Research on Compact Discovery Reference Signal for Future Synchronized Network

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Abstract

Dynamic on/off switching is a key Rel-12 feature of small cell enhancements for energy saving. When in "off-mode", the small cell needs to transmit a Discovery Reference Signal (Discovery-RS) periodically to notify its existence. In legacy sense, Discovery-RS consists of multiple signals, and Primary Synchronization Signal (PSS) could be involved to establish coarse time synchronization for User Equipment (UE). However in the future synchronized network, the legacy coarse time synchronization procedure for UE through PSS may be no longer needed, then we can propose a compact Discovery-RS structure that consists of only one signal to significantly reduce system overhead of radio-interface resource, as well as the interference between cells. A thoroughly preceding research and algorithm demonstration were then presented to analyze the feasibility of this approach. Theoretical analysis and computer simulation results show that this approach is practicable in the future synchronized network.

1. Introduction

Dynamic on/off switching is a key Rel-12 feature of small cell enhancements for energy saving. When in "off-mode", the small cell needs to transmit a Discovery-RS periodically to notify its existence [1]. 3rd Generation Partnership Project (3GPP) has an agreement in Rel-12 Study Item that "the Discovery-RS should support at least for cell identification, coarse time/frequency synchronization, intra-/inter- frequency Radio Resource Management (RRM) measurement of cells for UEs [2]". Currently, FDD is a non-synchronization system, so in legacy sense, Discovery-RS consists of multiple signals, and PSS could be involved to establish coarse time synchronization for UE [3]. However the development of network synchronization is the trend of future communication system, as 3GPP agrees that "for both TDD and FDD, it would be essential to consider the synchronization mechanisms between cells to bring benefit to the existing features and some potential techniques for small cell enhancements [1]". In the future synchronized network, the legacy coarse time synchronization procedure for UE through PSS may be no longer needed since UE in "RRC_CONNECTED" state can obtain coarse time/frequency synchronization automatically to any concerned off-cell once it has accessed the synchronized network through any synchronized cell.

Based on the observation, this paper proposes a future synchronized network oriented compact Discovery-RS structure, which consists of only one signal, e.g. Cell-Specific RS (CRS) or Channel State Information RS (CSI-RS) or Positioning RS (PRS). The compact Discovery-RS structure can significantly reduce system overhead of radio-interface resource, as well as the interference between cells by omitting PSS because in dense deployment scenario the PSS transmitted by the off-cell may collide with other ones, e.g. the PSS transmitted by on-cells, to cause serious interference, since there are only three candidate sequences for PSS [4]. How does one signal Discovery-RS work to fulfill 3GPP's requirements? The following of this paper will try to answer this question.

2. Feasibility Analysis of One Signal Discovery-RS

In order to work well with one signal Discovery-RS in the future synchronized network, some questions are to be answered.

Q1: Which signal is the "one signal" in Discovery-RS?
A1: CRS or CSI-RS or PRS all can be chosen as the "one signal" in Discovery-RS, as the reasons be explained later.

Q2: How to support cell identification, coarse frequency synchronization, intra-/inter- frequency RRM measurement of cells at the UE's side? Note that the requirement of establishing coarse time synchronization for UE has been neglected.
A2: CRS or CSI-RS or PRS all can be used for coarse frequency synchronization, intra-/inter- frequency RRM measurement of cells [3]. The non-trivial problem is how to identify cell identification through CRS or CSI-RS or PRS, since it is traditionally done through PSS and Secondary Synchronization Signal (SSS)? Fortunately when coarse

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time/frequency synchronization has been established, UE can easily obtain cell identification by blind detection, which is similar to the legacy procedure of SSS does [5].

Q3: How to establish and maintain time/frequency synchronization between cells at the eNB's side? As mentioned above, network synchronization between cells is the basic hypothesis for UE to work well with one signal Discovery-RS, therefore some physical layer mechanisms may be introduced to guarantee network synchronization between cells when small cell on/off is used.
A3: The legacy radio-interface based synchronization mechanisms between cells, e.g. as specified in Home eNode B scenario [6], were based on PSS/SSS acquisition and CRS tracking. In fact, either CSI-RS or PRS could be the potential RS candidate for synchronization tracking [7]. The non-trivial problem is how to establish coarse time/frequency synchronization between cells through CRS or CSI-RS or PRS, since it is traditionally done through PSS/SSS? One possible scenario is that the eNB who lost synchronization is completely surrounded by the off-cells unfortunately; therefore it cannot hear PSS/SSS to establish coarse time/frequency synchronization. Since some necessary information, such as Cell-ID, can be exchanged between cells through backhaul although the detail needs to be specified, therefore the above problem can be simplified as how to establish coarse time/frequency synchronization between cells through CRS or CSI-RS or PRS with the prior knowledge of Cell-ID? The new problem can be solved by time-domain cross-correlation operation. Since the frequency domain feature, as well as the processing procedure, is similar among CRS, CSI-RS and PRS, then a demonstration algorithm, with CRS based Discovery-RS be taken as an example, is presented in the next section.

As a conclusion, the proposed one signal Discovery-RS can work well in the future synchronized network.

3. CRS Based Synchronization Establishment Algorithm Between Cells

This section will take CRS as an example to answer the question of "how to establish coarse time/frequency synchronization between cells through one signal Discovery-RS with the prior knowledge of Cell-ID"? Direct time-domain cross-correlation algorithm can be taken as a starting point.

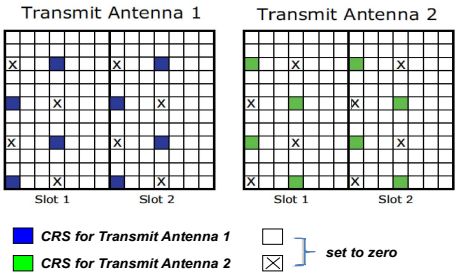

Fig. 1. RE mapping for CRS

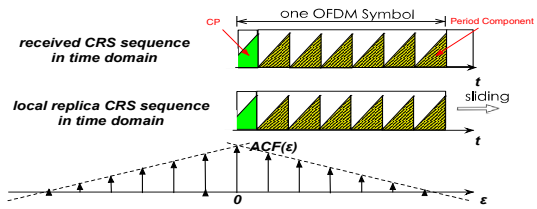

Fig. 2. ACF of CRS sequence in time domain (principle sketch) with one antenna port

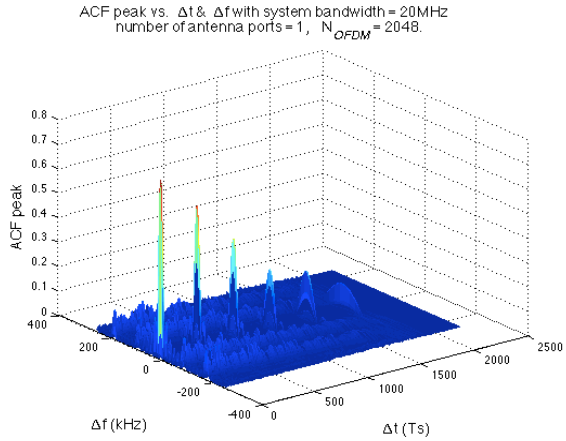

Fig. 3. ACF for CRS sequence in time and frequency domain with one antenna port and 20 MHz downlink bandwidth and there are 2048 samples in one OFDM symbol, where Δf is frequency error in unit of kHz, Δt is time error in unit of sampling intervals (T_S).

As specified in [4], the base sequences for CRS consist of complex-value entries, which are generated by a length-31 Gold sequence. The sequence elements are then mapped on the time-frequency resource grid on every sixth sub-carrier in every slot. In order to construct one signal Discovery-RS, the resource elements (RE) not used for CRS transmission is set to zero, as shown in Fig. 1. Since the CRS sequence in frequency domain is scattered, then the CRS sequence in time domain, obtained by IFFT, is periodic. For example, suppose there are N_{OFDM} samples in one Orthogonal Frequency Division Multiplexing (OFDM) symbol (e.g. $N_{\mathrm{OFDM}} = 2048$), then the cycle length is about $N_{\mathrm{OFDM}}/6$ (e.g., 341) samples for one antenna port and $N_{\mathrm{OFDM}}/3$ (e.g., 683) samples for two or four antenna ports. As a result, the auto-correlation function (ACF) of CRS sequence in time domain would appear multiple peaks whose amplitude decreasing with time error, as illustrated in Fig. 2. Simulations are then performed to calculate the ACF both

in time and frequency dimension, as shown in Fig. 3. It is clear that the main peak of ACF, which corresponding to correct estimation of time and frequency error between eNBs, is discernable to the background noise, as well as the sidelobes of the ACF. So it can be concluded that direct time-domain cross-correlation algorithm is feasible in principle.

However, the direct time-domain cross-correlation algorithm has one major disadvantage of high computational complexity. To overcome the difficulty, this paper will take use of periodic feature of the CRS sequence in time domain, and then propose an optimal algorithm with acceptable computational complexity, which is named as "time-domain-folded cross-correlation algorithm", as shown in Fig. 4.

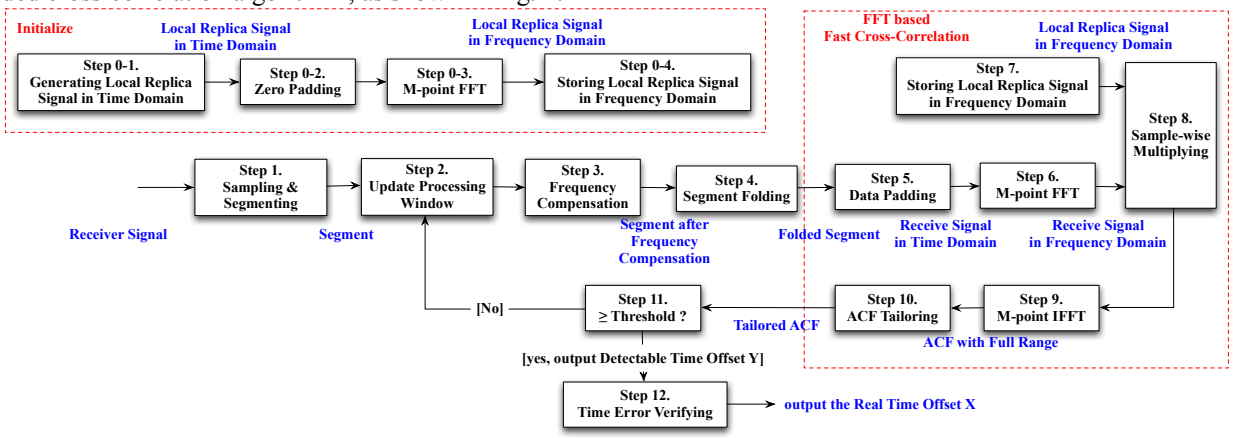

Fig. 4. Flow chat of proposed time-domain-folded cross-correlation algorithm

The procedures of the proposed time-domain-folded cross-correlation algorithm are as following:

1) **Step 0-1 ~ Step 0-4: Initializing**. Firstly generating a piece of periodic component (with length of $N_{\mathrm{OFDM}}/6$ sampes) of the CRS sequence in time domain (Step 0-1). And then padding it with zeros to the length of M samples (Step 0-2, as shown in Fig. 5(a)), where M is a proper FFT base which is greater then $2\times\mathrm{round}(N_{\mathrm{OFDM}}/6)$, where round(·) denotes rounding to integer. (e.g., when N_{OFDM}=2048, M can be chosen as $M=2^4 3^2 5^1=720$). Finally doing M-points FFT transform to generate the local replica signal in frequency domain (Step 0-3), and then storing the results into memory (Step 0-4).
2) **Step 1: Sampling the receiver signal and buffering them into segments.** As shown in Fig. 5(b), the segment n consists of a series of samples starting with $r_{b(n)}$ and ending with $r_{e(n)}$, where r_k is the k-th sample point, $b(n)$ = round($N_{\mathrm{OFDM}}/6*n$), $e(n) = b(n)+\mathrm{round}(N_{\mathrm{OFDM}}/6)$.
3) **Step 2: Update processing window.** Processing window is defined as a bundle of segments to execute the following operations. Processing window m covers 12 segments and it starts with segment $6m-6$, as shown in Fig. 5(b). The processing window will update by increasing m to m+1 if it is failed to establish synchronization in this iteration. Real time offset X is defined as the distance between the starting point of the valid OFDM symbol and the left boundary of current processing window. The remaining processes are carried out to estimate X.
4) **Step 3: Frequency compensation.** All the sample points in processing window m, denoted by r_k (k = 0, 1,2,…), will multiply by $\exp(-j\cdot 2\pi\cdot\Delta f\cdot k\cdot T_S)$ for frequency compensation, where Δf is the pre-estimated frequency error, and T_S is the sampling interval.
5) **Step 4: Segment folding.** After frequency compensation, all the 12 segments will be accumulated per sample points into a folded one, as shown in Fig. 5(c). It is clear that the signal waveform in each segment remains the same, from which we can estimate the detectable time offset Y, which is defined as the distance between the starting point of the periodic component and the left boundary of the folded segment. There is a relationship between X and Y that: Y = X mod round($N_{\mathrm{OFDM}}/6$).
6) **Step 5: Data padding for the folded segment.** The folded segment is firstly repeated, and then padded with zeros to the length of M points, as shown in Fig. 5(d).
7) **Step 6 ~ Step 12: FFT based fast cross-correlation algorithm and time error verifying.** It is well known that time domain cross-correlation can be fast calculated through FFT and IFFT transform. The cross correlation of above padding signals appears two peaks, as shown in Fig. 5(e). Tailoring is then followed to eliminate the extra sidelobe laying in the region Ⅱ. Simulations are performed to calculate the proposed time-domain-folded cross-correlation function (CCF) both in time and frequency dimension with additive white gaussian noise channel, and SNR = -10 dB, as shown in Fig. 5(f). It is clear that the main peak of CCF is discernable with good noise rejection

performance. Threshold comparison is then followed. If the peak of the CCF is greater than some given threshold, then we can claim acquisition success and output the detectable time offset Y. The real time offset X can be finally obtained by searching the max amplitude of the complete correlation function among certain positions of $p_n = p_0 + \text{round}(N_{\text{OFDM}}/6) \times n$, with $n \in [0,1,2,\ldots 11]$.

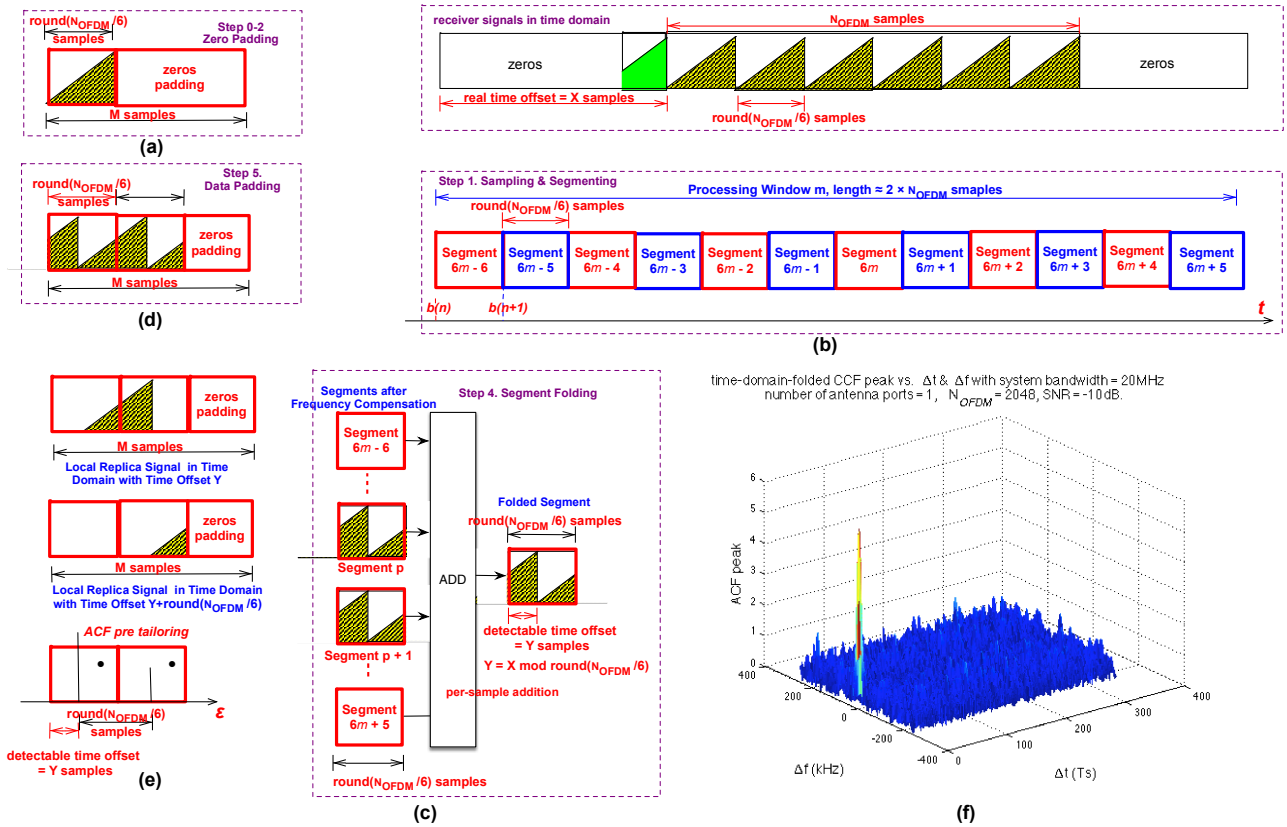

Fig. 5. Details of the proposed time-domain-folded cross-correlation algorithm

4. Conclusion

The development of network synchronization is the trend of future communication system. In the synchronized network, the legacy coarse time synchronization procedure through PSS for UE can be neglectable. Based on the observation, a future synchronized network oriented compact Discovery-RS structure, which consists of only one signal, e.g. CRS or CSI-RS or PRS, was proposed. A thoroughly preceding research and algorithm demonstration, with CRS based Discovery-RS be taken as an example, were then presented to analyze the feasibility of this approach. Theoretical analysis and computer simulation results show that this approach is practicable in the future synchronized network.

5. References

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