International Journal of Computer Architecture and Mobility
(ISSN 2319-9229) Volume 3 -Issue 1A, February 2015

RNS Based Pn Sequence code in WCDMA and DSCDMA

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Abstract : Code Division Multiple Access (CDMA) based on Spread Signal (SS) has emerged as one of the most important multiple access technologies for Second Generation (2G) and Third Generation (3G) wireless communication systems by its wide applications in many important mobile cellular standards. CDMA technique relies on spreading codes to separate different users or channels and its properties will govern the performance of the system.

It is known that orthogonal Codes are used to multiplex more than one signal for downlink transmission over cellular networks. This downlink transmission is prone to self interference caused by the loss of orthogonality between spreading codes due to multipath propagation. This issue is investigated in detail with respect to WCDMA standards, which is very good representative for CDMA based 3G mobile cellular systems where the channelization code is OVSF code. The problem of OVSF codes restricts the number of available codes for a given cell. Since the 3rd generation WCDMA mobile communication systems apply the same multiple access technique, the generated sequence can also be the channelization code for downlink WCDMA system to mitigate the same. The performance of the system is compared with Walsh Hadamard code over multipath AWGN and different Fading channels. This thesis work shows that RNS based PN sequence has enhanced performance to that of other CDMA codes by comparing the bit error probability in multiuser and multipath environment thus contributing a little towards the evolution of next generation CDMA technology.

Keywords : RNS, CDMA,2G,3G,PN sequence, WCDMA

I.Introduction

Residue number systems are based on the congruence relation as: two integers, a and b are said to be congruent modulo m if m divides exactly the difference of a and b; it is common, especially in mathematics tests, to write $a \equiv b(\mathrm{mod}\ m)$ to denote this. Thus, for example, 10 ≡ 7(mod 3), 10 ≡ 4(mod 3), 10 ≡ 1(mod 3) and 10 ≡ 2(mod 3). The number m is a modulus or base, and its values exclude unity produces only trivial congruence's [26, 27].

If q and r are the quotient and remainder, respectively, of the integer division of a by m i.e. $a = q * m + r$, Then, by definition a≡ r (mod m).The number r is said to be the residue of a with respect to m, and is denoted by $r = |a|_m$.

As an example, the residues of the integers zero through fifteen relative to the module two, three and five (which are pair wise relative prime) are given in the left half of Table 2.1. And the residues of the same numbers relative to the module two, three and four (which are pair wise relatively prime) are given in the right half of the same table. Observe that no sequence of residues is repeated in the first half, whereas there are repetitions in the second.

The set of m smallest values,{0,1,2,3…(m-1)} that the residue may assume is called the set of least positive residue modulo m. Consider a set {m1,m2,…mn },of n positive and pair wise relatively prime module. Let R be the product of the module for every j and k if $j \neq k$, then mj and mk have no common divisor larger than unity. Then every number X< R has unique representation in the residue number system [26,27]. A partial proof of this is as follows.

Suppose X1 and X2 are two different numbers with the same residue set, then

$$|X1|mi = |X2|mi =) \ |X1 - X2|mi = 0 \qquad (2.1)$$

Therefore X1 and X2 are the Least Common Multiple (LCM) of mi. But if the mi are relatively prime, then their LCM is R, and it must be that X1 and X2 is multiple of R. So it cannot be that X1 < R and X2 < R. Therefore, the set $\{|X|_{m_i} : 1 \leq i \leq n\}$ is unique and may be taken as the representation of X and such a representation can be written in the form $\langle x_1, x_2 \ldots x_n \rangle$ where $x_i = |X|_{m_i}$, and relationship between X and its residues can be indicated by writing $X \cong \langle x_1, x_2 \ldots x_n \rangle$. The number R is called the dynamic range of the RNS, because the number of numbers that can be represented is R.

II.WCDMA

One of the most promising approaches to 3G is to combine a WCDMA air interface with the fixed network of GSM without ignoring the numerous advantages of the already existing GSM networks. The standard that has emerged is based on European Telecommunication Standards Institute (ETSI) – UMTS and is commonly known as UTRA [56, 57, 58, 59], This air interface technology specified by 3rd Generation Partnership Project (3GPP) applies DS-CDMA technique for multiplexing different users [13, 60, 61, 62, 63]. The information is spread over a band of approximately 5 MHz. Due to this wide bandwidth it called as WCDMA i.e. Wideband CDMA. There are two different modes of WCDMA –

- Frequency Division Duplex(FDD) : The uplink and downlink transmissions employ two separated frequency bands for this duplex method. A pair of frequency bands with specified separation is assigned for a connection.

In this chapter all system description are provided in FDD Mode.

- Time Division Duplex (TDD) : In this duplex method, uplink and downlink transmission are carried over the same frequency band by using synchronized time intervals Thus time slots in physical channel are divided into transmission and reception part.

2.1.1 Physical Channel Structure

WCDMA defines two dedicated physical channels in both links:

- Dedicated Physical Data Channel (DPDCH)
- Dedicated Physical Control Channel (DPDCH)

Each connection is allocated one DPCCH and zero, one or many DPDCHs. In addition, there are common physical channels defined as Primary and secondary Common Physical Channel (CCPCH), Synchronization Channel (SCH) and Physical Random Access Channel (PRACH)

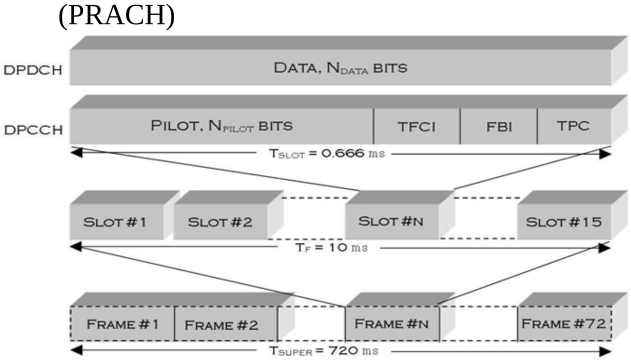

Figure 4.1: Frame Structure for Uplink c DPDCH/DPCCH

Figure 2.1 shows the basic frame structure of the uplink dedicated physical channels [61, 64, 65]. Each frame of 10 ms is split into 15 slot is of the length Tslot= 0.666 ms with 2560 chips, corresponding to one power control period. The super frame length is 720 ms ; i.e. a super frame corresponds to 72 frames. Pilot bits assists coherent demodulation and channel estimation. Transport Format Combination Indicator(TFCI) is used to indicate and identify several simultaneous services .Feedback Information (FBI) bits are to be used to support techniques requiring feedback. Transmit Power Control (TPC) which stands for transmit power control purposes. The Spreading Factor (SF) may range from 256 down to 4. The spreading factor is selected according to the date rate.

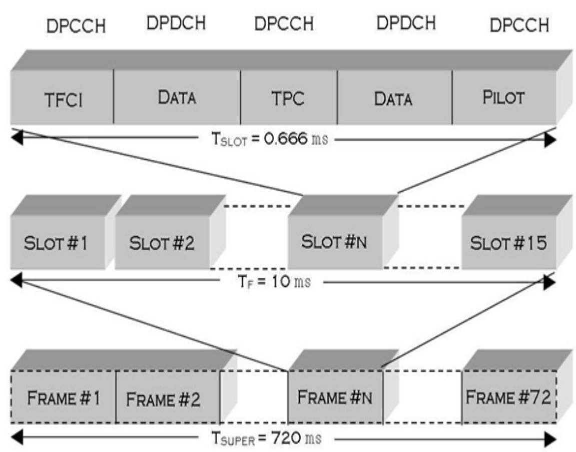

Figure2.2: Frame Structure for Downlink DPCH

Above figure i.e. Figure 2.2 shows the basic frame structure of the downlink dedicated physical channels . As in the uplink, each frame of 10 ms is split into 15 slots with a length of 2560 chips and 0.666ms duration. A super frame corresponds to 720 ms, i.e. the super frame length corresponds to 72 frames. The spreading factor thus has a range of 4 to 512. The different control bits have similar meaning to those in the uplink.

4.1.2 Spreading and Modulation

The basic modulation chip rate is 3.84 Mcps and can be extended to 2×3.84 Mcps and 4×3.84 Mcps. The block diagram of uplink spreading and modulation is shown in Figure 2.3. In the uplink the data modulation of both the DPDCH and the DPCCH is Binary Phase Shift Keying (BPSK). The modulated DPCCH is mapped to the Q-channel, while the first DPDCH is mapped to I-channel. Subsequently added DPDCHs are mapped alternatively to the I or the Q-channel. Quaternary Phase Shift Keying (QPSK) is applied for data modulation in the downlink. Each pair of two bits are serial-to-parallel converted and mapped to the I and Q branches respectively. The data in I and Q branches are spread to the chip rate by the same channelization code. This spread signal is then scrambled by a cell specific scrambling code.

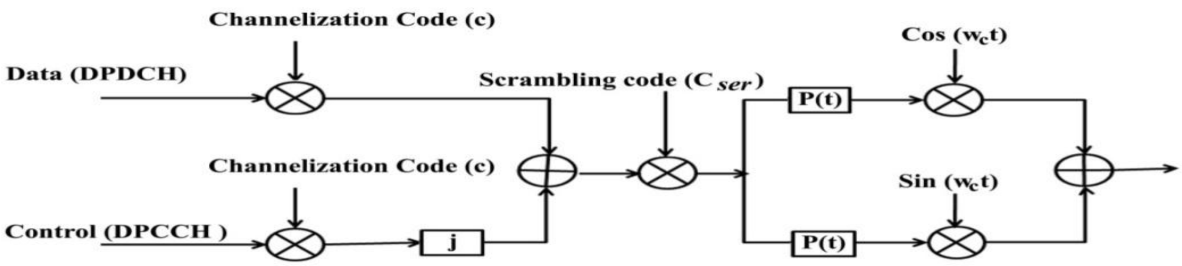

Fig 2.3 a cell specific scrambling code.

Figure 2.4 shows the spreading and modulation for a downlink user. Spreading modulation consists of two different operations. The first one is spreading where each data symbol is spread to the signal. The second operation is scrambling where a complex valued scrambling code is applied to spread signal.

fig4

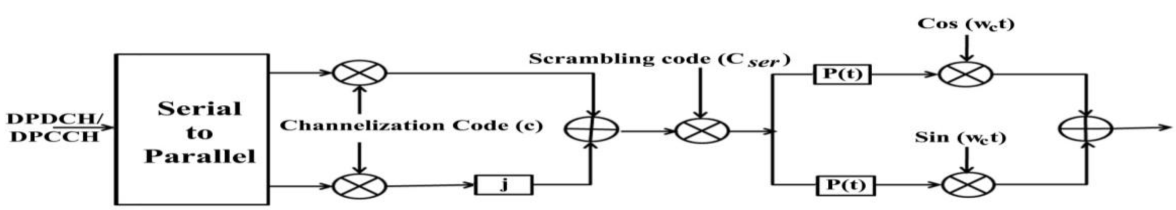

fig 2.4. a cell specific channelization code.

Channelization Code

OVSF codes are used for channelization. All the codes within the code tree cannot be used simultaneously by a mobile station. A code can be used by an MS if and only if no other code on the path from specific code to the root of the tree or in the sub-tree below the specific code is used by the same MS. Uplink channelization code may be allocated if more than one uplink DPDCH is required whereas different physical channels use different channelization code in downlink.

Scrambling Code

The scrambling codes are designed so that has very low cross-correlation among them. This ensures good Multiple Access Interference (MAI) rejection capability. Either short or long scrambling codes can be used in the uplink. Short scrambling codes are recommended for base stations equipped with advanced receivers employing multiuser detection or interference cancellation. Long scrambling codes are used since a simple rake receiver is employed in the simulator design. These are Gold codes generated from the position wise modulo 2 sum of two binary m-sequence.

III. RNS Based PN Sequence Generator

In most communication systems, spreading codes or sequences can be generated in an off-line way and is saved in a look-up table, which can be called whenever needed. Similarly RNS based PN sequence generation [27] also consists of an off-line process for the generation of Initial Primal Vector and finally the generation of the required PN sequence from the stored primal vectors which is done on-line. The off-line process is summarized in Fig 3.5. The external inputs to these blocks include spreading factor, and the Cross Correlation Threshold (CF). Module selection is used here. Table 3.1 shows the generated module set and dynamic range, R for various spreading factors using Consecutive module selection method. For a given spread factor, the number of users that can be accommodated is huge in comparison to other spreading codes.

A primal, J_1 is randomly selected from the range, R in eq. 2.10.The corresponding residue set, $R_s(J_1)$ is the output of Decimal to Residue Arithmetic Converter. The generated residue numbers are concatenated and converted into 8 bit (since k=8) binary sequence of 1 and 0. This sequence is passed through the NRZ encoder to get the sequence c_1 corresponding to primal J_1. This procedure is repeated for every primal in range, R. The generated sequences are tested for correlation amongst themselves such that

- Correlation between c_i and c_j, $i=j$ has to be unity.
- Correlation between c_i and c_j, $i \neq j$ has to preferably less than a threshold T. This threshold can vary for different applications based on the channel properties and error tolerance.

The primal which satisfies this criteria forms the Primal Pool, J. Consider an example for the proposed PN Sequence Generation for β=16, M=[255 254] and CF = 0.25. Table 3.2 shows the generated the PN Sequence for the randomly selected primals. These sequences are then tested for correlation among themselves which is listed in Table 3.3. Since the defined system requires a threshold of 0.25, discard J_5 and add J_1 , J_2, J_3 , J_4 to the final primal pool, J.

$$R_s(J_1) = \{|J_1|_{p_1}, |J_1|_{p_2}, \dots |J_1|_{p_m}\} \quad (3.4)$$

Figure 3.5: Offline process for RNS Based PN Sequence Generation

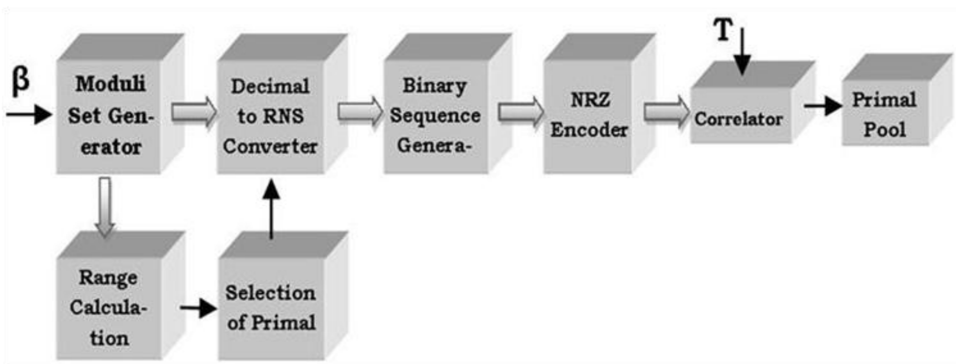

Figure 3.5: Offline process for RNS Based PN Sequence Generation

The next phase, shown in figure 3.6, starts when the system under consideration demands for signature waveforms. Depending upon the application and number of users active in the system, the primal vector, J

$$J = [J_1, J_2, J_3, \dots J_U]^T \quad (3.5)$$

is selected from the Primal Pool with spread factor, along with number of active users, U as input. The residue matrix $R_s = |J|_M$ is created in RNS converter block such that $R_s = [R_s(J_1), R_s(J_2), R_s(J_3), \dots R_s(J_U)]$. Finally the required RNS based PN code matrix, $c = [c_1, c_2 \dots c_U]$ of size U X β is formed after binary conversion and encoding. The maximum size of the proposed code set is very large with respect to other PN sequences. This offers the provision to vary correlation threshold based on the channel properties and error threshold of the system under consideration.

Table 3.2: RNS Based PN Sequence Generation

Primal, J Based on RNS, c | PN Sequence

1 -1 -1 -1 -1 -1 -1 -1 1 -1 -1 -1 -1 -1 -1 -1

321 | -1 1 -1 -1 -1 -1 1 -1 -1 1 -1 -1 -1 -1 1 1

550 | -1 -1 1 -1 1 -1 -1 -1 -1 1 -1 1 -1 1 -1

2356 | -1 -1 1 1 1 -1 1 -1 1 -1 -1 -1 1 1 -1 1

	C_1	C_2	C_3	C_4	C_5
C_1	1	0.15	-0.25	0	-0.65
C_2	0.1	1	-0.16	-0.13	0.07
C_3	- 0.2	-0.16	1	0.13	0.07
C_4	0	-0.13	0.13	1	0
C_5	- 0.6	0.07	0.07	0	1

64000 | 1 1 1 1 1 -1 1 -1 1 1 1 1 -1 1 1 -1

Primals are selected within the Range, R
R = 255X254 = 64770

a. DS-CDMA System Model

Consider a mobile receiver for CDMA with U simultaneous transmission plus Additive White Gaussian Noise (AWGN) as shown in Figure 3.7. The transmitted signal at time t is constructed by summing the spread sequence of each user.The noise corrupted received signal y(t) is defined- $y(t) = x(t) + \eta(t)$ (3.6)

Where η(t) denotes the white Gaussian noise. The uth users transmitted data bit for bit k is denoted ad $d_u(k)$ and is either +1 or -1 with equal probability and all users are transmitting with equal power, normalized to one. Then, the received signal x(t) due to the uth user is given by:

$$x_u(t) = \sum_{u=1}^{U} \sqrt{2P_u} \sum_{k=-\infty}^{\infty} d_u(k)\, s_u(t - kT_b - T_u) cos(\omega_c t + \phi_u) \qquad (3.7)$$

Table 3.3: Correlation Matrix of the Generated Sequence

Where $P_u, T_u,$ and φ_u are the power, delay, and carrier phase shift of the Uth user, and ω_c is the carrier frequency ; $S_u(t)$ is the uth spreading (signature) waveform given by

$$s_u(t) = \sum_{n=0}^{L-1} c_{u,n}\, \varphi(t = nT_c) \qquad (3.8)$$

Where $c_{u,n} \epsilon \{1, -1\}$ is the nth element of the spreading sequence for user u, φ(t) is the chip waveform and L the spreading sequence length. In order to simplify the notation, it is assumed that all carrier phases are equal to zero and baseband notation can be used [47]. Since the signal processing task is done on sampled signals, it is more convenient to make use of vector and matrix notation. Therefore Equation 3.6 can be rewritten for a fully synchronized downlink antipodal {+1,-1} DS-CDMA system with U independent users and a non-dispersive AWGN channel.

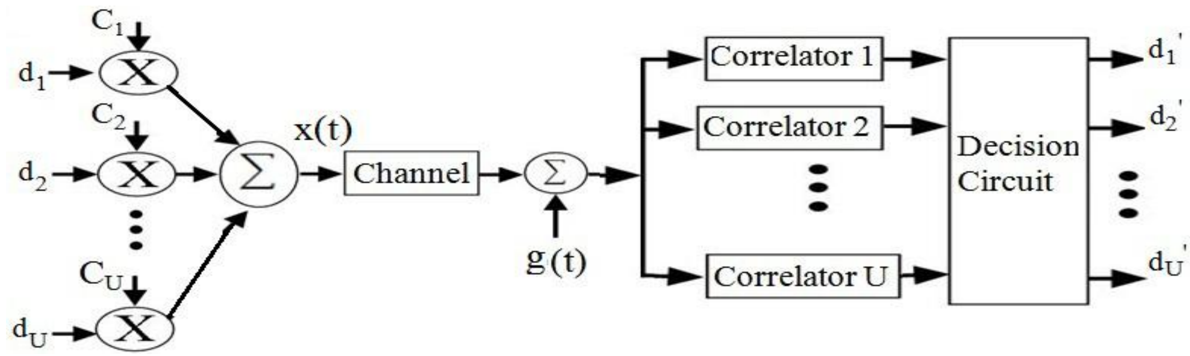

Figure 3.7 Block Diagram of DS-CDMA System

$$(kL+n)=\sum_{u=1}^{U} d_u(k)c_{u,n}+\eta(kL+n) \qquad (3.9)$$

The received signal becomes y(k) in vector notation, where k denotes the k^{th} user bit. If the signal is transmitted through a channel with ISI, then equation 3.6 becomes

$$y=(kL+n)=H(z)\otimes x(kL+n)+\eta(kL+n) \qquad (3.10)$$

Where ⊗ represents convolution operation and H(z) is channel impulse response [54]. A CDMA receiver processes the received signal with either a bank of matched filters (MFs) or RAKEs. To recover the data, the received signal is multiplied by the required sequence, which is generated locally by the receiver. For a multipath scenario, the spreading codes c_i where i=1 to U is replaced by the convolution between $C_i \otimes H_{ch}$ RNS based PN sequences are used as spreading sequence for the system under consideration.

b. Comparison of RNS based PN sequence with other CDMA codes

A comparison in terms of number of codes in the code set and correlation properties is made for the proposed sequence with respect to other CDMA codes that are used in various mobile cells.

3.4 Number of Sequences

Table 3.4 shows the comparison of number of available codes for cell for the proposed sequence with other CDMA codes for a given spreading factor. N length Walsh-Hadamard (WH) sequence are derived from Walsh-Hadamard matrix of size N×N to support N different users [52]. For a particular sequence length, the OVSF codes are basically the same as WH sequences. The only difference between the two is that the latter allow combinational use of WH sequences with different length [53].This creates Code Assignment Blocking problem thus limiting the number of users close to one fifth of the maximal spreading factor [1]. An n-stage shift register can generate a maximal spreading factor [1]. An n-stage shift register can generate a maximal length sequence of 2^n-1 bits [52].Shifted combinations of this sequence gives N=2^n-1 number of sequences. Gold Sequence is constructed by modulo-2 addition of two m-sequences of the same length with each other [51]. Including the two m-sequences used for addition a total of N+1 sequence are formed.

The data in Table 3.4 shows that the number of sequences from the proposed PN Sequence Generator with the module set in Table 3.1 is very huge. This range can also be altered by changing the module set.

IV. Correlation Properties

For comparing cross-correlation properties with other standard PN sequence, the proposed PN sequence are generated for β= 8 and module set P= [255].

The primal vector, J=[10 39 60 77 86 25 140], is generated varying the threshold value from 0 to 0.25. The correlation matrix of RNS based PN sequence; Gold sequence and Maximal Length sequence are tabulated in Table 3.5, Table 3.6 and Table 3.7 respectively. The data shows that the maximum cross correlation between any two sequences is limited to 0.25 for RNS based PN sequence whereas it come up to 0.41 and 0.73 for gold sequences, while the auto correlation reaches to 1.

Table 3.4: Length of the code set for different CDMA Codes

	Orthogonal Code		Pseudo Random Sequence		
	WH code	OVSF code	M sequence	Gold sequence	RNS based sequence
8	8	8	7	9	255
16	16	16	15	17	64770
32	32	32	31	33	411308931
128	128	128	127	129	10^19 = 10^{40}

Table 3.5: Correlation Matrix for RNS based PN Sequence, = 8

	PN_1	PN_2	PN_3	PN_4	PN_5	PN_6	PN_7
PN_1	1	0	0	0	0	0.14	0.14
PN_2	0	1	0	0	0	-0.2	-0.2
PN_3	0	0	1	0	0	0.2	0.2
PN_4	0	0	0	1	0	0.2	0.2
PN_5	0	0	0	0	1	-0.2	-0.2

PN_6	0.1	-0.2	0.2	0.2	-0.2	1	-0.0
PN_7	0.1	-0.2	0.2	0.2	-0.2	-.06	1

Table3.6 Correlation Matrix for Gold Sequence, $\beta = 8$

	PN_1	PN_2	PN_3	PN_4	PN_5	PN_6	PN_7
PN_1	1	0.41	-.09	-0.1	-.09	-.09	-.35
PN_2	0.41	1	-.09	0.4	.09	-.09	-.35
PN_3	-.09	-.09	1	-.09	-.40	-.40	0.25
PN_4	-.16	0.41	-.09	1	-.09	-.09	-.35
PN_5	-.09	-.09	-.40	-.09	1	-.40	.25
PN_6	-.09	-.09	-.40	-.09	-.40	1	0.25
PN_7	-.35	-.35	0.25	-.35	0.25	0.25	1

V.
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VIII.

Conclusion

The core of the next generation CDMA technology lies in CDMA code design approach which should take into account as many real operational conditions as possible and to maintain a sufficiently large code set size. In this context, this thesis work contributed a little towards the evolution of next generation CDMA technology because the generated PN sequence based on Residue arithmetic:

- Offers MAI-resistant operation for DS-CDMA systems in both synchronous and asynchronous MAI-AWGN channels, reducing co-channel interference and increasing capacity in a mobile cellular system. The joint effect of ideal auto-correlation functions and good cross correlation function makes RNS based PN sequence superior to all other standard PN sequence like Gold codes, Kasami codes and Maximal Length sequence

- Offers provision to vary correlation threshold based on the channel properties and error tolerance thus providing real operational conditions for spreading code design unlike any existing techniques.
- Inherits high dynamic key range to maintain large code sets such that large number of users can be accommodated.
- In multipath AWGN, Ricean Fading and Rayleigh Fading environments, the generated PN sequence outperforms the existing Walsh Hadamard code as channelization code for downlink WCDMA system. Thus the obtained spreading sequences can inherently address MAI in a multi-user system and MI imultipath environment without using other external auxiliary subsystems to overcome those impairments.

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