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role when GNSS receivers calculate positions by measuring pseudo-distances to transmitting satellites. A GNSS receiver performance mainly depends on the signal power in the receiver's tracking loops [2].

There are several methods to measure the GNSS signal strength. However, as the data sent by GNSS are through radio signals, it is a known fact that radio signals cannot maintain their strength for longer distances. The GNSS system employs phase modulation to superimpose data on the radio signals for better reception by the GNSS receiver and the manufacturers employ different algorithms to retrieve the data from the signals for offering the desired data.

All the factors correlating with the elevation angle of the transmitted GNSS signals like the SNR normally grow with increasing satellite elevation angle. SNR is usually expressed in decibels and it refers to the ratio of the signal power and noise power in a given bandwidth. Due to the fact that noise and signal are amplified in the same way, these ratios can be expressed as [3]:

$$\frac{C_{ant}}{N_{ant}} \approx \frac{S_{corr}}{N_{corr}} \approx S \quad (3)$$

Signal to noise ratio can usually be found in the context of signal baseband of the modulated signal at correlator output (S_{corr}). The quality of a received GNSS signal is commonly described by carrier to noise ratio of the modulated carrier at the receiving antenna (C_{ant}). The system noise affects the signal quality and the noise and signal are amplified in the same way in the antenna (N_{ant}) and at the correlator output (N_{corr}). As the system noise is several magnitudes smaller than C_{ant} and $S_{corr,}$ therefore the values are normally converted to decibels (dB) to represent a specific bandwidth, thus:

$$S(dB) = 10.log_{10}(S) \quad \text{and} \quad (4)$$

$$SNR(dB) = S/N \quad (5)$$

Assuming the GNSS signal strength is S and the noise level is N, the basic formula to measure the GNSS signal strength is S/N. If the carrier waves facing obstructions, S will get affected by attenuation, because many signals have a very wide dynamic range and are expressed using the logarithmic decibel scale, signal and noise may be expressed in decibels (dB). Assuming the system noise (N_0) is several magnitudes smaller than the signal strength (S), the normalized signal quality is [3][4]:

$$SNR\,(dBHz) = S - N = 10.log_{10}(S)(dB) - (N_0.B_L)(dBHz) \quad (6)$$

The user should be careful when comparing different GNSS receivers, particularly for older models e.g. Trimble that provided the signal quality in "arbitrary manufacture unit" (AMU). AMU units are dependent and need to be converted by a conversion formula because the value can differ by up to 3 dB from the original value [4]. Different generations of GNSS satellites have inherently different signal strengths, which could cause different SNR values with nothing wrong at all.

Different GNSS receivers with the same antenna tracking the same satellite at the same time may provide different SNR values. These differences could be from band limitation or processing algorithms. In case of independent acquisition and tracking algorithms used by a receiver, the values could be considered to indicate the quality of the received signal when antenna and receiver type, design, and performance are neglected. Hence the SNR depends on the receiver bandwidth, signal acquisition and tracking parameter.

In order to analyze the behavior of SNR and code multipath/noise, all GNSS signals were processed. By using an epoch by epoch method, each epoch was processed to get SNR and code range residuals and then an averaging method was adapted to get mean values for the figures.

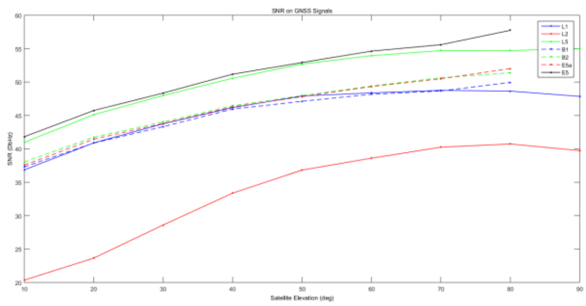

Fig. 2.3 SNR mean of GNSS signals (GPS, Galileo, and Beidou)

In case of the E1 Galileo signal, the SNR and the code multipath/noise residual seems to perform higher than the L1 GPS with up to 1-2 dBHz for signal strength and up to 0.1 m for residual difference, refer to figure 2.2 and 2.3. On the other hand, E5 Galileo performs best in SNR and code multipath/noise residuals at every station tested. When selecting promising signals for future real-time positioning, the combined E5 Galileo signal emerges as one of the alternatives (better than E5a) when using Galileo signals.

Because multipath errors are site-specific and particularly affect the code ranges, the use of E5 Galileo provides an advantage, as this signal shows a low multipath/noise residual behavior compared to all other GNSS signals. Moreover, due to its higher signal strength, the E5 Galileo signal is preferable for positioning because the signal is more resilient against outside interference than other GNSS signals and offers advantages to mitigate multipath/noise and ionospheric errors.

3. Performance Test

3.1 Relative Positioning

The performance of relative positioning was analyzed by using double difference (DD) positioning using carrier phase range that constructed by differencing two single

Modernized GNSS signals deliver a potency to provide best performance in static and kinematic positioning. Compared to GPS L1/L2 a clear advantage to use Galileo and Beidou linear combination becomes apparent in order to reduce signal noise and multipath significantly with reveals biases up to a few centimeters (~2 cm). These offsets might be caused by un-modeled intersystem biases between GPS, Galileo, and Beidou signals.

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