SPACE CORRELATED U-PN CODES – A POSSIBLE SOLUTION FOR THE NEW MICROWAVE COMMUNICATION AND RADAR SYSTEMS

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Abstract: *A retrospective review of a new approach, named Space Correlated U-PN codes, is given in this report. It is particular useful as spread spectrum radio access technology in the mobile broadband communication and radar systems with integrated terrestrial - satellite positioning. The principles of U-PN codes generation, as well as the basic methods of their acquisition and tracking, are given too. The proposed SC-CDMA principle uses several space distributed sources of radio-signals. The signals are phase modulated by appropriate PN-codes. The Mobile Stations (MS) receive these signals by means of the well known CDMA technology. For this purpose the same PN-codes are generated and synchronized in the MS receiver. The sum(mod2) of these codes creates a new code, which we named U (Unique)-PN code. This code is used for spreading the information, transmitted by the MS. Similar approaches are used for generation of the Base Station (BS) U-PN codes. Proposals of realistic SC-CDMA mobile communication and SC-MRN radar systems, based on the well developed GPS navigation, are shown in the end of the report.*

Keywords: SC-CDMA, MOBILE COMMUNICATIONS, SATELLITE, MULTISTATIC RADAR

1.Introduction

One of the main objectives of the Satellite Personal Communication Networks (S-PCN) is to complement terrestrial mobile networks by providing analogous services in areas where satellite technology is more effective and economic [1]. It can be achieved by the provision of dual-mode user equipment which communicates with both the satellite and terrestrial mobile networks so that when users roam outside of the terrestrial coverage, their requested services can still be supported via the satellite segment. An important topic in this field of research are the Connection Transference Schemes (CTS) with Soft Handover (SH). SH maintains the call connection through the old link until a new link is firmly established. SH is always associated with diversity (satellite - terrestrial or satellite – satellite). With soft handover, the service will not be interrupted since the old connection is still used for communication during the handover procedures. As a result, seamless handover can be achieved. The CDMA radio-access approach is particular suitable to realize seamless SH in the Integrated Satellite-Terrestrial Network Scenario.

CDMA Bandwidth efficiency is the main driving force in the use of CDMA since frequency re-use planning is not required. All available frequencies can be re-used in every single spotbeam. CDMA makes use of the Pseudo-Noise (PN) code concept in order to distinguish between different channels. It transmits modulated data onto wideband carriers that are distinguishable from each other by different PN sequences. Receivers retrieve their intended data by searching for their PN sequence. In order to avoid interference, the traffic carriers must be spread with synchronized and orthogonal PN sequences. Although synchronous-CDMA (S-CDMA) proves to be the most efficient to eliminate interference arising from other users sharing the same carrier and the same spot-beam, interference from other spot-beams which overlap the coverage of the intended spot is still considerable. The synchronization process to ensure orthogonality between all links requires signaling to adjust the transmission in both the time and frequency domains for every user independently. If dual satellite (or satellite – terrestrial base station) diversity is deployed, the timing advance will be addressed to only one satellite. Half of the users sharing the same frequency band will statistically be synchronized to this one particular satellite while generating intrinsic noise to the other. The system capacity is subsequently reduced. If orthogonality between PN sequences is not required, i.e. asynchronous CDMA, synchronization is not necessary. Under this situation, the number of available PN sequences will increase tremendously. However, this implies that interference levels generated by co-channel users cannot be suppressed as efficiently which may reduce the system capacity. However, since the number of PN sequences is increased, such a reduction in system capacity may still be well within the resource utilization efficiency of that offered by S-CDMA. In the case of multi-satellite diversity, longer codes may be required in order to discriminate between different links and consequently, synchronization among different satellites will be more complex. Another problem in the future integrated terrestrial-satellite S-CDMA systems could be the short length of the used PN-sequences, optimized for terrestrial usage, where the radiuses of the used cells are in order of several kilometers. The use of the same codes for the satellite segment will raise problems due to the ambiguity of their autocorrelation functions.

Bistatic radars and Multistatic Radar Networks (MRN) are subject to problems and special requirements that are either not encountered or encountered in less serious form by monostatic radars [2]. In general, the implementation of a MRN is more easily accomplished when the positions of all transmitting and receiving elements are fixed with respect to each other, for example when located on the ground. Because of the Line Of Sight (LOS) restrictions, they are often designed for operation on high altitude platforms such as satellites and airplanes. In these cases problems with PN code generation, synchronization and isolation appear when Continuous Wave - Phase Modulation (CW-PM) mode of operation is used. On the other hand CW-PM gives the opportunity for coherent signal processing, precise distance and 3-D coordinates measurements, as well as targets resolution by means of their Doppler spectra.

A retrospective review of a new approach, named Space Correlated Unique –Pseudo - Noise (SC U-PN) codes, is given in this report. It is particular useful as spread spectrum radio access technology in the mobile broadband communication and radar systems with integrated terrestrial - satellite positioning. The principles of U-PN codes generation, as well as the basic methods of their acquisition and tracking are given too. Proposals of realistic SC-CDMA mobile communications and SC-MRN radar systems, based on the well developed GPS navigation, are shown in the end of the report.

The proposed theory was published in several Conferences as scientific reports, some of them in Bulgarian language [3,4,5,6].

2. SC – CDMA approach

2.1. SC-CDMA basic

The proposed SC-CDMA principle [3] uses several space distributed sources of radio-signals, positioned at points O_1 and O_2 (in the case of only two sources) as it is shown in fig.1. The signals are phase modulated by appropriate PN-codes $C_1(t)$ and $C_2(t)$. The Mobile Stations (MS) receive these signals by means of the well known CDMA technology. For this purpose the same PN-codes are generated and synchronized in the MS receiver. The *sum(mod2)* of these codes creates a new code, which we named U (Unique)-PN code. This code is used for spreading the information, transmitted by the MS. Similar approaches are used for generation of the Base Station (BS) U-PN codes, named A and B, as follows:

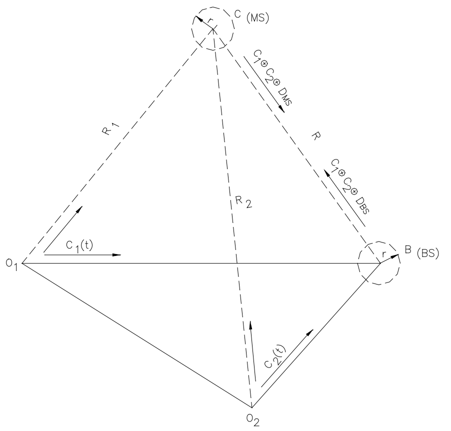

***Fig.1** The basic SC-CDMA geometry*

2.2.Variant SC-CDMA-A

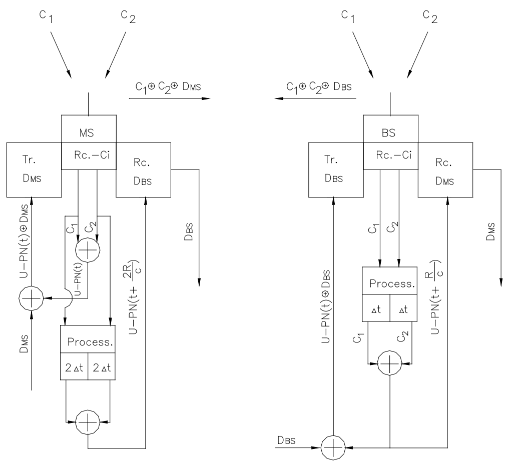

***Fig. 2** The basic SC-CDMA-A architecture*

The block schemes of the MS and BS, using SC-CDMA-A approach, are shown in fig.2. In this particular case the recovered in MS codes $C_1(t)$ and $C_2(t)$ are used as follows:

- In MS after *sum(mod2)* for U-PN(t) code generation, spreading the transmitted information from MS to BS by means of DS-SSS method;
- In MS for dispreading (correlation) of the transmitted from BS to MS information, delayed U-PN(t+2R/C), where R is the distance between the MS and BS, and C is the speed of the light;
- In BS for dispreading (correlation) of the transmitted from MS to BS information, delayed U-PN(t+R/C);
- In BS for spreading the information transmitted from BS to MS, delayed U-PN(t+R/C).

The information signal at Base Band (BB) from MS to BS will be:

$$S_{MSout}(t) = C_1(\Omega_C \cdot t + \frac{2\pi}{\lambda_C} \cdot R_1) \oplus C_2(\Omega_C \cdot t + \frac{2\pi}{\lambda_C} \cdot R_2) \oplus D_{MS}(t) \quad (1)$$

The BB signal, received by BS, will be additionally phase shifted as follows:

$$S_{BSin}(t) = C_1[\Omega_C \cdot t + \frac{2\pi}{\lambda_C} \cdot (R_1 + R)] \oplus C_2[\Omega_C \cdot t + \frac{2\pi}{\lambda_C} \cdot (R_2 + R)] \oplus D_{MS}(t) \quad (2)$$

The BB signal from BS to MS will be:

$$S_{BSout}(t) = C_1[\Omega_C \cdot t + \frac{2\pi}{\lambda_C} \cdot (R_1 + R)] \oplus C_2[\Omega_C \cdot t + \frac{2\pi}{\lambda_C} \cdot (R_2 + R)] \oplus D_{BS}(t) \quad (3)$$

Where $D_{BS}(t)$ is the information signal at BB, transmitted from BS to MS. The BB signal, received by MS, will be additionally phase shifted as follows:

$$S_{MSin}(t) = C_1[\Omega_C \cdot t + \frac{2\pi}{\lambda_C} \cdot (R_1 + 2R)] \oplus C_2[\Omega_C \cdot t + \frac{2\pi}{\lambda_C} \cdot (R_2 + 2R)] \oplus D_{BS}(t) \quad (4)$$

2.3.Variant SC-CDMA-B

The block schemes of the MS and BS, using SC-CDMA-B approach, are shown in fig.3. In this particular case the recovered in MS codes $C_1(t)$ and $C_2(t)$ are used as follows:

- In MS after *sum(mod2)* for U-PN(t) code generation, spreading the transmitted information from MS to BS by means of DS-SSS method (the same as in SC-CDMA-A case);
- In MS for dispreading (correlation) of the transmitted from BS to MS information, without delay U-PN(t);
- In BS for dispreading (correlation) of the transmitted from MS to BS information, delayed U-PN(t+R/C) (the same as in SC-CDMA-A case) ;
- In BS for spreading the information transmitted from BS to MS, forwarded U-PN(t-R/C).

The BB signals from MS to BS will be described with eq. (1) and (2). The BB signal transmitted from BS to MS and the received by MS signals will be:

$$S_{BSout}(t) = C_1[\Omega_C \cdot t + \frac{2\pi}{\lambda_C} \cdot (R_1 - R)] \oplus C_2[\Omega_C \cdot t + \frac{2\pi}{\lambda_C} \cdot (R_2 - R)] \oplus D_{BS}(t) \quad (5)$$

$$S_{MSin}(t) = C_1(\Omega_C \cdot t + \frac{2\pi}{\lambda_C} \cdot R_1) \oplus C_2(\Omega_C \cdot t + \frac{2\pi}{\lambda_C} \cdot R_2) \oplus D_{BS}(t) \quad (6)$$

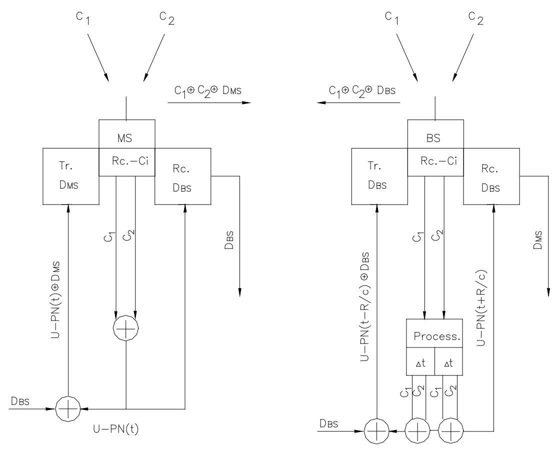

***Fig. 3** The basic SC-CDMA-B architecture*

2.4.EMI SC-CDMA A&B system

Proposal of a realistic SC-CDMA system, based on the existing navigation GPS system, is given in [4]. It was named EMI A&B (Enhanced Mobile Information, variants A & B).

The architecture of EMI - A system is shown in fig.4.

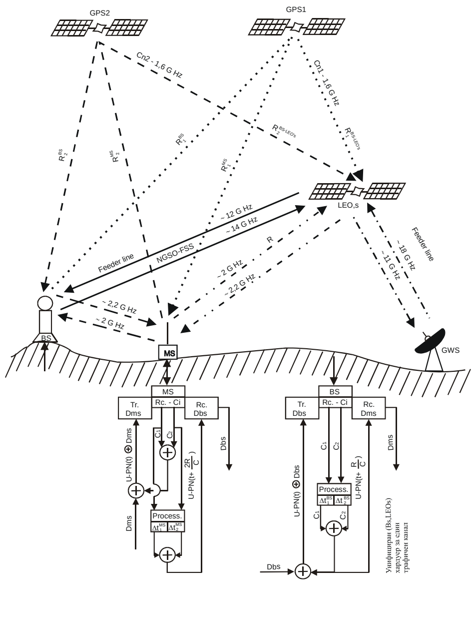

Fig. 4 *The basic EMI SC-CDMA-A architecture*

The system consists of satellite and earth segments, as follows:

- Earth segment, including subscriber mobile terminals (MS), terrestrial base stations (BS), as well as earth Gate Way Stations (GWS);
- Satellite segment, including Low Earth Orbit satellite base stations (LEO,s) and satellite based sources of PN signals (GPS).

The possible frequency allocations for the different parts of the system are shown in fig. 4, as follows:

- 2 GHz – terminal up-link SC-CDMA;
- 2,2 GHz – terminal down-link SC-CDMA;
- 1,6 GHz – GPS signals, used as satellite based sources of PN signals;
- 12 GHz down-link, 14 GHz up-link of Non Geostationary Orbit – Fixed Satellite Service (N-GSO-FSS) technology for the feeder lines of isolated BS without access to terrestrial telecommunication infrastructure;
- 18 GHz up-link, 11 GHz down-link, NGSO-MSS technology for the LEO,s feeder lines.

The distances among different elements of EMI A&B are important and in fig. 4 they are as follows:

- ***R*** – distance between MS and BS;
- ***Ri bs*** – distance between BS and the i-th GPS satellite;
- ***Ri bs leo,s*** – distance between a LEO,s and the i-th GPS satellite;
- ***Ri ms*** – distance between MS and i-th GPS satellite.

The most important element of the proposed system is the subscriber radio interface, using SC-CDMA method of access. Similar to the above described theory, we can use the both variants A and B. Obviously, from CDMA technology point of view, variant A is superior and we will focus on it. The time delays, introduced by the system processors, are ***Δt ms*** in MS and ***Δt bs*** in BS.

The calculations of the time delays, introduced by the system processors in order to ensure the space correlation of the used U-PN codes and the dispreading codes, need equalization, as follows in the equation (7):

$$\Delta t_{ibs} + \frac{R_{ibs}}{C} = \frac{R_{ims} + R}{C} \qquad (7)$$

and:

$$\Delta t_{ibs} = \frac{R_{ims} + R - R_{ibs}}{C} \qquad (8)$$

By means of (8) it is possible to calculate the time delay of the dispreading U-PN code in MS:

$$\Delta t_{ms} = \frac{2R}{C} \qquad (9)$$

The code acquisition procedure in a SC-CDMA system EMI A&B will be the follows:

- By means of a classical radio interface BS broadcasts information about its space coordinates ***X bs, Y bs, Z bs*** in Earth Centered - Earth Fixed (ECEF) coordinate system, used by GPS system.
- By means of a classical radio interface MS broadcasts information about its space coordinates ***X ms, Y ms, Z ms*** in ECEF coordinate system;
- The MS processor calculates the distance ***R*** as follows:

$$R = SQR\left[(X_{BS} - X_{MS})^2 + (Y_{BS} - Y_{MS})^2 + (Z_{BS} - Z_{MS})^2\right] \qquad (10)$$

After that computes ***Δt ms*** with equation (9);

- The BS processor computes the distances ***Ri bs*** and ***Ri ms*** in classical way, typical for GPS algorithms, calculates the distance ***R*** with (10) and ***Δt i bs*** with (8).
- The calculated ***Δt ms*** and ***Δt i bs*** are base only for the acquisition of the U-PN codes. The code tracking could be done by means of a modified "early-late" CDMA method.

The precise determination of the shape of a SC-CDMA autocorrelation cell is a complicate goal, which should be solved in the future. An approximation could be done, based on the assumption that that the position in the space of the MS can be determined by the crossing of three spheres with centers GPS1, GPS2 and LEO,s, with corresponding radiuses ***R1 ms, R2 ms*** and ***R***. The wall thickness of each sphere is determined by the width of the used PN code autocorrelation function ***2.tc***, where ***tc*** is the chirp time duration of the code and ***C*** is the speed of the light. The change of the "wall density" ***R(t)*** of each sphere can be calculated, as follows:

$$R(t) = A^2(1 - \frac{t}{t_C}) \qquad \text{for} \qquad t \le t_C \qquad (11)$$

$$R(t) = 0 \qquad \text{for} \qquad t \ge t_C$$

The mutual crossing of the spheres with finite wall thickness will form a cell with center located at MS and ***r=tc.C***. In order to avoid interference among several MS, in this cell only one MS should be positioned. It means that the minimum distance among MS should be greater than ***Rmin = 2.tc.C***

The GPS system uses two PN codes. First of them is the coarse-acquisition (C-A) code with speed 1,023 MCh/s. The second is the precise (P) code with speed of 10,23 MCh/s. When they will be used for generation of U-PN codes, the autocorrelation cell radiuses will be 293 and 29,3 мeters.

In principle in a static SC-CDMA system the generated U-PN codes will repeat in the time due to the repetition character of the primery PN codes. When several LEO or MEO satellites (as it is in GPS) are used as primary PN code sources, their phases will change fast due to their relative fast speeds (in order of several kilometers per second). The result will be generating of pure noise like U-PN codes with very good and unambiguity auto and crosscorrelation functions.

3. SC-MRN approach

The possible implementations of SC-CDMA approach in a bistatic radar geometry is shown in fig.5. BPSK modulated by PN-codes radio-signals are transmitted from the points O_1 and O_2 (both of them with known coordinates in a 2D coordinate system). These signals are received in the transmitter site and in the receiver site of a bistatic radar system, where the used PN-sequences $C_1(t)$ and $C_2(t)$ are recovered with their phases and used as follows:

- ***Transmitter site*:**

$C_1(t)$ and $C_2(t)$ are *sum (mod2)* and the resulting U-PN code is used for BPSK modulation of the transmitted radio-signals. The phases of the received PN-codes are determined by the transmitter position. These coordinates are sent to the receiver with appropriate radio-communication link.

$$U - PN_{transmitter}(t) = C_1(\Omega_C t + \frac{2\pi}{\lambda_C} R_1) \oplus C_2(\Omega_C t + \frac{2\pi}{\lambda_C} R_2) \qquad (12)$$

Where λ_C is the wavelength and Ω_C is the angle frequency of the used PN-code.

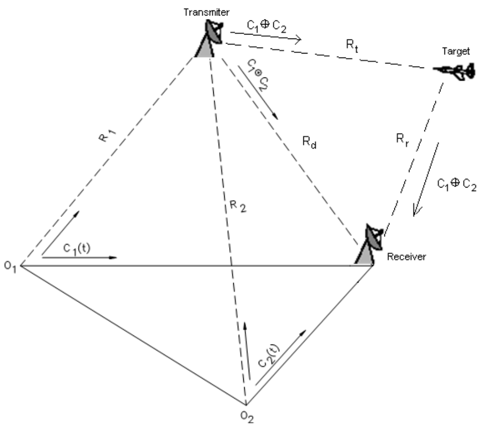

Fig. 5 *The basic SC-MRN geometry*

- ***Receiver site*:**

The phases of the received PN-codes are determined by the receiver position in the same 2D-coordinate system. Receiver processor computes the distances R_1, R_2, R_d in order to recovery the transmitted U-PN code in the receiver with phase, given with eq.13. The recovered U-PN code is used for acquisition and tracking of the synchronization link and with introducing the suitable time delay – for measuring the distance $R_t + R_r$ by means of eq.14 and the famous triangle method (using at least three receiver sites [2]).

$$U - PN_{receiver}^{synchronization}(t) = C_1[\ \Omega_C t + \frac{2\pi}{\lambda_C}(\ R_1 + R_d)\ ] \oplus C_2[\ \Omega_C t + \frac{2\pi}{\lambda_C}(\ R_2 + R_d)\ ] \qquad (13)$$

$$U - PN_{receiver}^{target-reflected}(t) = C_1[\ \Omega_C t + \frac{2\pi}{\lambda_C}(\ R_1 + R_t + R_r)\ ] \oplus C_2[\ \Omega_C t + \frac{2\pi}{\lambda_C}(\ R_2 + R_t + R_r)\ ] \qquad (14)$$

An attractive application of the SC-CDMA technology is the use of the satellites of the global positioning system GPS as sources of the PN-modulated signals. In this particular case the U-PN code is *sum (mod2)* of the recovered in the transmitter site GPS receiver C/A codes of the visible satellites. Because of the very fast relative satellite motion the created in this case U-PN code changes very fast – it looks like a pure random signal. U-PN code acquisition is based on the exchanged between transmitter site and receiver site information about their positions in ECEF geographic coordinate system, used by GPS.

4. ***Conclusions***

A new approach for pseudo-noise code generation and synchronization is proposed in this paper. It is suitable as spread spectrum radio access technology in the mobile broadband communication and radar systems with integrated terrestrial - satellite positioning. The basic Space Correlated system architectures, as well as mathematical description of the proposed method for U-PN code generation and synchronization, are explained. Proposals for real systems, using satellites of the global positioning system GPS as sources of the pseudo-noise signals, are given too.

The implementation of the proposed new Space Correlated – Code Division Multiple Access and Space Correlated – Multistatic Radar Network approach for U-PN code generation and synchronization will give new chance of the future sophisticated mobile communication and radar systems.

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