Performance analysis of Auto & Cross Correlation values of Spreading Sequences and comparison between PIC and PPIC & Computational complexity of DPIC for DS-CDMA system

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Abstract: — Spreading sequences is essential to wireless communication system. It is employed in direct sequence code division multiple access system (DS-CDMA) to serve increased user count with different spreading sequences like orthogonal and non-orthogonal spreading sequences. Reduction of MAI to improve system capacity without increasing computational Complexity is the motivation to do this work. The objective of this paper is to develop an efficient multiuser detection algorithms that reduce the computational complexity and increases the system performance in DS-CDMA system. The BER performance of the multistage multiuser PIC detection scheme is found to be better than that of a single stage multiuser PIC detection scheme but at the cost of computational complexity increasing with number of stages and users. It is found that the BER performance of the multistage multiuser PPIC detection scheme is better than that of the multistage multiuser PIC detection scheme but the computational complexity increases. Though the computational complexity is found reduced in the multistage multiuser DPIC when compared to the multistage multiuser PIC.

Keywords: — DS-CDMA, PIC, PPIC, DPIC, Multiuser Detection, MAI.

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1. Introduction

In order to effectively make use of the resources available bandwidth, Spread-Spectrum Communication Systems use spreading sequences where in each user is identified by a unique spreading sequence possessing apt (or desirable) correlation properties as these play an important role. In addition, code sequence length limits the system capacity. Hence, the selection of spreading sequences is a significant step in spread-spectrum systems. Code sets can be classified as binary and non-binary code sequences. The real numbers, ±1 are only the elements of the binary code sequence sets whereas the non-binary code sequences sets have elements more than two that are not real numbers like quadric-phase and poly phase-sequences. In the present era of binary logic circuits, spread spectrum systems utilize binary code sequences. Binary code sequences possess better auto-correlation and cross-correlation values when compared to those of non-binary code sequences. Spread-spectrum system performance depends on the correlation properties of the spreading sequence selected [1]. To have a better BER performance the spreading sequences used should possess high auto-correlation values. At the same time, the reduction in MAI is possible if the spreading codes possess minimum cross-correlation values amid a pair of spreading sequences used [2-4]. Taking the above salient aspects of spreading sequences into account, a critical review of existing ML sequences, Gold sequences and Kasami sequences are explored. CDMA uses a "spread spectrum" technology where in a large bandwidth spreading signal multiplies the narrowband message signal and the users are differentiated by their unique codes [5-10].

2. Literature Review

Yao Xie, et.al. presented a “Reduced-Dimension Multiuser Detection” for reducing the dimensionality [11]

Bo Ma, et.al. presented a “GMM-MUD: An Effective Multiuser Detection Algorithm for DS-UWB-Based Space Formation Flying Systems”[12].

Saif Hikmat Mousa, et.al. presented a “Effective Wide Spectrum Sharing Techniques Relying on CR Technology toward 5G”[13].

J.Ravindrababu, and E.V.KrishnaRao, Y.RajaRao, presented a “Interference and complexity reduction in multi stage multi-user detection”[14].

J.Ravindrababu, and E.V.KrishnaRao, presented a “Interference Reduction in fading environment using Multistage Multiuser Detection Techniques”[15].

Daniele Angelosante et al [16] have presented a Sphere Detection (SD) algorithm, it shows that computational burden can be drastically reduced, with little or no loss of performance, by applying a suitable version of the sphere detection (SD) algorithm.

Linglong Dai, et al [17] proposed the Gauss–Seidel (GS) method to iteratively realize the MMSE algorithm without the complicated matrix inversion.

Yang Du, et al [18] propose a novel low-complexity detector based on an edge selection approach, which remarkably reduces the computational complexity.

Yinman Lee, et al [19] a low-complexity hybrid analog-digital signal detector for uplink multiuser massive multiple-input multiple-output (MIMO) systems. In particular, both the hardware cost and computation load can be reduced.

Rong Ran and Hayoung Oh [20] Sparse-aware (SA) detectors have attracted a lot of attention due to their significant performance and low complexity, in particular for large-scale multiple-input multiple-output (MIMO) systems. Similar to the conventional multiuser detectors, the nonlinear or compressive sensing-based SA detectors provide better performance but are not appropriate for the over-determined multiuser MIMO systems in the sense of power and time consumption. The linear SA detector provides a more elegant tradeoff between performance and complexity compared to the nonlinear ones.

After the review of the existing relevant literature, the following observations are being made:

i. The overall BER performance among all the multi-user detectors was found better in the maximum likelihood detector/the optimum detector at the cost of very high computational complexity and thus not realistic for implementation.
ii. Reduced computational complexity exists in decorrelating detectors and MMSE detectors. However in these linear detectors, the calculation of the inverse cross-correlation matrix is difficult.
iii. The computational complexity increases linearly with the number of users in SIC, PIC, HIC, and PPIC techniques. Each type of interference cancellation detector has its level of complexity, processing time, and BER performance.

Given the above observations, there exists a need to make studies to enhance visual DS-CDMA system performance and reduce the difficulty of computing. Further, interference cancellation methods other than the existing ones are to be explored for DS-CDMA systems.

3. Multistage Multiuser Detection Techniques

3.1 Multistage Multiuser PIC with MMSE Detector

Data bit estimation and interference cancellation need to be done for each user at every stage in multistage PIC schemes. The MMSE detector estimates data bits and subtracts interference from the first stage onwards in this Multistage Multiuser PIC scheme [14-15]. The Multistage Multiuser PIC with MMSE Detector is shown in Fig 1.

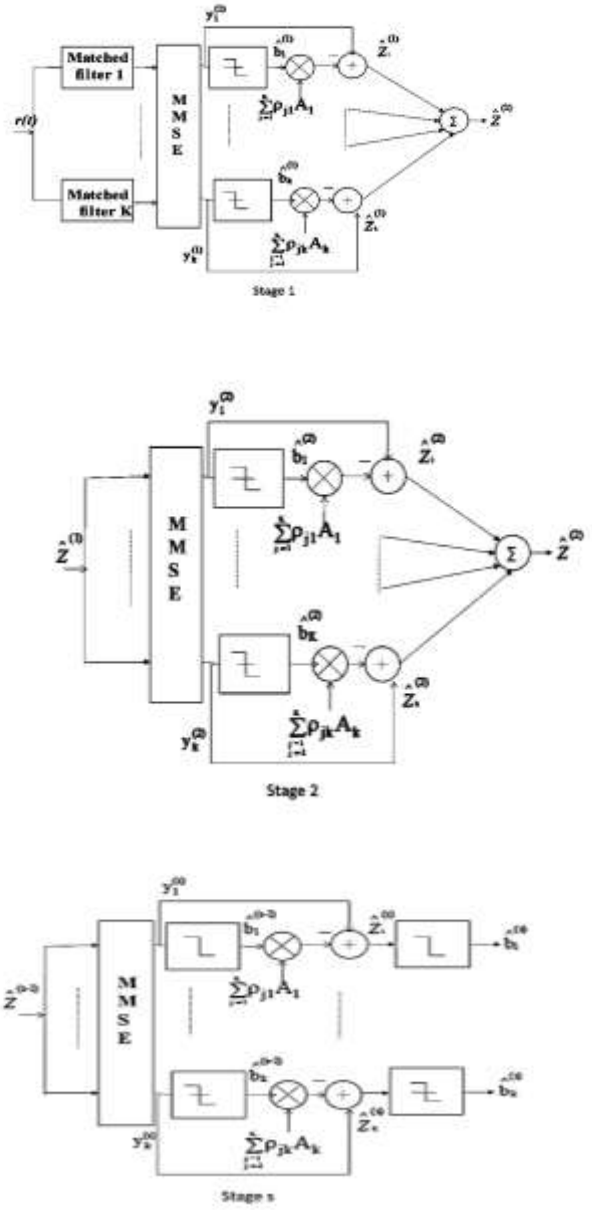

Fig 1: Multistage Multiuser PIC with MMSE Detector

- **Algorithm for Multistage Multiuser PIC with MMSE detector:**

```
$\hat{b}_1^{(1)} = \mathrm{sgn}(y_{mmse})$
For s=2 to S     %/ Cancellation of Interference s-1 stages/
    For k=1 to K %/ The interference is subtracted from every user signal at each stage /
        $Z_k^{(s-1)} = y_{mmse} - \sum_{\substack{j=1 \\ j \neq k}}^{K} A_j \rho_{jk} \hat{b}_j^{(s)}$
        where $\rho_{kj} = R_{kj} - \mathrm{diag}(R_{kj})$
        $z_k^{(s-1)} = y_{mmse} - \sum_{\substack{j=1 \\ j \neq k}}^{K} A_j (R_{kj} - \mathrm{diag}(R_{kj})) \hat{b}_j^{(s)}$
    End
    $\hat{b}_k^{(s)} = \mathrm{sgn}(z_k^{(s-1)})$     %/ Decision /
End
```

3.2 Computational Complexity of PIC

Computational Complexity involves the amount of time taken to accomplish the multiuser detection starting from the time of arrival of the transmitted signal at the first stage of the detector of the receiver. Therefore, the time required to perform the number of multiplications and the wide variety of additions in the detection process need to be calculated to arrive at the computational complexity.

The cancellation of MAI from the stronger user every time until the closing user requires the multiplication of two matrices. To accomplish the multiplication of an ($A_1 \times B_1$) matrix with a ($B_1 \times C_1$) matrix, $A_1B_1C_1$ multiplications and A_1B_1C additions are needed.

Therefore, assuming K users in the system wherein the transmission is a burst waveform, each user transmits D data symbols in the burst, B represents the number of chips in the spreading code for every user, and U is the complicated matrix which includes the factors that describe the channel impulse response, then one needs DB instances of multiplications and DB instances of additions for each user for one data symbol in a single path burst. If the bursts arrive along L multi-path channels, then the receiver would require DBL instances of multiplications and DBL instances of addition for one data symbol. Combine the D symbols transmitted from the dispersive paths, requires in addition DL instances of multiplications and DL instances of additions. Therefore, DBL+DL times of multiplications and DBL+DL times of additions are required to get the data estimates from the receiver. In the signal reconstruction process, the data estimates need to be respread with the spreading code first and then convolved with the corresponding channel impulse response, which leads to DBL multiplications and (DB+U−1) additions. To get the data estimate for every user, the effects of remaining users need to be subtracted. To cancel one user's MAI, it needs (DB+U−1) subtractions. Therefore, for every user, (K−1)(DB+U−1) subtractions are needed. For a system supporting K users, the whole number of mathematical operations are $S_{PIC1} = K$ [DBL+DL+DBL+DL+DBN+DBL+DB+U-1+(K-1) (DB+D-1)]

= K [3DBL+2DL+DB+K(DB+U-1)] for first stage

Therefore, for two-stage,

$S_{PIC2} = 2K$ [3DBL+2DL+DB+K(DB+U-1)]

Therefore, the number of operations needed by the two-stage PIC detector for every one symbol is

$$S_{PIC2\,/symbol} = S_{PIC2} / KD$$

3.3 Multistage Multiuser PPIC with MMSE Detector

In this scheme, the MAI Cancellation is implemented using a weight factor at every stage to decide about the amount of cancellation to be implemented [14-15].

In a Multistage Multiuser PPIC scheme, the weight factor used for interference cancellation affects a biased selection statistic. The bias has its strongest effect on the first stage of interference cancellation. In the subsequent stages, its effect decreases. However, if the biased selection statistic is unfair at the first stage leading to a wrong cancellation, then the effects of these errors can escalate in the subsequent stages [14-15].

One way to mitigate the effect of the biased selection statistic to enhance the overall performance of multistage PPIC is to multiply the amplitude estimates with a partial cancellation factor, $C_K^{(s)}$ lying between 0 and 1 [i.e., $0 \le C_K^{(s)} \le 1$] which varies with the stage of cancellation 's' and the number of users 'K'.

In this scheme also, various stages are involved for interference estimation and cancellation. The MMSE is used in the first stage to estimate the information bits whereas the subsequent stages also use MMSE detectors. The signal reconstruction and subtraction of the predicted interference from other users obtained by weighting the estimates of the information bit of the user in question is carried out at all stages [14-16]. The multistage multiuser PPIC with MMSE detector is shown in Fig 2.

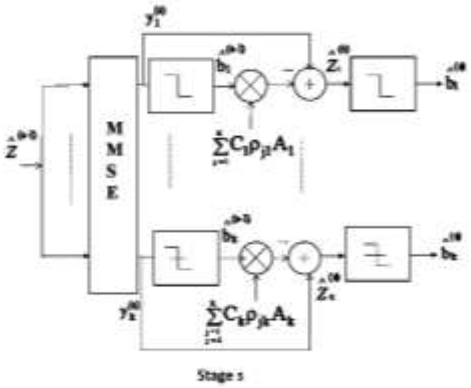

Fig 2: Partial PIC detector

- **Algorithm for Multistage Multiuser PPIC with MMSE detector:**

```
$\hat{b}_1^{(1)} = \mathrm{sgn}(y_{mmse})$

    For s=2 to S    %/ Cancellation of Interference s-1 stages /

    For k=1 to K    %/ The interference is subtracted from every user signal at each stage /

        $z_k^{(s-1)} = y_{mmse} - \sum_{j=1, j\neq k}^{K} c_k^{(s)} A_j \rho_{kj} \hat{b}_j^{(s)}$

        where $\rho_{kj} = R_{ij} - diag(R_{ij})$

        $z_k^{(s-1)} = y_{mmse} - \sum_{j=1, j\neq k}^{K} c_k^{(s)} A_j (R_{ij} - \mathrm{diag}(R_{ij})) \hat{b}_j^{(s)}$

    End

    $\hat{b}_k^{(s)} = \mathrm{sgn}(z_k^{(s-1)})$    %/ Decision /

    End
```

3.4 Computational Complexity of PPIC:

For this case, assuming K users in the system where the transmission is a burst waveform, each user transmits D data symbols in the burst, n represents the number of chips in the spreading code for every user, C represents the partial cancellation factor and U is the complicated matrix which includes the factors that describe the channel impulse response, then one needs CDBinstances of multiplications and CDB instances of additions for each user for one data symbol in a single path burst. If the bursts arrive along L multi-path channels, then the receiver would require CDBL instances of multiplications and CDBL instances of additions for one data symbol. Combining the q symbols transmitted from the dispersive paths requires CDL instances of multiplications and CDL instances of additions. Therefore, to get the data estimates from the receiver, CDBL+CDL times of multiplications and CDBL+CDL times of additions are required. In the signal reconstruction part, the detected data have to be re-spread with the spreading code first leading to CDB instances of multiplications and then convolve with the corresponding channel impulse response resulting in DBL times of multiplications and C(DB+U−1) times of additions. To get the estimate for every user, all of the different users' affects need to be subtracted. To cancel one user's MAI, it will need C(DB+U−1) instances of subtraction. Therefore, for every user, (K−1)C(DB+U−1) instances of subtractions are needed. For a system supporting K users, the whole number of mathematical operations are

S_{PPIC1} = KC [DBL+DL+DBL+DL+DB+DBL+DB+U-1+(K-1)(DB+U-1)]

= KC [3DBL+2DL+DB+K(DB+U-1)] for first stage

Therefore, for two-stage,

S_{PPIC2} = 2 KC [3DBL+2DL+DB+K(DB+U-1)]

Therefore, the number of operations needed by the two-stage PIC detectors for every symbol is

$$S_{PPIC2\ /symbol} = S_{PPIC2}/\ KD\ .$$

3.5 Multistage Multiuser Differencing PIC with MMSE Detector

In PIC schemes, the component of MAI from different users is eliminated from the acquired signal to get a higher-anticipated signal for a specific user in parallel. As the exact bit statistics for any user are not known, the anticipated bits are made use of at each stage [14]. As this process is iterative, it's highly possible to have $b_k^{(s)}=b_k^{(s-1)}$ after s^th^ iteration. Instead of managing with an estimated bit vector $b_k^{(s)}$ at each stage s, one can calculate the difference of the estimated bits in two consecutive stages. Then input at each stage s becomes $e_k^{(s)} = \hat{b}_k^{(s)} - \hat{b}_k^{(s-1)}$ and is called the differencing technique.

The multistage multiuser DPIC with MMSE detector is shown in Fig 3.

The first stage of this DPIC scheme remains the same as in DPIC with an MMSE detector. This scheme makes use of an MMSE detector from the second stage onwards also wherein the preceding estimations from stage-1 are utilized to generate a new vector of signals. Then sum up all the interfering users and subtract them from the MMSE output signal [14].

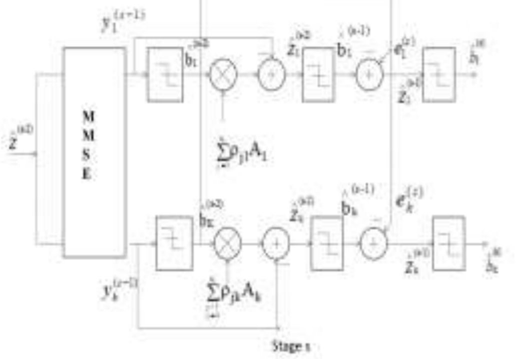

Fig 3: Difference PIC detector using MMSE

The first stage of this DPIC scheme remains the same as that in DPIC with an MMSE detector. This scheme makes use of MMSE detector from the second stage onwards also wherein the preceding estimations from stage-1 are utilized to generate a new vector of signals. Then sum up all the interfering users and subtract them from the MMSE output signal [14].

Algorithm for Multistage Multiuser DPIC with MMSE detector:

```
$\hat{b}_1^{(1)} = \mathrm{sgn}(y_{mmse})$

For k=1 to K   %/Interference is subtracted from each user at every stage /

        $z_k^{(2)} = y_{mmse} - \sum_{j=1, j\neq k}^{K} A_j (R_{ij} - diag(R_{ij})) \hat{b}^{(1)}$

    End

    $\hat{b}_1^{(2)} = \mathrm{sgn}(Z_1^{(2)})$

%detection/

For s = 2 to S %/ second and next stages: Subtracting multistage
    For k = 1 to K

        $z_k^{(s-1)} = z_k^{(s)} - \sum_{j=1, j\neq k}^{K} A_j (R_{kj} - diag(R_{kj})) \hat{e}_j^{(s)}$

            where $e_j^{(s)} = b_j^{(s)} - b_j^{(s-1)}$

End

$\hat{b}_1^{(s)} = \mathrm{sgn}(Z_k^{(s-1)})$            %/decision/

End
```

3.6 Computational Complexity of DPIC

The computational complexity of this DPIC system can be arrived at on similar lines to that for PIC and PPIC as discussed respectively in sections 3.3 and 3.4 previously. That is, it is based on the total number of multiplications and additions involved in this scheme. The procedure is similar to that in the first stage of PIC except only DB times more additions are required in differencing PIC. Since for a PIC system supporting K users, the total number of mathematical operations are

S_{PIC}= K [DBL +DL+ DBL +DL+DN+ DBL +DB+U-1+(K-1)(DB+U-1)]

$=K[3DBL+2DL+DB+K(DB+U-1)]$ for first stage of PIC.

Therefore, for a single-stage DPIC,

$S_{DPIC1} = K[3DBL+2DL+DB+K(DB+U-1)] + DB$

Therefore, the number of operations needed by the single-stage DPIC detector for every symbol is

$S_{DPIC1/symbol} = S_{DPIC1}/ KD$

Similarly, for a two-stage DPIC

$S_{DPIC2} = 2\{K[3DBL+2DL+DB+K(DB+U-1)] + DB\}$

and the number of operations needed by the two-stage DPIC detector for every symbol is

$$S_{DPIC2/symbol} = S_{DPIC2}/ KD$$

4. Simulation Results

The DS-CDMA basic multistage multiuser discrete time paradigm was applied. The customer's data is disseminated via BPSK modulation and Kasami odd spreading sequence.

It is evident from the below simulation results that with an increasing number of stages, the system's overall BER performance is improved as PIC with MMSE detector. However, the computational complexity also increases. The BER performance did not alternate dramatically beyond 4th stage (not shown here). Three stages are only considered for simplicity. BER performance is better at the 3rd stage when compared to that at the 1st stage and 2nd stage for all the cases like PIC, PPIC, and DPIC from Fig 4,5 and 6 for clarity.

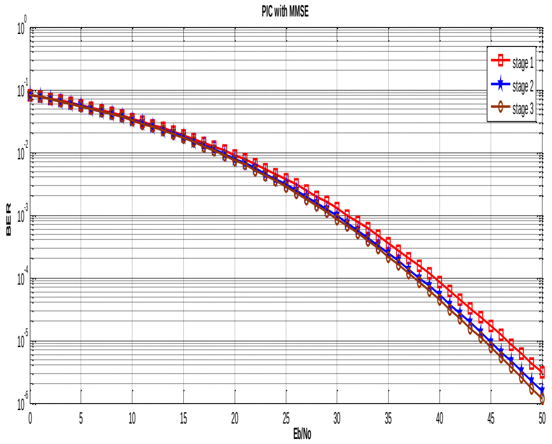

Fig 4: Bit-Error-Rate performance of PIC with MMSE for K=10 users

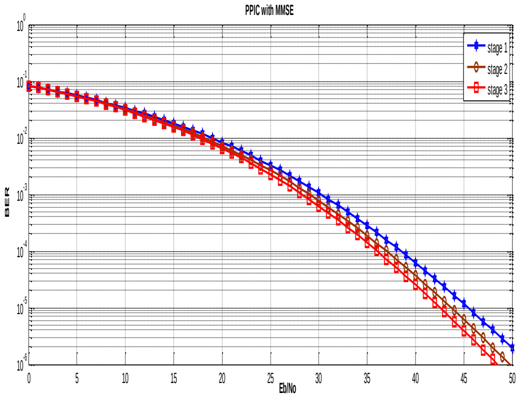

Fig 5: Bit-Error-Rate performance of PPIC with MMSE for K=10

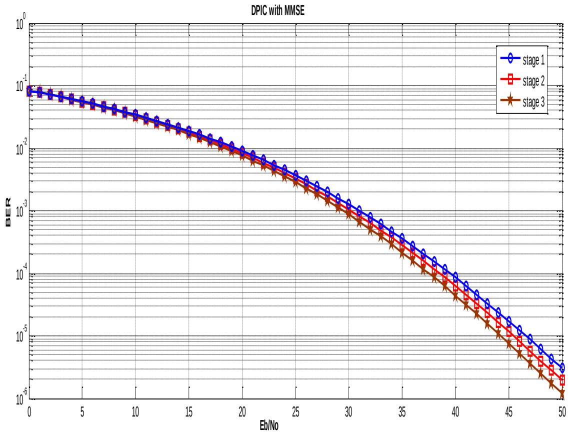

Fig 6: Bit-Error-Rate performance of DPIC with MMSE for K=10

Computational complexity increases with an increasing number of users as shown in Fig 7 .

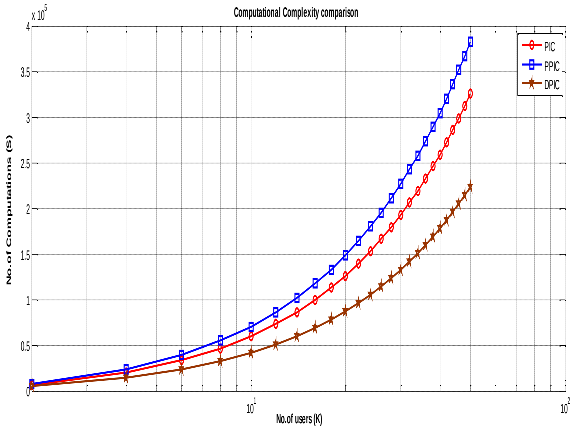

Fig 7: Computational complexity of PIC, PPIC & DPIC

5. Conclusions

Employing multiple-stage multiuser approaches in DS-CDMA systems can also minimize the complexity of computation and Multiple Access Interference. In the multistage PIC approach, bit error rate (BER) drops and detection becomes more dependable as the number of stages rises. The ability to increase in subsequent phases cannot be guaranteed by the PIC. In a DS-CDMA system, the effectiveness of the Partial Parallel Interference Cancellation (PPIC) technique is assessed. However there is no improvement in computational complexity. The computational complexity decreased by using DPIC. Ultimately, it may be concluded that DPIC outperforms PIC and PPIC.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

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Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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