Double Block Zero Padding Acquisition Algorithm for GPS Software Receiver

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Abstract:
Several methods of acquisition have been developed so far which aim at accelerating the acquisition process and detection of weak GPS signals. In many of these the search is parallelized in code or frequency space. However, sometimes the number of samples in code periods based on sampling frequency is not equal to required number of Radix-2 FFT algorithm. So it is again computing the DFT normal method without FFT. The main purpose and objective of this project is to implement a fast and robust for weak signal acquisition algorithm "Double Block Zero Padding Acquisition" (DBZP) for GPS L1 civilian signal. Technique is developed even for the signals where number of samples in the code period taken for correlation is not satisfying the required number for Radix-2 algorithm. It is also suitable for weak GPS signals acquisition, which require Pre-detection, or integration (correlation) Time (PIT) to be long.

Keywords: *GPS, Acquisition, Weak Signal, Multi-Constellation, DBZP, FMDBZP.*

1. Introduction

The Global Satellite Navigation technology has been playing a key role in the positioning and navigation applications. GNSS at present is more useful to the military, safety of life applications and for civilian user applications. There is a need at present to design and development of such system with more accuracy and reliability than ever before. To use GPS receivers in these challenging conditions and environments, high sensitivity algorithms has to be used. Software GPS receivers are more flexible and suitable for research and development and also useful for integration with sensors.

All the conventional acquisition algorithms work well on strong GPS signals with minimum dwell time but for weak signals to detect by these algorithms [1], [2] the dwell time needs to be increased which leads to increase of computational load and hence gets slower. For detecting weak GPS signals (for example, $C/N0 < 30$ dBHz)[14], a GPS receiver has to perform either a coherent accumulation with long integration time T ($\gg$1 ms) or a non-coherent integration of multiple ($Nnc \gg 1$) coherent accumulation outputs with a less coherent integration interval Tco. [4], [5] In practice, however, both these methods are expensive in computation, the longer the coherent integration interval the more the Doppler frequency bins which leads to the smaller step size in Doppler frequency search. Therefore there will be an increase of computational cost in the weak GPS signal detection and which is inevitable. The goal or principle of acquisition is to get the rough estimates of code phase and carrier frequency [11] which are initial values or parameters given to tracking module.

2. Literature Survey

There are many acquisition methods available so far traditionally. The serial search in time domain is the most basic of the search strategies in terms of algorithm complexity, but because of this simplicity is also the slowest of all the acquisition strategies. In the parallel search all bins of one dimension (frequency or code delay) are searched at the same time. In parallel code phase search acquisition scheme if the input vector to the Fourier Transform is not a power (radix 2) then DFT is performed [13].

There are several acquisition methods which exploit the circular correlation, to name a few like coherent integration, half sized circular correlation. The goal of these techniques is always to reduce the computation time and enhance sensitivity. The acquisition step requiring a lot of time and operations, there are many developed techniques, some of them are not based on circular correlation. This GNSS [3] receiver is meant for educational and research purposes, then the software technology is well adopted due to its reconfigurable nature and important flexibility.

The efficient and fast acquisition of GPS L1 [2] signal is still a challenge. An acquisition technique which seems adapted to these purpose due to its efficiency and computational speed is the Double Block Zero Padding (DBZP) [14], [15]. By comparing 8 of the previously cited acquisition methods, it was concluded that the DBZP seems to be one of the best for the acquisition of weak signals due to the reduced number of operations. DBZP is found as a relevant method to be used as a base for developing a new Galileo E1 OS [14] acquisition technique.

3. Double Block Zero Padding

Double Block Zero Padding is a method more suitable for acquisition of weak signals. This method was also referred to as Circular Correlation by Partition and Zero Padding. This method performs long coherent integration with fewer operations and higher sensitivity than other FFT based techniques. The concept of this technique relies on the use of partial correlations on duration equivalent to a few tens of chips. The computation time gain of this method is the FFT processing on small size vectors instead of large size vectors.

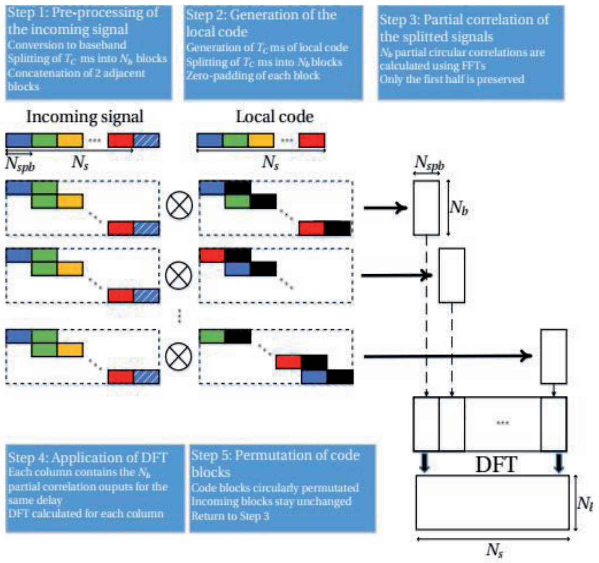

Fig. 1. Block diagram of DBZP

Figure 1 shows the block diagram of DBZP scheme, where the search is parallel in both code and frequency simultaneously and with partial correlations, where partial correlation length is generally taken as a fraction of spreading code period. This property enables this algorithm faster as well as highly computationally efficient.

The Doppler bins in double block-zero padding and their step value are fixed

$$N_b = \frac{f_{D,Max} - f_{D,Min}}{\frac{1}{T_C}} = 2f_{D,Max} \times T_C \quad (1)$$

As given below, the number of Doppler bins is always equal to the number of code delay blocks

– one block duration t_b is:

$$t_b = \frac{T_C}{N_b} = \frac{1}{2f_{D.Max}} \quad (2)$$

– the number of samples per block N_b is equal to:

$$N_{spb} = N_s / N_b = t_b \times f_s \quad (3)$$

– the Doppler frequency resolution Δ_f is:

$$\Delta_f = \frac{2f_{D.Max}}{N_b} = \frac{1}{T_C} \quad (4)$$

4. Implementation of DBZP

In total, there are five steps involved in this algorithm. Before defining and explaining step by step, we first define two parameters namely

- Coherent Integration Time (T_C),
- Maximum and Minimum Doppler Frequency ($f_{D,Max}, f_{D,Min}$).

The coherent integration time is defined as correlation time. The minimum integration time is 1 ms and is limited by the spreading sequence period. The minimum and the maximum Doppler frequency parameters represent the minimum and maximum variations from center carrier frequency as there is a relative motion between receiver and the satellites.

Step 1: Incoming signal Preprocessing. Figure 2 shows the preprocessing of incoming signal which is first step of this algorithm. The incoming complex data from the front end is converted into base band just by multiplying with the complex exponential function exp(j*2*π*f*n*T).

The resulting T_C ms long baseband samples are split into equal length of M blocks as shown in figure 2.

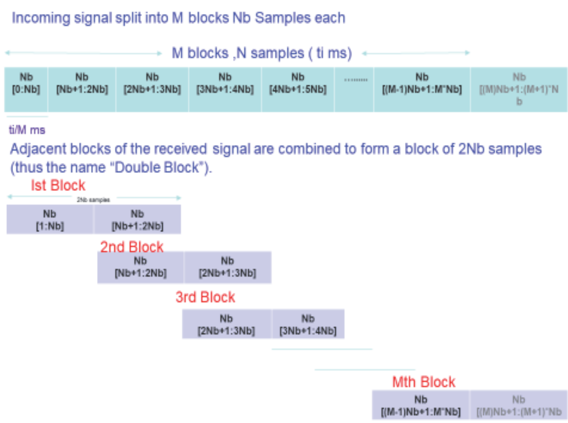

Fig. 2. Pre-processing of the incoming signal

Step 2: Local PRN spreading code. Figure 3 shows the generating local PRN spreading code. Second step in this method consists of generating local PRN spreading code, which is further split into same number of blocks as in step 1. After that each block is appended with same number of zeros to make it $2N_b$ Samples as shown in figure 3. The second box represents appended zeros of N_b samples, thus by adding those two blocks it makes $2N_b$ samples per each block.

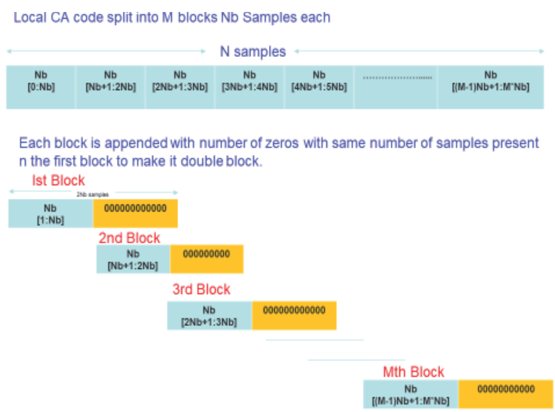

Fig. 3. Pre-processing of the local code

Step 3: Split signals and Partial correlations. The third step is to take the correlation output using FFT. The first two blocks of the incoming signal samples ($2N_b$ samples) and the first block of local PRN code along with the combined appended zeros block N_b samples of code and N_b samples of zeros are to be correlated using FFT method.

Zero-Padding is used in the DBZP acquisition method; when the padding of zeros is not used, the autocorrelation which is normalized function has a peak which suffers a degradation due to attenuation. When it is padded with zeros we can easily observe that there will be no degradation and the peak is isolated without any attenuation.

$$\left[T_0+(k-1)T_C+lt_b, T_0+(k-1)T_c+(l+1)t_b\right] \quad (5)$$

Furthermore, the phase at

$$t=T_o+(k-1)T_C+lt_b \quad (6)$$

The partial in-phase correlator output is

$$\tilde{i}(k)=\int_{To+(k-1)Tc+ltb}^{To+(k-1)Tc+(l+1)tb} B_{l+1}^{c}(t)*B_{l+1}^{s}dt \quad (7)$$

Finally

$$\tilde{I}_l(k)= \frac{A}{2}d(k)R_{c_1}\left(\varepsilon_\tau(k,l)\right)\cos\left(\pi f_D t_b+\varepsilon_{\varnothing_o}(k,l)\right)\mathrm{sinc}\left(\pi f_D t_b\right)+ \eta_{\tilde{I}_l}(k) \quad (8)$$

$$\sigma_{\tilde{n}}^2=\frac{N_o}{4t_b}=\frac{N_oN_b}{4T_C} \quad (9)$$

The partial correlator outputs for all permutations of the C/A code blocks are placed in a matrix form ($M \times N_b$).

Step 4: FFT application. FFT is applied to the partial correlation matrix output of size $M \times N_b$. An M point FFT is applied to each column corresponding to each delay and stored in another matrix column wise. The mathematical expression $(A/2)\,R_{c_1}(\varepsilon\tau)$ $\mathrm{sinc}(\pi f_D t_b)$ is constant for all l and can be approximated by $(A/2)\,R_{c_1}(\varepsilon\tau)\,\mathrm{sinc}(\pi f_D t_b)$ in the neighborhood of $\varepsilon\tau = 0$. Thus, the Fast Fourier Transform (FFT) of the partial correlator outputs will give the DBZP outputs.

$$L(k,m)= \frac{A}{2}d(k)R_{c_1}(\in_r)\mathrm{sinc}(\pi f_D t_b)F\Big(\cos\big(\pi f_D t_b+2\pi f_D l t_b + \in_{\varnothing_0}(k,0)\big)\Big)+\eta_l(m)\Big) \quad (10)$$

where:

$$(k)=\pi f_D t_b+\left((N_b-1)/N_b\right)(\pi f_D t_c-m)+\in_{\varnothing_0}(k,0)$$

– $m = 0 \ldots M$ – are the points FFT is taken which corresponds to a Doppler frequency bin.

Step 5: code block permutations. So far we tested for only one code delay time slice between $[0, t_b]$. C/A code blocks are permutated circularly in order to test for all code delays. On first permutation of local spreading block the last block appears to be the first block and the first block appears to be the second block.

5. Experimental Results

The DBZP and Parallel search in code and frequency algorithm is implemented in MATLAB. A Parallel search in code phase (1 ms integration time) + Parallel search in Frequency (10 ms integration time) Acquisition Algorithm using DFT.

GPS IF Data_1 specifications:
Filename=GPSdata-DiscreteComponents-fs4_774if1_1935_2MHz1.bin.
IF (Intermediate Frequency) = 1.19352MHz;
Sampling Frequency = 4.774MHz;
Data Type = int8;

Data contains strong satellite signals with PRNs 15, 18, 21, 22 along with weak signals 3, 6, 26.

Table 1. PRNs that are having a threshold 2.5 and above

PRN	Peak Metric	Code phase	Doppler
15	7.20	4606	1937.72
22	7.09	852	1710.08
21	5.26	1741	-557.24
18	4.35	2656	253.17

In Table 1, the peak metric is the ratio of first peak to second peak ratio. The figure 4 gives the peak for PRN 15.

The peaks for the PRNs 22, 21 and 18 are in the Figure 4, Figure 5 and Figure 6 respectively. The above same results may not be acquired for the weak signals. For the weak satellite vehicles like PRN 3, 6, 26 double block zero padding method is used, which suffers degradation due to attenuation. When it is padded with zeros we can easily observe that there will be no degradation and the peak is isolated without any attenuation

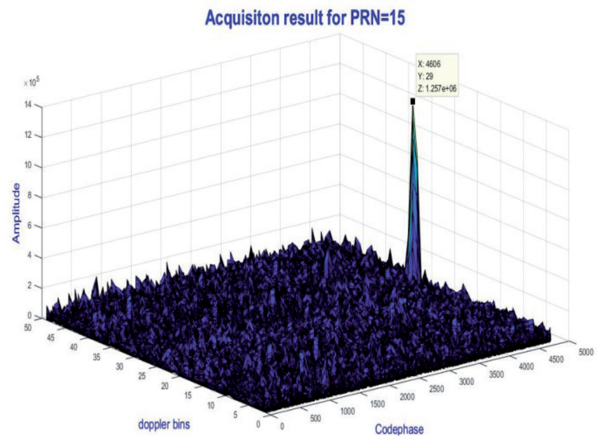

Fig. 4. Acquisition Result for PRN 15

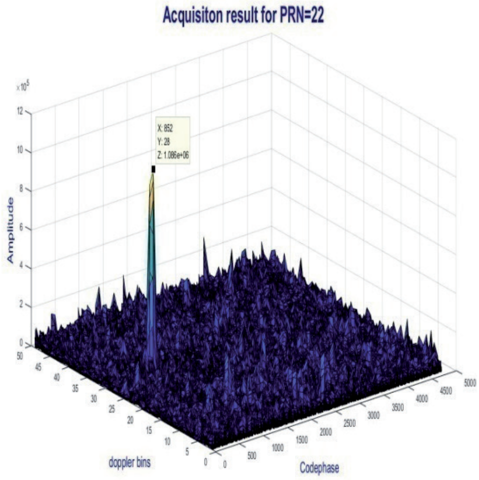

Fig. 5. Acquisition Result for PRN 22

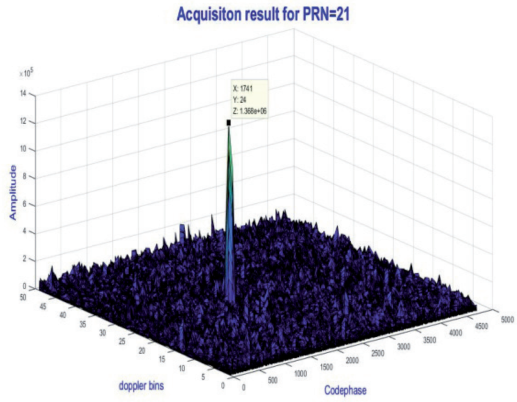

Fig. 6. Acquisition Result for PRN 21

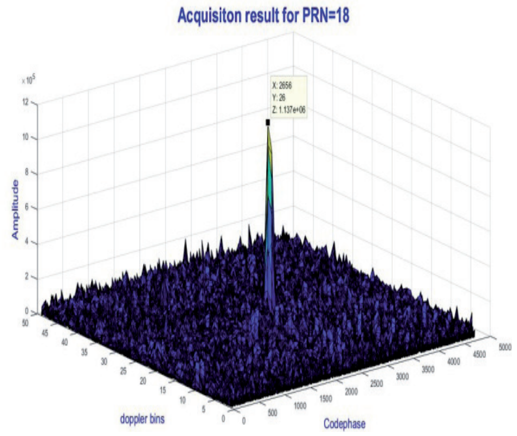

Fig. 7. Acquisition Result for PRN 18

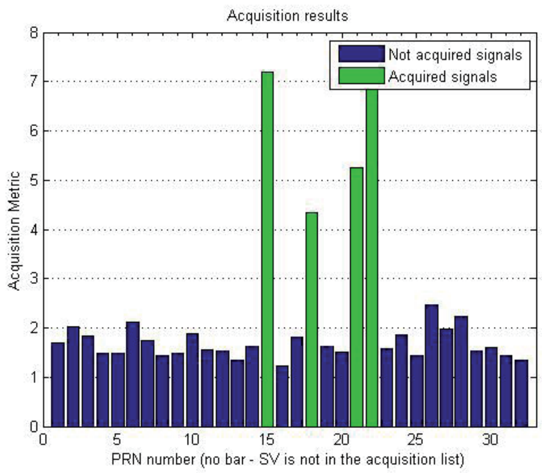

Fig. 8. Acquisition Results PRN vs Acquisition Metric

The Figure 8 shows the graph between acquisition metric and PRN number which in turn gives the information between acquired and not acquired signals.

Double block zero padding (DBZP) acquisition Algorithm for 10 ms Integration time

The DBZP method for 10 ms Integration time results the phase of the code and Doppler frequency as shown in Table 2.

Table 2. PRNs that are having a threshold 2.5 and above (DBZP)

PRN	Peak Metric	Code phase	Doppler
22	6.25	852	1800
18	5.27	2656	400
21	5.17	1741	-600
15	4.70	4606	2000
26	4.22	3419	-3000
6	3.56	3591	-3700
3	2.83	4342	2000

The acquisition results for weak signals by using DBZP acquisition algorithm is shown in the Figure 9, Figure 10 and Figure 11 respectively. The peak gives the PRNs 22, 18, 21 respectively.

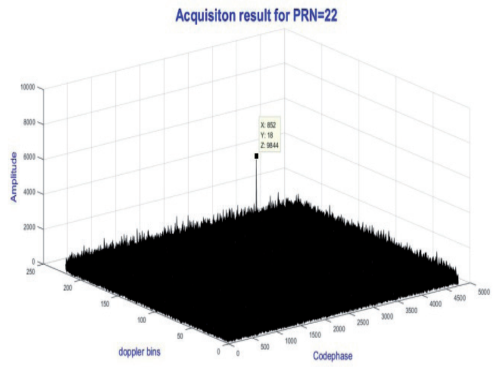

Fig. 9. Acquisition Result for PRN 22 (DBZP)

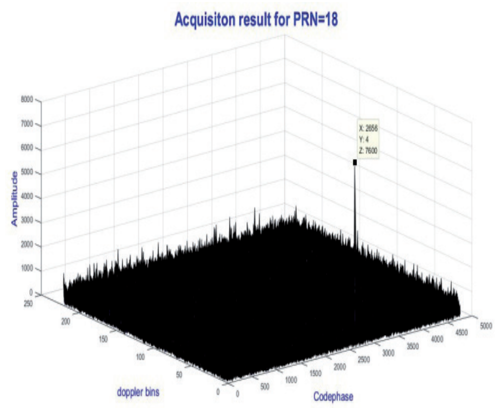

Fig. 10. Acquisition Result for PRN 18 (DBZP)

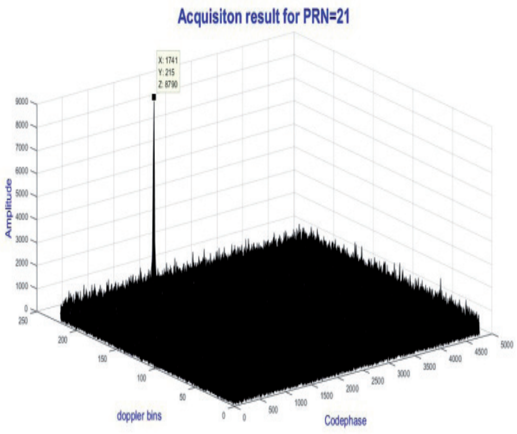

Fig. 11. Acquisition Result for PRN 21 (DBZP)

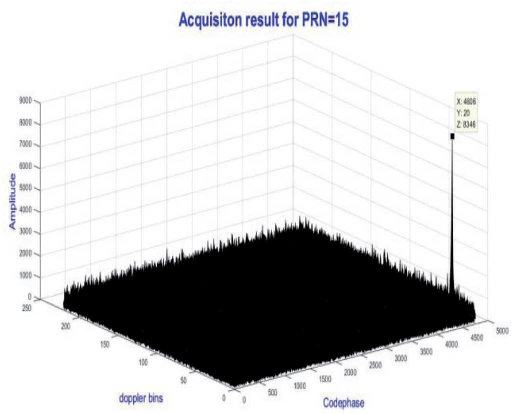

Fig. 12. Acquisition Result for PRN 15 (DBZP)

Figure 12 gives the acquisition result for PRN=15 using double block zero padding acquisition algorithm.

Comparison of Two Acquisition Schemes

Comparison of the above two methods is presented below and calculated absolute error and accuracy taking A Parallel search code phase (1 ms integration time) + Parallel search in Frequency (10 ms integration time) as reference acquisition scheme.

In DBZP scheme

PRNs 3, 6, 26 which are low sensitive satellite vehicles present in the data are detected by DBZP method of acquisition. DBZP acquisition method enhances peak metric of these PRNs approximately by 1.6 times. The table gives the comparison of peak metric with both the methods and corresponding increase in the peak metric value in decibels.

The Table 4 gives the comparison between peak metrics of weak satellites for 10 ms PIT by implementing double block zero padding acquisition algorithm.

The PRNs with the threshold value of 2.5 and above with code phase and Doppler is given in Table 5.

The absolute error and accuracy for the PRNs 15, 22, 21, 2, 10, 6, 3, 26 by taking parallel code phase search using FTT as 10 ms Doppler and 10 ms PIT is shown in Table 6.

Table 3. Comparison results (DBZP vs DFT method)

PRN	Parallel Code Phase Search using DFT (10 ms) Doppler X	DBZP Doppler (10 ms PIT) Y	% absolute error |(X-Y)/X*100|	% accuracy (100-% absolute error)
15	1937.72	1900	1.946	98.053
22	1710.08	1700	0.589	99.410
21	-557.24	-600	7.67	92.326
18	253.17	300	18.49	81.50

Table 4. Comparison of Weak satellite peak metrics

PRN	Parallel Code Phase Search using DFT (10ms) Peak Metric	DBZP (10ms PIT) Peak Metric	Increase in Peak metric
26	2.48	4.22	1.701
6	2.12	3.56	1.67
3	1.82	2.83	1.55

Table 5. PRNs that are having a threshold 2.5 and above

PRN	Peak Metric	Code phase	Doppler
15	10.69	4606	1937.72
22	6.88	852	1710.08
21	4.66	1741	-557.24
2	3.08	3714	81412.12
10	2.95	203	5243.08
6	2.84	3592	-3671.38
3	2.81	4342	1919.51
26	2.67	3419	-2970.24

Table 6. Comparison results (DBZP vs FFT method)

PRN	Parallel Code Phase Search using FFT (10 ms) Doppler	DBZP Doppler (10 ms PIT)	% absolute error	% accuracy
15	1937.72	1900	1.946	98.053
22	1710.08	1700	0.589	99.410
21	-557.24	-600	7.67	92.326
2	81412.12	9900	87.83	12.160
10	5243.08	7900	50.67	49.32
6	3671.38	-3700	0.77	99.23
3	1919.51	1900	1.01	98.98
26	2970.24	-3000	1.00	99

By using double block zero padding acquisition method, the PRNs 3, 6, 26 being low sensitive satellite vehicles present in the data enhances peak metric by 1.6 times when compared with other traditional acquisition methods by using double block zero padding acquisition algorithm which is shown in Table 6.

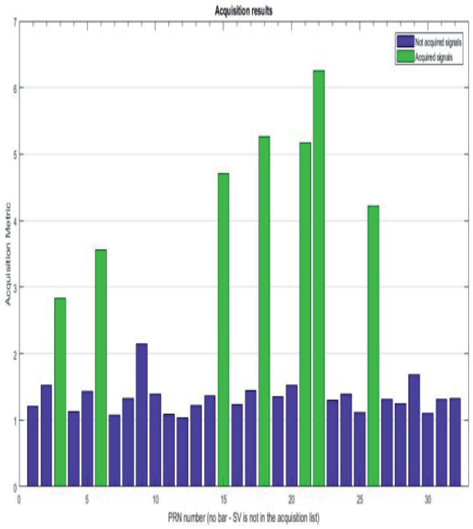

Fig. 13. Acquisition Results PRN vs Acquisition Metric

The graph between acquisition results and acquisition metric of PRNs using double block zero padding acquisition method by showing acquired signals in green color and non acquired signals in blue color is shown in Figure 13.

6. Conclusion

DBZP method is used in this work, where both code phase and Doppler search take place in parallel and the FFT vector is small compared to Parallel code phase search. This makes the algorithm execution very fast compared to 1+1 ms acquisition method which is mentioned in the literature. The DBZP scheme is implemented and tested in Matlab. It detects weak signals that are present in the IF data. The comparison of results both in absolute error and accuracy is presented. The results are shown in section 5 which shows that it can detect weak signals as compared to the other existing schemes of acquisition and the execution time is also faster due to the partial correlations. Since the FFT length is smaller, the correlations time is also lesser. So we can conclude that by replacing the traditional acquisition schemes in the software receiver with this new method makes the receiver work effectively even for weak signals. Hence it may enable the receiver to give the services indoor or in heavy canopy or in a high vegetation environments.

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