

THE OPTIMIZED CELL CONFIGURATION METHOD OF AVOIDING SRS INTER-CELL INTERFERENCE

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ABSTRACT

The issue of cell-to-cell interferences is a serious problem that has always been raised in digital communication system such as NR. The communication method of NR and LTE is OFDM. OFDM has many advantages, but has fatal disadvantage called ICI (Inter-Cell Interference) because resources among cells are always overlapped. For example, NR's typical interferences are ICIs among PDSCH (Physical Downlink Shared Channel), PDCCH (Physical Downlink Control Channel), PUSCH (Physical Uplink Shared Channel), PUCCH (Physical Uplink Control Channel), CSI-RS (Channel State Information-Reference Signal) and SRS (Sounding Reference Signal). Among them, it is important to determine the correct beamforming weight factor value by estimating the channel with SRS. Therefore, the ICI of SRS degrades the performance of downlink throughput. This paper analyses the impact of SRS's ICI in conventional scheme, introduces the proposed AC-CS (Auto-Correlation Cyclic Shift) schemes by the Zadoff-Chu sequence to overcome the ICI of SRS and analyses their performance. The method used for performance analysis is determined by the detection abilities, which are missing probability and false alarm probability.

KEYWORDS

SRS, beamforming, auto-correlation, missing probability, false alarm probability

1. INTRODUCTION

In digital communication system such as LTE and NR, the inter-cell interference issue is a problem that has always been raised particularly. In order to solve this interference problem in the OFDM communication method, but the like algorithms such as ICIC (Inter-Cell Interference Cancellation) or CoMP (Coordinated Multi-Point) are emerged as a solution, there are disadvantages such as dividing the resources used.

In particular, the estimated performance by the received SRS (Sounding Reference Signal) distortion in the serving cell due to the SRS of the adjacent cells to derive a weight factor of the inaccurate beamforming is significantly reduced in condition of the low power or interference.

Thus, first of all, this paper analyses the performance degradation of estimated SRS due to adjacent cell's SRS in the conventional conditions that are currently commercialized 5G system, compares the simulation results in the proposed AC-CS (Auto-Correlation Cyclic Shift) schemes

of the Zadoff-Chu sequence and the conventional scheme in the cell's configuration and recommends the conditionally-fitted schemes of each a morphology.

2. BACKGROUND

2.1. Sounding Reference Signal

SRS is the acronym of Sounding Reference Signal. When the UE transmits to gNB to estimate the status of the uplink channel sent to gNB, gNB uses a way to report to the UE based on the channel status it currently identifies and reflect on future UL. In particular, it is importantly used in MIMO (Multi-Input Multi-Output), which is referred to as the leading technology in NR.

First of all, the UE can transmit the SRS to beam in several directions. gNB understands the channel status in each direction based on SRS of receiver, which gives the uplink channel the information it needs, such as which beam to use and how much rank to use. Based on the reporting result of the received gNB, the UE proceeds uplink process. Here's one thing to go through about DL/UL's CSI (Channel State Information).

If UL and DL in FDD use different frequencies, each sub-band CSI is different. However, in UL and DL in TDD using the same frequency band divided only in time, there is a point to consider. Since the factors that determine the channel state are largely composed of interference and obstacles of the frequency, there is a concept called channel reciprocity in TDD.

2.2. Zadoff-Chu Sequence

Zadoff-Chu sequences exhibit the useful property that cyclically shifted versions of themselves are orthogonal to one another, provided that each cyclic shift, when viewed within the time domain of the signal, is greater than the combined propagation delay and multipath delay spread of the signal between the transmitter and receiver.

A generated Zadoff-Chu sequence that has not been shifted is known as a root sequence. The complex value at each position n of each root Zadoff-Chu sequence parametrized by u is given by

$$x_u(n) = e^{-j\left(\frac{\pi un(n+1)}{N_{ZC}}\right)} \quad \square\square\square(1)$$

Where $0 \leq n < N_{ZC}$, $0 < u < N_{ZC}$, $\gcd(N_{ZC}, u) = 1$ and $N_{ZC} = \text{length of sequence}$.

2.3. Properties of Zadoff-Chu sequence

- They are periodic with period N_{ZC} if N_{ZC} is odd.
- If N_{ZC} is prime, the DFT (Discrete Fourier Transform) of a Zadoff-Chu sequence is another Zadoff-Chu sequence conjugated, scaled and time scaled.
- The auto correlation of a Zadoff-Chu sequence with a cyclically shifted version of itself is zero, i.e., it is non-zero only at one instant which corresponds to the cyclic shift.
- The cross-correlation between two prime length Zadoff-Chu sequences, i.e. different values of u , $u = u_1$, $u = u_2$, is constant $1/\sqrt{N_{ZC}}$, provided that $u_1 - u_2$ is relatively prime to N_{ZC} .

2.4. Auto-correlation

Auto-correlation is an indicator of the similarity between source sequence and sequence of added noise channel. Also, it is a time series and its simple linear correlation with its own past.

Basically, the value $x(t)$ means the correlation with the sequence of the sequence and the value $x(t+\theta)$ after the θ in hours. The time displacement θ is called time difference. Auto-correlation function is a correlation related to variable time. The coefficient of auto-correlation relates to the variable $x(t)$ and the variable $x(t+\theta)$ as a product-moment correlation coefficient.

2.5. Cross-correlation

In digital signal processing, cross-correlation is a level of similarity of two different sequences as a function of one another relationship. Simply, it is a correlation between two sequences $x(t)$ and $y(t)$.

Two sequences are the same variable measured in different places or the same variable observed in the same place, which may have different observation times. As an example, $y(t)$ may represent $x(t+\theta)$, wherein θ means a time delay.

3. SRS SEQUENCE GROUP IN NR

For example, the sequence group $u = (n_{ID}^{SRS}) \bmod 30$ if *groupOrSequenceHopping* equals 'neither', neither group, nor sequence hopping shall be used. The SRS sequence identity n_{ID}^{SRS} is given by the higher layer parameter *sequenceId* in the *SRS-Config* IE, in which case $n_{ID}^{SRS} \in \{0, 1, \dots, 1023\}$ and is PCID (Physical Cell Identifier) generally.

4. CONVENTIONAL CELL CONFIGURATION BY SRS

The 5G commercialized vendors around the world use n_{ID}^{SRS} to PCID (Physical Cell Identifier) generally.

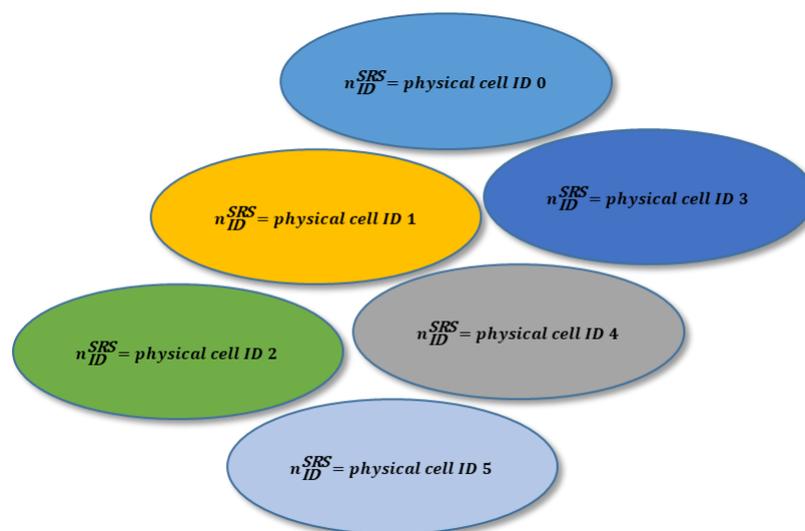


Figure 1. Conventional sequence group ID by SRS

In this case, the group ID is used differently between cells, so the type of Zadoff-Chu sequence is different between cells, as expressed in different colours, such as Figure 1. When decoding the received signal from the position of the base station, the signal coming from the other cell is to act as interference. In an environment such as Figure 1, because the SRS group id is different for each cell, it has the characteristics of cross-correlation rather than the characteristics of auto-correlation.

Since Zadoff-Chu sequence of other cell using other SRS group ID increases noise by $\frac{1}{\sqrt{N_{ZC}}}$ as mentioned above, the performance can only be degraded in environments such as UMa (Urban Macro) with many surrounding cells. Vendors are to configure the settings differently according to morphology, such as RMa (Rural Macro) or UMa (Urban Macro), so it has a very complex configuration, from a commercialization point of view.

All currently commercialized vendors want to be a stable and simple configuration. Therefore, they choose to configure the SRS group ID with PCID (Physical Cell ID). However, this method will reduce performance in the cell edge in an environment such as UMa (Urban Macro). Performance decreases with the number of nested cells is in the simulation results in the performance section below.

5. PROPOSED CELL CONFIGURATION SCHEMES

In order to overcome the degradation of conventional scheme such as Figure 1, two new schemes are proposed. Conventional method, the more nested cells, is the more disadvantageous of increasing the noise by the cross-correlation characteristics.

The two newly proposed methods are using the same SRS sequence to reduce the noise due to cross-correlation of the surrounding cells to overcome the conventional disadvantages, and between cells using the same sequence is applied a method of minimizing interference using a cyclic shift.

5.1. 1st Proposed Scheme

In the cell configuration, as shown in the example of Figure 2, 1st proposed scheme is a method of using the same SRS group ID in three cells' unit. That is, this scheme uses the same SRS sequence in three cells' unit, and they use a same sequence applied to different cyclic shift. At this time, other three cells can be deployed by same configuration. Blue cells use the same SRS sequence having the same SRS group ID, and that sequence is done by different cyclic shift. Green cells also use the same configuration.

The NR RRC message used can be configured as Table 1 with the PCID (Physical Cell Identify) of each cell, which is constituted by the cyclic shift with modulo 3. At this time, the shifted sequence should be configured as far away as possible for a good performance. For example, it is best as far as 4 units of 12 intervals to maximize performance in this condition of NR. The reason is that the peak by auto-correlation of the same sequence is not ideal and the peak is gradually growing. This shows in the simulation results' section below. The *combOffset-n4* and *cyclicShift-n4* are RRC Messages for the distinction of UEs.

If the cell is configured as the same SRS Group ID of three cells' unit, when there are many adjacent cells, such as Figure 2, there is still disadvantage that noise is increased by the interference of cross-correlation from cells of different colour.

The way to overcome this disadvantage is a 2nd proposed scheme.

Table 1. 1st proposed cell configuration

SRS RRC Message	Usage	Value	
<i>combOffset-n4</i>	Intra-Cell UEs	0, 1,2, 3	
<i>cyclicShift-n4</i>	Inter-Cell UEs	PCID % 3 = 0	0
		PCID % 3 = 1	4
		PCID % 3 = 2	8

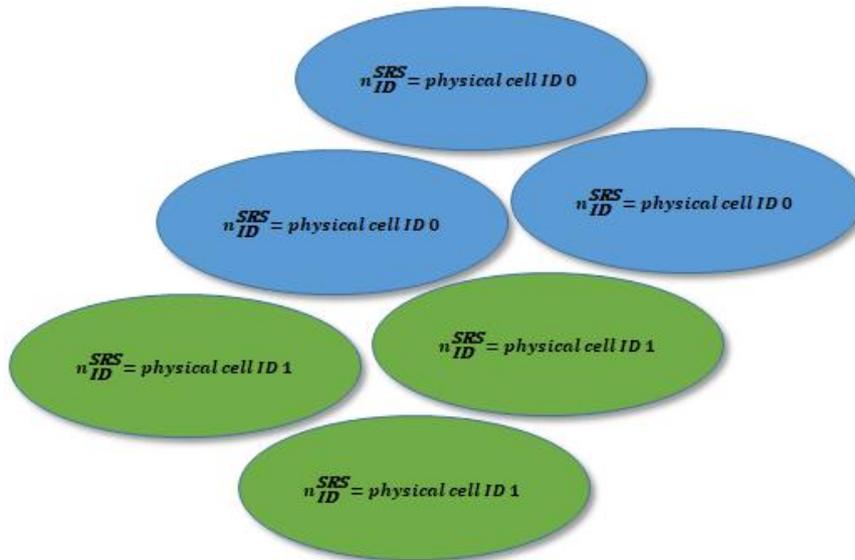


Figure 2. 1st proposed cell configuration by SRS sequence group ID

5.2. 2nd Proposed Scheme

As in the example of Figure 3, the 2nd proposed scheme is a method of using the same SRS group ID in six cell's unit in the cell configuration. That is, this scheme uses the same SRS sequence in six cells' unit, and they use a same sequence applied to different cyclic shift. At this time, cells of different colour can be deployed by same configuration. That is, blue cells are the same SRS sequence using the same SRS group ID and the sequence is done by different cyclic shift.

Table 2. 2nd proposed cell configuration

SRS RRC Message	Usage	Value	
<i>combOffset-n4</i>	Intra-Cell UEs	0, 1, 2, 3	
<i>cyclicShift-n4</i>	Inter-Cell UEs	PCID % 6 = 0	0
		PCID % 6 = 1	2
		PCID % 6 = 2	4
		PCID % 6 = 3	6
		PCID % 6 = 4	8
		PCID % 6 = 5	10

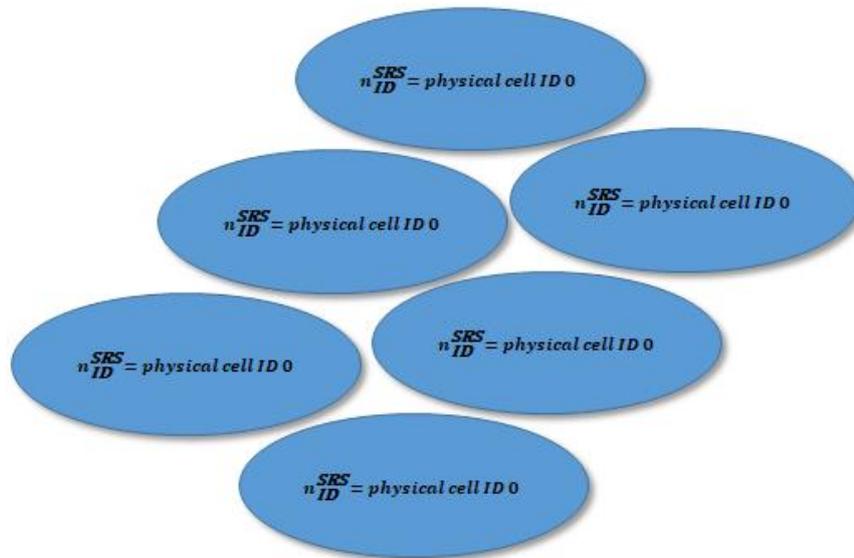


Figure 3. 2nd proposed cell configuration by SRS sequence group ID

The NR RRC message used can be configured as Table 2 with the PCID (Physical Cell Identify) of each cell, which is constituted by the cyclic shift with modulo 6. At this time, the shifted sequence should be configured as far away as possible for good performance. For example, it is best as far as 2 units of 12 intervals to maximize performance in this condition of NR. The reason is that peak by auto-correlation of the same sequence is not ideal and the peak is gradually growing. This also shows in the simulation results' section below.

5.3. Pros and Cons

The pros and cons for each scheme are expressed as table 3. Conventional scheme has an advantage that the cell configuration is simple, but there is a disadvantage that the SRS cross-correlation interference between cells is increased. To compensate for this disadvantage, the 1st proposed scheme has the best auto-correlation characteristics, but since only three cells are the same sequence, there is some SRS cell-to-cell interference. The 2nd proposed scheme is that configured all the cells (6 cells) have the same sequence. This method has an advantage that SRS inter-cell interference does not exist and the disadvantage that the characteristics of auto-correlation of closer peak by cyclic shift in same sequence may be worse.

Table 3. Each Scheme Comparison

Scheme	Comparison	
	Advantage	Disadvantage
Conventional	Easy cell configuration	High SRS ICI ^a
1 st Proposed	Good auto-correlation	Medium SRS ICI ^a
2 nd Proposed	Low SRS ICI ^a	Medium auto-correlation

^aInter-Cell Interference

6. PERFORMANCE COMPARISON

Based on what we've described so far, compare the performance of the conventional, 1st, and 2nd proposed scheme.

First of all, Figure 4 is the channel correlation of 1st proposed scheme and Figure 5 is the channel correlation of 2nd proposed scheme. According to Figure 4 and Figure 5, the 1st proposed scheme is cleaner around peak than the 2nd proposed scheme. The reason is that the 1st proposed scheme has low number of cyclic shift, so the overall noise can be elevated, but false alarm probability is reduced than 2nd proposed scheme such as Figure 7.

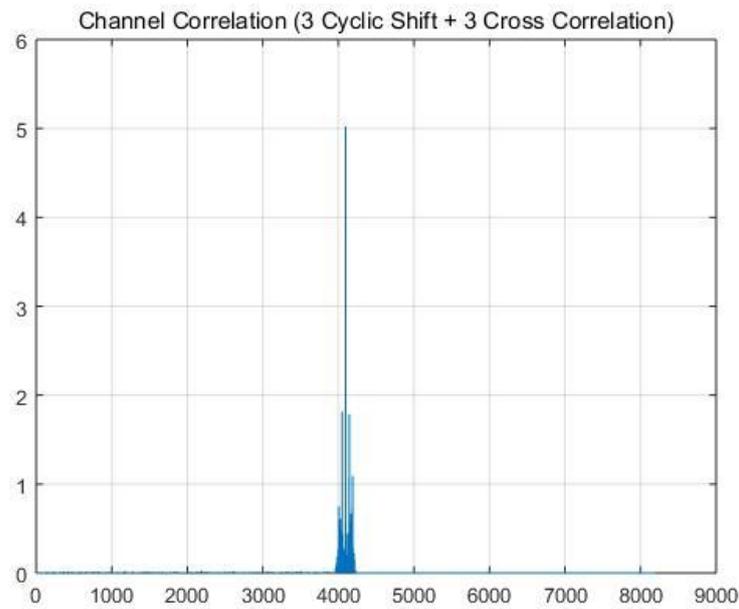


Figure 4. The channel correlation property of 1st proposed scheme

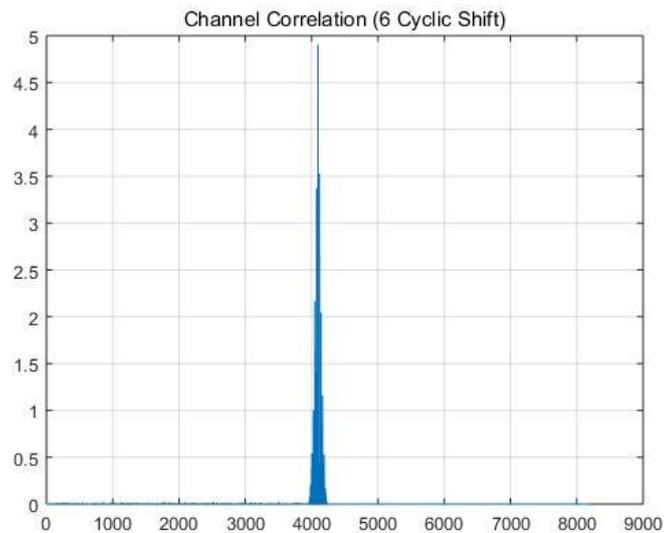


Figure 5. The channel correlation property of 2nd proposed scheme

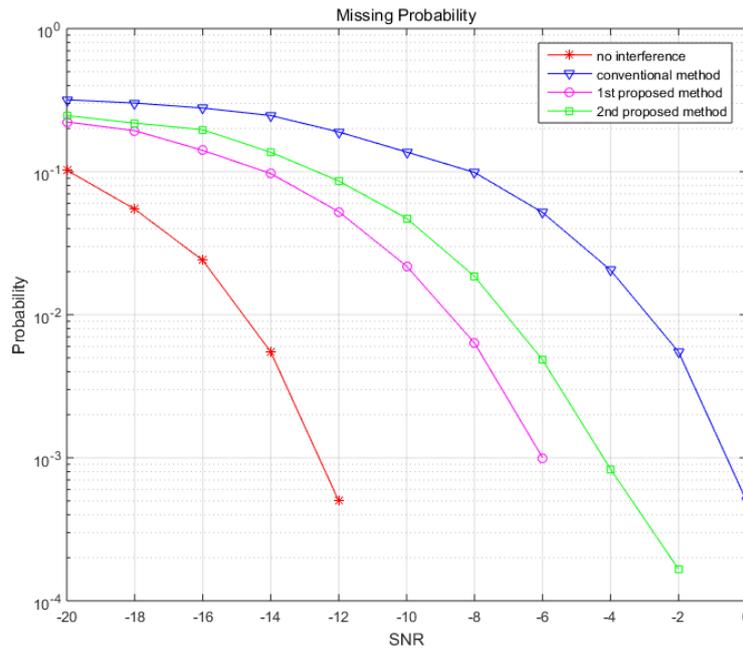


Figure 6. The Performance of no ICI, conventional and proposed scheme

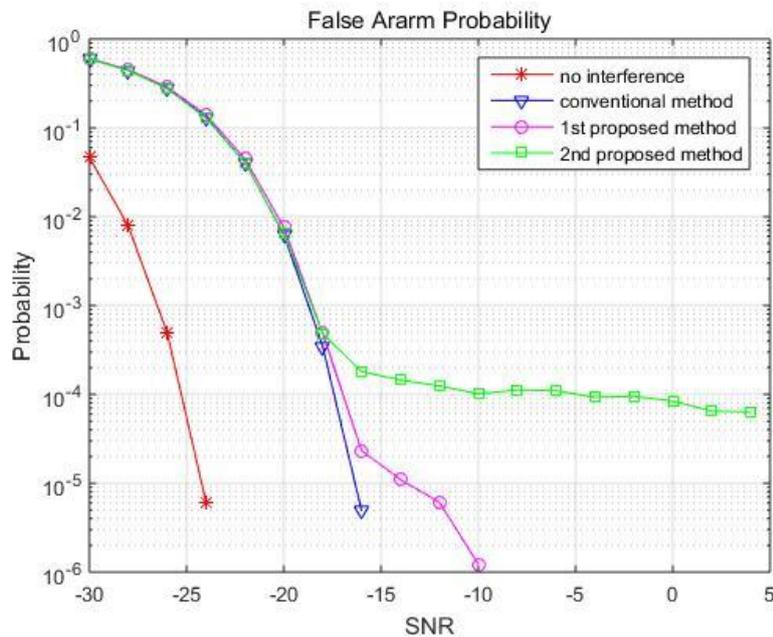


Figure 7. The False Alarm of no ICI, conventional and proposed scheme

The graph of comprehensive performance is Figure 6. Based on 1% missing probability, the conventional scheme has bad performance by 12 dB compared to no interference. However, 1st proposed scheme has good 6dB performance compared to a conventional scheme, and 2nd proposed scheme has 4dB gain compared to a conventional scheme.

Figure 7 is the comparison of false alarm probability in same condition of Figure 6. The 2nd proposed scheme looks relatively poor in good SINR conditions. The reason is that there are a lot of small peaks in addition to real peak due to the cyclic shift of same SRS sequence. However,

there is no issue of performance degradation since 3GPP standard recommends the false alarm conditions satisfy 0.1% generally.

Based on the performance graph, the morphology which 1st scheme is used in commercial environment is appropriate urban regions in typical, and 2nd scheme is a more suitable method in dense urban region where cells are tighter. Because, the tighter the cell, the worse the cross-correlation characteristics, so dense urban region is good to use the method of cyclic shift as much as possible with the same SRS sequence.

7. CONCLUSIONS

It is very important in digital beamforming algorithm to determine the correct beamforming weight factor by estimating the channel with uplink SRS. Thus, this paper analysed the level of interference between the cells receiving the SRS in various ways.

Using the new proposed AC-CS (Auto-Correlation Cyclic Shift) of Zadoff-Chu sequence, base station can overcome inter-cell interference when it receives SRS. Also, we compared its performance with conventional and proposed schemes. In order to maximize performance in the actual commercial environment, 1st and 2nd proposed schemes can be selected depending on the specific morphology.

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