SPACE DIVERSITY – ESSENTIAL FACTOR FOR THE SECURITY OF 5-th GENERATION COMMUNICATIONS

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Abstract: *5-th generation mobile networks aim higher capacity than current 4G, allowing higher number of mobile broadband users per area unit, and allowing consumption of higher or unlimited data quantities in gigabyte per month and user. 5G research and development is extremely important for the security of the human society. 5 G will have applications not only in the army and the police, but in the public transport, video monitoring, Internet of Things (IoT) etc. aiming at lower cost, lower battery consumption and lower latency at GHz frequency bands (millimeter waves). The use of directional antennas and space diversity at these extremely high frequency bands will improve the secure work of such systems. SCP-RPSC (Spatial Correlation Processing – Random Phase Spread Coding) is an entirely new approach in the field of microwave antenna theory, developed by the author one decade before. Its applications in the future terrestrial, High Altitude Platform Systems and satellite 5 G communications is considered in the report. Block schemes and advantages of the proposals are given too.*

Keywords: SECURITY, 5 G, IoT, SCP-RPSC

1. Introduction

5-th generation mobile networks aim higher capacity than current 4G, allowing higher number of mobile broadband users per area unit, and allowing consumption of higher or unlimited data quantities in gigabyte per month and user. 5G research and development is extremely important for the security of the human society. 5 G will have applications not only in the army and the police, but in the public transport, video monitoring, Internet of Things (IoT) etc. aiming at lower cost, lower battery consumption and lower latency at GHz frequency bands (millimeter waves).

The use of directional antennas and space diversity at these extremely high frequency bands will improve the secure work of such systems. SCP-RPSC (Spatial Correlation Processing – Random Phase Spread Coding) is an entirely new approach in the field of signal processing antenna arrays. It was developed by the author a decade before. SCP-RPSC space diversity applications in the future 5 G communications are considered in the report below.

2. 5 G communications and antenna diversity techniques

With the explosive growth of mobile traffic demand, the contradiction between capacity requirements and spectrum shortage becomes increasingly important [1]. The bottleneck of wireless bandwidth becomes a key problem of the fifth generation (5G) wireless networks. On the other hand, with huge bandwidth in the Millimeter Wave (mmWave) band from 30 GHz to 300 GHz, mmWave communications have been proposed to be an important part of the 5G mobile network to provide multi-gigabit communication services.

Most of the current research is focused on the 28 GHz band, the 38 GHz band, the 60 GHz band, and the E-band (71–76 GHz and 81–86 GHz). However, due to the fundamental differences between mmWave communications and existing other communication systems operating in the microwave band (2.4 GHz and 5 GHz), there are many challenges in physical medium access control and routing layers for mmWave communications. The high propagation losses, antenna patterns directivity, sensitivity to blockage, and dynamics due to mobility of mmWave communications require application of new principles and methods in the field of antenna diversity techniques also.

Antenna diversity [2], also known as space diversity or spatial diversity, is any one of several wireless diversity schemes that uses two or more antennas to improve the security, quality and reliability of a wireless link. Often, especially in urban and indoor environments, there is no clear Line of Sight (LOS) between transmitter and receiver. Instead the signal is reflected along multiple paths before finally being received, aiming the Non Line of Sight (N-LOS) environment. Each of these signal paths can introduce phase shifts, time delays, attenuations, and distortions over the different signals that can destructively interfere with one another at the aperture of the receiving antenna.

Antenna diversity can be realized in several ways. Depending on the environment and the expected interference, designers can employ one or more of these methods to improve signal quality. In fact multiple methods are frequently used to further increase reliability.

- **Spatial diversity** employs multiple antennas, usually with the same characteristics, that are physically separated from one another. Depending upon the expected incidence of the incoming signal, sometimes a space on the order of a wavelength is sufficient. Other times much larger distances are needed;
- **Pattern diversity** consists of two or more co-located antennas with different pointed radiation patterns. This type of diversity makes use of directional antennas that are usually physically separated by some (often short) distance;
- **Polarization diversity** combines pairs of antennas with orthogonal polarizations;
- **Transmit/Receive** diversity uses two separate, collocated antennas for transmit and receive functions;
- **Adaptive arrays** can be a single antenna with active elements or an array of similar antennas with ability to change their combined radiation pattern as different conditions persist.

3. SCP-RPSC approach used as pattern antenna diversity technique

The use of directional antennas and space diversity at mmWave frequency bands will improve the secure work of 5 G communications. SCP-RPSC is an entirely new very smart beamforming principle in the field of signal processing antenna arrays. It was developed and patented by the author in the beginning of 21-st century.

The main objectives of the SCP technology [3] are:

- To receive one or more radio signals coming from one or several spatially distributed signal sources (satellites, base stations), insuring high gain of the antenna systems and using fixed or mobile receiving terminals, equipped with SCP signal processing equipment;
- To ensure spatial selectivity high enough to cancel the same frequency channel interference, coming from different space directions, using simple one channel receiver.

The objectives stated above are achieved by a patented by the author method for radio communications, which proposes application of additional pilot signal transmitted in the band of information signals and available in the receiver by Code Division Multiple Access (CDMA). The SCP receiver terminal is equipped with antenna array with random phase aperture excitation. The phase shifts among the signals, coming from the antenna elements, are random at the antenna output, regardless of the information source direction. These random phases spread signals correlate with the recovered pilot signal, phase spread in the same manner, in a signal recovery unit. The result of the correlation process between pilot and information signals is the recovered information signal at base band.

The main features of the SCP approach are:

- Simple, cheap and flat passive antenna, suitable for mass production even in mmWave frequency bands;
- One channel convenient microwave receiver with simple signal processing;
- Omni directional for the cooperative signal source, but with high Figure of Merit G/T;
- Selection of the different signal sources and polarizations by PN-codes;
- Multibeam and soft handover features.

The RPSC technology was proposed and patented by the author too [3]. It is based on transmission of broadband microwave signals in the open space by means of multi element random phased antenna arrays. The sum of the different element signals in a given point in the space has Gaussian probability distribution and noise like properties. The sums in the different directions of the space are not correlated each other. In such way the proposed principle solves simultaneous the problems of spreading and beam forming.

The main features of the RPSC technology, when it is used in the up-links of the wireless communication links, additionally include:

- Omnidirectivity for the cooperative receiving terminal, but high equivalent (at base-band) Equivalent Isotropic Radiated Power (EIRP);
- Selection of different terminals and polarizations by Pseudo-Noise (PN) codes;
- Soft handover and virtual multibeam features;
- The coherent demodulation by means of pilots (specific property of SCP technology), cancelling the Doppler shift and the phase jitter, introduced by local oscillators in the wireless communication system;
- RPSC up-link protection against jamming, coming even from points, close situated to the transmitting stations;
- The knowledge of the receiving terminal positions for the transmitting equipment is not necessary;
- The SCP-RPSC approach is a breakthrough technology, leading to unpredictable increase of the frequency reuse factor in the wireless broadband networks. Close situated subscriber terminals could communicate with base stations, using the same frequency channel without interference. The isolation between the terminals is provided by their specific random phase spread coding, aiming to RPSC-MA (Multiple Access).

The presented above information leads to the conclusion, that the SCP-RPSC principles and technologies could be successfully used in the future mmWave 5 G communications as pattern diversity schemes.

4. *Practical implementations of SCP-RPSC in pattern antenna diversity*

4.1. SCP-RPSC terminals with pattern antenna diversity

In fig. 1 Soft handoff between Setting Satellite (SS) and Rising Satellites (RS) with a single and cheap antenna system without mechanical movement, is shown [4]. The same configuration could be used in mm Wave 5 G terrestrial and satellite communications as pattern antenna diversity scheme (in the case of partially path shadowing).

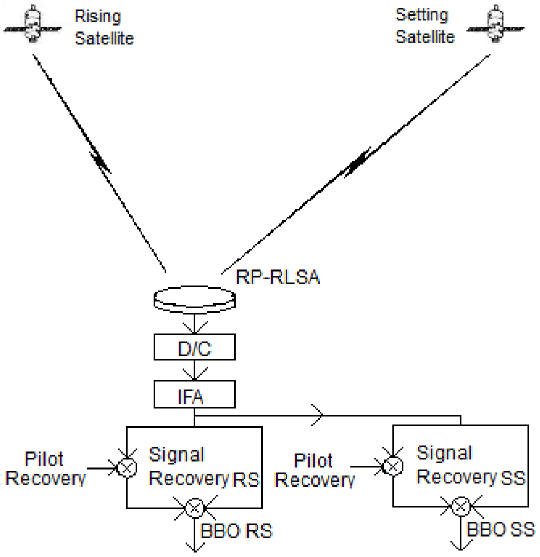

Fig. 1 *System architecture of a SCP-RPSC terminal*

4.2. SCP pattern antenna diversity in Global Navigation Satellite Systems (GNSS)

Historically, the Global Navigation Satellite Services (GNSS) have been delivered through the use of satellites transmitting in L-band. Targeted to military navigations at first, these services have evolved towards hundreds of civil applications, some of them (for example railway transport, 5 G connected cars) with great accuracy. The use of L-band gives important benefits, such as small on-board antenna size and little or no attenuation due to rain. However, the amount of L-band available, and more specifically the portion allocated to GNSS, is limited. Moreover, frequency reuse due to different orbital slots is extremely limited. The possible 5 G transport applications require a much greater accuracy than normally in L-band because of the ionosphere propagation effects.

To definitely overcome the problems due to the L-band, the only choice for the future 5 G navigation systems is the move to higher frequency bands [5]. A possible architecture of a SCP based GNSS, using pattern diversity and steering beams for separation of the different navigational satellites, is shown in fig. 2.

4.3. SCP-RPSC pattern antenna diversity in HAPS communications

The application of SCP-RPSC approach to solve the antenna problems of mmWave High Altitude Platform Systems (HAPS) was proposed by the author several years ago [6]. The proposed in the literature HAPS base stations use spot beams antennas, creating cellular type coverage on the earth surface. The problem here is the instability or the motion of the platform, leading to continuous handovers of the active terminals among different spot beams. The application of SCP-RPSC approach in HAPS base station will cancel the problem by creating individual virtual steering antenna beams toward each fixed or mobile earth terminal.

Possible use of SCP-RPSC technology in HAPS LOS terminals, based on pattern diversity, is shown in fig.3.

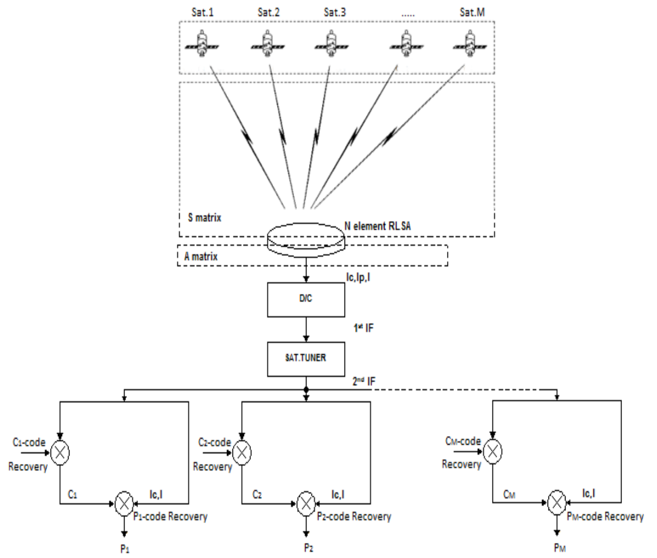

Fig. 2 *Architecture of SCP pattern antenna diversity system in GNSS*

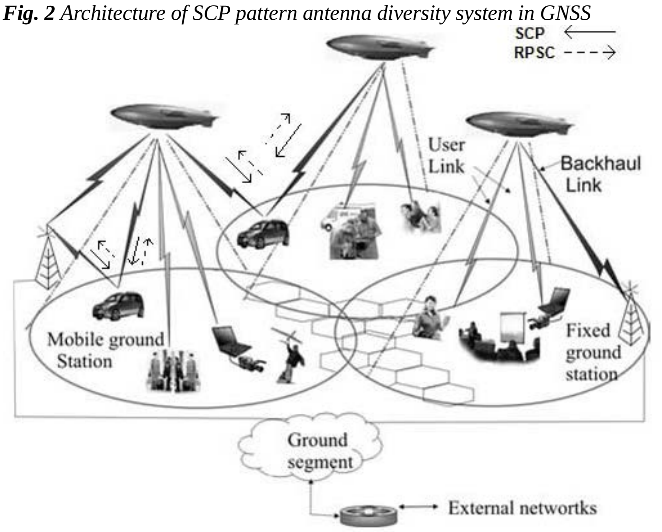

Fig. 3 *SCP-RPSC pattern antenna diversity in HAPS LOS terminals.*

In high building city environment most of the terminal links will be shadowed, leading to necessity of more and more new earth terminals and HAPS stations. The preliminary studies show that SCP-RPSC technology could successfully solve the problem. One of the main advantages of this technology is the possibility to create simultaneous several narrow virtual steering antenna beams, using pattern diversity approach. In N-LOS HAPS case this feature could be used in order to gather the energy of the multipath beams, reflected from the different buildings, in phase at baseband (similar to the CDMA), as it is shown in fig.4.

A block-scheme of a SCP Rake receiver for HAPS mixed LOS and NLOS propagation environment is shown in fig.5. Here a typical SCP receiver is used, but at low Intermediate Frequency (IF) several Rake channels are created. Each of them consists of pilot recovery unit and signal recovery unit. The pilot recovery units are fed by the used PN-code, properly time shifted according to the time offset of the different reflected signals. Each recovered pilot signal is sum of several thousand random phased signals (equal to the number of the antenna array elements). According to the Central Limit Theorem (CLT) such sum has Gaussian random probability distribution. In the signal recovery units the corresponding recovered pilots correlate with the spread in the same manner information signals, coming from the same reflecting points. The baseband outputs of the correlators are time delayed with the specific time delays, as follows:

$$\Delta t_1 = \frac{\Delta R_1}{c};\ \Delta t_2 = \frac{\Delta R_2}{c};\ldots\ \Delta t_n = \frac{\Delta R_n}{c};\ldots\ \Delta t_N = \frac{\Delta R_N}{c} \qquad (1)$$

Where:

$$\Delta R_1 = \max(R_{na} + R_{nb}) - (R_{1a} + R_{1b});$$

$$\Delta R_2 = \max(R_{na} + R_{nb}) - (R_{2a} + R_{2b});$$

………………………………..

$$\Delta R_N = \max(R_{na} + R_{nb}) - (R_{Na} + R_{Nb}), \qquad (2)$$

ΔR_{na} is the distance between the base station and n-th reflecting point, ΔR_{nb} is the distance between the n-th reflecting point and the terminal antenna and $\max(R_{na} + R_{nb})$ is the longest one way propagation trip base station – reflecting point – terminal antenna. For this finger channel the reflected beam is with maximum time delay and the introduced by the system additional time delay at baseband is zero.

The total baseband output signal of the proposed system is sum of the delayed signals of the different Rake fingers:

$$BBO_{total} = BBO_{LOS} + BBO_{NLOS1} + BBO_{NLOS2} + \\ + \ldots\ldots\ldots + BBO_{NLOSn} + \ldots\ldots\ldots BBO_{NLOSN} \qquad (3)$$

The created in such manner several virtual high gain antenna beams are directed towards the different reflecting points. The reflected signals will be received with high antenna gain and will be well isolated each other (they will not be separated only by the autocorrelation function of the used spreading code as it is in the famous CDMA techniques). The angles among the different reflecting points toward the terminal antenna should be larger than the created virtual antenna beams (the beam-width of the SCP Spatial Cross – Correlation Function).

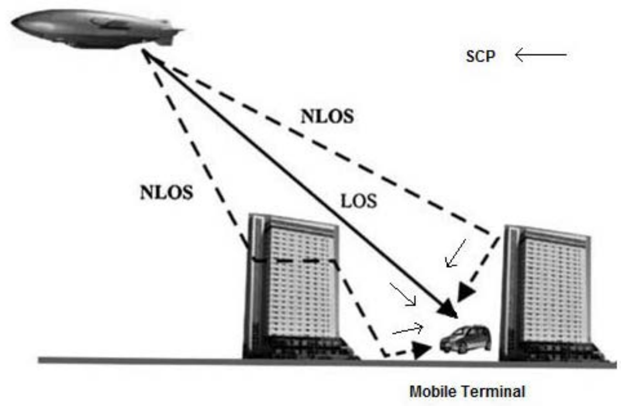

Fig. 4 *Possible use of SCP-RPSC pattern antenna diversity in HAPS mixed LOS and NLOS propagation environment*

The procedure for the HAPS up-links, using RPSC approach, will be similar to the previous case. The Rake receiver for the different pilots multipath components will be situated at the base station site and the signal processing will be similar too.

4.4. SCP-RPSC pattern antenna diversity in WiMAX communications

The application of SCP-RPSC principles for solving the antenna problems of mmWave World Interoperability for Microwave Access (WiMAX) was proposed by the author a decade before [7]. WiMAX is considered as wireless alternative of the existing cable technologies to realize the last mile between the end users and the nearest point with broadband connectivity. The benefits include possible services not only for fixed, but for mobile terminals too. Efficient frequency re-use schemes due to the used smart base stations antennas can be employed to maximize the Wi-MAX network capacity. Hence, broadband user interactive services can be delivered with a high degree of QoS. One of the major disadvantages of the existing Smart antennas is in their design and implementation in hardware.

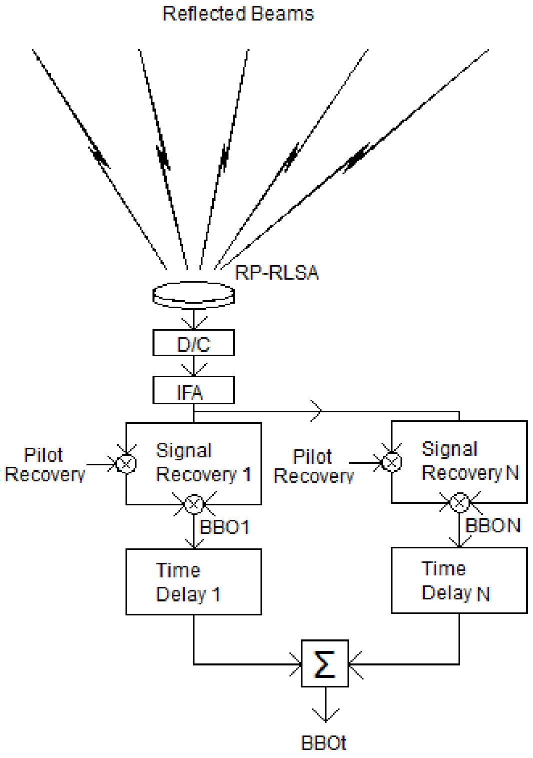

***Fig.** 5 Block-scheme of SCP Rake receiver in HAPS mixed LOS and NLOS propagation environment*

Multiple RF chains can increase the cost and make the transmitter bulkier. Most of the baseband processing requires coherent signals. This means that all the mixers Local Oscillators and ADC clocks need to be derived from same sources. The phase characteristics of the RF components can change over time. The problems appear too with the real time data processing in the case of multi-element antenna array. The existing smart antenna systems are used successfully in the low frequency microwave bands Wi-MAX systems. Here N-LOS propagation conditions are used and the number of the base station antenna array elements is low – in order of several units. In this particular case the complexity of the multiple RF chains in the transmitter and receiver site is acceptable.

The most promising frequency bands for the future WiMAX systems are in the upper centimeter and low millimeter wave microwave frequencies. Here LOS propagation conditions and high gain narrow beam antennas are used, leading to high link-budget potential, frequency reuse factor and system capacity. On the negative side, the existing multi-beam antennas, working in the upper microwave band, are costly and inefficient. The required number of the antenna array elements is in order of several thousands and the smart antenna principles, described above, are not applicable.

The main goal of report [7] was to discuss the possibilities and the advantages of the implementation of SCP-RPSC technology in Wi-MAX communications. The implementation of this technology in subscriber terminals was discussed first. After that the possible base station applications were treated too. The applications of SCP-RPSC technology simultaneous at base station and terminal stations are possible too, but they will need additional research and investigations.

- SCP-RPSC at WiMAX base stations

An important feature of the SCP technology is the ability to support multi beam reception by means of multi channel receiver, very similar to the famous Rake receiver in CDMA techniques. In such way antenna array with one meter in diameter, working in 30 GHz frequency band, will support more than one hundred simultaneous virtual orthogonal fixed and mobile beams, using the same frequency channel. As a result a huge increase of the frequency reuse factor and the system traffic capacity are expected.

In transmit mode RPSC technology, because of the omnidirectional phase spread transmission, does not need information about the angular coordinates of the different subscriber stations. It is very important feature for mobile applications too.

- SCP-RPSC at Wi-MAX terminals

The possible application of SCP-RPSC approach at Wi-MAX terminals will have the following features: Full duplex interactive system with one simple and cheap terminal antenna; Space diversity, the ability to connect the terminal with more than one base stations in fixed and mobile environment; According to the published data the gain of the receiving terminal Wi-MAX antenna should be in order of 35 dBi. A design, based on SCP-RPSC approach and random phased RLSA (Radial Line Slot Antenna) array, will be with 20 cm. in diameter and thickness of several mm. at 30 GHz frequency band. These compact dimensions and the lack of necessity for precise antenna beam pointing toward base station, will not need qualified personal for mounting and technical support.

5. *Conclusion*

A retrospective review of the author research, dealing with possible applications of SCP-RPSC pattern antenna diversity in the next generation mmWave 5 G communications, is given in the report, as follows:

- SCP-RPSC terminals with pattern antenna diversity;
- SCP pattern antenna diversity, using several virtual steering beams, in Global Navigation Satellite Systems;
- SCP-RPSC pattern antenna diversity in HAPS communications;
- SCP-RPSC pattern antenna diversity in WIMAX communications.

The practical SCP-RPSC implementation as pattern antenna diversity approach in mmWave 5 G communication systems will drastically change the existing paradigm in the broadband terrestrial, HAPS and satellite communication systems in general. Many of the existing problems will be solved successfully.

6. *References*

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