviation.

3.1 Augmentation for Aviation Applications

Several augmentation systems are purposely being developed for these applications such as Wide Area Augmentation System (WAAS) in the United States, European Geostationary Navigation Overlay Service (EGNOS) in the Europe, and the MTSAT Satellite-based Augmentation System (MSAS) in Japan. India is also developing its own SBAS the similar purpose. Beside these Satellite-Based Augmentation Systems (SBAS), a Ground-Based Augmentation System (GBAS) or a Local Area Augmentation System (LAAS) is also developed at selected airports in the countries. Furthermore, an Aircraft-Based Augmentation System (ABAS) or also known as a Receiver Autonomous Integrity Monitoring (RAIM) will also be installed in an aircraft, when necessary.

3.1.1 Wide Area Augmentation System (WAAS)

Wide Area Augmentation System (WAAS) is a Satellite-Based Augmentation System (SBAS) currently developed by the United States Federal Aviation Administration (FAA) to provide augmentation service throughout the United States. The users of WAAS receive correction in the Radio Technical of Civil Aviation (**RTCA DO-229)** data format, which provide satellite clock corrections, satellite orbital corrections and ionospheric corrections all in separate components. The WAAS system include a system of 25 ground stations strategically positioned across the country including Alaska, Hawaii, and Puerto Rico to collect GPS satellite data. Using this information, a message is developed to correct any signal errors. These correction messages are then broadcast through two communication satellites, INMARSAT satellites Atlantic Ocean Region-West, AOR-W PRN 122 and Pacific Ocean region, POR PRN 134, to receiver's onboard aircraft using the same frequency as GPS. When in full operation, WAAS will ensure users to rely on GPS for all phases of flight, from en route through approach for all qualified airports within the WAAS coverage area. WAAS achieved its Initial Operational Capability on July 10th , 2003 (Cannon, et al, 2002; WASS, 2003).

3.1.2 European Geostationary Navigation Overlay Service (EGNOS

European Geostationary Navigation Overlay Service (EGNOS) is a Space-Based Augmentation System (SBAS) to provide augmentation services to European airspace. The project started in 1993 by the European Triparte Group (ETG) which comprises of the European Union (EU), European Space Agency (EAS) and European Organisation for safety Air Navigation (EUROCONTROL) Unlike WAAS, EGNOS will complement both GPS and the Russian GLONASS systems, and it improves the accuracy to better than 5 meters. EGNOS will serve not only aviation but also other transport and non-transport applications, and it is interoperable with WAAS and MSASEGNOS space segment comprises of THREE transponders placed onboard of two INMARSAT (Atlantic Ocean Region-East, AOR-E PRN 120 and Indian Ocean Region, IOR) and ONE on ARTEMIS satellite (owned by ESA). The ground segment includes a number of reference stations, known as Ranging Integrity Monitoring stations (RIMS). The RIMS send data to the processing facilities known as Mission Control centre (MCC). The system will eventually deploy a total of 34 RIMS located mainly in Europe and 4 MCCs (Ventura-Traveset, et al, 2001; Vermij, et al, 1999).

3.1.3 MTSAT Satellite-based Augmentation System (MSAS)

MTSAT Satellite-based Augmentation System (MSAS) is developed by Japanese Civil Aviation Bureau (JCAB). MSAS has similar architecture to WAAS, and relies completely on GPS. Operation of MSAS using MTSAT-1R and MTSAT-2 is expected to commence in the year 2006. The performance of MSAS are continuously being tested by the Japanese Civil Aviation and several interested agencies . According to Matsunaga, et al (2002), based on his experiments, the MSAS average accuracies at 95% level are 4.26 meter and 7.46 meter for horizontal and vertical respectively. These figures meet the requirement of Approval with Vertical Guidance –II (APV-II) flight phase which require horizontal and vertical accuracies 16 meters and 8 meters respectively. MSAS is expected to function as a shared infrastructure within the Asia/Pacific region for GNSS use, and will interoperable with WAAS and EGNOS (Kondo, et al, 2000).

Beside the development of MSAS, the Japanese is also developing an augmentation system called **Quasi-Zenith Satellite System (QZSS).** This augmentation will have satellites in elevation angle more than 70 degrees at all times. With this constellation, signals will not be blocked by buildings and mountainous features. So, the QZSS will provide services in the town area where the other system services are not feasible.The gap between EGNOS and MSAS will be filled by The Indian GPS And Geo Augmented Navigation (GAGAN). The GAGAN is being developed by the Indian Space Research Organisation (ISRO) in collaboration with the Airports Authority of India (AAI), and will follow the recommendations of the Asia Pacific Air Navigation Plan for ICAO Regional Group (APANPIRG).(Mathur, 2002)

3.2 Augmentation for Marine and Land Applications

In the United States, **the U.S. Coast Guard** has successfully established a Nation Wide DGPS (NDGPS) to provide services along the coast and coastal area.(Allen, 1997). Similar effort done in Europe where 162 GNSS radio beacons transmitting differential correction signal have been established in the **Europe Maritime Area** (EMA) (Robert, 2001; Last, 2002). In Canada, the Canada-Wide Differential GPS (CDGPS) was launched in 2002 to augment the Canada Coast Guard’s marine beacon DGPS service as well as the U.S. WASS. (Kassam, et al, 2002)

The Maritime and Port Authority of Singapore (MPA**)** has also set up facilities to broadcast differential GPS (DGNSS) signal with effect from 9 Oct 1997. The aim of providing the DGNSS broadcast service is to further enhance navigational safety in the Singapore Strait, its approaches and the port waters as far as 200km from Singapore. The service offers mariners higher positioning accuracy of better than 5 metres.

Beside the government-owned systems, the commercial companies have also been involved in developing the DGPS. For example, the **OMNISTAR** Wide Area Differential GPS (WADGPS) service which utilizes geo-stationary satellites to broadcast the correction signals. The establishment of over 90 reference stations has allowed OmniSTAR coverage in over 90% of the world. System reliability is ensured by built-in redundancy in the system. System integrity is monitored 24 hours a day at the Network Control Centre by experienced, specialist staff.DGNSS correction data is logged and archived on a routine basis providing a capability for post-processing and data analysis. OmniSTAR DGNSS data is available 24 hours a day (Cannon et al, 2002).

4.0 GNSS Infrastructures in Malaysia

Progressively, Malaysia is moving forward to reliance on GNSS technology for navigation, positioning and timing standardization. Generally, the GNSS infrastructures have been developed and managed by the 'guardian department' in the related sectors.

4.1 Infrastructures of GNSS in the aviation sector

Department of Civil Aviation (DCA) is the 'guardian department' for the development of GNSS infrastructure to be used in aviation sector in Malaysia. For the time being, there has no such GNSS ground infrastructure been developed locally. However, in line with the requirement for global consistency in Air Traffic Management (ATM) system implementations, the Department of Civil Aviation , Malaysia has already embarked on study towards the development of appropriate augmentations to be used for approach and landing by aircrafts at Malaysian Airports. It is worth mentioning that GNSS-based navigation is already being used by aircrafts during en-route and terminal area in Malaysian airspace.

The establishment of infrastructure as well as application of the GNSS technology in the aviation sector in Malaysia will be implemented in accordance with transition timescales. The time scale for trials and demonstration of GNSS-based system for en-route and terminal is this year (2004). Meanwhile, the time scale for the implementation and operation of GNSS-based system for en-route and non-precision approach (NPA) will be made during 2002 to 2010. Against, Malaysia will follow the ICAO for any further development regarding the use of GNSS operation and implementation at Malaysian airports (Department of Civil Aviation Malaysia, 2004; ICAO Report, Issue 6).

4.2 Infrastructures of GNSS in the maritime sector

Marine Department of Peninsular Malaysia has already installed a ground-based augmentation known as SIStem PELayaran SATelit (SISPELSAT) to provide a safe navigation for maritime users. This system, which has operated and managed by the

Marine Department of Peninsular Malaysiasince 2003, is actually the first Malaysian Differential GNSS (DGNSS) in Malaysia.

The system consists of a Master Control Station (MCS) located at the Marine Headquarter, Port Klang; two Reference Station and Integrity Monitoring System (RSIM) equipped with a Medium Frequency (MF) radio transmitter at each location, one at Lumut, Perak and the other at Kuantan, Pahang; and a Remote Integrity Monitoring Station (RIMS) located at Langkawi Island. The RSIM with MF transmitter is also referred as a GNSS Radio Beacon station. Hence, SISPELSAT has two GNSS Radio Beacon stations, the Kuantan and the Lumut GNSS radio beacons provide DGNSS (DGPS) services for the east coast and the west coast of Peninsular respectively . They are not connected each other and operating individually (Department of Marine, Malaysia, 2004) .

As claimed by the vendor, the DGNSS can provide horizontal accuracy of better than 5 meters at 95% probability level with availability and reliability of the system are 99.8% and 99.97% respectively. Results of a study conducted in August 2003 to evaluate on the service availability and coverage of the system has shown that generally the system fulfilled the intended 250 km radius of area of service. In terms of signal strength, strength of more than 20 dBμV/m was still recorded beyond the 300 km range.(Subari and Che Awang, 2004). This value meets the minimum criteria of field strength adopted in Europe and International Telecommunication Union (Grant et al, 2003).

4.3 Infrastructures of GNSS in the surveying and mapping sector

Department of Survey and Mapping, Malaysia (DSMM) has played a role very positively regarding the development of GNSS infrastructures for surveying and related applications in Malaysia. According to Taib et al (2004), there are three GNSS infrastructures already available and one is under the developmental stage for use in survey and related sectors. The first is the ***Peninsular Malaysia GPS Scientific Network (PMGN).*** This PMGN was established through a collaborative effort between DSMM and Swedsurvey, Sweden. The PMGN is actually a GPS network consists of 238 ground control points covering the whole Peninsular Malaysia. The establishment of the network took 4 years time started in Dec 89 and ended in 1993.

The second infrastructure is the East Malaysia GPS Scientific Network (EMGN), a GPS network consists of 170 ground control points covering the whole Sabah and Sarawak, has been established in two years time (1995-1996) by the DSMM. Beside the two passive GPS networks, an active GPS network, known as Malaysia Active GPS System (MASS) has also been established for use in surveying and related sectors. The MASS is a network of 18 permanent, well-distributed GPS tracking stations covering Peninsular Malaysia, Sabah and and Sarawak. Basically, the MASS provide GPS observation data which includes coordinates and velocities at the particular MASS station. The data is in Receiver Independent Exchange (RINEX) format, usable in various applications such as surveying, geodesy, geodynamic, engineering and scientific studies. The MASS network only allows the GPS data to be made available to users on the DSMM's website at a delay of more than 24 hours.

The most recent GNSS infrastructure developed by DSMM is ***Peninsular Malaysia Real Time Kinematic Network (PMRTKNet).*** Real-Time Kinematic (RTK) technique is widely used for surveying and other precise positioning applications. The PMRTKNet will provide a real-time correction data to users through a communication system. The system is expected to be operational soon (in 2004)

4.4 Infrastructures of GNSS in the precision time keeping

GNSS especially GPS now become the primary tool for time and frequency distribution and comparisons worldwide. In Malaysia, the National Metrology Laboratory (NML) SIRIM Bhd (NMLS) has been given the responsibility for the distribution of accurate time to users NMLS has planned to embark on a project, called Low Frequency Time Transmission Project in the 9th Malaysian Plan.(Zainal, 2004)

5.0 CONCLUSION

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