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Analysis of Near-Far Problem using Power Control Technique for GNSS based Applications

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ABSTRACT: *Global Navigation Satellite Systems (GNSS) such as Global Positioning System (GPS), GALILEO and GLONASS need atleast four satellite signals to find out the accurate position. But in some areas, due to the non-availability or blockage of the signals, GNSS alone doesn't provide the accurate position of the object. Pseudolites (PLs) are ground based transmitters which provide GPS like signals that augment GNSS constellations to enhance the accuracy, integrity, continuity and availability. However, Near-Far effect which reduces the service area is one of the major problems where pseudolites are used. In order to account for such a problem, a step-by-step power control technique has been proposed to enlarge the service area. Simulation results show that the PL with step-by-step power control outperforms much better than conventional PL. The service area using proposed PL resulted in 4 times wider service area than conventional PL. Also, coverage and outage probability are analytically obtained and comparative analysis of coverage probability for conventional and proposed PL has been presented.*

KEY WORDS: Pseudolite, Near-far, Coverage probability, Outage probability**.**

I. INTRODUCTION

The Global Positioning System (GPS) developed by the U.S Department of Defence (DOD), GLONASS of the Russian Federation and GALILEO of the European Union are worldwide, satellite based navigation systems used for finding out the current three dimensional location. The accuracy, availability and continuity of the GNSS-based positioning services depend heavily on the number of satellites being tracked. But, there are times when the GNSS receiver is located in areas such as urban canyons and deep open cut mines etc, it is not able to receive signals from sufficient number of satellites for positioning. Hence, Pseudolites or Pseudo-satellites (PLs) which are ground-based transmitters can be employed for providing additional navigation ranging signals forming a Local Area Augmentation System (LAAS). Generally, PLs can be installed whenever they are needed; when placed appropriately, they can provide additional signals to users in locations that obscure signals from GNSS satellites.The PLs can significantly enhance the satellite geometry, and when used in multiple numbers it can even form a GPS constellation independent navigation system for use over smaller local area.

The principle of PL is directly derived from the GPS technology. However, some of its features that differ from GPS are

- The 50 bps data messages of PLs are different.
- PL uses a low price, relatively less stable TCXO (Temperature Compensated Crystal Oscillator).
- Ionospheric errors are ignored in PL due to its fixed location near the ground.
- The PLs expected ranges are much more dynamic due to its power variation with respect to distance.

The origin of PL is proposed in a navigation experiment using terrestrial transmitters conducted at the United States in 1973, the confirmation phase of satellite navigation of GPS [1]. However, setting the PL transmission power to cover the desired service area occasionally blocks the signals from the satellites. This is because the receiver in the close proximity to the PL, and the phenomenon is referred to as the Near-Far problem.The various techniques to mitigate the Near-far problem are spreading PRN codes, Frequency offset, frequency hopping, Successive Interference Cancellation (SIC), Signal pulsing and power control technique. Among all, power control technique has found to be most component technique for Near-Far problem. In 1986, the Radio Technical Committee for Marine Service (RTCM) proposed the burst pulse transmission for PL. In that report, the duty ratio should be less than 10%, and RTCM recommended to set the duty ratio as 1/11. For indoors where the satellite signals are unavailable, a repeater satellite was proposed [2]. An experiment of repealite was proposed using a GPS signal generator and Radio of Fibre (ROF) [3]. GPS satellite reception experiment was conducted in metropolitan Tokya areas to obtain statistical visibility of communication satellites [4].

In this paper, a method of reducing the transmission power of pseudolite step-by-step has been proposed to overcome the near-far problem. The method doesn't need any modifications of the commercial receiver and the assumption is that reception signal from PL does not vary due to the reception antenna directivity, but varies with the shadowing.

II. NEAR-FAR PROBLEM

The 'near-far' problem occurs when the power of the signal received from one transmitter is so strong that the signal received from another transmitter is completely jammed. This arises due to the large variation between the transmitter and receiver range. The average power being received from the GPS Satellite Vehicles (SVs) remains approximately constant due to the large distance of the satellites from users. The PL power varies with the inverse square of the user's distance from the PL, compared to constant power from Satellite Vehicle [5]. As a result, in certain regions called as near region, when the receiver is close to the PL, the signals from it cause interference with the GPS satellite signals and may jam the receiver. However, beyond a particular distance away from the PL called as far region, the PL signals will be too weak to be tracked by the GPS receiver as shown in the Figure1. To navigate with signals from both GPS and PL, the receiver must remain in the zone between these two boundaries called as Effective Dynamic Range (EDR) or Service Area, where both sets of signals can be tracked. EDR is defined as the ratio of the strongest and the weakest signals that the receiver can demodulate without excessive noise or distortion.

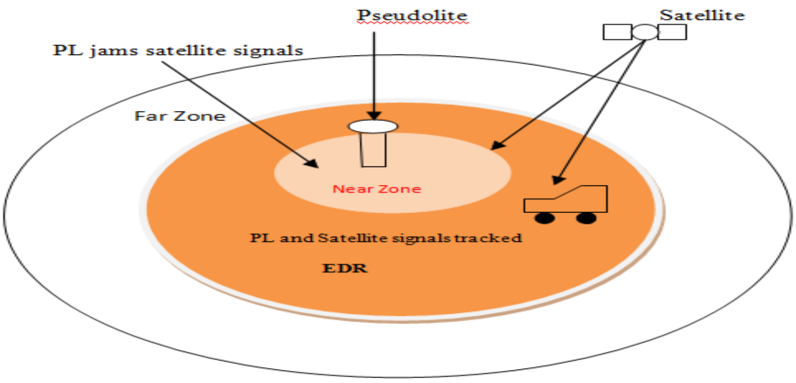

Figure 1.Near-Far regions

For example, we assume service area of 500m radius and the reception power of PL at the service area fringe is set to the minimum reception power of -130dBm. Then, the reception power at a location whose distance from PL is 10m is 20log (500/10) =33 dB higher than the minimum reception power (i.e,-97dBm) and it results in blocking of the satellite signal.

III. PROPOSAL OF A PSEUDOLITE WITH STEP-BY-STEP POWER CONTROL

A step-by-step reduction of pseudolite transmission power has been proposed to overcome near-far effect. In this method, PL power is transmitted in the form of pulses with different power levels and the analysis of near-far mitigation is observed by obtaining the coverage and outage probability of pseudolite.

A. Cell Designing Method for Cellular Communications

If the distance between transmission and the reception antennas is increased then the radio wave signal strength is exponentially decreased whose statistic is log-normal distribution [6]. Buildings, cars, and human bodies would shadow the radio wave path and the shadowing also attenuates the radio wave. In these environments, the receiver needs the signal above the minimum reception power within the desired area. The method of finding out the transmission power under such environments is explained in reference [7]. The reception power in decibels P_r (d) at the distance d can expressed as

$$P_r (d) = P_t - 20\log_{10} K - 10\gamma\log_{10} d/d_o - \varphi dB \qquad (1)$$

Where P_t is the transmission power in decibels, K is the ratio of the transmission and reception powers at a distance of d_o, γ is the attenuation coefficient with respect to change in distance, φ dB is a Zero mean Gaussian random variable. The relation between received power with respect to distance at a power of -10dBm is shown in Figure2.

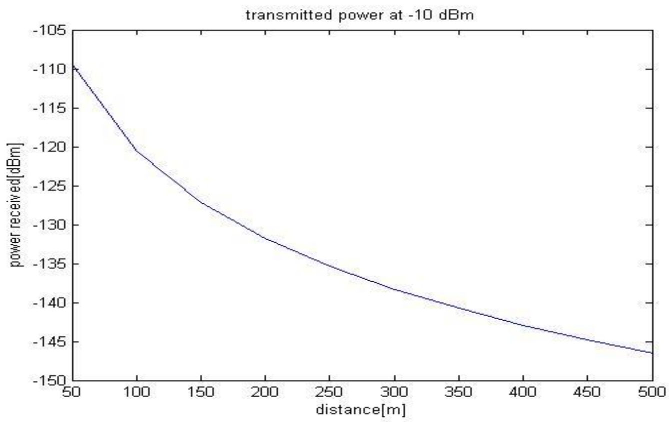

Figure2. Variation of received power with respect to distance

The outage probability P_{out} (P_{min}, d) is the probability that the reception signal power P_r (d) is below the minimum reception power P_{min}

$$P_{out}(P_{min}, d) = p(P_r(d) < P_{min}) = 1 - Q\left(\frac{p_{min} - \overline{p_r(d)}}{\sigma dB}\right) \quad (2)$$

where $P_r\overline{(d)}$ is the mean reception power at d

$$P_r\overline{(d)} = Pt - 20\log_{10} K - 10\gamma\log_{10} d/d_o$$

K is the power ratio at d0, and

$$Q(z) = \int_z^{\infty} \frac{1}{\sqrt{2\Pi}} \exp\left(\frac{-x^2}{2}\right) dx$$

is the Q-function ,the probability that a Zero-mean Gaussian random variable with a variance of 1 exceeds z, and Q(z) is 1/2erfc(z/1.414).

If the service area of the communication systems is considered as a circle with a radius R and the location of transmitting antenna at the centre, then the coverage probability one can use the system within the desired area is derived by partial integration as [7].

$$C = \frac{1}{\Pi R^2} \int_0^{2\Pi} \int_0^{R} \{1 - P_{out}(P_{min}, r)\} r dr d\theta$$

$$= \frac{2}{R^2} \int_0^{R} r Q\left(a + b \log \frac{r}{R}\right) dr$$

$$C = Q(a) + \exp\left(\frac{2 - 2ab}{b^2}\right) Q\left(\frac{2 - ab}{b}\right) \quad (3)$$

where

$$a = \frac{\overline{p_{min}} - \overline{p_r(R)}}{\sigma dB}, b = \frac{10\gamma \log_{10} e}{\sigma dB}$$

Assuming K is the free space propagation loss at d_0=1m

$$K = 4\pi/\lambda = 65.991$$

where the operating frequency is 1575.42 MHz (L1 frequency of GPS). Considering P_{min} as -130dBm, R=500m, σ as 3.65dB and γ =3.71, the outage probability and the coverage probability as a function of transmission power are calculated and plotted in Figure 5. The values of the parameters were derived by cellular system measurements in [6].

B. Coverage Probability of Pseudolite

First, the coverage probability and the outage probability of a PL will be obtained by using the cell designing concept. The PL is available when the reception power $P_r(d)$ is between P_{min} and P_{max}. So, the outage probability of PL can be derived by changing Eq. (2) as

$$P_{out}(P_{min}, P_{max}, d) = p(P_r(d) < P_{min} \mid P_r(d) < P_{max})$$

$$= 1 - Q\left(\frac{p_{min} - \overline{p_r(d)}}{\sigma dB}\right) + Q\left(\frac{p_{max} - \overline{p_r(d)}}{\sigma dB}\right) \quad (4)$$

The Coverage probability of the service area assuming the radius of R is calculated using Eq. (3) as

$$C = \frac{1}{\Pi R^2}\int_0^{2\Pi}\int_0^R \{1 - P_{out}(P_{min}, P_{max} r)\} r dr d\theta$$

$$= \frac{2}{R^2}\int_0^R rQ\left(a + b\log\frac{r}{R}\right)dr - \frac{2}{R^2}\int_0^R rQ\left(a + b\log\frac{r}{R}\right)dr$$

$$= Q(a) + \exp\left(\frac{2 - 2a_{min}b}{b^2}\right)Q\left(\frac{2 - a_{min}b}{b}\right) - \exp\left(\frac{2 - 2a_{max}b}{b^2}\right)Q\left(\frac{2 - a_{max}b}{b}\right) \quad (5)$$

where

$$a_{min} = \frac{p_{min} - \overline{p_r(R)}}{\sigma dB}, a_{max} = \frac{p_{max} - \overline{p_r(R)}}{\sigma dB} b = \frac{10\gamma \log_{10} e}{\sigma dB}$$

The coverage probability within the desired service area and the outage probability at the service area fringe are shown in Figure 6.The transmission power P_t was set where the reception power at the service area fringe was -130dBm as Pmin. The outage probability at the service area fringe can be reduced and increase the coverage probability as an increase in the transmission power, but the coverage probability was decreased when the transmission power exceeds 10dBm and this is because of Near-Far problem as shown in Figure 6. Because of this problem, the maximum coverage probability was about 0.72.

C. Pseudolite with step-by-step power control

For mitigating the Near-Far problem, step-by-step power control of PL is proposed and is explained in Figure 3. The duty ratio, the normalized pulse duration, the pulse transmission cycle is 1, of the conventional PL is $\tau 1$ in Figure 3(a). On the other hand, the proposed PL shown in Figure 3(b) transmits the second pulse after the first pulse, and the duty ratio is $\tau 2$ and the power is reduced by α [dB] than the first pulse power and the procedure is repeated for third pulse and so on. The proposed PL is capable of providing a wider service area. The superposition of service area rings as shown in figure 4. Suppose if we transmit the first pulse at 10dBm that will covers an area of A1, then the second pulse is at (10-α) dBm and covers an area of A2 and the third pulse should transmit at (10-2α) dBm and covers an area of A3.Because area of the ring is in proportion to the radius and the radii are at regular interval in exponent, A3<A2<A1. For different radii R1=500m, R2=344m and R3=250m, the coverage probability is calculated for these service areas as a function of the PL transmission power with Eq. (5) and shown in Figure 7 at P_{max} =-122dBm, P_{min} =-130dBm, σdB=3.65, =3.71 and α=5 dB and there is an optimum transmission power for each service area radius and is shown in Figure. 7. The coverage probability was asymmetric with respect to the power, because excessive transmission power only reduces the coverage probability but a weaker transmission power provides coverage probability in the close proximity of the PL.

Next, the proposed PL coverage probability is calculated and is shown in Figure 9 at L1 (1575.42MHz) frequency and the proposed PL coverage probability is calculated by the way as 1-(1-C1) (1-C2).(1-C3) where C1,C2,C3 are the coverage probabilities for 1st pulse, 2nd pulse and 3rd pulse because the receiver is available when the receiver can use one of these pulses and the coverage probability is shown as total in the Figure 9, and the maximum coverage probability was about 0.89. The coverage probability in a shadowing environment at E5a or L5 (1176.44 MHz) frequency for different pulses is shown in Figure10 and the coverage probability of a proposed PL at E5a or L5 is shown in Figure11. The coverage probability of a PL in a shadowing environment at E5b (1207.10MHz) frequency is shown in Figure 12 and the coverage probability of a proposed PL at E5b is shown in Figure 13. The coverage probability of a PL in shadowing environment for different pulses at GLONASS satellite2 frequency and the proposed PL coverage probability at GLONSS satellite2 frequency i.e 1246.874 MHz is shown in Figure14, 15 respectively, and a comparison between the coverage probabilities of conventional and proposed PLs for different frequencies is shown in Table 1.

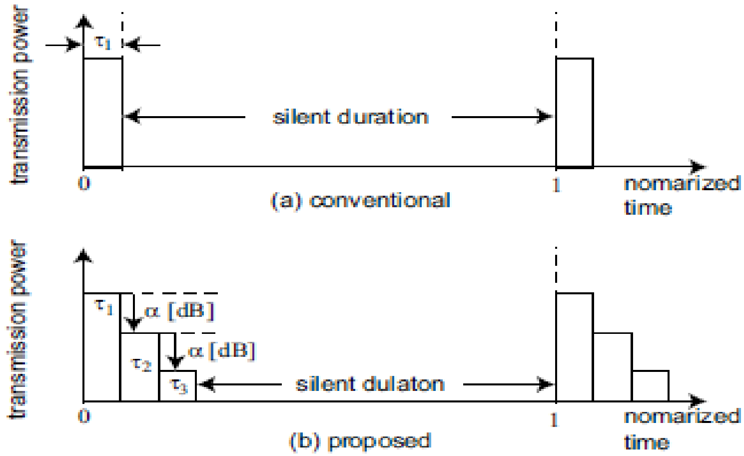

Figure 3.Transmission power of conventional and proposed pseudolite

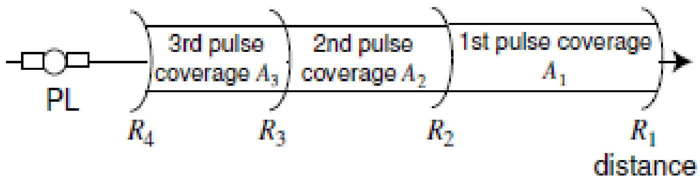

Figure 4.The service area of each pulse

IV. RESULTS AND DISCUSSIONS

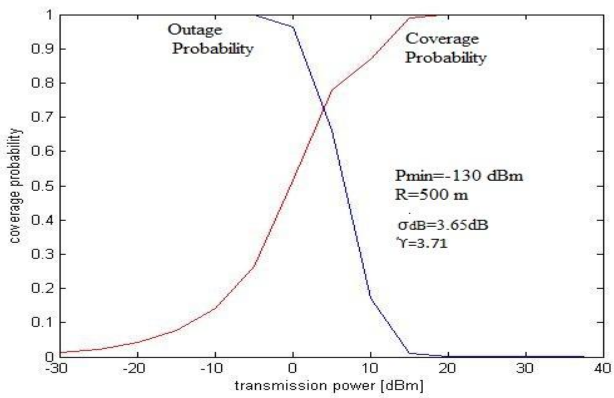

Figure5.Outage probability and the coverage probability the reception power is above the minimum reception

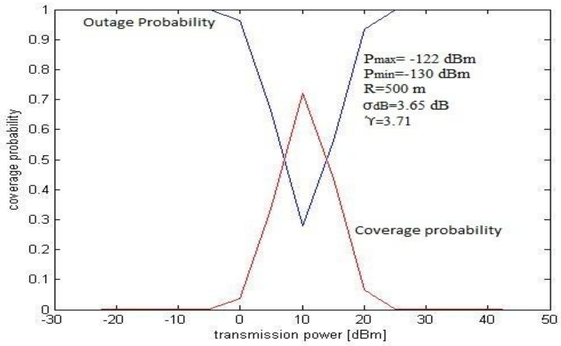

Figure6.The coverage probability and the outage probability of a PL

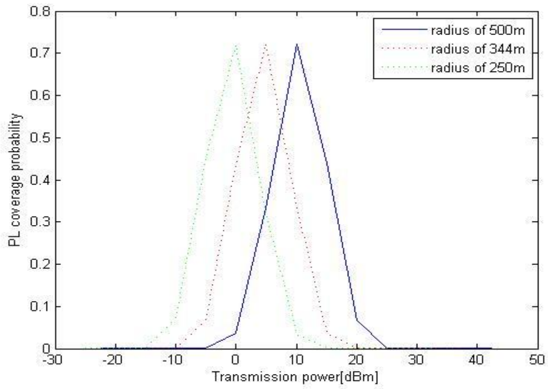

Figure 7.PL coverage probability as a function of transmission power

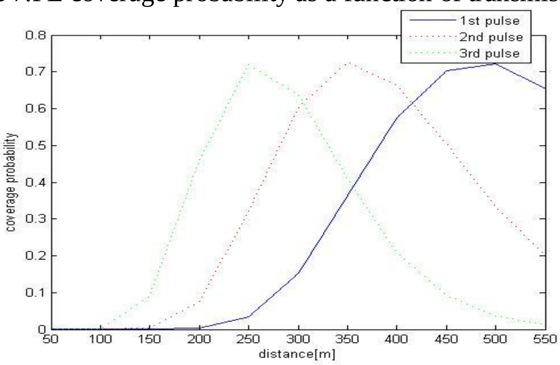

Figure8. Coverage probability of a PL in a shadowing environment at L1

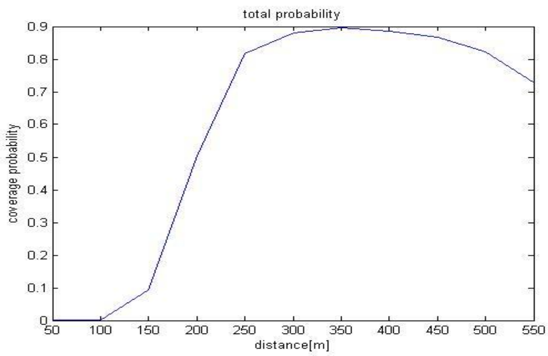

Figure9.Coverage probability of a proposed PL in a shadowing environment at L1

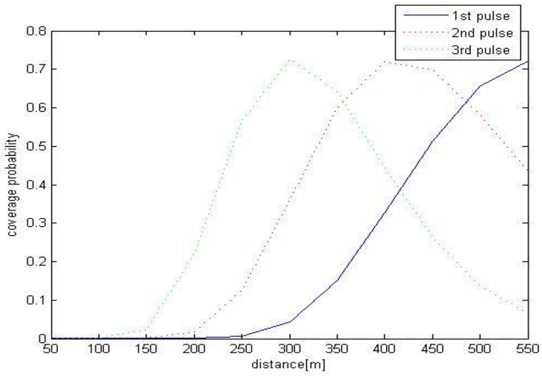

Figure10.Coverage probability of a PL in a shadowing environment at E5a or L5

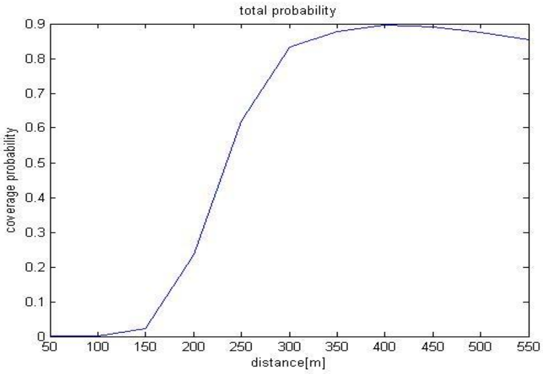

Figure11.Coverage probability of a proposed PL in a shadowing environment at E5a or L5

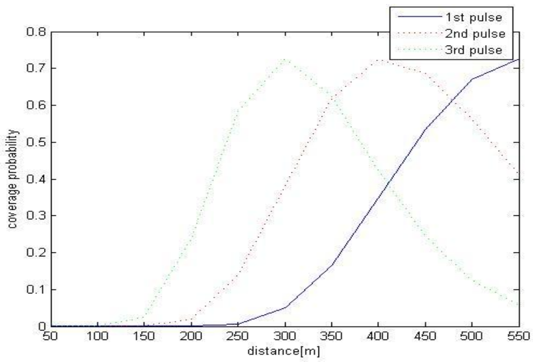

Figure12. Coverage probability of a PL in a shadowing environment at E5b

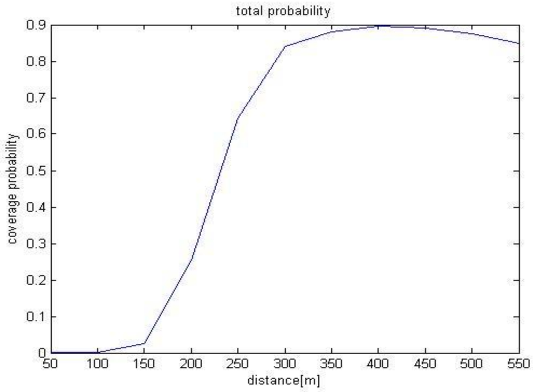

Figure13. Coverage probability of a proposed PL in a shadowing environment at E5b

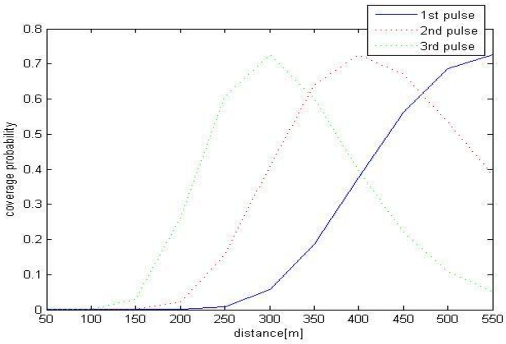

Figure14.Coverage probability of a PL in a shadowing environment at GLONASS sat-2 frequency

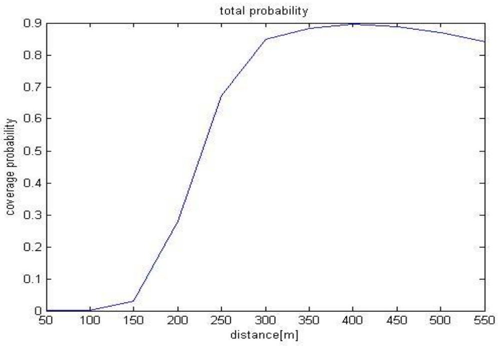

Figure15.Coverage probability of a proposed PL in shadowing environment at GLONASS sat-2 frequency

Table1. Coverage probability of PL at different frequencies

Coverage Probability	L1	E5a or L5	E5b	GLONASS SAT-2
Conventional PL	0.72	0.72	0.72	0.72
Proposed PL	0.89	0.89	0.89	0.89

V. CONCLUSION

In this paper, PL with step-by-step power control has been proposed to mitigate the Near-Far problem. Simulation results show that the maximum coverage probability for conventional PL is limited to 0.72. However, the maximum coverage probability has been increased to 0.89 by using power control technique. Also, the ring radius of conventional PL was from 450-500m as measured from 1st pulse of L1 frequency where as the ring radius of proposed PL was from 300-500m. That is, the service area using proposed PL resulted in 4 times wider than that of conventional PL.

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