Experiment Analysis Support Document

Wang Hu, and Jay A. Farrell

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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.
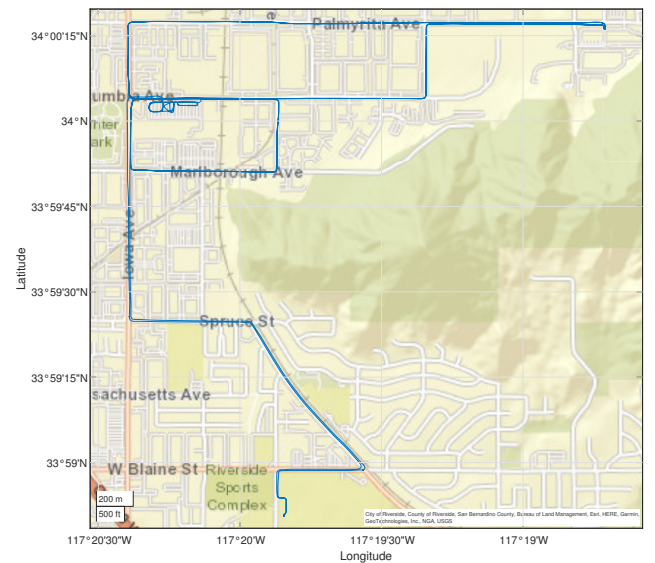
2   Moving test

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 (VN-DGNSS repository: `https://github.com/Azurehappen/Virtual-Network-DGNSS-Project`.). 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.

2.1   Vehicle Trajectories

Fig. 1a and Fig. 1b show the vehicle trajectory for the moving test using single-band and dual-band antenna, respectively. Since the receivers were all connected to the same antenna, the effects on the experiment of the surroundings are the same for all receivers.
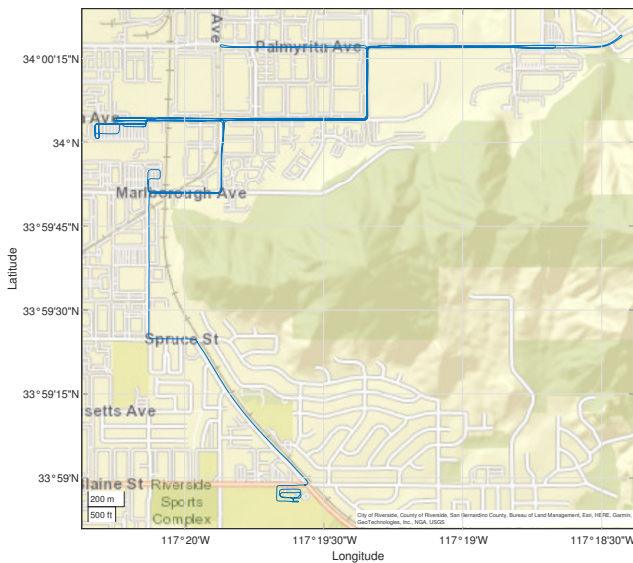
(a) Vehicle trajectory for moving test using single band antenna.

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

Figure 1: Vehicle trajectory for moving test.

2.2 Satellite Sky Plots

The sky plots in Fig. 2 and 3 show the satellites that were tracked during the F9P SBAS experiment. Fig. 2a and Fig. 3a show the sky plots with satellite ID marking its final location. Each satellite includes a system identifier: 'G' stands for GPS, 'E' stands for Galileo, 'B' stands for BeiDou. The number following the system identifier is the satellite PRN. The receivers using the VN-DGNSS approach do not use SBAS satellites. The receiver performing RTK did not have SBAS and Galileo satellites because u-blox M8P does not support them.

Fig. 2b and Fig. 3b more clearly show each satellite orbit, without the satellite ID. Green indicates those satellite used in navigation. Cyan indicates satellites whose signal was available but not used because their elevation is lower than the elevation that user set. Purple indicates satellites whose signal was available but not use in navigation for other reasons. Red indicates satellites whose signal is not available. Several reasons will cause purple or red [2], e.g.: unhealthy status reported by satellite, lack of ephemeris, low signal strength, below the elevation cutoff angle. The orbits for some satellites, such as B21, E5, and G24, change colors in Figs. 2 and Fig. 3. This means that their available or unavailable status changed during the time interval of the experiment. For example, when a satellite is at a low elevation and rising, it may switch from unavailable to available.

2.3 Vehicle Speed, Number of Satellites, and Signal Quality during the Moving Tests

Fig. 4a and Fig. 5a show the horizontal position error relative to the RTK ground truth trajectory as discussed in Section VI.D of [1]. Fig. 4b and Fig. 5b show the vehicle speed over ground as computed using the RTK data.

Fig. 4c and Fig. 5c show the number of satellites used in the navigation solution for each of the experimental configurations listed by acronym in Table IV of [1]. The number of satellites per experimental configuration are similar, and always more than sufficient to yield a good GDOP, but have minor variations. The purple line in Fig. 4c shows that the SF GNSS OS, F9P SBAS, SF GNSS VN configurations all use the same number of satellites. These numbers do not count for the SBAS satellites since they provides corrections, but are not used for positioning. The number of satellites used in RTK is less than others is because the u-blox M8P does not support the Galileo system.

The reason that the number of satellites change is satellite signal loss. The attached video shows an example of the satellite information interface from the u-center during rerun of the moving test data from the F9P SBAS experiment. The following definitions are required to support the discussion:

- The column 'Qi' is the signal quality indicator. The values of 'Qi' are defined in Table 1. Each satellite will only be used for pseudorange positioning when $Qi \geq 4$. Use of carrier data for RTK, requires $Qi = 7$.

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

When a satellite's signal fades, is blocked by obstructions, or a cycle slip is detected [3], the receiver may change the signal quality indicator to code unlocked statuses ($Qi = 0, 1, 2, 3$). Fig. 6 and the attached video show the Qi of satellite E3 was dropped from 7 to 0 when the signal was lost. Then, the Qi changes back to 7 when the receiver re-locks the satellite. In Fig. 6b, satellite E3 is not used when $Qi \geq 4$, which explains the change in the total number of satellites used as shown in Fig. 6a.

| 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

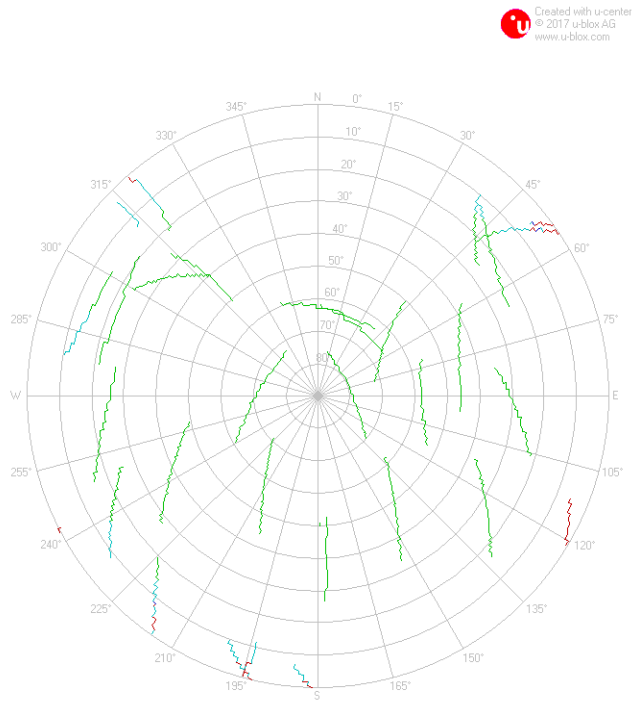Table 1: Definition of signal quality indicator
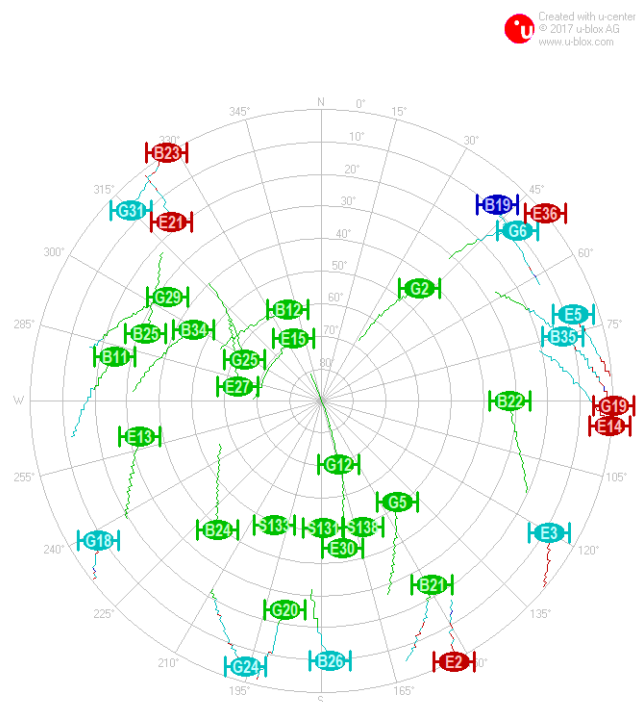
(a) With satellite ID.
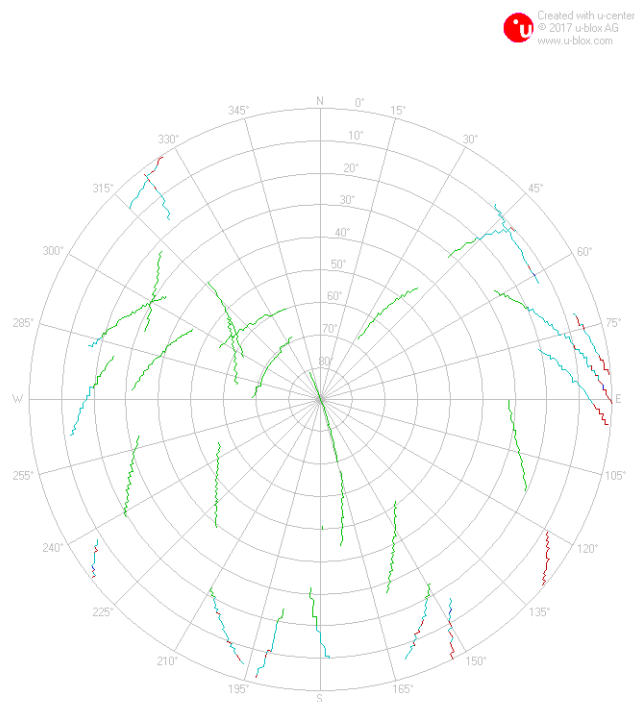
(b) Without satellite ID.

Figure 2: Sky plot and satellite orbit during the moving test that used the single band antenna.
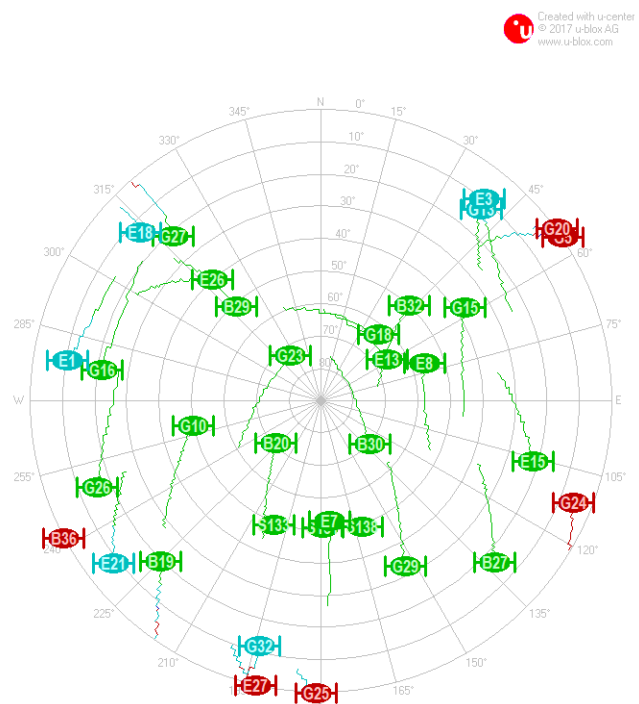
(a) With satellite ID.

(b) Without satellite ID.

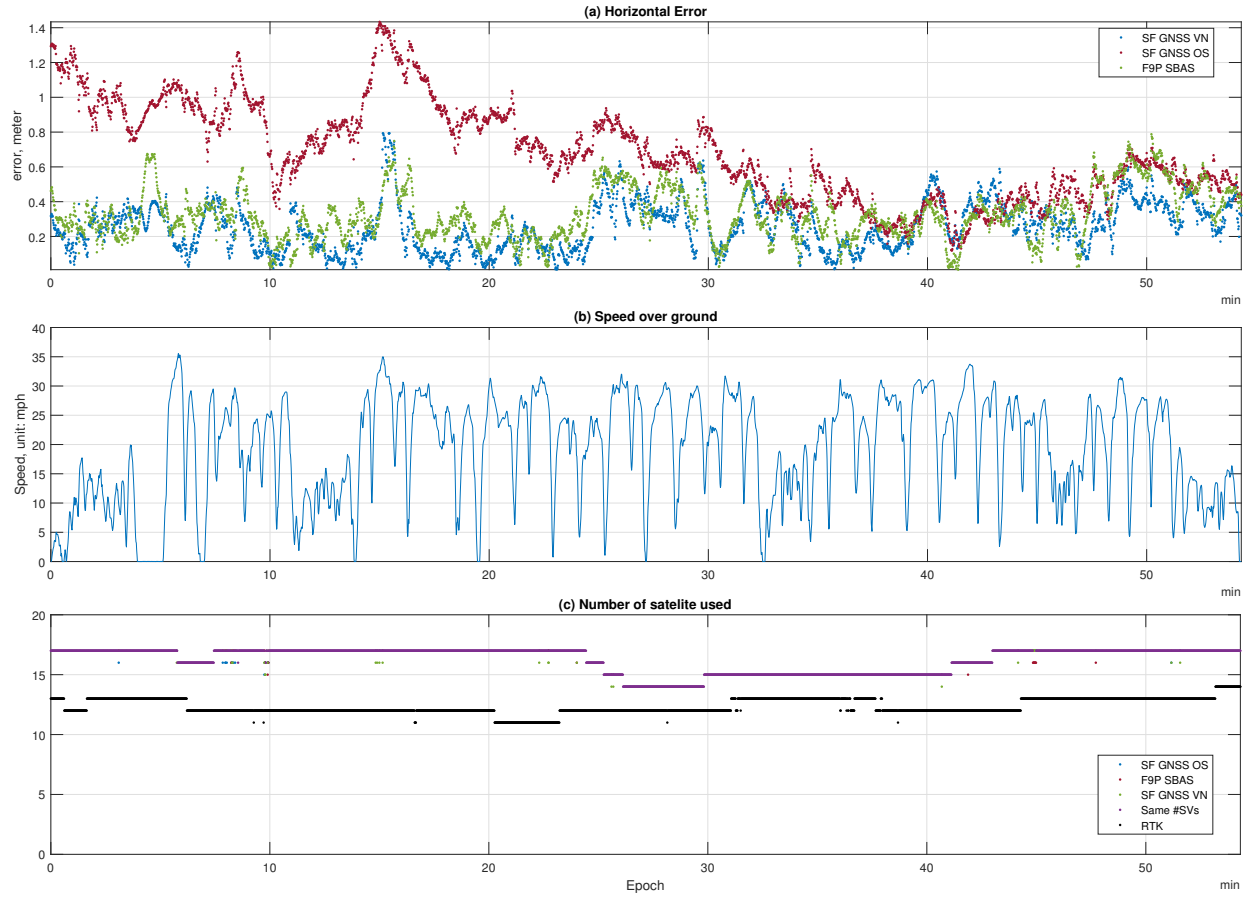Figure 3: Sky plot and satellite orbit during moving test that used the dual band antenna.

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

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[1] TO DO: WH: Please address the following:

1. See the marked up pdf. Implement all changes.

2. In tex documents, never hardcode a table or biblio entry. Use labels. I had to fix two in this document.

3. There are two moving experiments. Clearly state which experiment corresponds with Fig. 6 .

4. The horizontal axis of Fig. 6 needs to match the units of Figs 4 and 5. One is in epochs while the other is in minutes. When I look at Fig. 6, I should be able to see the same number of satellites use in one of Figs 4 and 5.

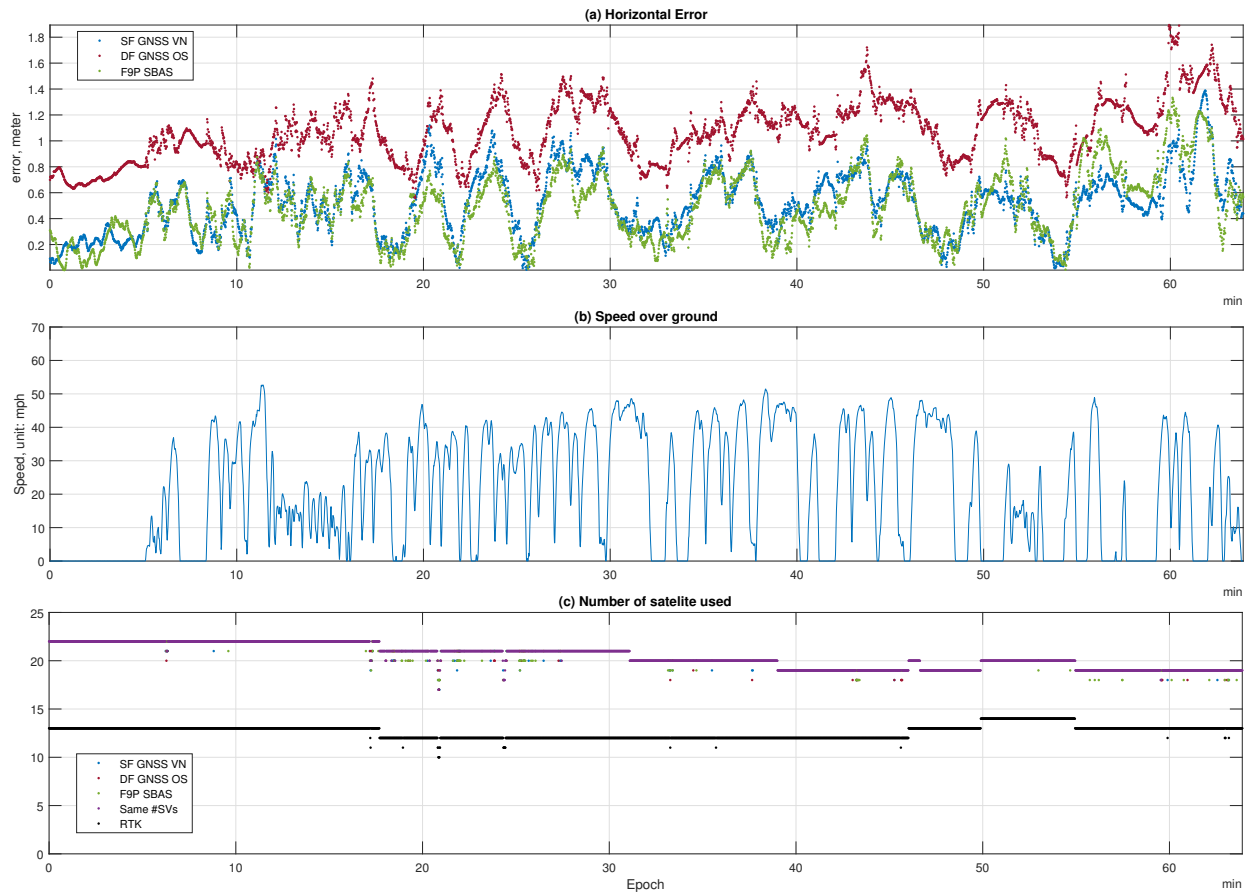I have made changes throughout. Please proofread carefully

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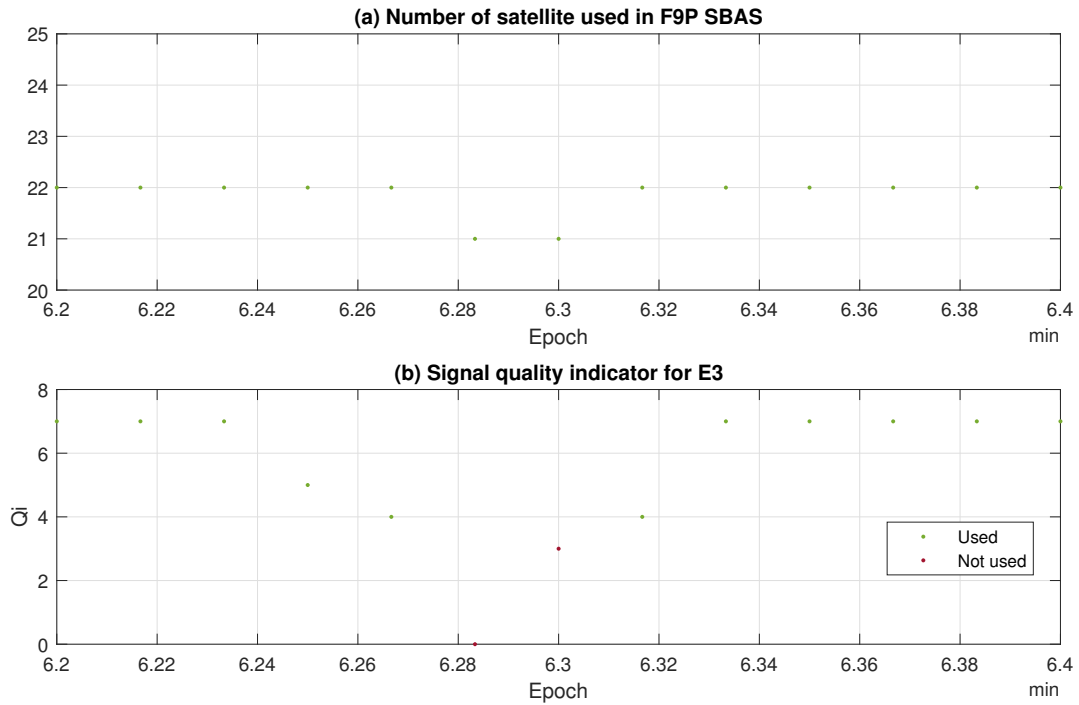

Figure 6: An example of signal quality indicator corresponding to satellite usage status.

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.