System Development For Low Cost Data Acquisition For Mobile Satellite Signal Performance Measurement In Low-Latitude

I Abba, W A W Z Abidin, T Masri, K H Ping, M S Muhammad, B V Pai

Abstract: Mobile Satellite (MS) Signal performance is affected by many factors such as ionospheric effect, multipath fading tree-shadowed and building-shadowed. These cause variations in the received signal quality. Although many studies have been carried out in order to improve the performance of MS signal, there are still many areas lacking data especially from the less-developed and developing countries. Furthermore, costly data acquisition method hinders more study to be carried out in these regions. This paper discusses the cost effective alternative method for MS data acquisition for satellite operating in the L-band by utilizing the GPS satellites data. Details methodology for doing the experimental works will be discussed. The measurements of the signal performance are performed for open space environment in Sarawak. The analysis of the signal performance under different MS environments is performed with respect to the information such as elevation and azimuth angles. The analysis produced forms an important part in the studies of the signal performance. From this research work, we characterized the MS received signal for Sarawak.

Index Terms: GPS, Mobiles Satellite, Sarawak, Hyper-terminal intercept, Cost-effect.

1 Introduction

MOBILE Satellites (MS) in communication system has become a vital part in human daily life as these can be seen from the number of antennas or parabolic dishes which are fixed in many homes for the television broadcast services. Besides, satellite also play an essential part such as navigation and position allocation, terrain observation, weather monitoring, deep-space exploration, remote sensing and others, as stated [1-3]. The ionosphere is a partially ionized region of the earth's upper atmosphere that extends from roughly 60km to 1000km in altitude, as discussed [4]. The ionization modifies the refractive index of the neutral atmosphere and when it becomes structured or turbulent, can cause strong scintillation of radio waves passing through the disturbed region. If sufficiently intense, these fluctuations can dramatically impact the performance of space based communication and navigation systems [5]. Ionosphere consists of D, E and F layers of varying ion density with the increasing of the altitude, as stated in [6]. The schematic representation of the electron density is shown in Figure 1.

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The density of charged particles in the ionosphere changes from day to night as the production of ions requires direct solar radiation. D layer is at the low altitude and E regions are weaken compare to F region [7] as they only present during day and disappear at night where F region is present both day and night. F2 layer has the highest electron densities of the normal atmosphere and electron densities remains higher at night than in the D and E layers. Ionospheric effects include Faraday rotation and ionospheric scintillation as mentioned by Ippolito and others [8-10]. Communication satellites function as a microwave repeater station for the exchanging of information between the users in different forms [11]. However, Global Positioning System (GPS) is best known as a worldwide positioning system and the main purpose is to provide accurate positioning location at all points on the earth's surface at all times [12-13]. It is intended mainly for military defense purposes but the civilian community now constitutes the bulk of users. The GPS signals consist of carrier frequencies such as; L1:1575.42MHz (0.19029m wavelength) C/A-Code (Code acquisition) and L2: 1227.60MHz (0.24421m wavelength) which normally controlled by the Military users with basic signal of higher precision [14-16], Table I gives the summary of the frequency bands [17-18]. The satellites constellation comprises 24 satellites such that at least 4 satellites are visible everywhere on earth at any time. The orbits are essentially circular at an altitude of about 20,200km, with orbital inclinations of 630^{o} and with 12h (sidereal time) duration [19]. The 24 satellites constellation is shown in Figure 2, as stated [20-21]. In order to provide accurate data and cost effective, a simple and low cost data acquisition system experiment can be used to carry out measurement for different mobile satellite signals. The signal performance of the MS is affected by factors such as ionosphere effect [22], tree-shadowed, building-shadowed and multipath, but this paper only focuses on the satellite signals for an open space environment in which the arriving satellite signal does not experience significant fading effect due to trees or building. Handheld receivers are used for positioning and geo-catching [4] using DGPS-service or WASS/EGNOS signals. This position is realized using code pseudo-range [23-26]. By using Garmin handheld receiver the phase and code information may be transformed in real time on a computer and stored in text file. Some experiment works have been carried out in some developed countries such as Europe, North America, Japan and Australia [27-28], but little data represents the less developed countries such as Latin America, Africa and some part of Asia. Therefore experiments works are needed in those less develop countries.

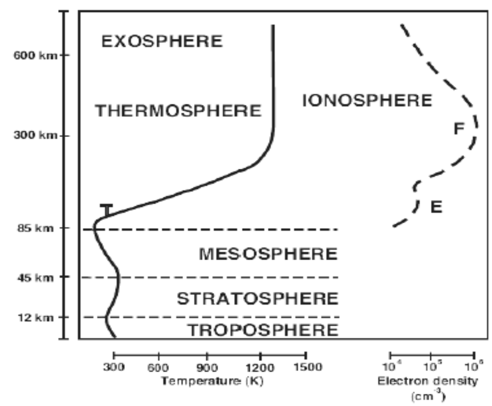

Fig. 1. Ionosphere regions as a function of height above the earth's surface

Finally, a simple and low-cost data acquisition system refers to the experimental setup of the equipments that is the connection formed between the GPS receiver and the computer as discussed [29]. The satellite propagation parameters received from the GPS satellite are recorded. The signal statues command to view the satellites currently tracked by the receiver and the sentences allocated are saved in a .txt' file in series of NMEA sentences. i.e. GPGSV.

*$GPGSV,3,1,12,02,40,083,49,04,15,114,47,05,18,024,45,09,36,173,50*78*
*$GPGSV,3,2,12,12,22,205,47,15,64,355,50,18,09,282,37,26,07,219,42*7F*
*$GPGSV,3,3,12,27,44,157,50,29,42,307,50,30,15,236,42,34,00,000,00*74*

GP refers to the prefix for the GPS receiver. GSV refer to the satellite in view. '3' refers to the number of sentences for full data. '1' means the sentence 1 of 2. '12' refers to the number of satellites in view. '02' is the satellite PRN number. The satellite elevation and azimuth angles are both represented by the number of '40' and '083' respectively. '49' refers to the SNR and *78 is the checksum data and always begin with *. Since the sentence contained four satellites propagation data, thus, the numbers will be repeated continuously for the other satellite in view. Sarawak is one of two Malaysian states on the island of Borneo. Known as Bumi Kenyalang ("Land of the Hornbills"), it is situated on the north-west of the island. It is the largest state in Malaysia; the second largest, Sabah, lies to the northeast as shown in Figure 3 [30]. The administrative capital is Kuching which has a population of 579,900. As of last census (December 31, 2006), the state population was 2,357,500. It is covering an area of 124,449.51 square kilometers, making up some 37.5% of the country's total area of 329,750 sq km.

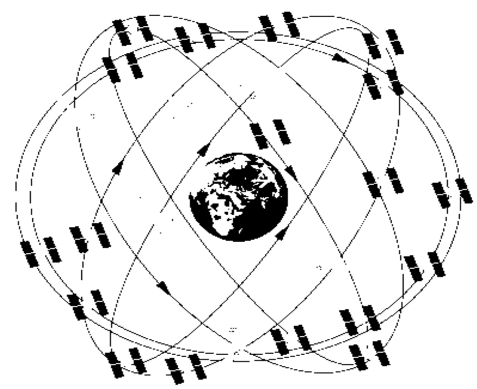

Fig. 2. The 24 Satellites Constellation

Located immediately north of the equator between latitude 2° 0' N and longitude 113° 0' E, Sarawak stretches some 800km along north-west coast of the island of Borneo. Sarawak is separated from Peninsular Malaysia by a distance of 600 km by the South China Sea. On the island of Borneo, it directly adjoins the state of Sabah to the north-east where by the Sultanate of Brunei forms a double enclave. Inland the state borders with Kalimantan, Indonesia [31]. With a tropical climate, Sarawak is warm and sunny throughout the year. Daily temperature ranges from 33ºC in the afternoon to 22ºC during the night. Sarawak's mean annual rainfall is 3283mm.

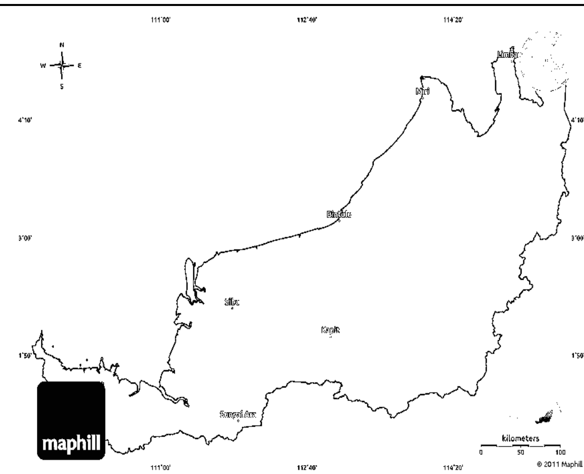

Fig. 3. Geographical map of Sarawak

The signal measurement is carried out under open space condition [32] and the analysis is then performed to determine the relationship between the signal performance with respect to the elevation and azimuth angles. Then graphs of the selected satellites SNR, azimuth and elevation angles are plotted against propagation time in seconds.

2 Data acquisition system

The system design includes developing a simple and low-cost data acquisition system to carry out the measurements for the signal strength under different MS environments. A program used to extract the satellite parameters from the GPS receiver is then developed. A data acquisition system is the communication method between the computer and the GPS

TABLE 1
L-BAND FREQUENCIES RANGE UNITS

Frequency Band	**Centre Frequency (MHz)**	**Applications**
L1	1575.42	Transmit C/A code, military P-codes, NAV message & new L1C on future Block III satellite
L2	1227.60	P-code, NAV message & new L2C code on the Block IIR-M and newer satellite.
L3	1381.05	Used for the signal detection of nuclear detonations and other high-energy infrared event.
L4	1379.913	Used for the study of the ionospheric correction

receiver to receive the propagation information from the satellites. For the Garmin GPS receiver, the standard NMEA data format is used. The GPS receiver is connected to the computer via serial port. Figure 4 shows the experimental setup for the open space [33].

Fig. 4. Experimental setup for open space data acquisition

The GPS signal status command to view the satellites currently tracked by the receiver and the sentences collected by a developed program (known as hyper terminal intercept) which saved the files according to the time and date for later analysis. Figure 5 show hyper terminal intercept flow chart. A continuous series of the NMEA sentences and hyper terminal intercept [34] is shown in Figure 6a and 6b, respectively. From these sentences, information about satellites and their respective propagation parameters can be obtained for analysis. The measurements are performed by measuring the SNR with respect to the satellite elevation angle and satellite azimuth angle at different time under a clear sky condition. The elevation angle is important because it determines the slant path through the earth's atmosphere [35], and will be the parameter in evaluating atmospheric degradation such as rain attenuation, gaseous attenuation, and scintillation on the path. Thus, the lower the elevation angle the more serious the atmospheric degradations will be, because more of the atmosphere will be present to interact with the radio wave on the path to the satellite [36].

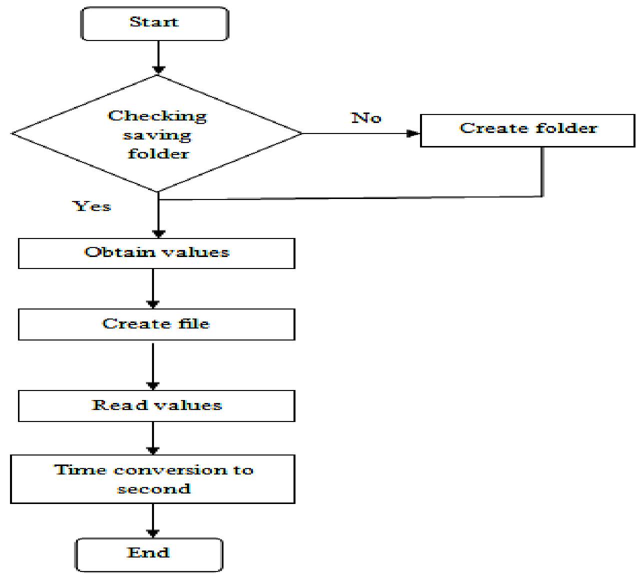

Fig. 5. Hyper-terminal intercepts flow chat

The receiver SNR for the line of sight (LOS) condition is in order of 45dBHz to 50dBHz while the lost of lock threshold is between the 28dBHz and 30dBHz. The 44dBHz was chosen as the reference SNR [37-38]. The experimental setups for the open space MS environments were described. The measurement carried out at the top of the rooftop of the Faculty of Engineering building, Universiti Malaysia Sarawak where the LOS condition can be observed. The receiver has been placed flat facing the sky in order to make it acts as an omni-directional antenna. The receiver has the ability to reject signals arriving from behind and this removes the effect of much multipath signal due the ground. The open space data is collected for the month of September 2010, continuously under clear sky condition (eliminating the attenuation due to rain, ionosphere effect, storms, heavy cloud and strong wind) for 24h hours. If it is raining at certain interval of time, then the data obtained during that interval will not be considered for analysis. The computer system is placed in the laboratory. Figure 7 shows the actual experiment setup at the site at the rooftop of the Faculty of Engineering building in which the receiver was placed facing the open sky. For the open space, the effect of the elevation and the azimuth angles on the received SNR will be analysed for different satellites. This will enable propagation characteristics for different satellites to be determined. A program is developed using Visual C++ programming language [39] (known as NMEA sentences extractor) which was used to extract the satellites azimuth angles, elevation angles and signal to noise ratio (SNR) from the raw data. Once the raw NMEA sentences are found, the program will process the sentences by line and by column. The sentences that have been processed will be output to the excel file. The NMEA extractor flow diagram is shown in Figure

8. The parse program will decode the number of sentences for full data, number of sentence decoded and UTC at the upper part. The satellite PRN, SNR, elevation angle and azimuth angle will be assigned to each corresponding satellite PRN in column at the lower part.

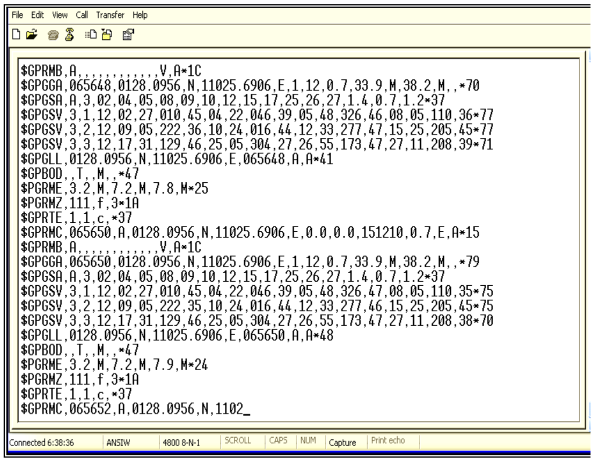

Fig. 6a. NMEA sentences from GPS receiver

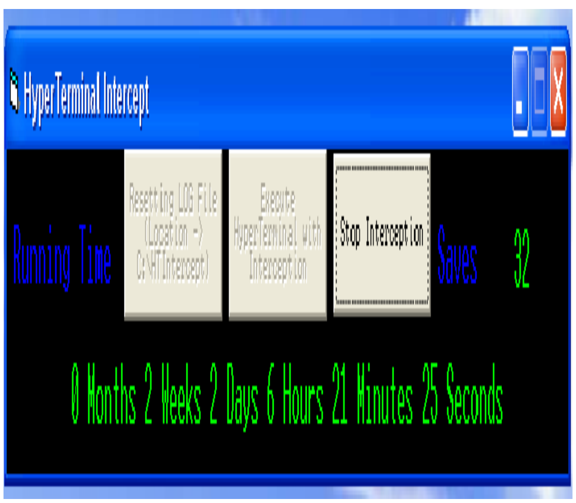

Fig. 6b. Hyper terminal intercept

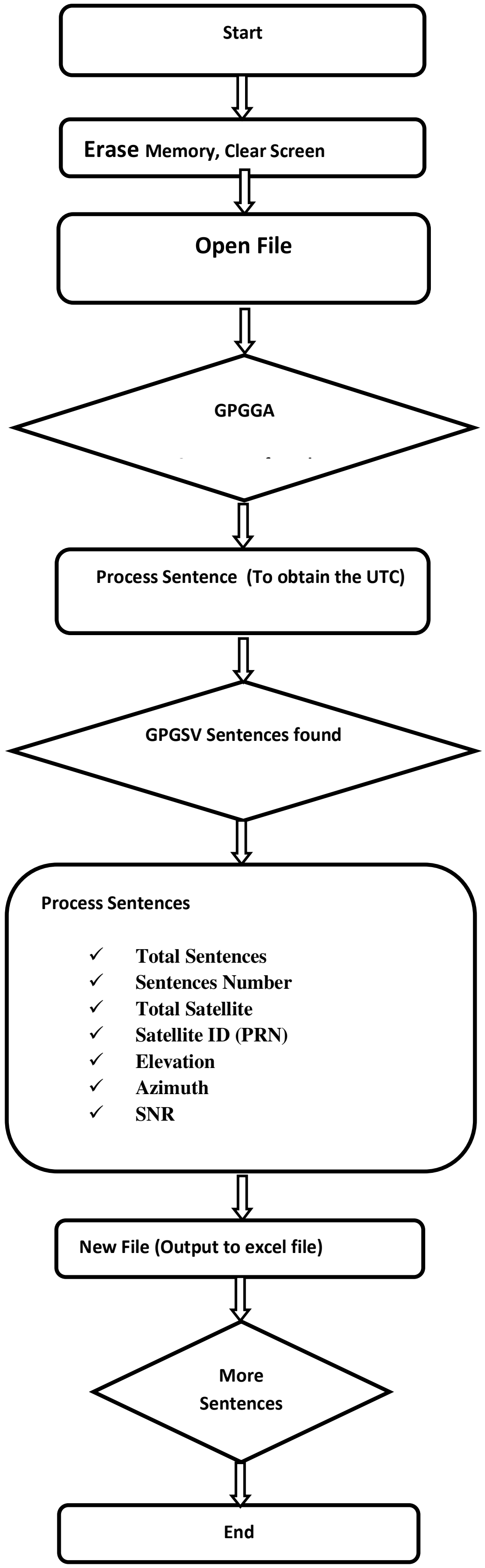

Fig.8 NMEA extractor flow chart

Fig. 7. Experiment setup for open space on rooftop at Faculty of Engineering building, UNIMAS

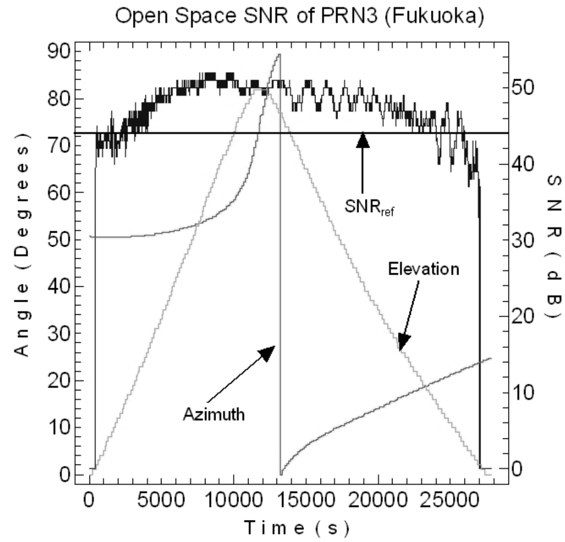

Fig. 9 SNR of PRN 3 [21].

3 RESULT AND DISCUSSION

The analysis of the satellite SNR are carried out for the measured satellites PRN 3, 14, 15, 18, and 29. The comparison will be made based on the measured range of the satellite. SNR for the signal arriving at elevation $\theta \geq 15$ o should be ≥ 44 dBHz based on the study conducted in Japan [37]. If the SNR is less than 44dBHz, then the received signal is considered experiencing attenuation effect. Figure 9 show the received SNR of PRN 3 obtained from the measurement carried out in Japan under the open space condition and used as a reference. For the entire graph, the azimuth angle will be divided by a factor of 4 so that the axis of elevation and azimuth are well suited. Local Time (MTime) will be replaced by the numbering at x-axis to give a suitable range for the axis. The time axis is standardized to start at 0 s with the increment of every 2 s. This is to simplify the analysis process. The graph of 44 dBHz will be plotted onto the other SNR graph as a reference for the comparison of SNR from the other satellites (SNRref). For the purpose of analysis, only SNR of $\theta \geq 15^o$ will be considered because the signal drops significantly at lower θ angle due to the antenna design [37]. The radiation pattern of the patch antenna used in this GPS receiver allows perfect signal reception from boresight with the response attenuated as elevation angle decrease. Satellite signals are received via the right-hand circularly polarized (RHCP) antenna. Typical coverage is 160^o with gain variations from about 2.5dBic at zenith to near unity at an elevation angle of 15^o. Below 15^o of elevation, the gain is usually negative [18] [40].

There will be a several conditions for the analysis of the open space. If elevation angle $\theta \geq 15$o, the SNR should be equal or greater than 44 dBHz. If SNR < 44 dBHz, the signal will have an attenuation. For open space, the effect of the multipath effect and receiver noise will cause signal drop in ±5dBHz from peak-to-peak [12]. The second condition is if the SNR is dropped below 44 dBHz at $\theta \geq 15$o, this happened due to the ionospheric effect. For the GPS receiver used in this study, if the received SNR is below 30 dBHz, the SNR will be given as 0 dBHz. This means that there is a lost of signal lock which means that the received signal quality is not good for communication. The last condition is if the SNR is dropped below 44 dBHz at $\theta < 15$o, this happened due to the design of the antenna as the received signal is weak at lower elevation angle. From Figure 9, the time axis starts at 0 s to 25000 s. This means that the data is collected for 6 hours 56 minutes 4 s. From 0 s to 24000 s, the SNR is above the reference 44 dBHz most of the time which is an indication of a good signal. The azimuth angle starts from 200o to a maximum of 356o then rolls down to 00 then finally ends at 212o. The signal come with a sequence of fluctuations due to the multipath effect as for open space, the signal will experience less than 5 dBHz drops from peak-to-peak as explained in [12]. From 24000 s to 27000 s, the SNR starts to drop below 44dBHz and dropped to 0dBHz at 27000 s with the decrease in the elevation angle. This is due to the design of the antenna as the gain is low at lower elevation angle [37, 41]. Analysis: The analysis of the SNR is carried for satellite arriving at the north direction that are PRN 14, 15 and 29 then the satellite arriving from the south position will be the PRN 3 and 18. For open space, the SNR for satellite are divided into two measure ranges of the azimuth angle, which are arriving from the north direction in the range of azimuth from 320o to 40o and arriving from the south direction in the range of azimuth from 220o to 140o. The radio communication engineers are more familiar with azimuth and elevation angles in satellite location with respect to the look angles. Figure 10 shows the geometry and definitions of the looks angles with respect to the receiver.

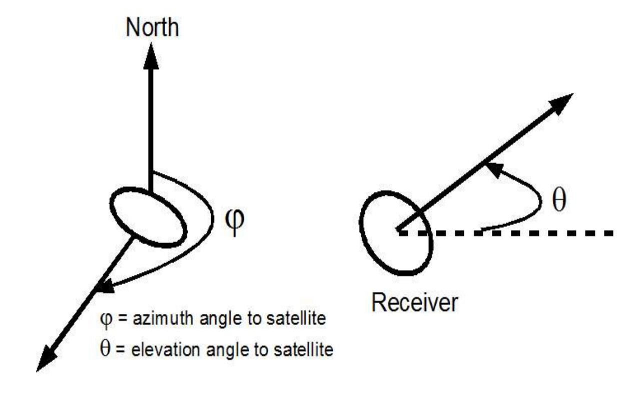

Fig. 10 The geometry of looks angles with respect to the receiver.

In Figure 11, the NMEA data for PRN 3 which collected within 6 hours 23 minutes 20 seconds. The SNR is above the reference, 44 dBHz most of the time. Then some fluctuations were observed on the signal which caused due to the multipath effect encountered by the arriving signal in open space [12]. The elevation angle reached it is peak value 89^{o} then rolls to 0^{o}, while the satellite azimuth angles moves from 200^{o} down to 0^{o}. The satellite signal strength is good for communication.

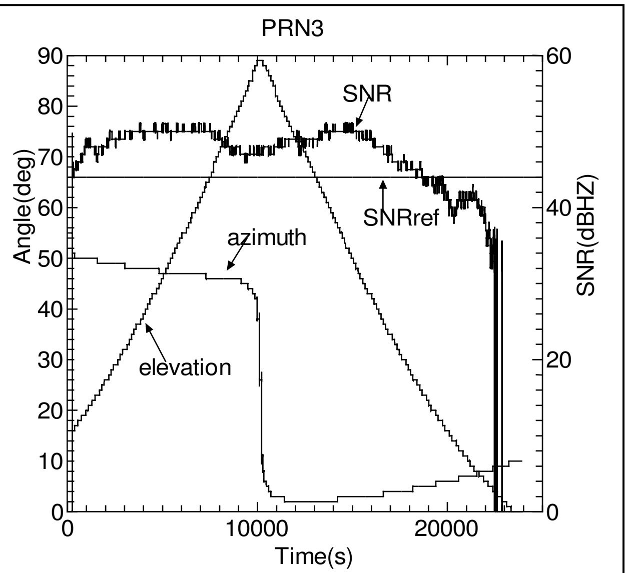

Fig. 11 SNR for PRN 3 (Sarawak)

3.1 Analysis of PRN 14

In Figure 12a, the data was taken within 9 hours 4 minutes 0 seconds. The SNR is within the reference SNR, 44 dBHz. At point 6000 seconds the SNR signal dropped below the reference value due to the receiver elevation angle dropped lower. The SNR fluctuates along the signal path and drops below the reference SNR 44 dBHz due to elements of multipath effect [12] from the surroundings. The SNR drop will not have much effect on the communications. Figure 12b shows SNR signal performance for PRN 14 from Japan data whereby SNR is above the reference value 44 dBHz as compared with the Sarawak data.

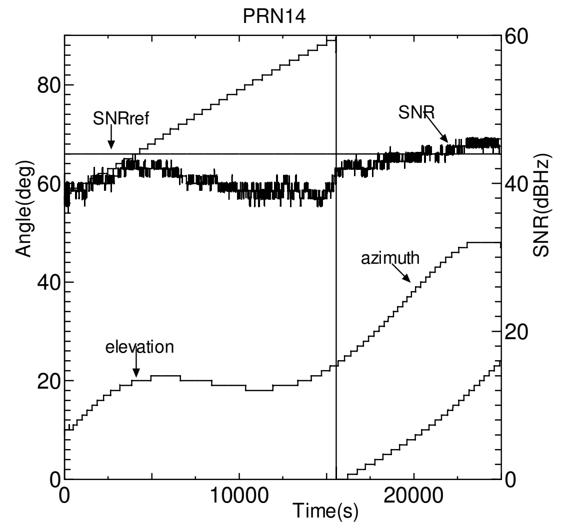

Fig. 12a SNR for PRN 14(Sarawak)

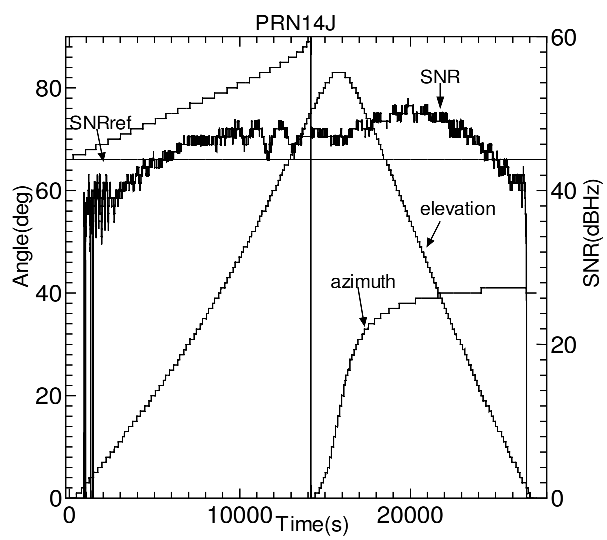

Fig. 12b SNR for PRN 14 Japan

3.2 Analysis of PRN 15

In Figure 13a, the SNR maintains above the reference SNR value, 44 dBHz with the elevation angle rises from 0^{o} to 77^{o} maximum then declined to 16^{0}. The azimuth angle rises from 200^{o} to maximum of 356^{o} then declined to 0^{o} and rises again to 40^{o}. At a point (highlighted in circle), the signal is dropped below to 38 dBHz. And this drop lasts for 43 seconds, and caused LOS not present, this is due to the receiver elevation angle is below 15^{o}. The SNR finally dropped to 0 dBHz at 26000 s, when the elevation angle is less than 10^{o}. Where as in the figure 13b, the graph of PRN 15 from Japan data was analyses and SNR performance is compared with the data for Sarawak.

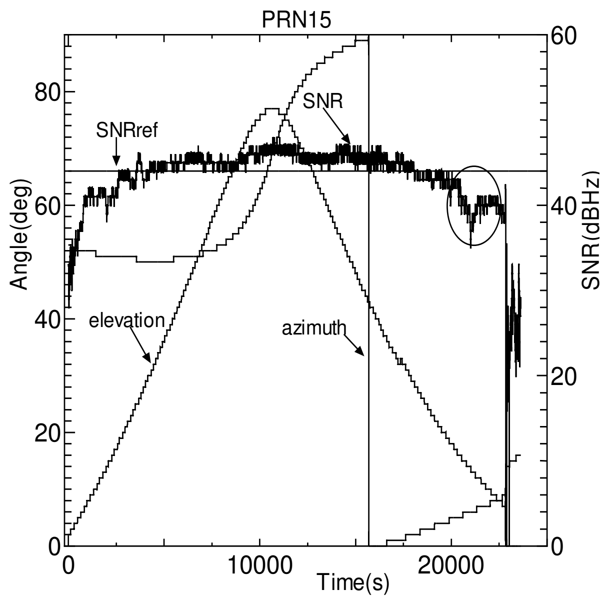

Fig. 13a SNR for PRN 15 (Sarawak)

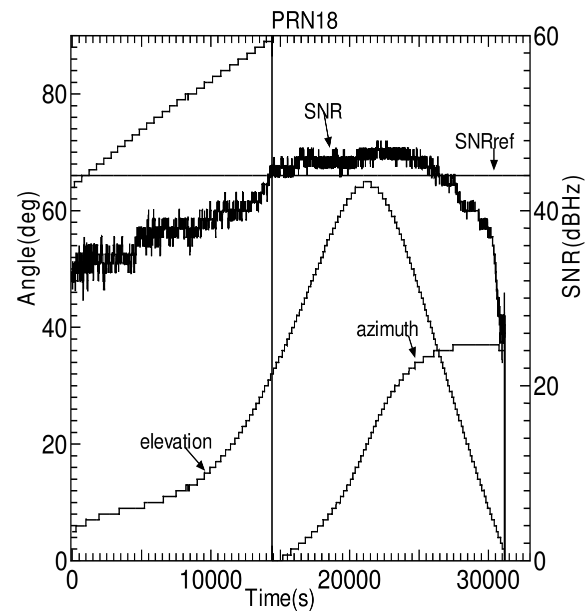

Fig. 14a SNR for PRN 18 (Sarawak)

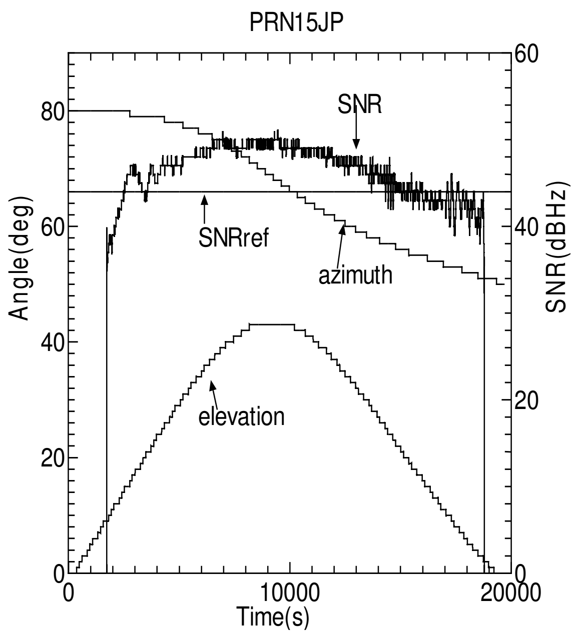

Fig. 13b SNR for PRN 15 Japan

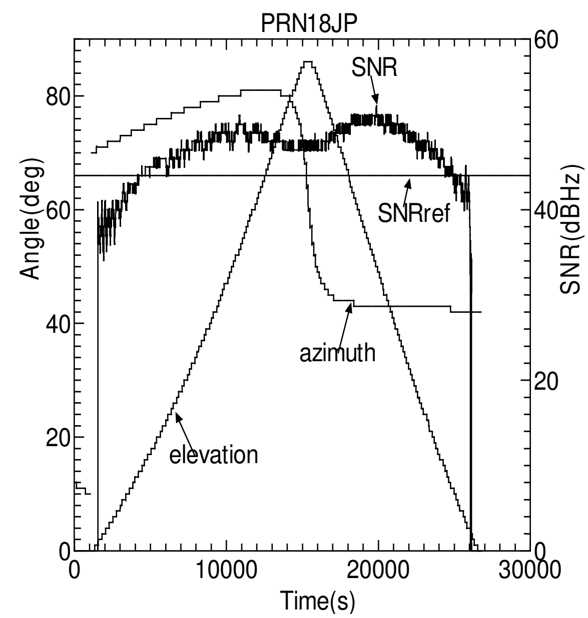

Fig. 14b SNR for PRN 18 Japan

3.3 Analysis for PRN 18

In Figure 14a, the data was taken for a period of 8 hours 39 minutes 58 seconds. The elevation angle rises from 6° to 69° then declines to 0° while the azimuth angle rises from 256° to 356° maximum then descends to 0° and closed at 36°. The SNR signal strength is below the reference value 44 dBHz at 14500 seconds, and also fluctuates. This fluctuation is due to the receiver noise encountered in an open space [9]. The signal performance for data obtained from Japan maintained above the reference value 44 dBHz as shown in Figure 14b, and the elevation angle reaches the maximum of 344° while the azimuth angle is at lower position as compared to the Sarawak data which the azimuth reached the maximum of 359°.

3.4 Analysis of PRN 29

In Figure 15a, the data was taken within 8 hours 39 minutes 58 seconds. Elevation angle rises from 8° to 48° maximum then declines to 0° with azimuth angle from 324° to 7° with the signal fluctuations. The signal strength SNR is above the reference 44 dBHz. Then suddenly at point 20400 seconds (highlight in circle) the SNR drops below the 44 dBHz reference value for almost 6600 seconds, this fading effect resulted due to ionospheric effect [19]. There is sequential signal fluctuations for the SNR due to the receiver noise encountered in an open space [12]. The SNR signal strength is good for communication purposes. The signal performance for data obtained from Japan maintained above the reference value 44 dBHz as shown in Figure 15b, but comes with fluctuation patterns due the receiver noise effect for an open space measurement.

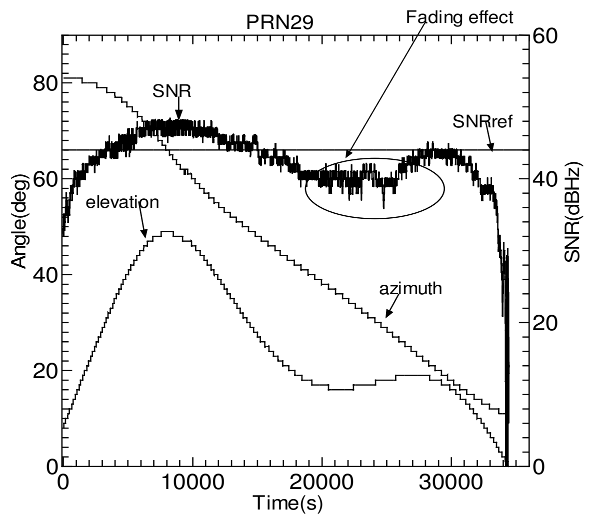

Fig. 15a SNR for PRN 29 (Sarawak)

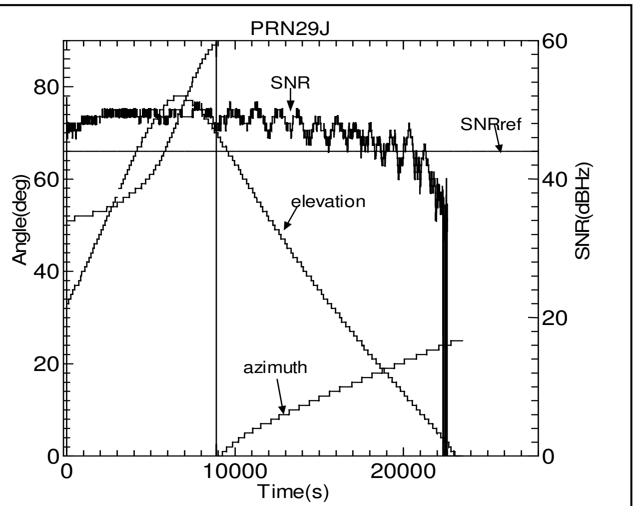

Fig. 15b SNR for PRN 29 Japan

The average SNR result also computed using the bar chart for the overall results shown in Figure 16, the reference data from Japan for PRN 3 with average SNR value of 44.25 dBHz was compared with the PRN 3, 14, 15, 18 and PRN 29 for Sarawak data. The PRN15 and PRN29 signal strength are acceptable for communication purposes for this data recorded on September 30 2010, while the PRN 3, 14 and PRN 18 have weak signal performance.

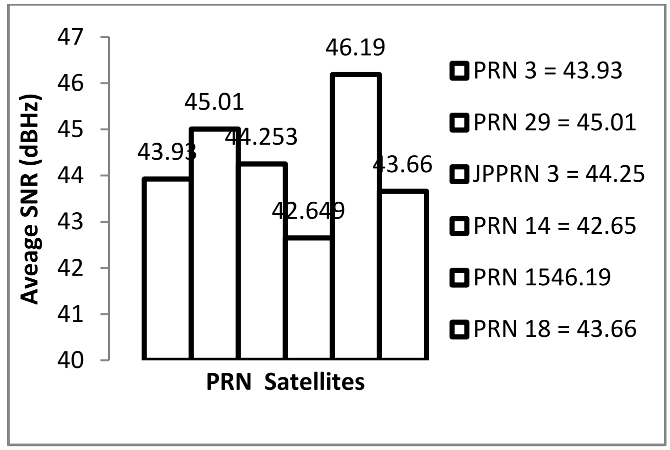

Fig. 16 SNRs performance chart

4 Conclusion

The analysis of the signal performance under different MS environments is performed with respect to the elevation and azimuth degree. The analysis produced forming an important part in the studies of the signal performance. Simple and low cost data acquisition system was used to carry out the measurement of signal degradation of the MS which is due to factors such as the ionospheric effect, multipath fading. The proposed experimental method of using the commercially available, portable, handheld, GPS receiver with built-in small size patch antenna can closely imitate the actual MS receiver's signal performance due to their similar characteristics. By using the open space data reference from Japan, the effect of signal degradation was determined. It was observed that without the presence of effects from trees and building, the attenuation of satellite signal is due to the ionospheric effect. The attenuation can be very severe in which the quality of received signal is considered not acceptable for communication. This method allows the measurements to be carried out with much reduced cost and less complicated equipment. Therefore the method can be used to encourage more experimental works in less develop countries. Propagation data for the open space environment can be used as a reference to determine the MS signal quality for shadowing environment. However the evaluated data will help the MS network service providers to mitigate the problems faced by the MS users and it therefore improves the quality of service offered to them.

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