

Improved Positioning Reference Signal Pattern for Indoor Positioning in LTE-Advanced System

Su Min Kim, Sukhyun Seo, and Junsu Kim¹

*Department of Electronics Engineering,
Korea Polytechnic University,
15073 Siheung, Republic of Korea.*

Abstract: In this paper, we propose an improved positioning reference signal (PRS) pattern which provides a better correlation property than the conventional PRS pattern for 3GPP LTE-advanced system. The performance of the proposed PRS pattern is evaluated for both normal and extended cyclic prefix (CP) through multi-link simulations. The results show that the proposed PRS pattern removes strong side peaks in pattern correlation caused by non-identical frequency allocation in the conventional PRS pattern. Consequently, the proposed PRS pattern can provide also a better auto-correlation property for position estimation at the end.

AMS subject classification:

Keywords:

1. Introduction

Recently, US federal communications commission (FCC) has announced new regulatory requirements on indoor positioning in cellular systems for some emergency services, e.g., enhanced 911 (E911) [1],[2]. According to the requirements, the cellular systems need to support better accuracies in both vertical and horizontal positions, e.g., by 2020, 70% of all wireless 911 calls within 50 meter of horizontal accuracy and by 2021, 80% of cellular population should be covered by z-axis technology with reasonable accuracy.

Accordingly, third generation partnership project (3GPP) has initiated a study item for indoor positioning improvement in long-term evolution (LTE)-advanced system (Release 13)

[3]. In LTE system, there exist a wide range of positioning methods such as cell identity (CID), enhanced CID, angle of arrival (AoA), time difference of arrival (OTDOA), observed TDOA (OTDOA), uplink TDOA (UTDOA), assisted-global navigation satellite system (A-GNSS), RF fingerprint, and so on [4]. Some of such methods are applied together for positioning accuracy enhancement, e.g., CID and OTDOA.

Among them, the OTDOA method is one of promising technologies for positioning accuracy enhancement in down-link scenarios [5]. It is based on time delay estimation with a special reference signal, so called positioning reference signal (PRS) in LTE system. In OTDOA, the enhanced NodeB (eNodeB) transmits data symbols embedding the preallocated PRSs. Then, at a desired user equipment (UE), the received signal time difference (RSTD) information is estimated based on a time correlation with the desired PRS pattern. Finally, the desired UE can estimate RSTDs from several different eNodeBs and then, it estimates the position information based on the multilateration technique which is a way to determine a geometrical position from intersection of multiple surfaces. Thus, it is important to estimate accurate time delay information (converted to distance at the end) for each link since it affects the positioning accuracy directly.

In this paper, we propose a frequency-shifted PRS pattern in order to improve the performance of time delay estimation, which also leads more accurate position estimation at the end. The proposed frequency-shifted PRS pattern equally spreads PRS symbols to whole subcarriers so that there is no subcarrier without a PRS symbol. The performance of the proposed PRS pattern is evaluated in terms of auto-correlation value at the desired receiver, compared to the conventional PRS pattern used in LTE system, through multi-link simulations in

¹ Corresponding author: E-mail: junsukim@kpu.ac.kr

multi-user and multi-cell environments. The results show that the proposed PRS pattern removes strong side peaks in the auto-correlation performance for both normal and extended cyclic prefix (CP) cases. As a result, the proposed PRS pattern can improve the position estimation accuracy since it is directly affected by the time delay estimation at each link.

The remainder of this paper is organized as follows. In Section II, PRS and time delay estimation in LTE system is presented. The proposed frequency-shifted PRS pattern is presented, compared to the conventional PRS pattern in Section III. In Section IV, the performance of the proposed PRS pattern is evaluated through multi-link simulations. Finally, conclusive remarks are drawn in Section V.

2. Background

In this section, we review the PRS in 3GPP LTE standard and explain how to estimate time delay information. Even if there exist diverse methods for time delay estimation, we consider maximum-likelihood (ML)-based time delay estimation in this paper.

2.1. Positioning Reference Signal (PRS) in LTE

In principle, it is possible to measure RSTD on any downlink signals, e.g., cell reference signal (CRS). However as in OTDOA the UE requires to detect multiple neighbor cell signals, these signals suffer from poor hearability. Hence, PRSs have been introduced in 3GPP LTE Release 9 to improve OTDOA positioning performance.

Fig. 1 shows the arrangement of the PRSs in a single resource block (RB) for normal CP and extended CP. In such PRS subframe, in order to reduce the interference with neighbor cells, no PDSCH data is carried. PDCCH and CRSs are retained in the subframe, while PRSs are distributed in a “diagonal” way in between CRSs. Similar to CRS, cell-specific frequency shift (the number of frequency shift given by physical cell identifier (PCI) modulo 6) is applied to PRS pattern, which helps avoid time-frequency PRS collision up to six neighbor cells.

In LTE system, consecutive PRS subframes are transmitted periodically in the downlink. According to the standard [6], one positioning occasion may contain up to six consecutive PRS subframes. The period of one positioning occasion can be configured to every 160, 320, 640, and 1280 msec. It is noted that, in time division duplex (TDD) mode, uplink

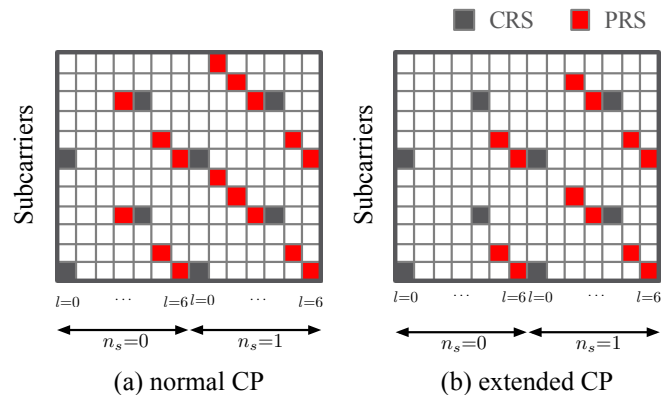


FIG. 1. PRS arrangement in a single RB of LTE-advanced system: (a) normal CP and (b) extended CP.

subframe and other special frames cannot contain PRSs. In some cases, in particular dense deployment, only cell-specific frequency shift may not be sufficient to reduce interference from neighbour cells. Therefore, PRS muting has been introduced to further reduce inter-cell interference by muting PRS transmission in other cells based on a periodic *muting pattern*.

2.2. Maximum-Likelihood (ML) Time Delay Estimation

To apply the OTDOA for the position estimation, the time of arrival (TOA), which is converted to the distance between an eNodeB and a UE, has to be first estimated from the received signal for each link. Here, we employ a threshold-based maximum-likelihood (ML) TOA estimation [7], which detects the first tap delay by choosing the earliest peak among multiple peaks larger than a predetermined threshold value based on the correlation between the received signal sequence and the transmitted reference signal sequence.

In LTE, the QPSK-modulated PRS sequence is defined by [6]

$$Z_{l,n_s}[m] = \frac{1}{\sqrt{2}} (1 - 2c[2m]) + j \frac{1}{\sqrt{2}} (1 - 2c[2m + 1]), \quad (2.1)$$

where $m = 0, 1, \dots, 2N_{RB}^{\max,DL} - 1$, $N_{RB}^{\max,DL}$ is the maximum number of downlink RBs allocated for the PRS, n_s is the slot number within a subframe, l is the orthogonal frequency division multiplex (OFDM) symbol number within the slot, and $c[\cdot]$ denotes the pseudo-random sequence generated by a length-31 Gold sequence.

According to the PRS mapping criterion, the complex-valued symbols are mapped to resource elements (REs).

Let us denote the mapped transmitted signal sequence in frequency domain be $S_{l,n_s}[k]$ determined by

$$S_{l,n_s}[k] = \begin{cases} Z_{l,n_s}[m] & \text{if } m \text{ is mapped to } k, \\ 0 & \text{otherwise,} \end{cases} \quad (2.2)$$

where $k = 0, \dots, N_{\text{fft}} - 1$ and N_{fft} is the fast Fourier transform (FFT) size. Then, the OFDM modulated reference signal sequence in time domain after inverse FFT (IFFT) is given by

$$x_{l,n_s}[n] = \sqrt{N_{\text{fft}}} \sum_{k=0}^{N_{\text{fft}}-1} S_{l,n_s}[k] e^{j \frac{2\pi kn}{N}}, \quad (2.3)$$

where $n = 0, \dots, N_{\text{fft}} - 1$. Since we have multiple PRS subframes within one positioning occasion which consists of multiple subframes, all the sequence should be concatenated. Let us define N_{frame} as the number of subframes within one positioning occasion, N_{slot} as the number of slots per subframe, and N_{symp} as the number of symbols per slot. By extending (2.3) to multiple subframes, i.e., $x_{l,n_s,n_f}[n]$ for the n_f -th subframe, the total transmitted signal sequence including CP can be constructed by

$$x[i] = x_{l,n_s,n_f}[n], \quad i = i_{\text{symp}} + i_{\text{samp}}, \quad (2.4)$$

where the symbol index $i_{\text{symp}} = (N_{\text{slot}} \cdot n_f + N_{\text{symp}} \cdot n_s + l) \times (N_{\text{CP}}^{(l)} + N_{\text{fft}})$ in which $n_f = 0, \dots, N_{\text{frame}} - 1$, $n_s = 0, \dots, N_{\text{slot}} - 1$, $l = 0, \dots, N_{\text{symp}} - 1$, $N_{\text{CP}}^{(l)}$ is the CP length for the l -th symbol in terms of the number of time samples¹, and the sample index $i_{\text{samp}} = 0, \dots, (N_{\text{CP}}^{(l)} + N_{\text{fft}}) - 1$. Due to the CP insertion, $x[i_{\text{symp}} + i_{\text{samp}}] = x[i_{\text{symp}} + i_{\text{samp}} + N_{\text{fft}}]$ for $i_{\text{samp}} \in [0, N_{\text{CP}}^{(l)} - 1]$.

Since the CPs include inter-symbol interference after applying the multipath channels, its impact should be removed from the correlation between the reference and received signals at the receiver. Therefore, we replace the CPs by zeros in the reference signal sequence from the transmitted signal sequence. As a result, the reference signal sequence is given by

$$r[i] = \begin{cases} 0 & \text{if } i_{\text{samp}} \in [0, N_{\text{CP}}^{(l)} - 1], \\ x[i] & \text{otherwise,} \end{cases} \quad (2.5)$$

where $i = i_{\text{symp}} + i_{\text{samp}}$.

Next, we consider the following tapped delay line channel model to describe indoor multipath channels.

$$h(t) = \sum_{l=0}^{L-1} a_l \delta(t - \tau_l), \quad (2.6)$$

where L is the number of multipath taps, a_l denotes the amplitude of the l -th tap, τ_l indicates the time delay of the l -th tap and $\delta(t)$ is the delta function, which is one when $t = 0$ and zero otherwise. However, we need the sampled tap delays in terms of sampled time index at the receiver. Thus, we manipulate the time delays by rounding operation, i.e., $\tilde{\tau}_l = \lfloor \tau_l / T_s + 0.5 \rfloor$, where the sampling time interval is T_s is determined by $1/\text{BW}_{sc}/N_{\text{fft}}$ in which BW_{sc} is the bandwidth of a single subcarrier, e.g., 15 kHz in LTE. As a result, we have the sampled tap delay line channel as follows:

$$h[i] = \sum_{l=0}^{L-1} a_l \delta(i - \tilde{\tau}_l). \quad (2.7)$$

After going through the delay tapped channel, the received signal sequence becomes

$$y[i] = h[i] * x[i] + w[i], \quad (2.8)$$

where $i = i_{\text{symp}} + i_{\text{samp}}$, $*$ denotes the convolution operation, and $w[i]$ denotes the additive thermal noise at the receiver.

To detect the first tap, we compute the correlation values between the received signal sequence and the reference signal sequence as follows:

$$R(\tau) = \sum_{i=-N_w/2}^{N_w/2-1} y[i] r^*[i - \tau], \quad (2.9)$$

where N_w is the search window for the positioning and $(\cdot)^*$ denotes the complex conjugate.

Finally, according to the ML criterion, the first tap is estimated with the predetermined threshold value ζ as

$$\hat{\tau}_1 = \arg \min_{\tau} \left\{ \frac{|R(\tau)|}{|\max\{R(\tau)\}|} > \zeta \right\}, \quad (2.10)$$

The threshold value has to be carefully chosen considering the multipath channels in the position estimation. However, in this paper, we do not consider the threshold value since we focus on not the position estimation performance but the time delay estimation performance given by $R(\tau)$ in (2.9). If each RSTD is estimated for each link, the position of the desired UE can be estimated by using a wide range of different methods based on the RSTD estimates as in [8]. We omit the details since it is out of scope of this paper.

¹ In LTE with 20 MHz bandwidth, for normal CP, $N_{\text{CP}}^{(0)} = 160$ and $N_{\text{CP}}^{(l)} = 144$, $l = 1, \dots, 6$, and for extended CP, $N_{\text{CP}}^{(l)} = 512$, $l = 0, \dots, 5$.

3. Proposed Frequency-Shifted Positioning Reference Signal (PRS) Pattern

In this section, we propose a time-varying frequency-shifted PRS pattern which can allocate the number of PRS symbols equally across whole subcarriers. As a result, the proposed frequency-shifted PRS pattern removes strong side peaks after time correlation in time delay estimation, which also leads more accurate position estimation.

Fig. 2 shows a comparison between conventional and proposed PRS patterns for normal CP in a single RB across six subframes in time. As shown in the figure, in the conventional PRS pattern, the PRS pattern is fixed across all subframes, while in the proposed PRS pattern, it is shifted in frequency domain by one symbol at every subframe. As a result, in the conventional pattern, two subcarriers do not have PRS symbols, while in the proposed pattern, there is no vacant subcarrier. Moreover, in the proposed pattern, each subcarrier has the same number of PRS symbols, i.e., 8 PRS symbols are equally allocated to a single subcarrier. However, in the conventional pattern, 6 subcarriers have 12 PRS symbols, 4 subcarriers have 6 PRS symbols, and the others have nothing. The total number of PRS symbols are the same in both the conventional and proposed PRS patterns as 96. We will show that this non-identical frequency allocation of PRS patterns in the conventional PRS pattern causes strong side peaks in the time correlation property in Section IV.

The proposed PRS pattern can be allocated by slightly modifying the cell-specific frequency shift parameter v_{shift} , originally set to $(N_{\text{ID}}^{\text{cell}} \bmod 6)$ in LTE standard [6], as follows:

$$v_{\text{shift}} = (N_{\text{ID}}^{\text{cell}} + \lfloor n_s/2 \rfloor) \bmod 6, \quad (3.11)$$

where $N_{\text{ID}}^{\text{cell}}$ denotes the cell ID, n_s denotes the slot index (two slots in a subframe), and mod represents the modulo operation, i.e., remainder after division. After all, the proposed time-varying frequency-shifted PRS pattern is able to be easily applied to the current LTE standard without additional efforts.

Fig. 3 shows both conventional and proposed PRS patterns for extended CP in a single RB across six subframes. For the extended CP case, less number of PRS symbols are allocated due to longer CP period in order to guarantee inter-symbol interference (ISI) elimination. Hence, in the conventional PRS pattern, 4 subcarriers among 12 subcarriers do not have PRS symbols. However, in the proposed PRS pattern, it still guarantees the same number of PRS symbols per subcarriers. More specifically, in the conventional PRS pattern, 4 subcarriers have 12 PRS symbols, 4 subcarriers have 6 PRS

Table 1. Simulation Parameters

Parameter	Value
System bandwidth	10 MHz
Carrier frequency	2.0 GHz
Total power per carrier	46 dBm
Antenna gain	17 dBi
Path Loss	3D-UMa [9]
Shadowing/Fast fading	3D-UMa [10]
Penetration for indoor UEs	20 dB + $0.5d_{in}^{\dagger}$
UE noise figure	9 dB
UE speed	3 Km/h

$^{\dagger}d_{in}$: independent and uniform random value in $[0, \min(25, \text{UE-to-cell distance})]$.

symbols, and the others have nothing, while in the proposed PRS pattern, all subcarriers have the same 6 PRS symbols individually. Both conventional and proposed pattern use the same total number of PRS symbols as 72 for this extended CP case. The proposed PRS pattern for extended CP can be also allocated by using (3.11) in the system.

4. Numerical Results

In this section, we evaluate the performance of the proposed and conventional PRS patterns through multi-link simulations. We consider a multi-user and multi-cell environment, which consists of 21 cells (7 macro sites, 3 cells for each site) and 105 UEs randomly deployed. In this setup, each UE selects the best serving eNodeB based on the received CRS power. In simulation results, we show the performance of a target UE. The detailed simulation parameters are listed in Table I.

Fig. 4 shows the normalized auto-correlation between the received and reference PRS patterns at the target UE for normal CP case. It is normalized by the maximum auto-correlation value and the time delay estimates are converted to distance values in meter. As shown in the figure, the normalized auto-correlation value of the conventional PRS pattern have some side peaks around 350, 650, and 1000 meters. This is because of non-identical frequency allocation in the conventional PRS pattern as shown in Fig. 4. Some vacant subcarriers without PRS symbols generate a periodicity in frequency domain. As a result, this occurs some periodic side peaks in the time correlation. Such strong side peaks can cause some errors in the time and position estimations and would be severer if we additionally consider other-cell interference using the same PRS pattern. On the contrary, in the proposed PRS pattern, the strong side peaks are completely

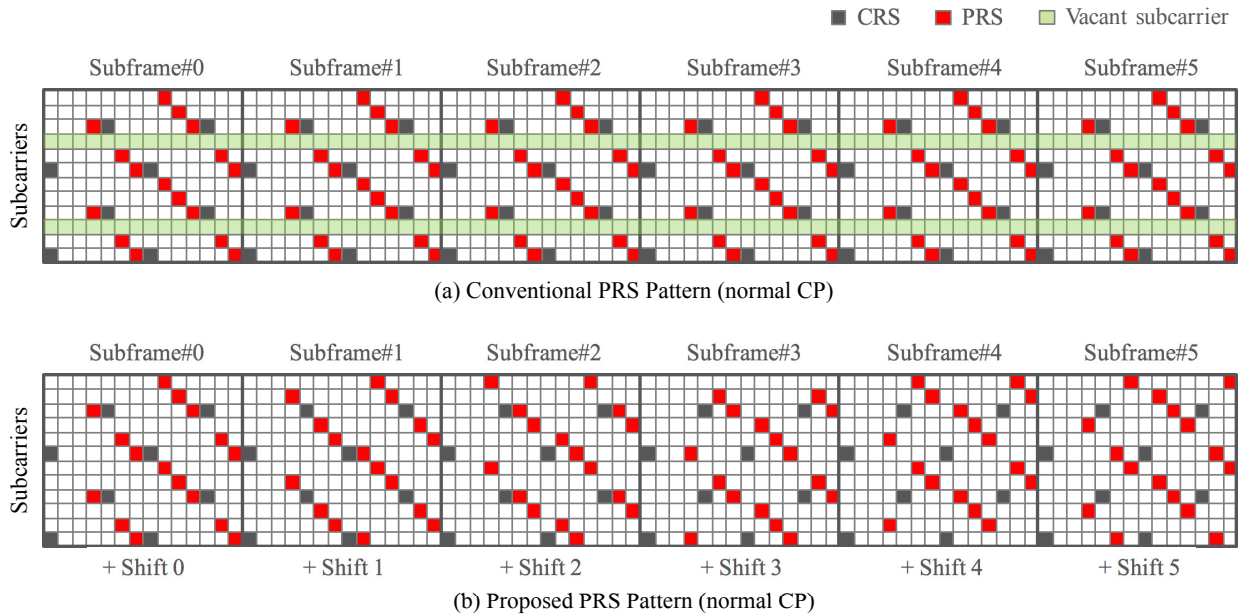


FIG. 2. Conventional and proposed PRS patterns for normal CP in a single RB: (a) conventional PRS pattern and (b) proposed PRS pattern.

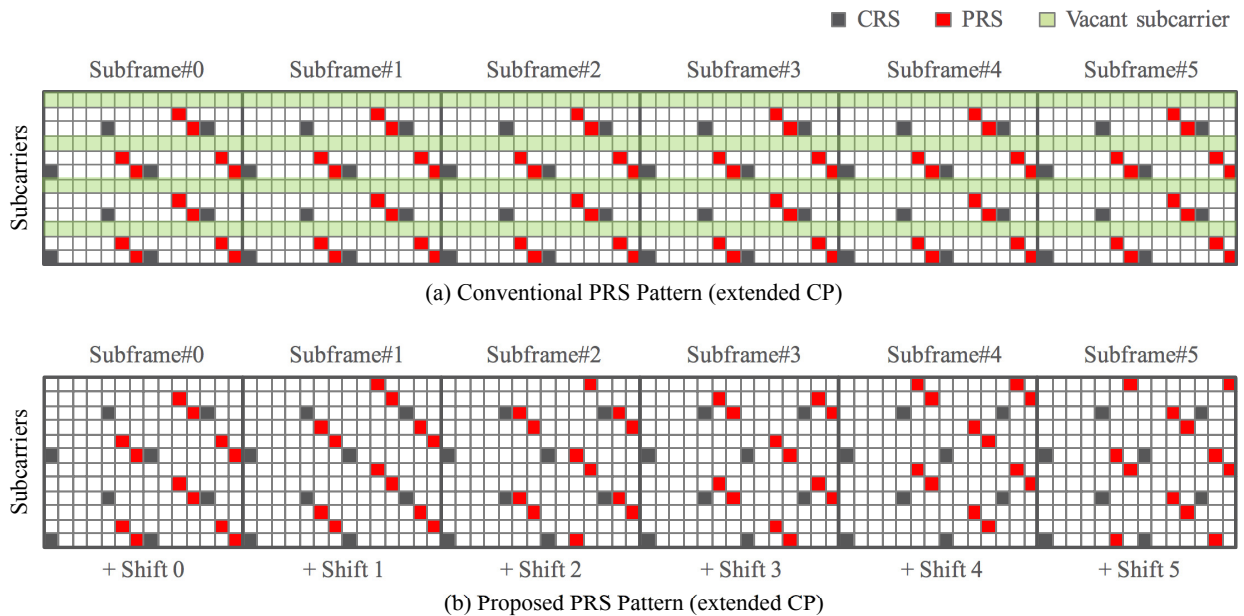


FIG. 3. Conventional and proposed PRS patterns for extended CP in a single RB: (a) conventional PRS pattern and (b) proposed PRS pattern.

removed. Therefore, it can be stated that the proposed PRS pattern fundamentally removes the possibility of estimation errors coming from the PRS pattern itself.

Fig. 5 shows the normalized auto-correlation between the received and reference PRS patterns at the target UE for extended CP case. As in Fig. 4, in the conventional PRS

pattern, there are several side peaks, which are strong and periodic, around 350 and 650 meters. Furthermore, it is more significant than normal CP case since the differences between these peaks and the strongest correlation value at 0 meter are smaller. This is natural because the extended CP is used for severer multipath environment to reduce the ISI in OFDM

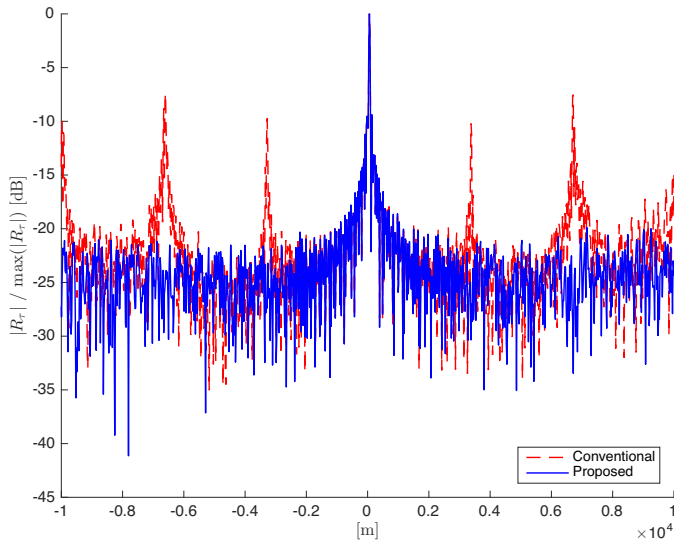


FIG. 4. Normalized auto-correlation at the desired receiver for normal CP

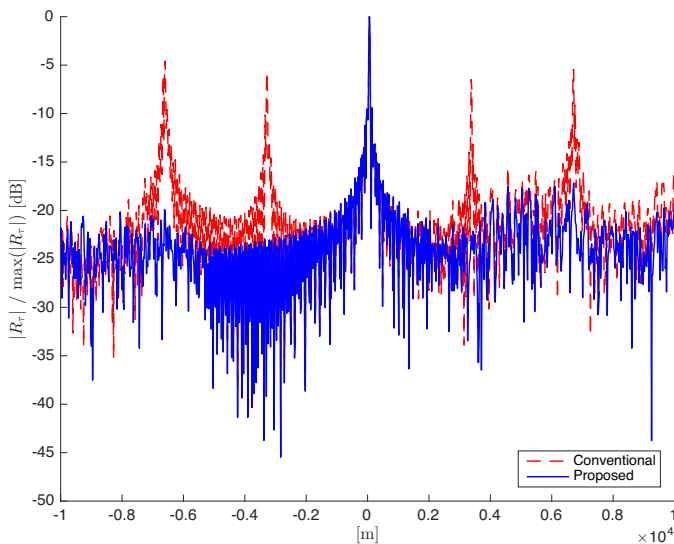


FIG. 5. Normalized auto-correlation at the desired receiver for extended CP

system. After all, the performance of the time delay estimation is degraded for extended CP due to less PRS symbols. Thus, the effect of non-identical frequency allocation in the conventional PRS pattern becomes more significant than that for normal CP case. In contrast, the proposed PRS pattern removes such strong side peaks and maintains the correlation values except for the center value similar to that for normal CP. Thus, the proposed PRS pattern becomes more efficient for extended CP.

5. Conclusion

In this paper, we proposed a time-varying frequency-shifted PRS pattern which improves the auto-correlation property for time delay estimation in LTE-advanced system. The proposed PRS pattern enables to equally allocate the PRS symbols to whole subcarriers by shifting the pattern in frequency domain by one at every subframe. The performance of the proposed PRS pattern was evaluated in terms of auto-correlation of the PRS pattern for time delay estimation through multi-link simulations in a multi-user and multi-cell environment. The results show that the conventional PRS pattern causes some strong and periodic side peaks in the auto-correlation, which could cause some errors in time and position estimations, while the proposed PRS pattern completely removes such side peaks. Moreover, it was more efficient for extended CP. As a result, the proposed PRS pattern can improve the performance of time and position estimations by providing a better auto-correlation property in time delay estimation.

Acknowledgment

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References

- [1] Federal Communications Commission, 2014, *Wireless E911 Location Accuracy Requirements*, Third Further Notice of Proposed Rulemaking.
- [2] Federal Communications Commission, 2015, *Wireless E911 Location Accuracy Requirements*, Fourth Report and Order.
- [3] 3GPP RP-141002, 2014, *Revised SID: Study on Indoor Positioning Enhancements for UTRA and LTE*.
- [4] E. Dahlman, S. Parkvall, and J. Skold, 2013, *4G: LTE/LTE-Advanced for Mobile Broadband*, 2nd Ed., Academic Press.
- [5] S. Fischer, 2014, *Observed time difference of arrival (OTDOA) positioning in 3GPP LTE*, Qualcomm Technologies, Inc.
- [6] 3GPP TS 36.211, 2014, *Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation (Release 12)*.

- [7] J.A. Del Peral-Rosado, J.A. Lopez-Salcedo, G. Seco-Granados, F. Zanier, and M. Crisci, 2012, “Achievable localization accuracy of the positioning reference signal of 3GPP LTE,” in Proc. International Conference on Localization and GNSS (ICL-GNSS).
- [8] F. Gustafsson and F. Gunnarsson, 2005, “Mobile positioning using wireless networks,” *IEEE Signal Processing Magazine*.
- [9] 3GPP TR 36.873, 2015, *Technical Specification Group Radio Access Network; Study on 3D channel model for LTE (Release 12)*.
- [10] 3GPP TR 36.819, 2011, *Technical Specification Group Radio Access Network; Coordinated multi-point operation for LTE physical layer aspects (Release 11)*.