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ONE METHOD FOR TV PICTURE TRANSMISSION OVER TROPOSPHERIC SCATTER COMMUNICATION SYSTEMS

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Abstract. In this paper a new method for bandwidth capability enhancement of tropo-scatter communication systems is proposed. First, the most important reasons concerning motivation of the work are indicated. After that, the basic elements of the proposed method are presented, together with the main advantages that can be achieved by this method. Special attention is payed to diversity gain improvement and to higher propagational reliability achievement, as well as to intermodulation distortion reduction and frequency bandwidth broadening. At the end, simulation results concerning this method application for one path in Yugoslavia are given.

1. Introduction

Reasons for which we suggest a new method for tropo–scatter links realization are numerous. In essence, however, all of them may be reduced at two basic:

1) A need to achieve as higher reliability of tropo–scatter systems as possible, and
2) A need to widen frequency bandwidth of tropo–scatter systems in order to simplify wide spectrum signals transmission (for example, TV signals).

The tropospheric scatter mode of propagation, which enables communications between the points on distances much greater than line–of sight, is characterized by the severe and rapid fading. There are two general classes of fading associated with tropospheric scattering: a short–term or Rayleigh fading and a so–called long–term or log–normal fading. Because of that,

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it is necessary to use large powers and high–gain antennas to realize long–distance communication links of several hundred kilometers. Also, when higher propagational reliabilities are required, it is practically indispensable to use diversity reception techniques. Their use, however, reduces the influence of short–term fading only. Long–term fading simultaneously affects equally all the diversity channels, and consequently, no improvement is effected in the long–term fading by the use of classical diversity techniques. Also, their use has as a result increased number of receiving and transmitting antennas, or the greater frequency spectrum occupation. This is why it is very hard to realize diversity systems of higher order (for example, 10, or higher) and to achieve greater diversity gain. Usually, two–fold or four–fold diversity systems are in use now.

Bandwidth capability of tropo–scatter systems depends of many factors. The geometry of a typical over–the-horizon path suggests an inherent multipath transmission problem. Signal components reflected to the receiving antenna from successively higher points in the atmosphere are delayed by increasing amounts of time behind the earliest–arriving component. This could result in significant intermodulation distortion, especially when wider basebands are used. Also, as the bandwith of the transmitted signal increases and begins to approach the correlation bandwidth of the channel, a frequency–selective fading begins to manifest itself; that is, not all frequency components in the transmitted signal undergo the same random modulation. Because of this, for the wideband transmissions, it is necessary to use the high–powered transmitters together with highly directive antenna systems. Television is transmitted via tropo–scatter between France and Algeria and in Japan, but by the use of very narrow radiation beamwidths.

Method that is proposed in this paper makes it possible to achieve a significantly higher order of diversity, without additional frequency spectrum occupation, and without the use of great number of antennas. It is based on the tracking of maximal reflected power of transmitting signal, coming from one transmitting antenna. At the receiving side several receiving antennas, forming space diversity, are predicted. These antennas are supposed to have possibility of rotation, and their beams are shaped so that less values for the maximum differential path delay (τ) could be achieved. In this way it is possible to use transmitting antennas with wider beamwidths (for the same bandwidth), and to decrease the influence of long–term fading.

2. Description of the proposed method

During the designing of some tropospheric–scatter links in Yugoslavia, we have proposed a method that makes it possible to increase significantly diversity gain without additional frequency spectrum occupation. It is based on a space diversity technique, but realized in a new way [1]. Its basic characteristics are:

1) One transmitting antenna with relatively wide antenna beam;
2) Several receiving antennas, forming space diversity, with antenna beams more narrow than transmitting antenna beam;
3) The receiving antennas have possibility to rotate and each of them can take one of several previously defined positions with independent fading;
4) Algorithm according to which receiving antennas rotation and select the best position.

The sketch of tropospheric–scatter circuit with these elements is given in Fig. 1.

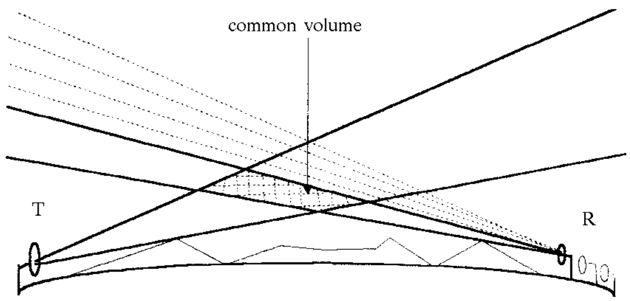

Fig. 1. A sketch of proposing tropo–scatter circuit

All of these elements are crucial for the realization of two mentioned aims:

– To increase diversity gain and
– To widen frequency bandwidth.

Transmitting antenna beam is supposed to be wide about the beams of receiving antennas because it is necessary to provide a high probability of interception at the various locations along the transmission path, and to provide a large number of reflexions directed to the receiving antenna.

At the other side, the beams of the receiving antennas are supposed to be narrow about the transmitting antenna beam, because it is necessary to provide more homogeneous electromagnetic field within a common scattering volume, defined by the solid–angle intercepts of transmitting and receiving antenna patterns. Thanks to the less dimensions of common scattering volume it is possible to receive a reflected signal of better quality because of:

– Less changes in the electromagnetic field strength with common volume,
– Less changes of refractive–index within the common volume, and
– Reduced mean path delay.

Possibility of rotation is foreseen for receiving antennas mainly because of diversity gain improvement. We will set an example to show how much diversity gain improvement can be attained by this way. Suppose that we have a tropo–scatter communication system consisting of one transmitting and three receiving antennas forming space diversity, at each side. Also assume that each receiving antenna can take one of five possible independent positions within the range of rotation. Under the independent positions we understand the positions of antenna with independent fading, or with so different scattering angles that difference $\Delta\theta$ between two neighboring positions corresponds to antenna move equal or greater than 100 wavelengths. Maximal order of diversity which can be achieved in this way is $N = 15$, since we have 3 receiving antennas, and each of them can take one of five possible positions, i.e., can select the best of five possible signals.

It is known from literature [2,3] that diversity gain in tropospheric–scatter systems can be obtained by the next formula:

$$G = \frac{\ln\left(1 - r^{\frac{1}{N}}\right)}{\ln(1-r)}, \tag{1}$$

where r is the outage rate, and N is order of diversity. In this way it is possible to estimate diversity gain in the case when selection combining technique is applied.

In our case diversity gain, for the outage rate $r = 0.01\%$ will be:

$$G_{15} = \frac{\ln\left[1 - \left(\frac{0.01}{100}\right)^{\frac{1}{15}}\right]}{\ln\left(1 - \frac{0.01}{100}\right)} = 7790.3 = 38.9\ dB \tag{2}$$

This value is for 8.9 dB greater than in the case of four–fould diversity.

It is easy to notice that diversity gain $G = G(N)$, given by the equation (1), will grow slowly after $N = 4$. Because of that, for the significantly greater diversity gain it is necessary to achieve as higher order of diversity as possible. Of course, it is desirable to do this without additional frequency spectrum occupation.

Moreover, by the higher order of diversity it is possible to reduce intermodulation noise introduced into the tropospheric–scatter systems. Bello

[4] had derived an essentially linear relation between the order of diversity and the noise power:

$$\left(\frac{D}{S}\right)_{\text{with diversity}} = \frac{1}{N} \cdot \left(\frac{D}{S}\right)_{\text{without diversity}} \tag{3}$$

where N is the order of diversity.

To achieve better efficiency, and to avoid undefined situations, receiving antennas have to rotate according to some algorithm. We shall describe in short one possible algorithm, based on a previous example, to show how much is it important.

Suppose, again, that we have three receiving antennas and that each of them can take one of five possible independent positions. Also, assume that, at the first moment, all receiving antennas start with the position testing. After that each antenna takes the best position and, at the same time, marks the reserve position (the best alternative position). If the level of the receiving signal, from any antenna drops under the minimum acceptable value, this antenna automatically takes the reserve position. (This is necessary to avoid the complete process of position testing, if possible.) Only if in this position the signal level is under the desired value too, the antenna starts the new process of position testing.

To provide continuity in system operation, and minimal order of diversity $N = 2$, it is necessary to assume that antenna begins to test other possible positions only if other two antennas are in active positions. This means that only one of three receiving antennas is allowed to be in the process of position testing.

In this way the result for the maximal order of diversity ($N = 15$) is valid only in the case when the changing of receiving signal level is slower than the process of position changing of receiving antennas. This means that if the speed of signal level changing is less than the speed of position testing of all three receiving antennas, obtained order of diversity will be $N = 15$. This is the case of slow fading for example, caused by the gross changes of atmospheric conditions. But, if the speed of signal level changing increases the order of diversity falls down. So, if we suppose that the speed of receiving signal level changing is greater than the speed of position testing of all receiving antennas, but less than the speed of position testing of two receiving antennas, obtained order of diversity will be $N = 10$. In the same manner, for the speed of signal changing that is less than the speed of position testing of one receiving antenna, obtained order of diversity will be $N = 5$. Finally, for the fastest change of signal level, we have minimal value for the order of diversity $N = 2$, because only one receiving antenna is allowed to be in the process of position testing.

As we see, order of diversity in this case is not a constant value. It is a function of time which directly depends of the speed of signal level changing and with the range of values between $N = 2$ and $N = 15$.

3. Simulation results

We have simulated a tropospheric–scatter transmission according to proposed method on a personal computer for one concrete path in Yugoslavia (between places A and B). The basic data concerning this path characteristics are summarized in Fig. 2, together with the path profile.

We assumed one transmitting antenna and three receiving antennas forming space diversity. Each receiving antenna had a possibility to take one of five possible fading independent positions. The algorithm for position choosing was assumed to be the same as it is described in previous chapter. Also, we have supposed that a receiving antenna starts to change its position only if the average value of receiving signal level during the last 5 seconds stays below minimal acceptable value. The time which was necessary for the receiving antenna to get reserve position was 5 seconds. However, for the complete cycles of testing all possible positions we assumed that it was necessary 30 seconds.

Distance: $180km$
$\theta = 12.075mrad$
Operating frequency: $2GHz$
Transmitting antenna beamwidth $0.9deg.$
Receiving antenna beamwidth $0.3deg.$

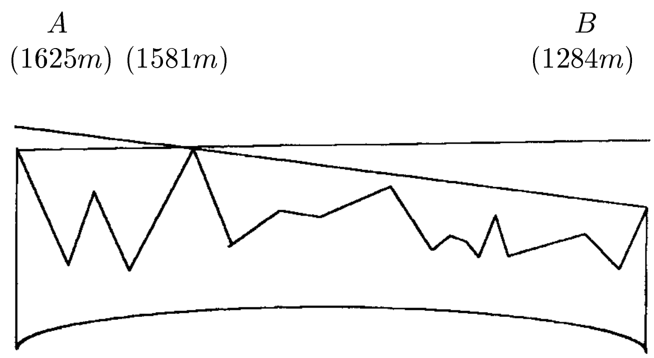

Fig. 2. Path profile

Results we have obtained, for arbitrary assumed receiving signal level changing concerning order of diversity, were in the range from $N = 2$ (100% of time) to $N = 15$ (62.8% of time) as it is given in Table 1. The maximal order of diversity was obtained for the slowest changing of receiving signal level. This shows that this method makes tropo–scatter systems able to eliminate slow fading in a great measure. This is because the rotation of receiving antenna causes horizontal and vertical transfer of common volume. In this way it is possible to avoid gross changes in the atmosphere common to the beams of the transmitting and receiving antennas, and to receive signal from the part of the atmosphere with less meteorological variability. In our case the maximal horizontal transfer of common volume was approximately $30km$. The maximal vertical transfer was $2.5km$.

Thanks to the reduction of the maximal differential path delay for approximately 30%, the maximum permissible baseband frequency was increased approximately for 40%, relating the situation when the beamwidths of the transmitting and receiving antennas are the same. The maximum permissible baseband frequency we have estimated by the following equation [5]:

$$f_{bmax} = \frac{0.22}{\tau}, \tag{4}$$

In our case, maximal baseband frequency $f_{bmax} = 7MHz$ (maximal differential path delay $\tau = 0.033\mu s$) was achieved for the transmitting antenna beamwidth of $0.9°$ and receiving antenna beamwidth of $0.3°$. If we had both antennas with the beamwidths of $0.9°$, we would have had $f_{bmax} = 5MHz$. Also, if we use average value for multipath delay, which is just half of maximum differential delay, as it is suggested by Parry [5], bandwidth capability of proposed tropo–scatter system becomes considerably enlarged.

Finally, three receiving signals we were combining using equal–gain technique. In this way diversity gain was increased approximately for additional $3.0\ dB$. So, the total diversity gain for the maximal order of diversity was:

$$G_T = G_{15} + 3.0\ dB = 41.9\ dB. \tag{5}$$

4. Conclusion

A method that is proposed in this paper offers a reliability enhancement of tropo–scatter communication links based on:

1) The order of diversity increasing, and
2) The reduction of slow fading.

It is important to emphasize that it does not require great number of transmitting and receiving antennas or additional frequency spectrum occupation. Moreover, it enables the bandwidth broadening of tropo–scatter

Table 1. Obtained order of diversity

obtained order of diversity	percent of time	obtained order of diversity	percent of time
2	100.0	9	91.7
3	98.7	10	88.5
4	96.7	11	79.4
5	95.1	12	76.8
6	94.6	13	70.2
7	93.3	14	68.1
8	92.3	15	62.8

systems, thanks to the reduction of common volume dimensions. The importance of slow fading reduction lies in a fact that there is no any reduction of this class of fading by the use of classical diversity techniques. Thanks to the possibility of common volume transfer, it is possible to avoid various meteorological disturbances in the atmosphere.

All of this allows TV signals transmission in a more simple way, especially when frequency compression is used [6].

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