Recent trends and future developments of SCP-RPSC high altitude platform systems

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A new technology for broadband wireless access to the fixed networks, named High Altitude Platform Systems (HAPS) is under development now as an effective solution of the "Last mile" communication problems. The application of the proposed by the author SCP-RPSC approach in broadband HAPS communications was reported in several previous reports. It is based on a new principle for virtual electronic beam steering of high gain antennas with sufficient isolation among the space distributed radio sources. A retrospective review of the step by step approach, used by the author for development of SCP-RPSC technology in HAPS, is given in this report. Applications, dealing with Line of Sight, Non-Line of Sight and Feeder Lines are considered too. The traffic capacity of such systems is compared with the conventional HAPS system, based on multiple "spot beams" approach.

Последни тенденции и бъдещото развитие на SCP-RPSC системи на високи платформи (Веселин Демирев). *Една нова технология за широколентов радиодостъп до фиксираните мрежи, наречена Системи на високи платформи (HAPS) навлиза в борбата за евтина и ефективна "Последна миля – Last mile" на широколентовия пренос. Приложението на разработения от автора принцип SCP-RPSC в широколентовите HAPS комуникации е изложено в няколко предишни публикации. При технологията SCP-RPSC се осъществява виртуално електронно сканиране на един или няколко антенни лъча с голям коефициент на усилване и с висока пространствена избирателност. В настоящата работа са представени различните етапи от развитието на предлагания подход за условия на директна радиовидимост, многолъчево разпространение и за фидерни HAPS линии. Резултатите от анализа на трафичния капацитет на една SCP-HAPS система са сравнени с тези на конвенционална HAPS система, използваща технологията "spot beams".*

Introduction

The HAPS (High Altitude Platform System) denomination was defined in the World Radio communications Conference (WRC-97) as a station located on an object at an altitude of 20 to 50 km and at a specified, nominal, fixed point relative to the earth. The systems based on HAPS represent a technological alternative that has been under development for the last few years [1, 2], although the investigation of unmanned aerial vehicles had started around the world about 40 years ago.

These systems could have many advantages compared with both terrestrial and satellite systems. Various applications and services are planned to be provided by HAPS, which could be classified as narrowband or broadband, depending on the bandwidth required, as well as fixed or mobile. Subscribers will transmit their information directly to the platform, where on-board switching devices will route traffic directly to other subscribers within the same platform coverage area or through heterogeneous networks. A system based on HAPS will allow a better signal quality to be obtained in the receiver, owing to the fact that during most of the transmission time, the system is under a Line-Of-Sight (LOS) condition. This reduces shadowing effects in comparison with terrestrial systems. HAPS also experiences less propagation delay with regards to satellite systems. On the other hand, HAPS and satellite systems suffer less from shadowing and multipath distortions because they are exposed to high angle of arrival signals. Each HAPS can deploy a multi-beam antenna capable of projecting numerous spot beams within its potential coverage area. The platforms act as the highest cell tower in town. In a system based on HAPS, the platform is positioned above the ground to create a radio electric coverage area or a service area of up to 500 km in diameter.

There are several reasons for using a kind of aircraft station-keeping as a base station for broadband wireless systems, such as:

- The platforms do not require a launch vehicle, i.e. they can move under their own power or remain stationary, and they can be brought down to Earth, refurbished and re-deployed;
- Once a platform has reached its final position, it can immediately start operating within its service area without the need to deploy a global infrastructure or constellation of platforms to operate;
- The platform altitude enables the system to provide a higher frequency reuse and thus higher capacity than other wireless systems;
- Each platform can be retrieved, updated, and re-launched without service interruption;
- The stratospheric altitude provides subscribers with short paths through the atmosphere and unobstructed line-of-sight to the platform;
- With the use of small antennas and having low power requirements, the HAPS allows for a wide variety of fixed and portable user terminals to meet almost any service requirement;
- HAPS can be classified as the third layer of communications infrastructure after satellite and terrestrial systems. It can provide rapid coverage and high capacity, capable of serving densely populated cities, suburban as well as rural and remote areas where there still exists poor mobile and narrowband connections, hence complementing the existing wired and wireless infrastructure.

Figure 1 shows an example of the architecture required in a HAPS communication system. Elements such as stratospheric stations, ground stations for telecommunications and flight control and fixed or mobile subscriber stations for broadband services are shown.

A communication system based on HAPS can be composed basically of two main elements: a stratospheric segment and a ground segment. The HAPS ground segment supports operations between the HAPS and users on the ground, as well as controlling some functions related to the operation of the HAPS itself. The interface with other existing terrestrial networks is performed here, where flight control and gateway operations also take place. Every object in a position under the HAPS radio coverage can communicate using the communication air interface from subscribers up-linking to the HAPS and down-linking to the ground station, which delivers the signals to the subscriber terminal or other system signal-processing platform. At the same time, the ground station equipment controls the flight of the HAPS to ensure that it stays in the proper relationship to the coverage areas on the ground, allowing the on-board antennas to do their work efficiently. The HAPS is connected to the rest of the terrestrial telecommunications network via the backhaul link through the ground station.

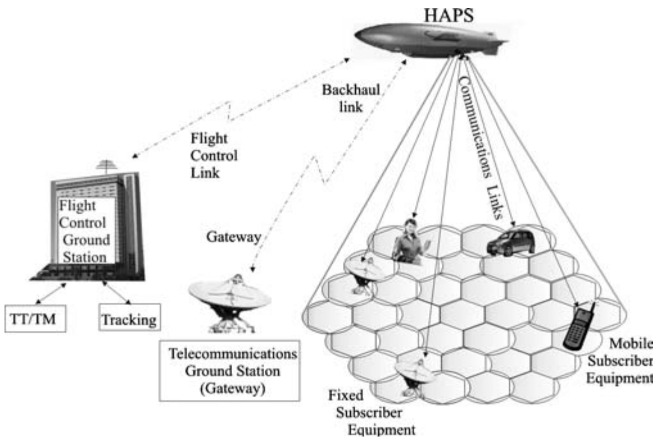

Fig. 1. HAPS architecture concept.

At WRC-97 the concept of HAPS was formally introduced into the Radio Regulations as a separate category of radio stations and a new provisional rule of procedure was decided upon. On this occasion, the conference made provisions for operation of HAPS within the fixed service in the bands 47.2/47.5 and 47.9/48.2 GHz. The potential use of HAPS in 12 countries was later agreed, in the bands 27.5–28.35 and 31.0–31.3 GHz (28/31 GHz bands), since the 47/48 GHz bands are more susceptible to rain attenuation in some areas for ground to HAPS operations.

HAPS problems

Being an entirely new telecommunication technology in a new very high frequency band, HAPS technology still suffers many problems, as follows:

- The position and orientation of the platform must be carefully maintained within a particular location and direction to ensure that coverage on the Earth is fixed. The stratosphere is characterized by strong winds; hence some means of controlling the location of the platform is needed. The shaking of the platform due to the wind or other reasons will shift the position of the cells on the ground, leading to system blockage and use of tracking terminal antennas;

- The high speed mobile terminals will suffer high Doppler shift due to the used frequency band were the tracking terminal antennas are unpractical;
- The number of the platform spot beams should be in order of thousands, impossible for the existing mm wave-length antennas;
- In urban areas, situated in the end of the served area, only the roofs of the buildings have LOS visibility conditions. Suitable Non-LOS HAPS technologies should be developed in such cases.

These problems could be solved by means of the developed in the last decade SCP (Spatial Correlation Processing) - RPSC (Random Phase Spread Coding) technology.

SCP-RPSC technology in HAPS

The main objectives of the SCP technology [3], [4], [6] are:

- To receive one or more radio signals coming from one or several spatially distributed sources (satellites, HAPS stations), insuring high gain of the antenna system.
- To ensure spatial selectivity high enough to cancel the same frequency channel interference, coming from different space directions, using simple one-channel receiver and specific signal processing techniques.

The objectives stated above are achieved by a patented method for radio communications, which proposes application of additional pilot signal transmitted in the band of information signals and available in the receiver by CDMA method of access. The SCP receiver terminal is equipped with random phased antenna array. 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 phase 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.

One of the main parts of the SCP system is the random phased antenna. In principle all kind of antenna arrays could be used, but particular suitable for Ka band is the Radial Line Slot Antenna (RLSA).

The main features of the SCP approach, when they are used in HAPS, are:

- Simple and cheap passive RLAA, suitable for mass production in Ka frequency bands.
- One channel microwave receiver with simple signal processing.
- Omni-directional for the cooperative HAPS station, but with high figure of merit G/T.
- Selection of different HAPS stations and polarizations by Pseudo-Noise (PN)-codes.
- Soft handover and virtual multi-beams features.

The application of the SCP principle in transmit mode [5, 6] was named Random Phase Spread Coding (RPSC). The main features of this technology, when it is used in HAPS communication links, include:

- One channel convenient microwave receiver with simple signal processing;
- Omnidirectional for the cooperative HAPS station, but with high equivalent (at base-band) EIRP;
- Selection of different terminals and polarizations by Pseudo-Noise (PN) codes;
- Soft handover and virtual multi-beam features;
- The coherent demodulation by means of pilots cancels the Doppler shifts and phase jitter, introduced by local oscillators in the HAPS system;
- Providing of full duplex HAPS communications with one simple and cheap transmit-receive terminal antenna, using combined SCP-RPSC technology in both directions;
- The transmitted random poly-phase spread signals are uniformly radiated in the space above the terminal antennas. Several HAPS stations, equipped with the same SCP receivers and providing space diversity, receive them. The knowledge of the receiving HAPS station positions for the transmitting equipment is not necessary (as it is for a conventional ground terminals);
- The transmitted random poly-phase spread signals have low power spectral density and low detection probability for the conventional microwave receivers, as well as high protection against active jamming;
- The SCP-RPSC approach could be a breakthrough technology, leading to unpredictable increase of the frequency reuse factor in HAPS wideband networks. Close

situated ground terminals could communicate with HAPS stations, using the same frequency channel without interference. The isolation among the terminals will be provided by their specific random phase spread coding.

The application of SCP-RPSC approach to solve the antenna problems of mm-wave HAPS was proposed by the author several years ago [7, 8, 9]. The first reports deal with LOS mm-wave propagation environment, which is accepted by the communication community as the only way to communicate in these frequency bands. Possible applications of SCP-RPSC technology in a HAPS LOS base station are shown in fig.2. 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, as it is shown in fig.2.

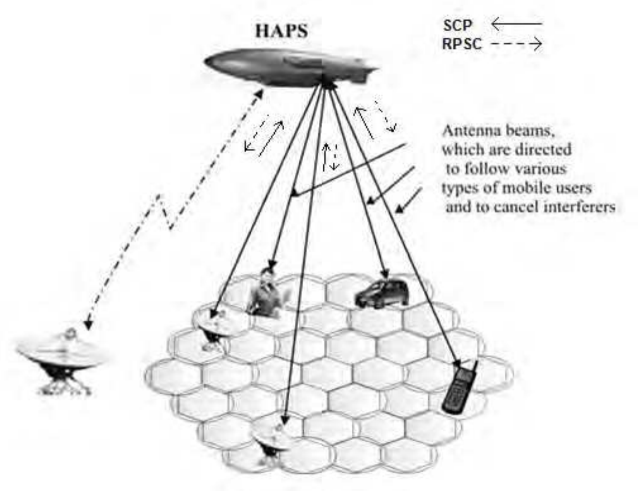

Fig.2. Architecture of a SCP-RPSC HAPS base station.

Possible use of SCP-RPSC technology in HAPS LOS terminals are shown in fig.3.

Possible uses of SCP-RPSC technology in HAPS feeder lines and inter HAPS links are shown in fig.4.

Non Line of Sight (N-LOS) mm-wave HAPS

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 [10] 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 antenna beams.

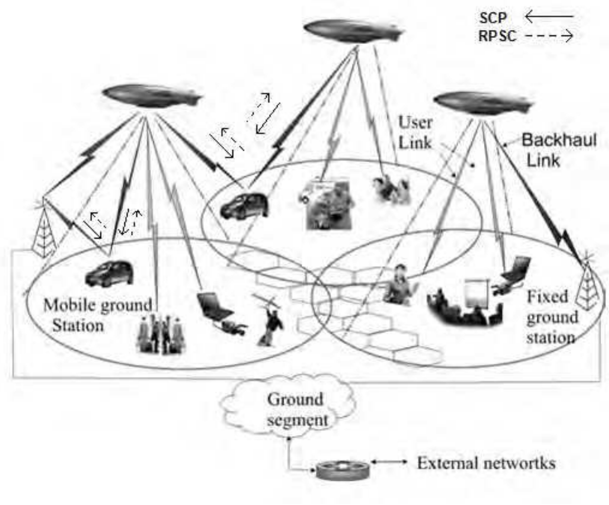

Fig.3. Possible applications of SCP-RPSC technology HAPS LOS terminals.

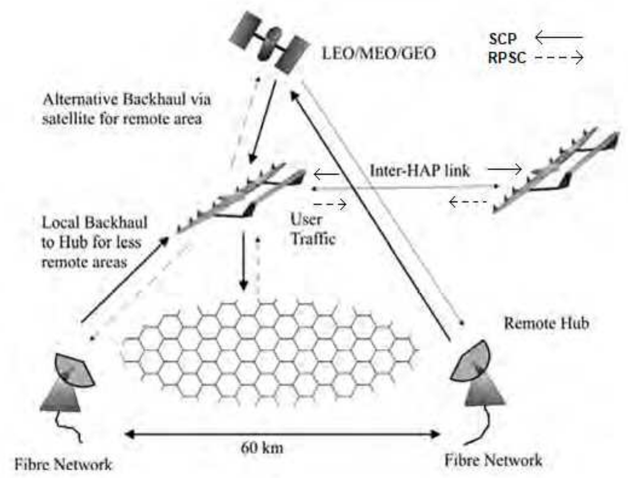

Fig. 4. Possible use of SCP-RPSC technology in HAPS feeder lines and inter HAPS links.

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.5.

A block-scheme of a SCP Rake receiver for HAPS mixed LOS and NLOS propagation environment is shown in fig.6. 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 CLT (Central Limit Theorem) 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.

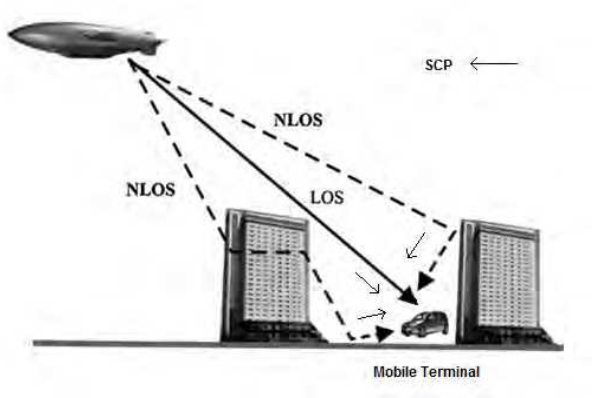

Fig. 5. Possible use of SCP-RPSC technology in HAPS mixed LOS and NLOS propagation environment

The baseband outputs of the correlators are time delayed with the specific time delays, as follows:

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

where:

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

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

....

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

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:

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

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 wider than the created virtual antenna beams (the beam-width of the SCP Spatial Cross – Correlation Function).

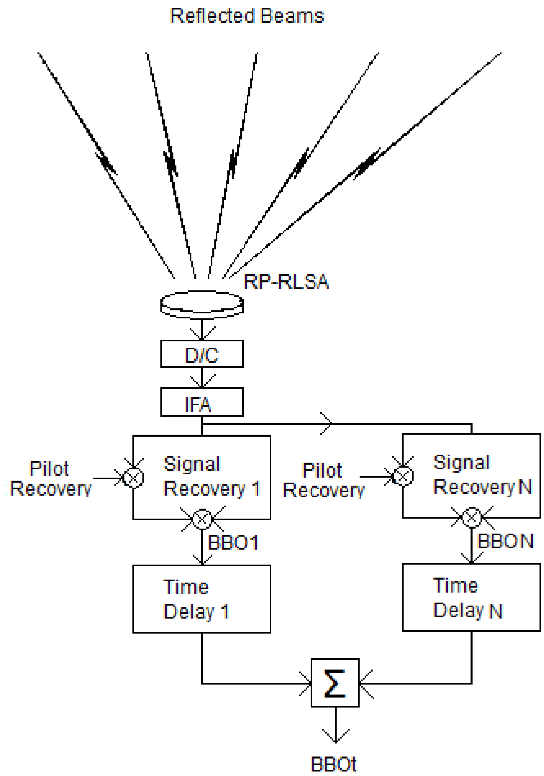

Fig. 6. Block-scheme of SCP Rake receiver in HAPS mixed LOS and NLOS propagation environment.

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.

Analysis of traffic capacity of SCP HAPS

As it was mentioned above, the proposed in the literature HAPS base stations use spot beams antennas, creating cellular type coverage on the earth surface. The application of SCP-RPSC approach in

HAPS base station will create individual virtual steering antenna beams toward each fixed or mobile earth terminal, as it is shown in fig. 2. In such way additional advantage appears - significant improvement of the traffic capacity. The detailed analysis, based on the theory of the "spatial sterradians" [11], shows an increase of more than 10 times comparing with the traditional "spot beams approach", reaching about 4000/km^2. It is shown in [11] too that by means of SCP technology it is possible to create several hundred individual steering virtual antenna beams on the HAPS station for tracking the active fixed and mobile ground terminals.

Doppler shift immunity of SCP-RPSC HAPS

The Doppler shift in wireless communications, due to the relative motion between transmitter and receiver site, is:

(4) $$f_d = \pm \frac{V}{\lambda} \cos\theta$$

where $V\cos\theta$ is the radial speed between two sites and λ is the used wavelength. The expected Doppler shifts in HAPS communication lines when high speed vehicles as trains, cars ets. are equipped with HAPS terminals, is in order of several KHz due to the used very high frequency band. These high values of Doppler shifts lead to problems in the receiver coherent demodulation systems. In SCP-RPSC technology this problem is solved due to the used pilot signals, as follow [4]:

Consider the matrix presentation of the signals in a SCP system, given in [3].

Let s_{nc} be the transfer function between the cooperative HAPS station and the n-th element of the random phased RLSA. Then:

(5) $$s_{nc} = L_{snc}.e^{-j\psi_{nc}}.e^{j\Omega t}$$

where L_{snc} are the free space propagation losses, $\psi_{nc} = k.r_n.\sin\theta_c.\cos(\phi_c - \phi_n)$ is the phase of the signal received by n-th element of RLSA relative to its center, $k = 2\pi/\lambda$ - free space phase constant, r_n, ϕ_n - the coordinates of the n-th element of RLSA, ϕ_c, θ_c - the angular coordinates of the cooperative satellite, $\Omega = ^{+}_{-} 2\pi f_d$ - the Doppler shift due to motion between the cooperative HAPS station and the mobile terminal antenna. Correspondingly the output signal, product of the multiplication process in the correlator unit, will be:

(6) $$G(\mathbf{i_c}.\mathbf{p}) = G\begin{vmatrix} i_{c1}\cdot p_1 & i_{c2}\cdot p_1 \cdots & i_{cn}\cdot p_1 \cdots & i_{cN}\cdot p_1 \\ i_{c1}\cdot p_2 & i_{c2}\cdot p_2 \cdots & i_{cn}\cdot p_2 \cdots & i_{cN}\cdot p_2 \\ \cdots & \cdots & \cdots & \cdots \\ i_{c1}\cdot p_n & i_{c2}\cdot p_n \cdots & i_{cn}\cdot p_n \cdots & i_{cN}\cdot p_n \\ \cdots & \cdots & \cdots & \cdots \\ i_{c1}\cdot p_N & i_{c2}\cdot p_N \cdots & i_{cn}\cdot p_n \cdots & i_{cN}\cdot p_N \end{vmatrix}$$

The real part of the n-th diagonal term of the matrix (6) consists of:

(7) $$\mathrm{Re}(i_{cn}.p_n) = ^{+}_{-} i_c.\cos^2\left[(\omega_{II} + \Omega)t - k.r_n.\sin\theta_c.\cos(\phi_c - \phi_n) + k_g.r_n\right]$$

By means of eq. $\mathbf{cos}^2 A = 0{,}5.(1 + \mathbf{cos}\,2A)$:

(8) $$\mathbf{Re}(i_{cn}.p_n) = ^{+}_{-} 0{,}5.i_c {}^{+}_{-} 0{,}5.i_c.\mathbf{cos}(2\omega_{II}.t + \ldots)$$

The second term of Eq. (8) vanishes after Low Pass Filtering (LPF). The first term represents the demodulated information signal per antenna element at base-band and it does not depend on the Doppler frequency shift. The total base-band output signal will be N times more, equal to the trace of the matrix (6) (the N diagonal elements of (6) are in phase, not depending on the Doppler shift too):

(9) $$BBO_c = ^{+}_{-} 0{,}5.G.i_c.N$$

The conclusion is that due the similar Doppler shifts for the pilots and information signals (they use the same frequencies), during the correlation process the Doppler influence over the HAPS SCP-RPSC communication channel vanishes.

Conclusion

The proposed at WRC-97 new HAPS technology is very promising for the future fixed and mobile "last mile" broadband connections. It is very important for areas without telecommunication infrastructure, as well as for urban areas, where it is narrowband and supports only voice telephony. The allocated HAPS extremely high frequency band and the need of high traffic capacity create many problems, which could be solved only by the use of SCP-RPSC technology both on the HAPS platforms and in subscriber terminals.

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