Mask Angle Effects on GNSS Speed Validity in Multipath and Tree Foliage Environments

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ABSTRACT— ***Global Navigation Satellite System (GNSS) receivers are now widely used for speed measurements. Theoretical studies suggest that speed accuracy parameter of the receivers might be improved by simple elevation of the receiver's mask angle. However, little practical information is provided regarding a link between the speed accuracy parameter and the specific mask angle values. Also, little practical research activities were conducted to determine how tree foliage can degrade the speed accuracy parameter and whether or not attenuation of GNSS signal caused by tree foliage represents a higher challenge for GNSS receivers than multipath. Finally, no activities were conducted to understand if enabling more constellations, for example, Globalnaya Sputnikovaya Navigatsionnaya Sistema (GLONASS) provides any value in speed accuracy in the environment where tree foliage is present. To cover the above gaps, this research firstly aims to practically estimate the performance of high end GNSS receivers for measuring speed in multipath environment and determine if elevation of mask angle can always lead to speed accuracy improvements. Secondly, the research also aims to determine if the receivers with higher mask angle perform better in tree foliage environment. The next goal of the research is to discover whether tree foliage or multipath related environment is the most challenging for GNSS speed measurements. The last aim of the research is to practically determine if adding GLONASS on top of GPS provides any value in speed accuracy determination in the environment when tree canopies cause multiple scattering and absorption of GNSS signal. A calibrated test vehicle was used to conduct two tests with four identical high end GPS/GNSS receivers having different mask angles in the environments where multipath and tree foliage are present. The main contributions can be summarised as follows: firstly, it was identified that elevation of the mask angle in GNSS receivers may not necessarily improve the speed accuracy parameter both in multipath and tree foliage related environments. Secondly, the research also determined that attenuation and scattering of GNSS signal in tree foliage environment may represent a higher threat for GNSS speed measurements compared to multipath related environment. Third, for a specific receiver adding GLONASS might not necessarily improve the performance in speed accuracy in the environments when tree canopies or overpasses are present. Forth, it was practically validated that the average single tree attenuation at GNSS band frequency may not be handled well by even high end GPS/GNSS receivers when conducting speed measurements. The research recommends that every GNSS receiver shall be individually tested in tree foliage and multipath related environments to determine the degradation in speed accuracy parameter.***

Keywords— Mask, Angle, Speed, Multipath, Tree, Foliage, GNSS

1. INTRODUCTION

Speed validity parameter is important in a number of applications to enhance safety and compliance. Global Navigation Satellite System (GNSS) receivers are currently widely used for speed measurements. However, GNSS signals are radio navigation ones and therefore might be impacted by multipath or tree foliage.

Multipath occurs when GNSS signal is reflected from surrounding objects, such as buildings, bridges, road gantries and other structures. Multipath represents one of the biggest sources of error in GNSS measurements and specifically in speed related applications [1]. For multipath mitigation, existing approaches can be classified into several groups: tracking loop based, antenna based, mask angle based and extra information based. The first approach focuses on tracking loop improvements and the other receiver based techniques [2]. Antenna based methods include the use of special antennas [3], [4]. The extra information based method might use a number of sub-methods trying to improve the performance in multipath environments. Such sub-methods might include determination of signal to noise ratio (SNR) and determination of probable multipath based on SNR values [5], [6] or elevation enhanced maps [7]. All the above methods are relevant to situations when GNSS receivers or antennas are designed rather than used by the end user and therefore might be applicable for stages of research and development rather than practical applications with the receivers already in use. As a result, the only method available to the end user to mitigate multipath is to change the mask angle through configuration settings of the receiver, if such settings are available [6], [8] and [9]. Mask angle, also very often referred to as cutoff angle, is a parameter in the receiver configuration when signals below a particular elevation angle would be effectively filtered out by the receiver and would not participate in positional or speed computations. Therefore, the use of cutoff angle to mitigate multipath related problems might be a sound strategy and in theory it is considered that such strategy would help to improve speed accuracy parameter of GNSS receivers [1] or positional accuracy [6], [8], [9]. On the other hand, implementing higher mask angles would drop the availability of satellites used for navigation and speed measurements and therefore reduce the number of records available. Hence, a compromise should always take place between the high mask angle to mitigate multipath related speed errors and the low mask angle to get the required satellites availability. It is required to highlight that no one from the above mentioned research stipulates a dependency between the cutoff angle and the speed accuracy and it is considered in theory that the higher the cutoff angle, the better the speed accuracy [1].

It is also worth mentioning that if a reflected GNSS signals comes out from an object located by more than 160 meters from a vehicle, it is highly unlikely that such signal could cause errors in GNSS performance [10]. However, the majority of overpasses located along freeways or buildings along the roads are located much closer to the road and therefore shall be taken into consideration when analyzing GNSS speed errors. Therefore, it is important to understand if the strategy of elevation of mask angle would always work and help to improve the speed accuracy in such multipath environments.

In addition to that, it is also known that tree foliage and forest canopy might significantly impact the performance of GPS receivers. However, the research activities to prove that were conducted for positional accuracy only [11], [12] and only for GPS rather than GNSS receivers. Therefore, it is unclear how the GPS/GNSS receivers would perform in tree foliage environments and whether such conditions represent more or less challenge to the receivers in comparison to the environments where multipath is present. It is also unclear if elevation cutoff angle variations would influence the performance of GNSS receivers in foliage related environments.

As a result, it is important to practically investigate a link, if any, between the mask angle implemented in GNSS receivers and the speed accuracy parameter. The speed accuracy parameter in this instance would be characterized by both the statistical performance and outliers generated in multipath and tree foliage related environments. Therefore, the main research objectives are as follows:

- to determine if mask angle increases would always improve the speed accuracy parameter in multipath related environment;
- to determine if the tree foliage environment is more or less stressful for GNSS receivers compared to multipath;
- to determine if there is a link between the mask angle values in GNSS receivers and the speed accuracy in tree foliage environment;
- to establish if adding some other constellations on top of GPS in tree foliage environment provides any value and improves the GNSS reported speed accuracy.

2. EXPERIMENTAL SETUP

A test vehicle Mazda 3 with calibrated speed measurement system capable to test GNSS receivers for speed was used in the experiments. The speed measurement system of the test vehicle was based on PIC18F458 PIC microcontroller and the GPS receiver with 5^0 mask angle was used for time synchronization of the output speed records of the microcontroller with the Universal Coordinated Time (UTC). The above synchronization provided a match between the speed records of the microcontroller and the speed records generated by GNSS receivers under test. Design concepts and calibration principles of the test vehicle are beyond the scope of this article. However, it is worth mentioning that the speed measurement system's uncertainty of speed determination was equal to 0.4 km/h within the speed range of up to 110 km/h. Before each test the speed measurement system was calibrated to maintain the integrity of measurements. After each test the performance of the speed measurement system was again verified through the same calibration methodology which was used for calibration.

All GPS/GNSS receivers under test had their GPS/GNSS antennas installed on the rooftop of the test vehicle. Speed data records from all GPS/GNSS receivers were logged to a rugged personal computer (PC) powered from 12V power supply of the test vehicle. The program named Terminal [13] was used to download and store data records from each receiver via the RS232 interface. The above program represents a freeware package and is available for downloading from the Internet.

GNSS receivers under test represented four identical high end GNSS receivers, three of which were configured to operate in GPS only mode and one in GNSS mode, specifically in GPS + Globalnaya Sputnokovaya Navigatsionnaya Sistema (GLONASS) mode. GPS only receivers had all settings identical except the mask angle, which was set up to 5^0 for the first GPS receiver, 10^0 for the second and 15^0 for the third one. The forth receiver was configured to operate in GNSS mode with the mask angle set up to 15^0. A block diagram of the test setup is shown on Fig.1. All receivers under test had 72 channels signal tracking L1 capabilities and operated in non-differential GPS mode. Velocity accuracy claimed by the manufacturer was ±0.1 km/h Root Mean Square (RMS) with no conditions specified if it depends on GNSS environments, such as: open skies with no obstructions, roads with tree foliage, roads with surrounding buildings or any other structures.

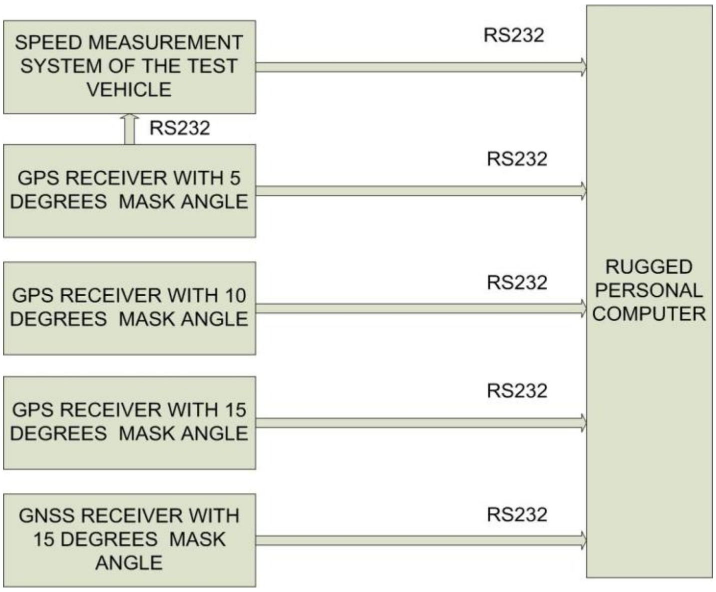

Figure 1: Test setup diagram

3. TEST ROUTES

Two tests were conducted in different GNSS environments in 2015 posing different challenges to GPS/GNSS receivers. The test No1 was conducted on Monash Freeway in Melbourne between Narre Warren and Chadstone and the route for this test is shown on Fig.2. The challenge of this route was that on top of open sky environments the receivers passed through a number of overpasses causing the multipath to occur. Overpasses mainly represented bridges for traffic or narrow pedestrian bridges that crossed over Monash Freeway and for the entire route the number of overpasses was equal to 40. In addition to overpasses, a number of road gantries or wide metal signs crossing over Monash Freeway were also represented. It was expected that the receivers under test would generate a number of speed outliers around some overpasses with the magnitude and frequency dependent on the mask angle. It was expected that the best performer would be the GNSS receiver as it had the highest mask angle of 15^0 and used two constellations available, i.e. GPS and GLONASS. Subsequently, the second best performer was expected to be the GPS receiver with the highest elevation mask of 15^0, followed by the GPS receivers with 10^0 and then 5^0 elevation masks. The expectation was based on the fact that the receivers had completely identical GPS/GNSS settings. In addition, the receivers were of the same type. Finally, the expectation was based on the fact that higher elevation masks would filter potential multipath occurrences as described in [6], [8] and [9]. This test was conducted at normal speeds in the range between 80 km/h and 100 km/h with the cruise control disabled.

The test No2 was conducted with the same receivers and the test vehicle passing the following route through South Eastern suburbs of Melbourne: Berwick- Upper Beaconsfield – Emerald – Narre Warren East – Harkaway – Berwick as shown on Fig.3. This specific route was selected as it has a high percentage of tree-lined roads with a mixture of 5m to 30m high evergreen trees. Trees can be a significant source of signal loss, and there are a number of parameters involved, such as: the specific type of tree, whether it is wet or dry, and in the case of deciduous trees, whether the leaves are present or not. It was expected that even isolated trees might represent a problem for GNSS signals; however, a dense group of trees or trees staying all along a particular section of the road might represent a major problem. The expectation was based on the fact that the attenuation of signals in general depends on the distance the signal must penetrate through the forest or leaves, and the attenuation increases with frequency. According to [14], the attenuation generally is of the order of 0.05 dB/m at 200 MHz, 0.1 dB/m at 500 MHz, 0.2 dB/m at 1 GHz, 0.3 dB/m at 2 GHz and 0.4 dB/m at 3 GHz. As GNSS L1 frequency equals to 1575.42 MHz, the GNSS signal sits in the middle of Ultra High Frequency (UHF) range and therefore is vulnerable to propagation along tree lined roads.

However, the challenge of the test route No2 is not only related to tree foliage and signal propagation. The second challenge relates to the test vehicle moving along the road when unobstructed line of sight (LOS) for every epoch is achieved for relatively short periods of time and the satellites availability would vary significantly from one second to another. This means the receivers are put under stress of operating with constantly changing satellites because of LOS variability and signal variability from each satellite due to GNSS signal attenuation.

For the test route No2 the driving speed varied between 50 km/h and 90 km/h and the mask angle of the top of the trees varied reaching 90^0, i.e. reaching situations when trees completely prevented GNSS signals to be received.

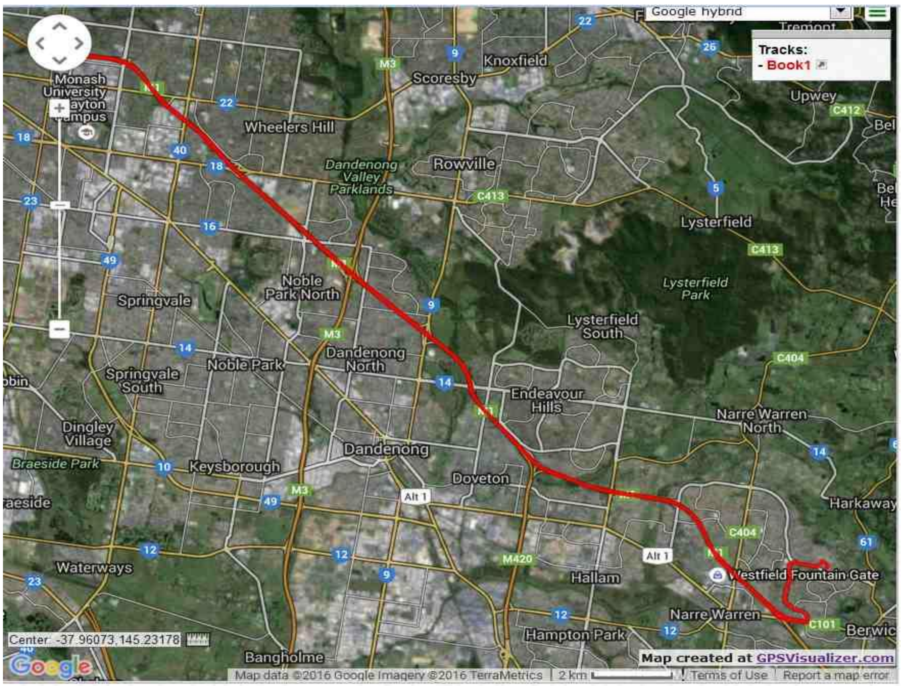

Figure 2: Test route No1

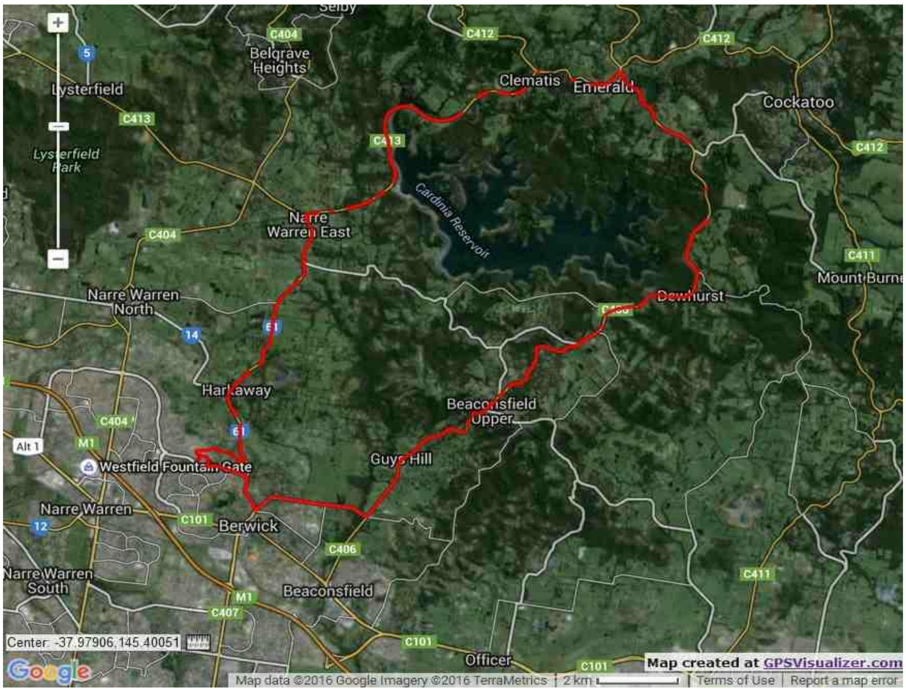

Figure 3: Test route No2

4. RESULTS

4.1 Number of speed outliers for test routes No1 and No2

Speed outliers were generated by all receivers under test on both test routes. The number of outliers where

GNSS/GPS reported speed differed from the true speed produced by the calibrated speed measurement system of the test vehicle is shown in Tables 1 and 2 for routes No1 and No2 respectively.

Table 1: Number of speed outliers for the test route No1

GPS/GNSS Receiver	Number of GPS/GNSS speed records with the speed error greater than ± 2 km/h	Number of GPS/GNSS speed records with the speed error greater than ± 3 km/h
GPS receiver with 5^0 mask angle	3	1
GPS receiver with 10^0 mask angle	9	5
GPS receiver with 15^0 mask angle	1	1
GPS + GLONASS receiver with 15^0 mask angle	2	2

Table 2: Number of speed outliers for the test route No2

GPS/GNSS Receiver	Number of GPS/GNSS speed records with the speed error greater than ± 2 km/h	Number of GPS/GNSS speed records with the speed error greater than ± 3 km/h
GPS receiver with 5^0 mask angle	3	0
GPS receiver with 10^0 mask angle	14	4
GPS receiver with 15^0 mask angle	9	2
GPS + GLONASS receiver with 15^0 mask angle	10	6

Note. In Tables 1 and 2 the second column includes values from the third column. This means, for example, that for the test route No1 and the receiver with 5^0 mask angle the number of speed records where the speed error is greater than ±2km/h equals to three, among them one record has a speed error of more than ±3km/h.

It is required to emphasize that speed outliers were generated by GPS/GNSS receivers in a number of locations where overpasses or road gantries / metal signs across the road were present and generally the locations of generation did not necessarily match for all receivers.

From both tables it is visible that the higher mask angle does not necessarily improve the performance in generation of outliers. Despite theoretical expectations, for the test route No1 the best performer is the GPS receiver with 15^0 mask angle, followed by the GPS + GLONASS receiver with 15^0 mask angle, the next is the GPS receiver with 5^0 mask angle and the worst performer is the GPS receiver with 10^0 mask angle. For the test route No2 the sequence is not the same and looks as follows: the best performer is the GPS receiver with 5^0 mask angle, followed by the GPS receiver with 15^0 mask angle, the next one is the GPS + GLONASS receiver with 15^0 mask angle and the worst performer is the GPS receiver with 10^0 mask angle. Considering that the types of receivers were the same and all of them had identical GPS/GNSS settings except the mask angle and remembering that the GPS + GLONASS receiver has the additional constellation enabled, there is no clear dependency between the mask angle and the number of speed outliers generated. This effectively means that a simple theoretical solution of increasing the mask angle to improve the speed accuracy might not necessarily work in practice. The second conclusion is that enabling the additional constellation does not automatically improve the performance of the receiver in speed determination.

4.2 Statistical speed accuracy parameters for the test routes No1 and No2

The main statistical parameters for speed errors and two test drives look as follows:

Table 3: Statistical speed difference parameters of GPS/GNSS receivers for the test route No1

	GPS receiver with 5^0 mask angle	GPS receiver with 10^0 mask angle	GPS receiver with 15^0 mask angle	GPS + GLONASS receiver with 15^0 mask angle
Mean, km/h	-0.11	-0.15	-0.10	-0.09
Standard deviation, km/h	0.3	1.0	0.3	0.4
Speed difference range, km/h	7.6	32	5.5	10.8
Minimum speed difference, km/h	-2.1	-27.9	-0.9	-1.0
Maximum speed difference, km/h	5.5	4.1	4.6	9.8

Table 4: Statistical speed difference parameters of GPS/GNSS receivers for the test route No2

	GPS receiver with 5^0 mask angle	GPS receiver with 10^0 mask angle	GPS receiver with 15^0 mask angle	GPS + GLONASS receiver with 15^0 mask angle
Mean, km/h	0.16	0.17	0.19	0.21
Standard deviation, km/h	0.5	0.7	0.6	1.1
Speed difference range, km/h	5.1	10.8	9.3	29.9
Minimum speed difference, km/h	-2.2	-4.8	-6.1	-5.6
Maximum speed difference, km/h	2.9	6.0	3.2	24.3

Speed difference distributions for both test drives and all GPS/GNSS receivers under test are shown on the below Figures 4-7.

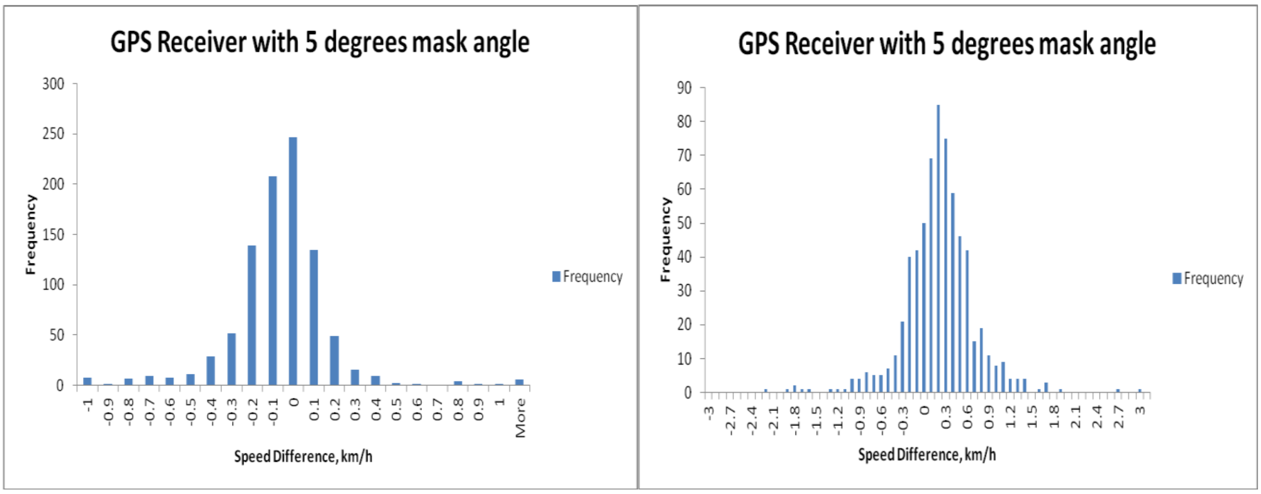

Figure 4: Speed difference distributions for the GPS receiver with 5^0 mask angle for the test runs No1 (left) and No2(right)

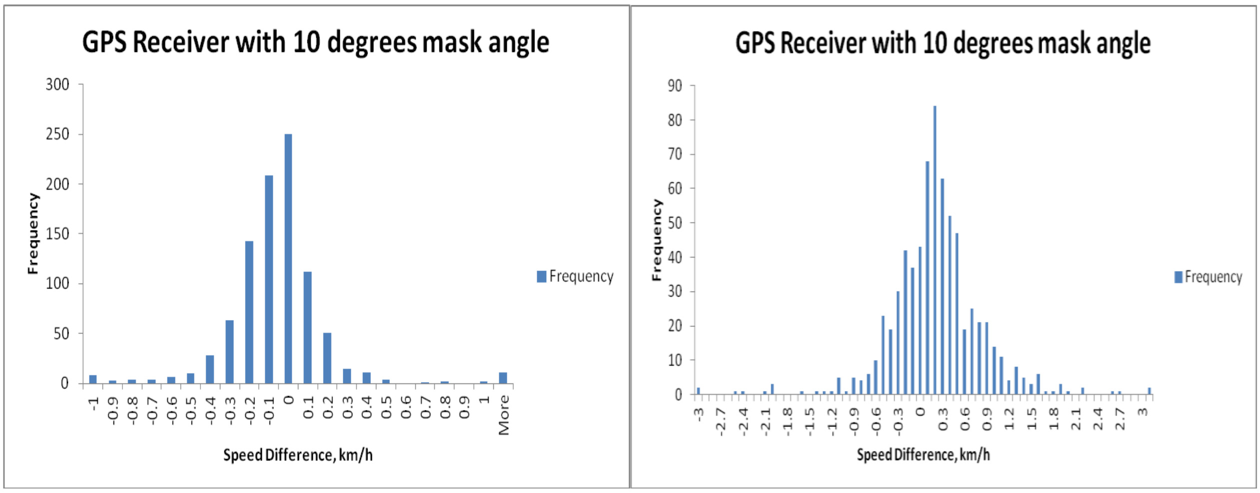

Figure 5: Speed difference distributions for the GPS receiver with 10^0 mask angle for the test runs No1 (left) and No2(right)

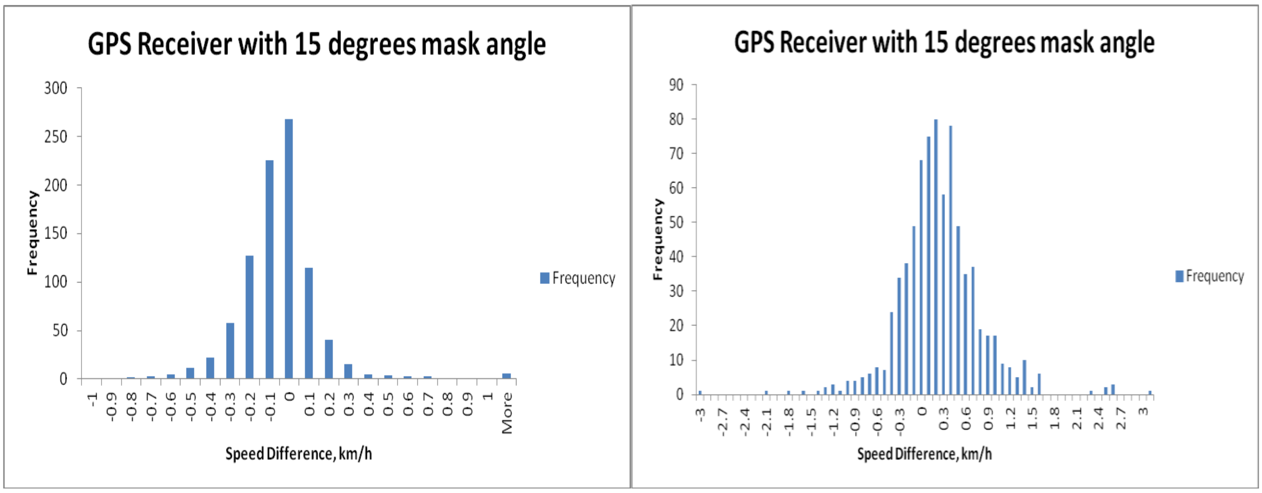

Figure 6: Speed difference distributions for the GPS receiver with 15^0 mask angle for the test runs No1 (left) and No2(right)

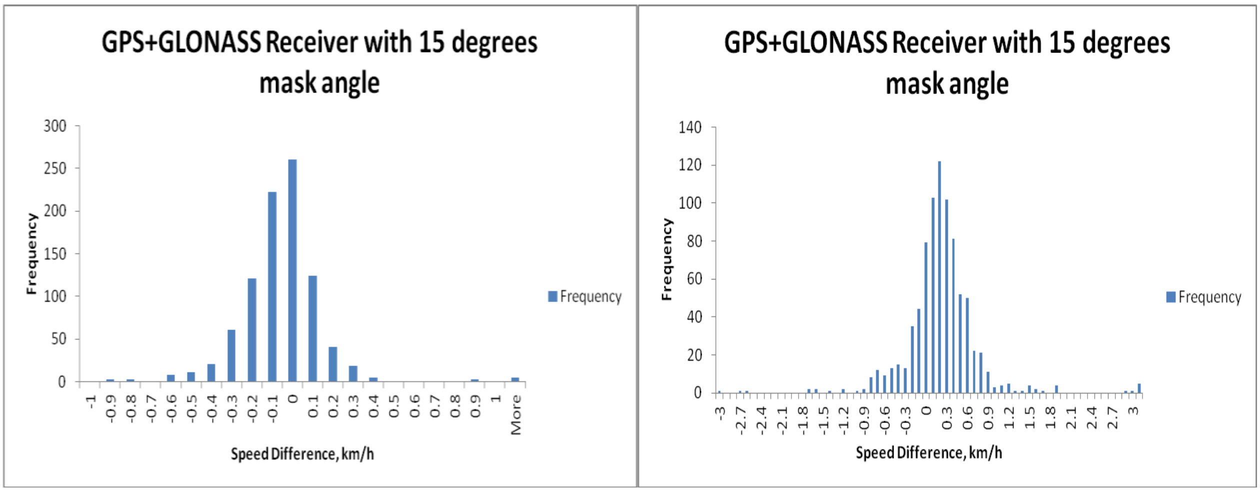

Figure 7: Speed difference distributions for the GPS+GLONASS receiver with 15^0 mask angle for the test runs No1 (left) and No2(right)

The results from two tests with four GPS/GNSS receivers having different mask angles demonstrate the following:

- Speed difference distributions for the test where occasional overpasses are seen along a freeway and for the test where tree foliage is represented are completely different.
- Despite theoretical approaches that higher mask angles would lead to better speed accuracy results, this is not always the case for the tests conducted. Firstly, in two tests conducted in different GNSS environments the worst performers are different for both the magnitude of outliers and statistical parameters, specifically the standard deviation values. Secondly, the GPS receiver with 5^0 mask angle in theory was expected to be the worst performer; however, in practice this receiver was not the worst in any test conducted. The result highlights the fact that in GNSS speed accuracy measurements the following factors might play a bigger role than expected:

  - relative positioning of the GPS/GNSS antenna on the rooftop of the vehicle;

  -relative positioning of the vehicle on the road;

  -differences in electronic components of the receivers even in case the receivers are of the same type.
- GPS+GLONASS solution did not improve the speed accuracy parameter in any environment where the receivers were tested.

5. DISCUSSION

From the test No1 it is evident that even high end GPS/GNSS receivers with different mask angles varying from 5^0 to 15^0 generate relatively high speed outliers. A theoretical statement that signals from low satellite elevation manifest greater multipath errors than signals from high elevation and a simple mitigation method is to raise the allowable elevation cutoff angle [1], [8] may not always work perfectly in practice of GNSS speed measurements. Moreover, it is required to highlight that changing the receiver's mask angle is the only method available to the end user of GPS/GNSS receivers, while the others are all applicable at the design and validation stages of the receivers. The end user might not be even capable to use the National Marine Electronics Association (NMEA) data produced by the receivers to try filtering potentially unreliable speed records and finding the outliers generated around overpasses. Below two instances of the speed outliers are shown as examples where the GPS receiver with 5^0 mask angle generated speed spikes when driven along the test route No1. GPS parameters for these specific outliers and times of their generation in UTC are as follows:

Table 5: Examples of GPS parameters for selected outliers of the test route No1

	Speed error, km/h	Horizontal Dilution of Precision (HDOP)	Number of satellites used for navigation
Outlier No1 (time 01:37:46 UTC)	2.2	1.2	9
Outlier No2 (time 01:50:32 UTC)	5.5	1.3	9

From Table 5 it is evident that simple filtering of individual outliers based on HDOP and number of satellites is not always possible because both values represent situations with very good GPS visibility. However, as HDOP values are calculated by the receiver, it appears the receiver is misled by multipath signal coming from the specific GPS satellite(s) and is incapable to calculate a proper HDOP. The environments where such outliers were generated (see Figure 8) represent typical freeway situations.

Figure 8: Example of the environments where speed outliers were generated on the test route No1 by the GPS receiver with 5^0 mask angle with speed differences 2.2 km/h (left) and 5.5 km/h (right)

Below is an example of NMEA data records generated by the GPS receiver with 5^0 mask angle when the first outlier was generated as indicated in Table 5.

Note. NMEA data format is stipulated in NMEA 0183 Standard [16] and the relevant $GPGSV messages generated by the receivers according to this Standard have the following structure:

*$GPGSV,2,1,08,01,40,083,46,02,17,308,41,12,07,344,39,14,22,228,45*75*
Where:

GSV = Satellites in view;
2 = Number of sentences for full data;
1 = Sentence 1 of 2;
08 = Number of satellites in view;
01 = Satellite Pseudo Range Noise (PRN) number;
40 = Elevation, degrees;
083 = Azimuth, degrees;
46 = SNR - higher is better for up to 4 satellites per sentence;
**75 = the checksum data, always begins with *.*

```
$GPRMC,013745.00,A,3801.0802690,S,14518.5338176,E,53.386,316.1,200496,0.0,E*7D
$GPGSV,4,1,13,28,72,232,49,30,67,114,50,19,57,043,49,13,46,236,50*7E
$GPGSV,4,2,13,07,37,080,48,17,36,358,48,11,23,101,45,08,12,140,45*74
$GPGSV,4,3,13,15,12,221,,01,10,084,40,05,08,291,,09,06,020,*78
$GPGSV,4,4,13,20,03,245,*49
$GPRMC,013746.00,A,3801.0695343,S,14518.5208871,E,52.306,319.1,200496,0.0,E*7F
$GPGSV,4,1,13,28,72,232,49,30,67,114,50,19,57,043,49,13,46,236,50*7E
$GPGSV,4,2,13,07,37,080,48,17,36,358,48,11,23,101,45,08,12,140,45*74
$GPGSV,4,3,13,15,12,221,,01,10,084,39,05,08,291,,09,06,020,*76
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$GPGSV,4,3,13,15,12,221,,01,10,084,,05,08,291,,09,06,020,*7C
$GPGSV,4,4,13,20,03,245,*49
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Figure 9: NMEA data for the outlier generated at 01:37:46 UTC and the surrounding records

From the above NMEA data it is visible that the outlier with the magnitude of 2.2 km/h was generated in the environment where the speed record generated 1 sec before is valid but the record after the outlier is determined by the receiver as invalid, i.e. excluded by the receiver from the assessment. Validity of records is based on the relevant field in $GPRMC message where V or A symbol is represented. It is also visible that there is no any difference in SNR for all satellites visible by the receiver. As a result, the user is totally unaware of the outlier looking at NMEA data. Further analysis demonstrated that similar situations are present for the outlier No2 (see Table 5) and in fact for almost any other outliers generated by GPS/GNSS receivers during this test. More importantly, neither the standard deviation of the speed error nor the magnitude of speed outliers (see Table 3) proportionally depend on the mask angle or the use of additional constellations, i.e. GLONASS in this instance. This highlights the fact that the performance of the specific receivers in speed measurements when such receivers have different mask angles may heavily depend on the actual specimen or relative positioning on the receivers on the rooftop of the vehicle at a particular moment of passing an overpass rather than on the mask angle. Despite being identical, GPS/GNSS receivers under test may still have electronic components with slightly different parameters or settings. Also, the GPS/GNSS antennas of the receivers despite being located on the same rooftop of the test vehicle still stay up to 2 meters apart from each other. This location discrepancy might have slightly different environmental GPS situations at the specific locations. As a result, the speed accuracy performance might or might not be improved by simple elevation of the receivers mask angle.

From the results of the test No2 it is evident that the tree foliage environment might be more challenging for GPS/GNSS receivers than the environment where occasional multipath is present. Variations of the mask angle to improve the speed accuracy performance of the receiver in tree foliage environment might not be a solution. It appears that shadowing from the tree canopies when attenuation of GPS/GNSS signal occurs is generally handled by the receivers much worse than multipath (see Tables 3 and 4 and speed distribution graphs).

Below two speed outliers are shown as examples for the test route No2 where the GPS receiver with 10^0 mask angle generated speed spikes. GPS parameters for these specific outliers and times of their generation in UTC are as follows:

Table 6: Examples of GPS parameters for outliers on the test route No2

	Speed error, km/h	Horizontal Dilution of Precision (HDOP)	Number of satellites used for navigation
Outlier No1 (time 23:25:42 UTC)	3.1	2.4	4
Outlier No2 (time 23:36:43 UTC)	-4.8	7.6	4

Table 6 represents mixed examples of GPS parameters. While for the outlier No2 an indication of the problem might be obtained from the high value of HDOP, this is not the case for the outlier No1 because both the number of satellites and HDOP parameters for this outlier are within reasonable limits. Also, the environments where such outliers were generated (see Figure 10) do not represent a significant challenge in the form of a grove of trees. This emphasizes the fact that even individual trees may represent a challenge for GPS/GNSS receivers when precise speed measurements are required.

Figure 10: Example of the environments where speed outliers were generated on the test route No2 by the GPS receiver with 10^0 mask angle with speed differences 3.1 km/h (left) and -4.8 km/h (right)

For the test route No2 it also appears that the speed measurement issues are caused by combination of multiple scattering of GPS signal from tree canopies and signal absorption. It is known that attenuation from a single tree at GPS frequencies takes place [16] with different values depending on tree types:

Table 7: Examples of attenuation of signal at GPS frequency L1

Tree type	Coefficient of attenuation, dB/m	Average attenuation, dB
Pine	1.8	18.0
Maple	1.2	16.2
Poplar	0.7	3.5

Such signal attenuation as 18.0 dB or 16.2 dB, if happens fast and randomly because of scattering and absorption from both foliage and tree branches might not be handled by the receivers effectively. Below are two examples from the NMEA data generated by the relevant receiver at times of generation of the above outliers No1 and No2 (see Table 6).

```
$GPRMC,232541.00,V,,,,,,,111215,0.0,E*70
$GPGSV,3,1,11,07,64,150,48,30,57,229,48,09,53,033,,28,36,316,*76
$GPGSV,3,2,11,08,36,101,44,05,23,246,,27,19,132,,23,16,039,*70
$GPGSV,3,3,11,19,11,010,,13,06,225,,11,04,060,*43
$GPGGA,232542.00,3756.1629,S,14527.0477,E,1,04,2.4,304.29,M,5.33,M,,*40
$GPRMC,232542.00,A,3756.1629208,S,14527.0476882,E,22.664,345.3,111215,0.0,E*74
$GPGSV,3,1,11,07,64,150,49,30,57,229,48,09,53,033,48,28,36,316,*7B
$GPGSV,3,2,11,08,36,101,,05,23,246,,27,19,132,43,23,16,039,*77
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$GPRMC,232543.00,V,,,,,,,111215,0.0,E*72
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$GPGSV,3,3,11,19,11,010,38,13,06,225,,11,04,060,*48
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Figure 11: NMEA data for the outlier generated at 23:25:42 UTC and the surrounding records

From the NMEA data it is noted that the outlier with the magnitude of speed error equal to 3.1 km/h was generated in the environment where the immediately preceding and succeeding speed records were invalid, i.e. excluded by the receiver from the assessment. It is also noted that there is a significant difference in SNR for the satellites with PRN numbers 30, 8, 27 and 19 at the time when the outlier was generated compared to the immediately succeeding speed record generated at 23:25:43 UTC. It is very likely that shadowing from the tree canopies changed the SNR values for a number of satellites or completely prevented some satellites availability within a particular second and the receiver could not handle this situation. A similar occurrence could be seen for the outlier No2 (see Figure 12 below) where satellites PRN 8 and PRN 19 also have completely different SNR values in 1 sec timing interval, although at a lesser scale compared to the outlier No1.

```
$GPRMC,233642.00,V,,,,,,,111215,0.0,E*71
$GPGSV,3,1,11,07,62,139,49,30,60,221,49,09,48,030,48,28,41,312,47*71
$GPGSV,3,2,11,08,35,107,,05,23,251,,27,16,136,,19,15,012,39*71
$GPGSV,3,3,11,23,12,038,38,13,11,224,,11,07,064,*48
$GPRMC,233643.00,A,3758.4230781,S,14521.6608562,E,41.132,179.0,111215,0.0,E*73
$GPGSV,3,1,11,07,62,139,48,30,60,221,49,09,48,030,49,28,41,312,47*71
$GPGSV,3,2,11,08,35,107,38,05,23,251,,27,16,136,,19,15,012,42*76
$GPGSV,3,3,11,23,11,038,,13,11,224,,11,07,064,*40
$GPRMC,233644.00,A,3758.4334101,S,14521.6607809,E,38.693,180.1,111215,0.0,E*75
$GPGSV,3,1,11,07,62,139,48,30,60,221,49,09,48,030,49,28,41,312,48*7E
$GPGSV,3,2,11,08,35,107,47,05,23,251,,27,16,136,,19,15,012,38*73
$GPGSV,3,3,11,23,11,038,,13,11,224,,11,07,064,*40
```

Figure 12: NMEA data for the outlier generated at 23:36:43 UTC and the surrounding records

6. CONCLUSION

This paper presents experimental results for handling tree foliage and multipath by several high end GPS/GNSS receivers of the same type with different mask angles. There are four main contributions of the research matching the research objectives.

Firstly, the research practically proved that errors in speed records generated by GPS/GNSS receivers might not be directly proportional to mask angle values in the range between 5^0 and 15^0. Both the statistical speed accuracy parameters and the magnitude of outliers generated by the receivers are not necessarily improved with elevation of the receivers mask angle. Individual parameters of the specific receivers of the same type or relative installation of their antennas on the rooftop of the vehicle might play an important role in generation of speed errors caused by multipath.

Secondly, it has been demonstrated that speed errors of GNSS receivers might be considerably worse in the areas where tree foliage is present compared to areas where occasional multipath might be observed. In such instances tree foliage provides both scattering and attenuation of the GNSS signal causing a challenge to accurately measure GNSS speed.

Thirdly, it was validated that elevation of the mask angle of the receiver is not a factor to improve the speed accuracy in tree foliage environments. Also, an implementation of some other constellations on top of GPS might not improve the speed accuracy performance of the receivers. In particular, adding GLONASS to GPS did not improve the speed accuracy parameter.

Finally, it was practically validated that even a single tree can significantly influence the speed accuracy parameter even in case when the receiver does not report any deterioration in the number of satellites in view and HDOP.

The above conclusions cannot be generalised for all receivers but rather highlight an importance of individual testing of each receiver to derive its true behaviour in different environments, including when multipath or tree foliage are present.

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