Experiment Analysis Support Document

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This support document provides additional information related those experiments that could not fit within the page constraints of VN-DGNSS paper [1].

1 Stationary test

For the stationary test, all the receivers were connected to a high quality antenna mounted on the roof of Winston Chung Hall at the University of California, Riverside. That antenna location was determined by Online Positioning User Service (OPUS). This antenna is located on the roof of Winston Chung Hall at the University of California, Riverside. The antenna has a clear view of the open sky. The elevation angle cutoff for all receivers was set by $15°$. For a long duration test, to analyze position estimation accuracy, UTC time, geodetic and geocentric coordinates were saved using u-center software. The underlying u-blox raw data (e.g., measurements, satellite status) were not saved.

2 Moving test

For the moving tests, the raw data was stored as '.ubx' files using u-center software. The data file are available in the 'test_data' folder at the open-source repository [1]. The files are named according to the acronyms defined in Table IV of the paper [1]. The files that are named as 'RTK' are those for which the receiver was operating ground truth trajectory. The elevation angle cutoff for all receivers was set by $15°$. During the experiment, the u-blox RTK status always maintained integer fixed solution. Fig. 1a and Fig. 1b show the vehicle trajectory for the moving test using single-band and dual-band antenna, respectively.

(a) Vehicle trajectory for moving test using single band antenna.

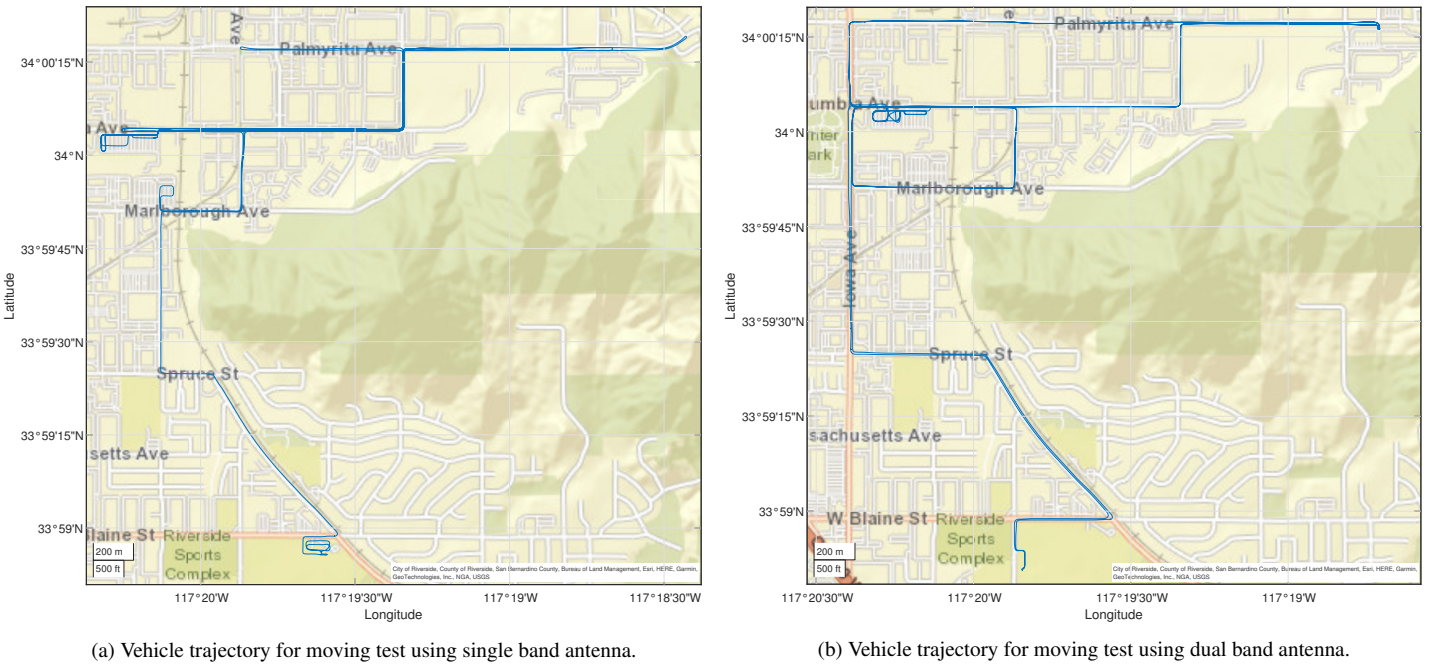(b) Vehicle trajectory for moving test using dual band antenna.

Figure 1: Vehicle trajectory for moving test.

Since the receivers were all connected to the same antenna, the effects of the experiment at surroundings are the same for all receivers. The sky plots in Fig. 2 and 3 show the satellites were tracked from the F9P SBAS experiment. The receivers using the VN-DGNSS

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[1]VN-DGNSS repository: `https://github.com/Azurehappen/Virtual-Network-DGNSS-Project`.

Fig. 2a and Fig. 3a show the sky plots with satellite ID at its last destination. Each satellite includes a system symbol and its identifier. 'G' stands for GPS, 'E' stands for GALILEO, 'B' stands for BeiDou. Fig. 2b and Fig. 3b show more clear satellite orbits without the satellite ID. The green orbit or satellite indicates satellite was used in navigation. The cyan color indicates satellite signal available but not used (In this implementation, they were not used because satellite elevation is lower than elevation cutoff angle). The blue color indicates satellite signal available but not available for use in navigation. The red color indicates satellites signal is not available. Several reasons will cause color blue and red, such as unhealthy status reported by satellite, lack of ephemeris, low signal strength, below elevation cutoff angle setup, and so on [2].

Some orbits in both Fig. 2 and Fig. 3 have different colors shift between available status and unavailable status, such as B21, E5, and G24 in Fig. 2. When the satellites are at low elevation and the vehicle is moving, the receiver may lose tracking of the satellites blocked by high buildings or trees.
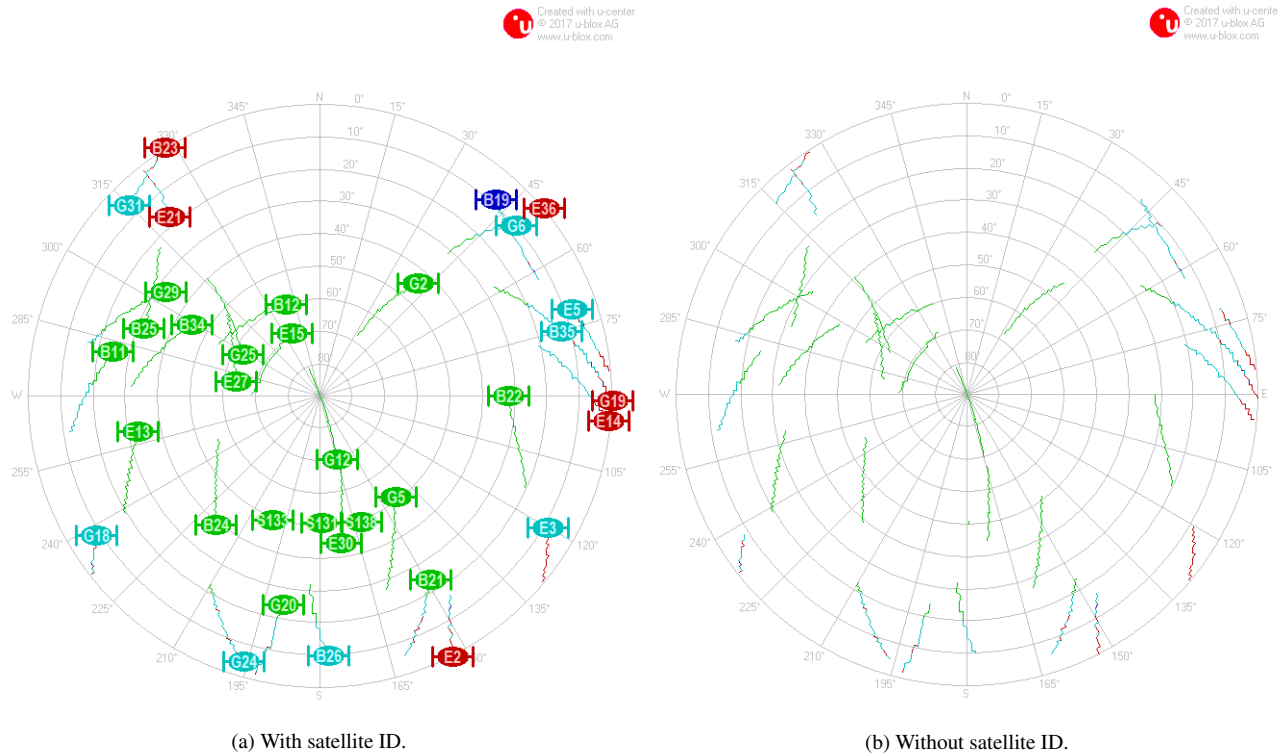

(a) With satellite ID.　　(b) Without satellite ID.

Figure 2: Sky plot and satellite orbit during the moving test that used the single band antenna.

(a) With satellite ID.
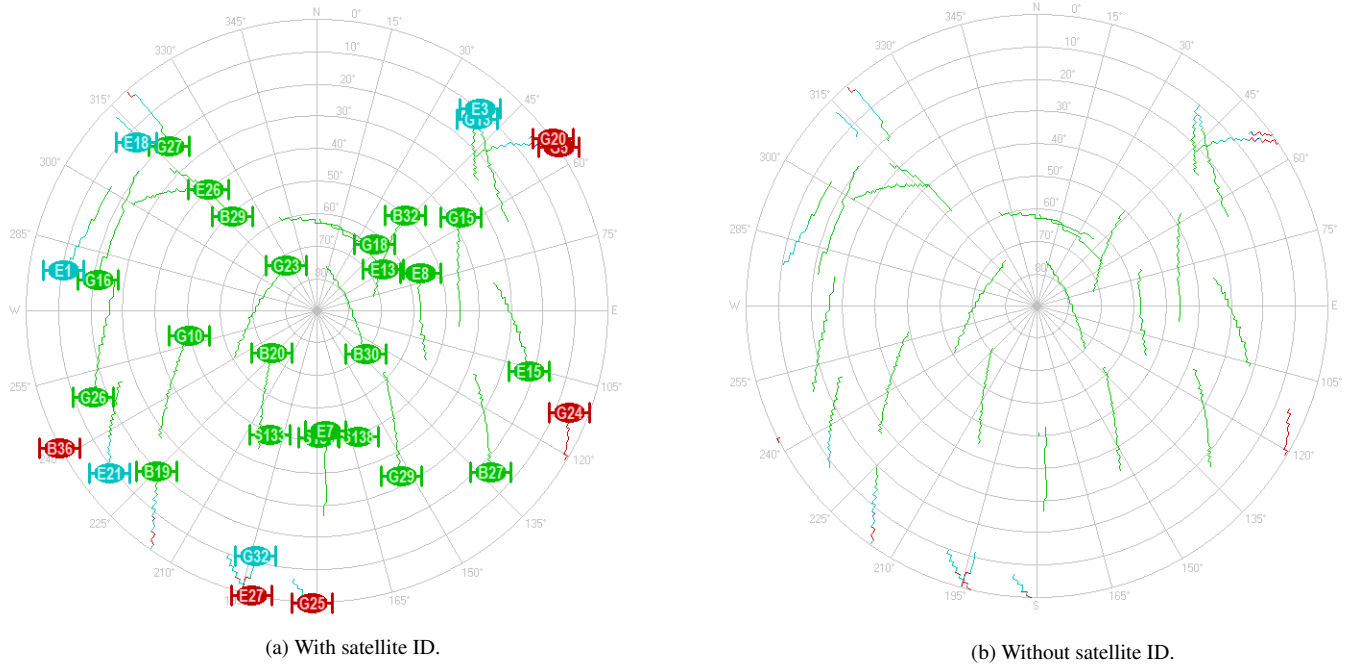

(b) Without satellite ID.

Figure 3: Sky plot and satellite orbit during moving test that used the dual band antenna.

Fig. 4a and Fig. 5a show the horizontal error relative to the RTK ground truth trajectory (see Sec. VI.D in [1]) during the moving test. Additionally, the analysis can be found in [1]. Fig. 4b and Fig. 5b show the vehicle speed over ground. The vehicle speed plots are based on the results from RTK. Fig. 4c and Fig. 5c show the number of satellites used in navigation. The plots for the number of satellites used are shown by all receivers since different setup results in different satellite usage scenarios. The definition of these acronyms can be founded in Table IV from the paper [1]. The purple line in Fig. 4c means the SF GNSS OS, F9P SBAS, SF GNSS VN have the same number of satellites used. These numbers do not count for the SBAS satellites since they provides corrections but not used for positioning.

In Fig. 4c, at most time instances, all experiments have the same number of satellite in most cases but have exceptions which are colored as blue, red, and green for SF GNSS OS, F9P SBAS, and SF GNSS VN, respectively. The reason that the number of satellites used suddenly dropped is due to satellite signal loss. The attached video shows an example of the satellite information interface from the u-center from the rerun of moving test for dual-band antenna in F9P SBAS. The following features is needed for the discussion.

- The column 'Qi' is the signal quality indicator. The description of 'Qi' is followed by Table 1. The satellite will be used in pseudorange positioning only when $Qi \geq 4$ which means code locked and time synchronized. In RTK for using carrier data, it requires $Qi = 7$.

- The 'PR used' indicate that if the satellite code measurement is used, Y for yes and N for no.

When the satellite signal fades or is blocked by obstructions, such as buildings and trees, the receiver will lose tracking of the signal and the signal quality indicator will be changed to code unlocked statuses ($Qi = 0, 1, 2, 3$). Fig. (not yet plotted) and the attached video show the Qi of satellite E3 was dropped from 7 to 0 when signal lost, and then back to 7 when the receiver re-lock the satellite. 'Qi' change from 7 to other values refers to cycle slip. Cycle slip can be caused by deep rapid signal fading [3]. When the receiver detects the cycle slip for a satellite, it will not use this satellite for RTK positioning.

The number of satellites used in RTK is less than others is because the u-blox M8P does not support the GALILEO system.

Value	Description	Additional remarks
0	no signal	
1	searching signal	
2	signal acquired	
3	signal detected but unusable	
4	code locked and time synchronized	
5	code and carrier locked and time synchronized	carrier lock has not been achieved
6	code and carrier locked and time synchronized	carrier lock is intermittent
7	code and carrier locked and time synchronized	carrier lock achieved

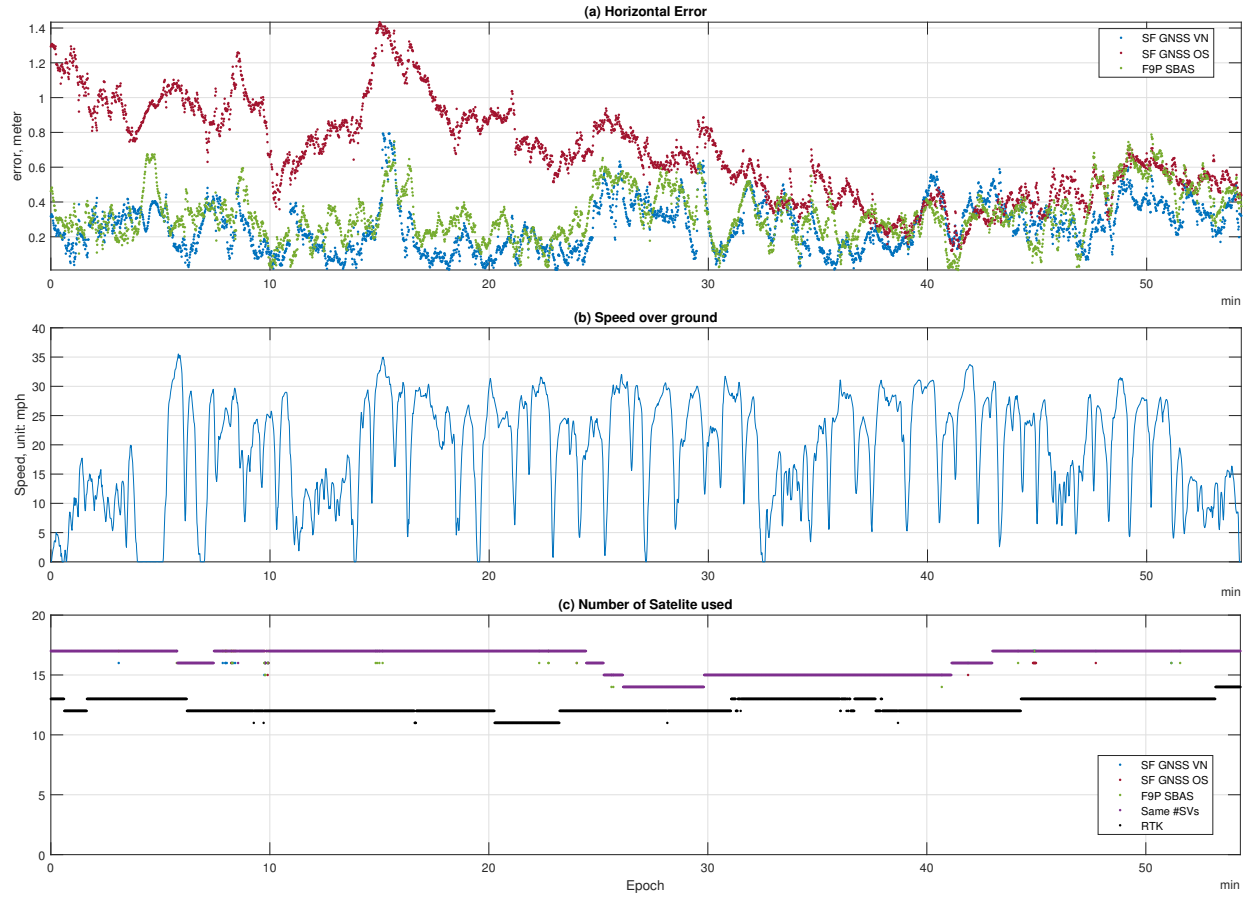Table 1: Definition of signal quality indicator

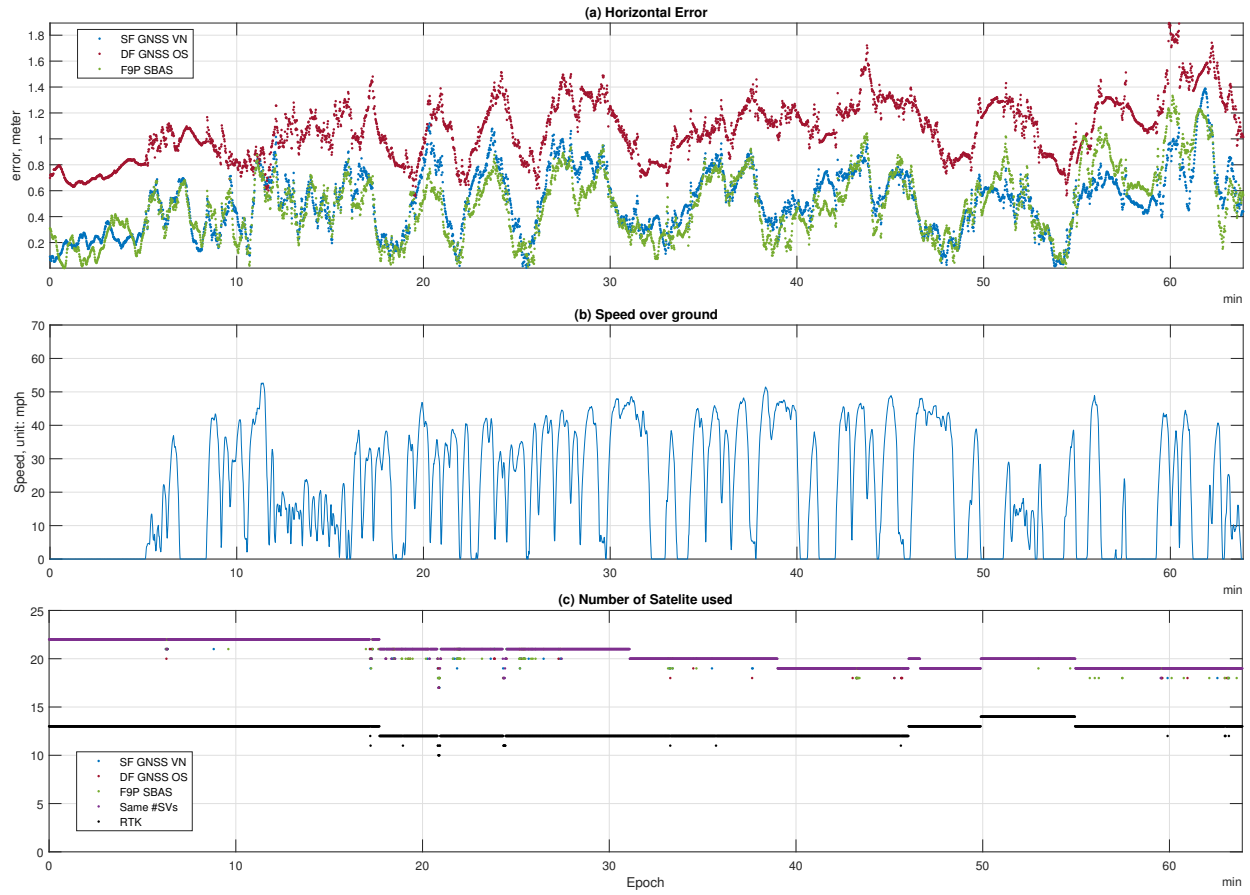Figure 4: Vehicle speed and number of satellites used for moving test using single band antenna.

Figure 5: Vehicle speed and number of satellites used for moving test using dual band antenna.

References

[1] W. Hu, A. Neupane, and J. A. Farrell, "Using ppp information to implement a global real-time virtual network dgnss approach," *arXiv preprint arXiv:2110.14763*, 2021.

[2] "u-center GNSS evaluation software for Windows: User guide," *u-blox company*.

[3] J. W. Sennott and D. Senffner, "The use of satellite geometry for prevention of cycle slips in a GPS processor," *NAVIGATION, Journal of the Institute of Navigation*, vol. 39, no. 2, pp. 217–236, 1992.