PERSONAL COMMUNICATION NETWORKS WITH GLOBAL COVERAGE-ESSENTIAL FACTOR FOR THE SECURITY OF THE MODERN HUMAN SOCIETY

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***Abstract**: The Personal Communication Systems with global coverage use Integrated Satellite-Terrestrial approach with Low Earth Orbit satellite constellations. The frequency reuse problems in such systems are discussed. The advantages of the implementation here the proposed by the author Space Correlated - Code Division Multiple Access are considered too. The principles of generation and synchronization of used Unique Pseudo Noise codes are shown. The system architecture of a IST PCN, based on the proposed by the author Spatial Correlation Processing – Random Phase Spread Coding technology for LEO,s terminal and feeder lines, is given too.*

Keywords: PERSONAL COMMUNICATION SYSTEM, SATELLITE, SCP RPSC, SC-CDMA.

1. Introduction

The Personal Communication Systems (PCNs) with global coverage are of great importance not only for the government (army, police) and emergency services, but even for extreme tourists and sport practicing people in the high mountains, isolated deserts, water basins etc. Usually such kind of PCNs use Integrated Satellite-Terrestrial (IST) approach with Low Earth Orbit satellite (LEO,s) constellations. The main parameters of such IST PCNs, using LEO,s, are considered in the report from human security point of view. The conclusion of the analysis is the necessity of very high number LEO,s (in order of several hundred or even thousands) in order to achieve very high percent line of sight links even in mountain or urban areas. The frequency reuse problems in such IST PCNs are discussed. The advantages of the implementation here the proposed by the author Space Correlated - Code Division Multiple Access (SC-CDMA) are considered. The principles of generation and synchronization of used Unique Pseudo Noise (U-PN) codes are shown too. The system architecture of a IST PCN, using the proposed by the author Spatial Correlation Processing – Random Phase Spread Coding (SCP-RPSC) technology for LEO,s terminal and feeder lines, is given too.

2. Integrated Satellite-Terrestrial approach with LEO,s

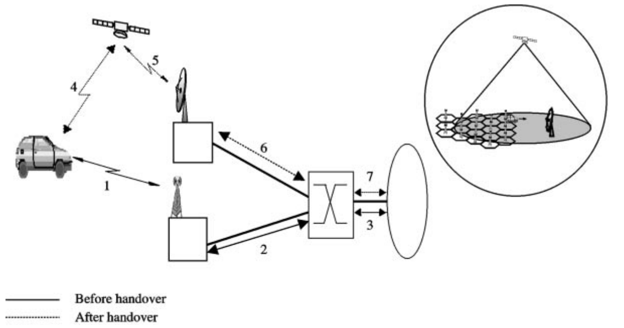

Fig.1. Terrestrial to satellite handover

One of the main objectives of the Satellite - PCNs 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. Two main types of inter-segment handover are involved in an integrated satellite-terrestrial network: satellite to terrestrial handover and terrestrial to satellite handover. Fig. 1 shows the procedure of terrestrial to satellite handover [1].

The received land mobile-satellite signal consists of the combination of three components, shown in fig.2 [1]: the direct Line-Of-Sight (LOS) wave, the diffuse wave and the specular ground reflection. The direct LOS wave arrives at the receiver without reflection from the surrounding environment. The only L-/S-band propagation impairments that significantly affect the direct component are free space loss (FSL) and shadowing. FSL is related to operating frequency and transmission distance. Shadowing occurs when an obstacle, such as a tree or a building, impedes visibility to the satellite. This results in the attenuation of the received signal to such an extent that transmissions meeting a certain Quality of Service (QoS) may not be possible. The diffuse component comprises multipath reflected signals from the surrounding environment, such as buildings, trees and telegraph poles. Unlike terrestrial mobile networks, which rely on multipath propagation, multipath has only a minor effect on mobile-satellite links in most practical operating environments.

The first step towards modeling the mobile-satellite channel is to identify and categorize typical transmission environments. This is usually achieved by dividing the environment into three broad categories:

- Urban areas, characterized by almost complete obstruction of the direct wave;
- Open and rural areas, with no obstruction of the direct wave;
- Suburban and tree shadowed environments, where intermittent partial obstruction of the direct wave occurs.

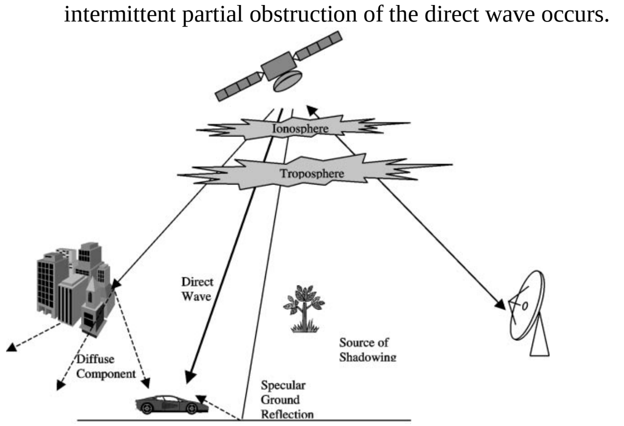

Fig. 2. Mobile S-PCN propagation environment.

As far as land mobile-satellite systems are concerned, it is the last two of the above environments that are of particular interest. In urban areas, visibility to the satellite is difficult to guarantee, resulting in the multipath component dominating reception. Thus, at the mobile, a signal of random amplitude and phase is received. This would be the case unless multi-satellite constellations are used with a high guaranteed minimum elevation angle. Here, satellite diversity techniques allowing optimum reception of one or more satellite signals could be used to counteract the effect of shadowing. For example, in order to achieve a fade margin in the region of 6–10 dB in urban and rural environments, a continuous guaranteed minimum user-to-satellite elevation angle of at least 50 deg. is required. However, to achieve such a high minimum elevation angle using a LEOs would require a constellation of upwards of 100 satellites, as shown in fig.3 [2]. On the other hand, for a guaranteed minimum elevation angle of 20 deg., a fade margin in the region of 25–35 dB, would be required for the same grade of service, which is clearly unpractical. While these figures demonstrate the impracticalities of providing coverage in urban areas, in reality, for an integrated space-terrestrial environment, in an urban environment, terrestrial cellular coverage would take priority.

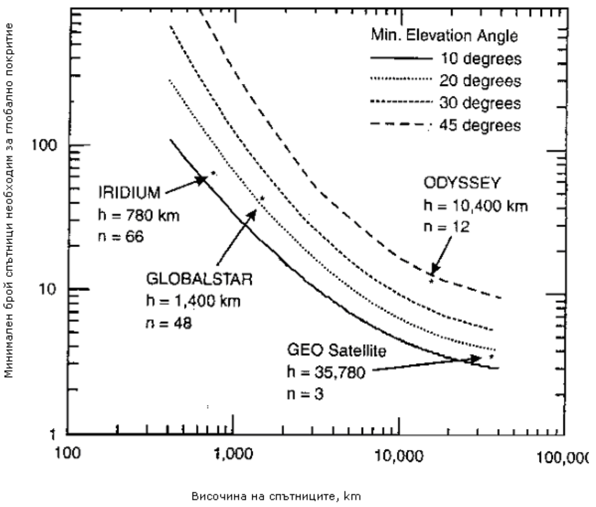

Fig.3. Number of required LEO,s for a global coverage IST PCN

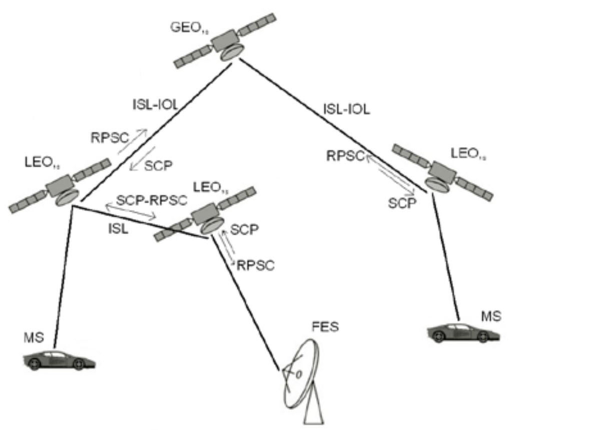

Fig.4. Architecture of a IST PCN using LEOs with different feeder lines

Bearing in mind the requirements to a IST-LEO PCN with several hundreds or even thousands satellites, two new important problems appear, as follows:

- Complicated satellite constellation architecture and corresponding Inter Satellite Lines (ISL), Inter Orbit Lines (IOL) and Satellite – Mobile Station Lines (S-MSL), shown in fig.4. The proposed by the author solution of this problem is given in paragraph 3 below.
- Frequency and code sharing among different S-MSL, using Code Division Multiple Access methods. The proposed by the author solution of this problem is considered in paragraph 4 below.

3. *SCP-RPSC technology in IST-LEO PCN*

In fig.4 a two-tier satellite network is formed through the use of a hybrid constellation. Interconnection between LEO satellites is established through ISL and inter-satellite inter-orbit links (IOL) (ISL-IOL) via a data relay Geo Stationary Orbit (GEO) satellite is employed. In this configuration, the GEO satellite is directly accessed by an LEO,s.

The main problems of the Fixed Earth Station (FES)-satellite feeder lines deal with the pointing of the high gain satellite antennas to the tracking FES antennas because of LEO,s continuous relative movement. For this reason low gain omni-directional antennas are used in the LEO satellites at the moment. It leads to low feeder lines link margins and poor frequency reuse capabilities.

Another way to connect LEOs is the use of ISLs to establish links with other satellites within the same orbital configuration. This option is used by the famous ***Iridium*** LEO,s system. The main problem here deals with the precise pointing of the narrow microwave antenna beams (the used frequencies are in 23 GHz band) and the need of tracking techniques to support the ISL work. It imposes very strong limitations over station keeping characteristics – about 2 km in cross-track, 5,7 km in-track and 4,7 km in radial direction. We should add the similar pointing problems of IOL narrow antenna beams of the mobile LEO satellites to the fixed GEO satellite positions.

SCP-RPSC Technology was proposed by the author [3] as cheap and effective solution of the Mobile Satellite Services (MSS) antenna problems. The unique properties of this technology could be very useful if it will be implemented in the feeder lines, ISL and IOL of the future LEO satellite communication networks [4]. In the analysis below the considered options are discussed from SCP-RPSC technology implementation point of view.

The existing satellite omn-directional antennas of the satellite-FES feeder lines can be replaced with SCP (up-link) and RPSC (down-link) with the following benefits:

SCP (up-link FES-LEO,s):

- The LEO,s receiving antenna systems will be omni-directional for the cooperative FES, but with high figure of merit G/T;
- The different FES and polarizations could be selected simply by the use of specific allocated PN-codes;
- Soft handover between different FES is feasible because of the LEO,s movement and multiple beam forming properties of the SCP technology;
- Space diversity scheme: one LEO,s – several FES with possible frequency reuse is feasible too.

RPSC (down-link LEO,s-FES):

- Providing full duplex system with one simple and cheap transmit-receive antenna;
- The transmitted random poly-phase spread signals will not cause significant harmful interference to the

conventional FES, using the same frequency channels. The interference will be similar to that, caused by the side-lobes of a phased antenna array with random inter elements spacing;

- The transmitted random poly-phase spread signals are uniformly radiated in the space below the LEO,s. Several FES, equipped with the same SCP receivers and providing space diversity, receive them. The knowledge of the receiving FES positions for the transmitting LEO,s is not necessary;
- Close situated LEO,s could communicate with FES, using the same frequency channel without interference. The isolation between the LEO,s will be provided by their specific random phase spread coding, due to their specific random design. This method was named by the author as Random Phase Spread Coding – Multiple Access (RPSC-MA).

The existing directional antennas of the ISL feeder lines can be replaced with SCP (both directions) and RPSC (both directions) with the following benefits:

- The virtual electronic scanning of the LEO,s ISL antenna patterns, typical for SCP-RPSC technology, will reduce significantly the limitations over station keeping characteristics and increase the satellite system reliability;
- LEO,s constellations with random orbits could be implemented instead the existing deterministic LEO,s orbits with their specific problems.

The LEO,s omni-directional antennas of the LEO,s – GEO,s IOL can be replaced with SCP (down-link) and RPSC (up-link) with the following benefits:

SCP (down-link GEO,s-LEO,s).

- The LEO,s receiving antenna system will be omni-directional for the cooperative GEO,s, but with high figure of merit G/T;
- The different GEO,s and polarizations could be selected simply by the use of specific allocated PN-codes;
- Soft handover between different GEO,s is feasible because of the LEO,s movement and multiple beam forming properties of the SCP technology;
- Space diversity scheme: one LEO,s – several GEO,s with possible frequency reuse is feasible too.

RPSC (up-link LEO,s-GEO,s).

- Providing full duplex system with one simple and cheap transmit-receive antenna.
- The transmitted random poly-phase spread signals will not cause significant harmful interference to the conventional GEO,s, using the same frequency channels. The interference will be similar to that, caused by the side-lobes of a phased antenna array with random inter elements spacing;
- The transmitted random poly-phase spread signals are uniformly radiated in the space above the LEO,s. Several GEO,s, equipped with the same SCP receivers and providing space diversity, receive them. The knowledge of the receiving GEO,s positions for the transmitting LEO,s is not necessary;
- The use of RPSC-MA is feasible.

4. Space Correlated - Code Division Multiple Access in IST-LEO PCN

4.1. Introduction

An important topic in IST-LEO PCN are the Connection Transference Schemes (CTS) with Soft Handover (SH) [1]. 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 spot-beam. 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 signalling 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 IST 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.

4.2. SC-CDMA basic

The proposed SC-CDMA principle [5] 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.5. 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.

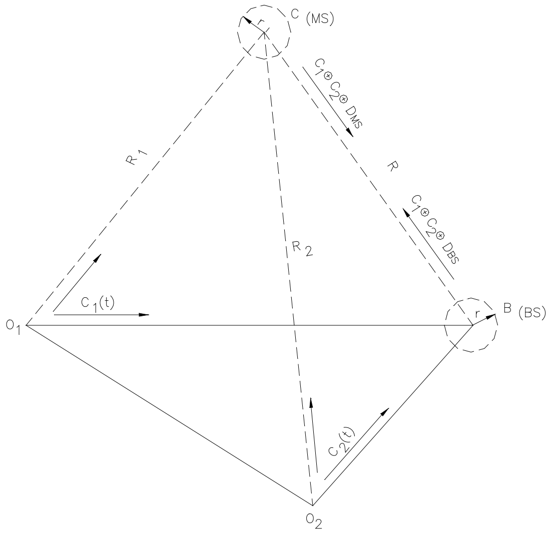

Fig.5 The basic SC-CDMA geometry

The block schemes of the MS and BS, using SC-CDMA approach, are shown in fig.6. 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).

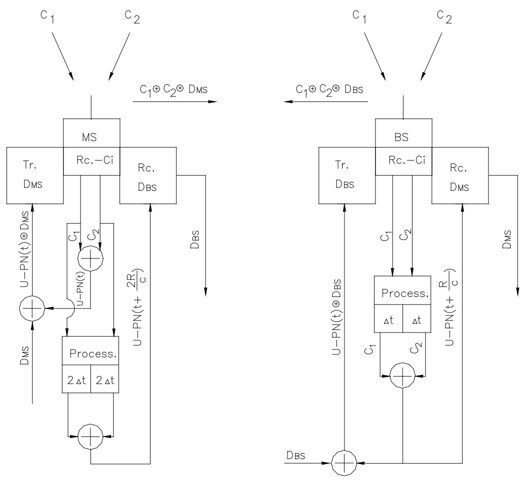

Fig. 6 The basic SC-CDMA-A architecture

A proposal for a realistic SC-CDMA system, based on the existing navigation GPS system, is given in [5] too. It was named EMI (Enhanced Mobile Information).

5. Conclusion

The practical SCP-RPSC and SC-CDMA principle implementations in the feeder lines, inter-satellite, inter-orbit and terminal lines will change the existing paradigm in the IST-LEO PCN communication business. Many of the existing problems of the proposed mobile systems with global coverage, very important for the security of the modern human society, will be solved successfully.

6. References

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