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Technical Report

Fixed Radio Systems;
Point-to-point and point-to-multipoint equipment;
Use of circular polarization in multipoint systems;
Part 1: Systems aspects

Reference

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Foreword

This Technical Report has been produced by the ETSI Technical Committee Transmission and Multiplexing (TM). The purpose of the present document is to set out the format of a standard for the use of circularly polarized antennas in conjunction with MultiPoint (MP) systems in the frequency bands 1 GHz to 3 GHz and 3 GHz to 11 GHz.

The present document is part 1 of a multipart deliverable covering the Fixed Radio Systems; Point-to-point and point-to-multipoint equipment; Use of circular polarization in multipoint systems as identified below:

Part 1: "Systems aspects";

Part 2: "Antenna parameters";

Part 3: "Antennas for multipoint fixed radio systems in the 1 GHz to 11 GHz band".

Introduction

Multipoint (MP) systems are traditionally used for rural applications where line-of-sight paths between the central station and terminal stations can be ensured by conventional path planning process. To overcome problems of non line-of-sight paths, repeaters are often used. In the urban/suburban areas, however, the situation is quite different. Radio coverage could be provided from a tower located outside a town or from a tall building in the centre of the town. In either case line-of-sight paths to all potential customer locations is more difficult to guarantee than in a rural area, and Fresnel zone clearance is not always possible. The multipath problem needs to be tackled, since the use of terminal station antennas with beamwidths in excess of 20 degrees is not uncommon.

Increasingly access technologies for MP systems are being optimized for greater spectral efficiency [1]. For example, in Direct Sequence Spread Spectrum Systems (DSSS) using Code Division Multiple Access (CDMA), synchronous transmissions are used in both directions in order to minimize inter-system interference. Additionally, by selecting orthogonal codes, inter-system interference could be reduced considerably, thereby increasing the number of channels usable simultaneously in a given bandwidth. However, multipath signals of the type experienced in urban areas could increase the noise level and hence reduce the number of users able to share the channel simultaneously. Unlike mobile systems, wireless local loop systems do not necessarily have rake receivers to combat multipath interference. The effect of multipath is to increase inter-system noise. It is the overall signal-to-(noise + interference) ratio which sets the limit on the number of users able to share a given channel simultaneously. This is particularly important where orthogonal codes are used to minimize inter-system interference.

What techniques could be employed to reduce multipath signals in environments where MP systems are deployed? It is well known that Circular Polarization (CP) can change polarization sense (right hand to/or from left hand) upon reflections (for instance, from building surfaces) and hence has the potential of minimizing inter-system interference. This effectively translates into greater spectral efficiency of the channel.

1 Scope

The present document examines the systems aspects of using circular polarization in environments where linear polarization is traditionally used. The requirements for linearly polarised antennas are covered by EN 301 525 [5] and EN 302 085 [6]. Electronically steerable antennas, and linearly polarized antennas are not considered under the present document.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication and/or edition number or version number) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies.

[1] ETSI TR 101 274: "Transmission and Multiplexing (TM); Digital Radio Relay Systems (DRRS); Point-to-multipoint DRRS in the access network: Overview of different access techniques".

[2] ITU-R Recommendation F.1247-1: "Technical and operational characteristics of systems in the fixed service to facilitate sharing with the space research, space operation and earth exploration-satellite services operating in the bands 2025-2110 MHz and 2200-2290 MHz".

[3] ITU-R Recommendation F.699-4: "Reference radiation patterns for line-of-sight radio-relay system antennas for use in coordination studies and interference assessment in the frequency range from 1 to 40 GHz".

[4] Miller P A, MacKichan J C and Staker M R:"New technology printed antennas", British Telecom Technology Journal, vol 7, no 3, July 89, pp 48-6.

[5] ETSI EN 301 525: "Fixed Radio Systems; Point-to-Multipoint Antennas; Antennas for Point-to-Multipoint fixed radio systems in the 1 GHz to 3 GHz band".

[6] ETSI EN 302 085: "Fixed Radio Systems; Point-to-Multipoint Antennas; Antennas for point-to-multipoint fixed radio systems in the 3 GHz to 11 GHz band".

3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ATPC	Automatic Transmit Power Control
CDMA	Code Division Multiple Access
C/I	Carrier to Interference
CP	Circular Polarization
CS	Central Station
DRS	Data Relay Satellite
DSSS	Direct Sequence Spread Spectrum
EIRP	Effective Isotropic Radiated Power
FDMA	Frequency Division Multiple Access
FH-CDMA	Frequency Hopping-Code Division Multiple Access
FS	Fixed Service
ISM	Industrial, Scientific and Medical
LAN	Local Area Network
LP	Linear Polarization
MP	MultiPoint
TDMA	Time Division Multiple Access

TS Terminal Station

4 The multipath problem

Here the multipath problem is explained with wideband transmission as an example. However, similar considerations apply to MP systems employing other access technologies.

Consider an isolated MP system using wideband transmission technology. Let the system be capable of supporting N users simultaneously. Assume that orthogonal codes are allocated to different users. The use of orthogonal codes eliminates inter-system interference provided that the system is fully synchronous and that the implementation loss is negligible. The overall system performance is dictated by the performance of the up-link (terminal stations to the central station) path. In such a system power control is essential and it is assumed here that perfect power control exists. The signal-to-noise ratio for any user channel at the central station is then given by:

$$\frac{\text{Signal}}{\text{Noise}} = \frac{\text{Average signal power per user bit rate}}{\text{Noise power density}}$$

Here there is no contribution to noise power from emissions of other users because perfect orthogonality is assumed. In a multipath scenario, multipath signals from the other (N-1) users would (because of different path delays) add to the noise power, i.e. the signal-to-noise ratio is now given by:

$$\frac{\text{Signal}}{\text{Noise}} = \frac{\text{Average signal power per user bit rate}}{\text{Noise power density + sum of reflection coefficients x (N -1) x Average signal power per user bit rate}}$$

Here the reflection coefficients correspond to multipath reflected signals from (N -1) other users. If all the reflection coefficients were unity, for instance, then this would be similar to employing pseudorandom codes for different users rather than orthogonal ones. In practice the reflection coefficients are unlikely to be unity and the number and magnitudes of reflected multipath signals would also depend on the environment and locations of the terminal stations.

In addition to inter-system interference, one must also consider intra-system interference where similar systems are operational in the neighbourhood.

5 Circular polarization (CP)

CP can be considered as a vector sum of two linearly polarized components of equal amplitude but with a constant 90 degrees phase shift between them. At any fixed point along the direction of propagation, the electric field traces a circle. The wave is left hand CP or right hand CP depending on the direction of rotation of CP wave.

Axial ratio or the ratio of the magnitudes of the two field components is used as a measure of how circular the polarization is. In practice, the axial ratio can be measured by using a spinning linearly polarized source. For calculating interference from LP systems into CP systems, for instance, it is generally assumed that additional isolation is 3 dB. This, however, assumes that the axial ratio is 0 dB. In practice, it is difficult to maintain this axial ratio over the entire antenna beamwidth. Figure 1 shows the polarization isolation as a function of the axial ratio. Thus, for example, for an axial ratio of 4 dB, the polarization isolation could vary between 1,5 dB and 5,5 dB, depending upon the alignment of the polarization ellipse.

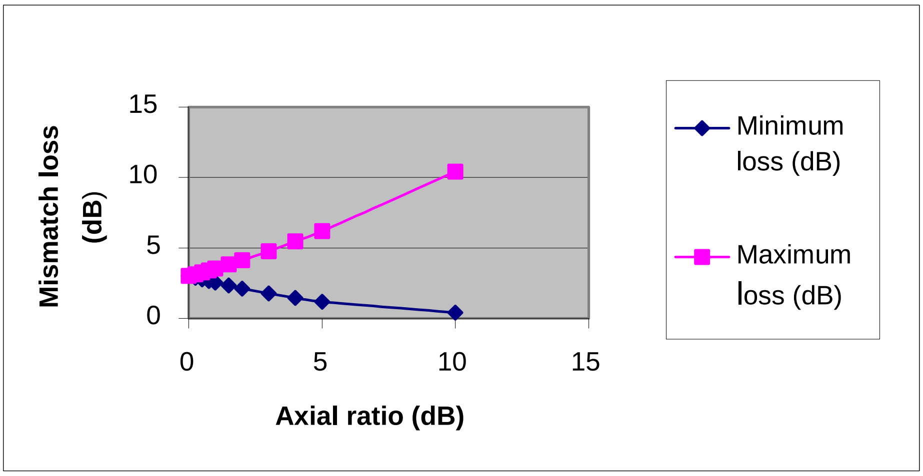

Figure 1: Polarization mismatch loss between CP and LP as a function of axial ratio

It should be noted that although the above discussion concerns the axial ratio of the antenna, the suggested standard refers to cross-polar and co-polar signal strengths as a function of angle. This is to preserve parity with the existing standards for linearly polarized antennas. Axial ratio is merely another term for expressing the relative sizes of the co-polar and cross-polar signals. It would have been possible to use axial ratio instead, but this was not felt to be the best terminology in the light of the precedent that had been set with existing antenna standards.

6 Considerations in the use of CP

Traditionally, fixed link radio systems employ linear polarization (either vertical or horizontal). CP is used in satellite systems where the difficulty of antenna pointing is alleviated. It is also used for outside broadcast fixed links and outdoor mobile platforms. CP is commonly used for indoor wireless Local Area Networks (LAN) and also on outdoor systems based on wireless LAN products such as in the ISM (Industrial, Scientific and Medical) bands.

6.1 Advantages of using circular polarization

Circular polarization gives better discrimination than plane polarization against the reception of multipath propagated signals. Linear polarization is good for ground bounces whereas horizontal polarization is good for reflections off vertical surfaces. However, where random reflections from random surfaces (e.g. rooftops) are concerned, CP fares better than LP. This is particularly true where the reflections are as a result of the presence of a reflecting ground plane, rather than a dielectric discontinuity.

The benefit of CP over LP has been demonstrated at 10 GHz over 4 km paths in a series of environments, heavily urban, suburban and rural. These tests were conducted using the same transmitters and receivers, where the antennas were alternately linearly and circularly polarized. The radiation characteristics of the antennas were otherwise generally similar. CP has been shown to reduce passband signal variation over 5 MHz bandwidth compared to LP in the same environment. The effectiveness of the reduction in signal variation varied according to the nature of the reflector responsible for multipath interference. In the case of conducting multipath reflectors such as cars and buses, the multipath suppression was almost total, whereas in the case of a dielectric reflector, such as an empty road or a hedge, the multipath suppression was minimal. This indicates that the benefits of circular polarization would be greatest in a heavily urban environment, where multipath reflections from conductors would be the greatest. More extensive measurements would need to be carried out over different ranges, weather conditions and terrain types, to provide complete statistics on any benefits.

6.2 Disadvantages of using circular polarization

Some bands defined in 1 GHz to 3 GHz and 3 GHz to 11 GHz have high percentage bandwidths and maintenance of cross-polar performance over a wide bandwidth is difficult for circularly polarized designs.

It is notoriously difficult to achieve low axial ratio and hence low cross-polar over wide angles of coverage, and this is especially true if it also has to be achieved over a wide frequency range too. Despite this, for low gain antennas at 2 GHz, good axial ratios are achievable over octave bandwidths from commercial products.

An additional factor for consideration is the cross-polar performance at higher frequencies where rain gives different attenuation rates for the vertical and horizontal vector components.

Rain attenuation depends on the rainfall rate and the path length. It is given by:

$$A = K R^{alpha} \text{ in dB/km}$$

K and alpha are factors dependent on frequency and polarization and R is the rainfall intensity measured in mm/h. K and alpha factors for vertical and horizontal polarization are shown in the table 1. For example, rainfall attenuation at 10 GHz for horizontal and vertical polarizations are 0,61 dB/km and 0,52 dB/km respectively for rainfall rate of 25 mm/h. Thus even at 10 GHz, the effects of rainfall are minimal.

Table 1: Attenuation Factors for Vertical and Horizontal Polarizations

Frequency (GHz)	K_H	K_V	Alpha $_H$	Alpha $_V$	Range for 1 dB axial ratio change/km
1	$3,87^{-05}$	$3,52^{-05}$	0,912	0,880	7645
2	$1,54^{-04}$	$1,38^{-04}$	0,963	0,923	1379
4	$6,5^{-04}$	$5,91^{-04}$	1,121	1,075	193
10	0,0101	$8,87^{-03}$	1,276	1,264	11
11	0,0139	0,0124	1,25	1,25	12
26	0,135	0,123	1,052	1,024	1,5
42	0,386	0,342	0,924	0,916	1,0

Although at millimetre wave frequencies, rainfall attenuation for vertical and horizontal polarization components are different, and consequently CP signals would effectively be elliptically polarized depending on the rainfall rate and path length, in the 1 to 11 GHz band this change in polarization will not be significant. At millimetre wave frequencies it is also important to have line-of-sight path clearance and multipath may be less significant than at lower frequencies. The benefits of using CP at lower frequencies may be greater than at higher frequencies. For short range, and indoor use, this variable attenuation will be a negligible factor, and CP may still be beneficial.

Corner reflections: Corner reflections which involve two successive reflections and will result in no net polarization change although the resultant signal amplitude will be reduced somewhat.

7 CP and LP antenna cost comparisons

Terminal station antennas in this frequency band tend to be in planar printed circuit form. Patch antennas for both LP and CP can be produced with the same technology and hence there is unlikely to be a significant difference in costs and sizes of CP and LP antennas.

8 Impact of using CP on other systems

Where CP is used in networks, the following interference scenarios are considered in some detail:

- use of CP systems in a band flanked on either side by linear polarized systems;
- interference into satellite systems;
- co-channel interference into systems sharing the same band but using linear and circular polarizations.

Preliminary data indicates that with circular polarization, higher orders of modulation are capable of achieving better efficiencies. It should be stressed that this data was obtained from a single link. With these higher order modulation schemes, generally a high carrier-to-interference ratio is required. It is more difficult to use orthogonal polarizations for frequency re-use as cross polar isolation is generally not as good as with linear systems. Nevertheless, the improved C/I ratio achieved with CP can more than offset this and result in a more spectrally efficient system.

8.1 Use of CP systems in a band flanked on either side by linear polarized systems

Axial ratio or the ratio of the magnitudes of the two field components is used as a measure of how circular the polarization is. The energy transfer from a circularly polarized antenna to a linearly polarized system is a function of the axial ratio. For example, for an axial ratio of 0 dB, the polarization mismatch loss is 3 dB since only one of the two components of the wave would be aligned to the linearly polarized antenna (the other being orthogonal to it).

Assume that linear polarized antennas are being used in three adjacent frequency bands A, B and C.

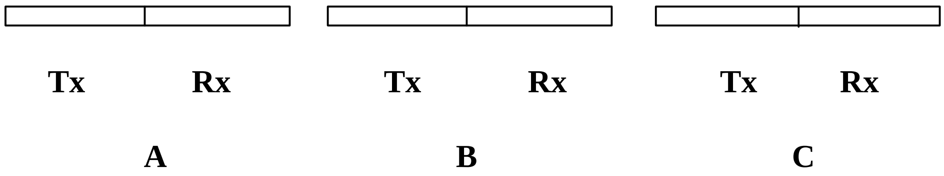

Figure 2: Frequency Allocation for 3 systems

If circular polarized antennas were to be used in frequency band B (assuming an axial ratio of 0 dB), then

- transmit end interference from B to A would decrease by 3 dB;
- transmit end interference from B to C would decrease by 3 dB;
- interference susceptibility of receivers in B would improve by 3 dB.

If the axial ratio were 5 dB, then the above interference level would vary between 1,2 dB and 6,2 dB.

To summarize, if systems employing linear polarization can co-exist in adjacent bands, then changing the polarization in one band to circular reduces the interference from this band into adjacent band systems and improves adjacent band interference susceptibility of systems using circular polarization.

8.2 Interference into satellite systems

Where a terrestrial band is shared with satellite paths, as shown in figure 3, it is essential to verify that the impact of using CP instead of linear polarization is not detrimental to other systems.

For example, ITU-R Recommendation F.1247-1 [2] shows that in the band 2 200 MHz to 2 290 MHz, the effective isotropic radiated power (EIRP) spectral density towards a geostationary data relay satellite (DRS) from a single fixed services station should not exceed:

$$\text{EIRP} <= -147 + 191 - 36 + 3 - \mathit{3} = +8 \text{ dB (W/MHz)}$$

where:

- -147 dB (W/MHz) is the sharing criteria in this case;
- 191 dB is the free space loss;
- 36 dBi is the DRS antenna bore-sight gain; and
- 3 dB is an allowance for polarization discrimination between the DRS and the FS antennas.

Therefore if the fixed services system antenna is changed from linear to CP, the 3 dB allowance for polarization discrimination must be obtained in some other way. One cannot always rely on using CP of opposite sense to that used in the satellites.

ITU-R Recommendation F.1247-1 [2] also suggests that the following interference mitigation techniques may be used by the fixed service stations:

a) Automatic transmit power control (ATPC): this has been found to be the most effective way of minimizing the interference experienced by satellites.

b) Lowest practical transmitted power spectral density: this is desirable since satellite systems for space-to-space links operate on low margins.

c) Transmitting antenna locations: if the satellite earth stations are located in low-lying areas, clutter produced by adjacent buildings or surrounded by foliage will provide additional attenuation (circa 20 dB at 0 degree elevation, decreasing linearly to 0 dB at 10 degrees).

d) Transmitting antenna radiation patterns: since the radiation patterns of fixed service antennas affect the interference level, the use of antennas that conform to or exceed the performance of ITU-R Recommendation F.699-4 [3] will reduce the interference level.

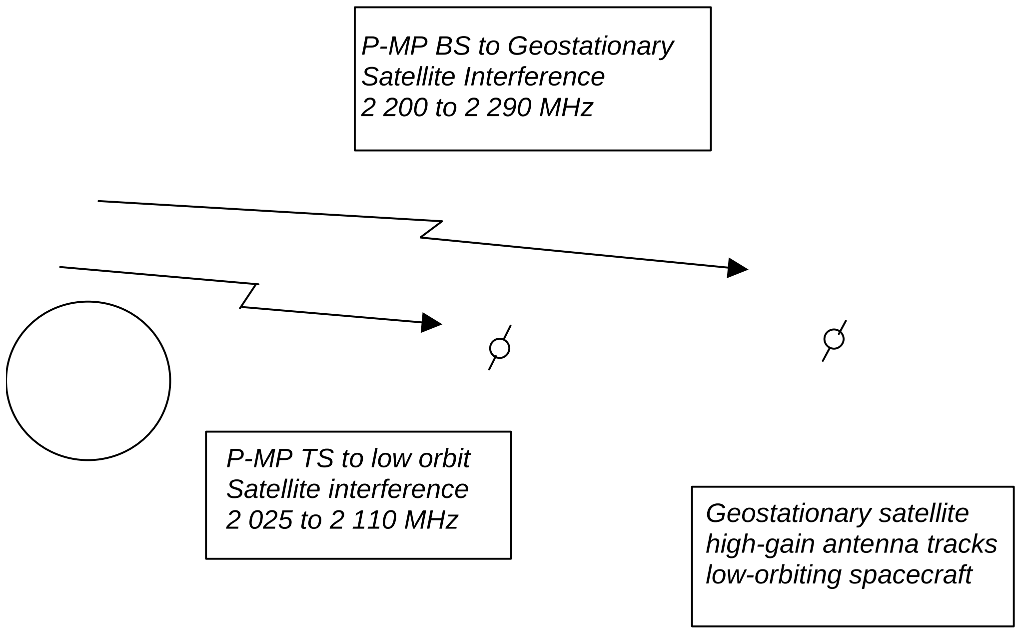

Figure 3: Satellite/fixed link interference scenario

8.3 Co-channel interference in MP systems

In MP systems the up-link interference is generally more serious than down-link interference. Three simplified interference scenarios are shown in figure 4. Figure 4a shows two cells with omni-directional antennas and using the same frequency. Both central stations are assumed to use Linear Polarization (LP). A terminal station (TS1) in the top cell receives the wanted signal from its central station CS1 and also receives an interfering signal from CS2. Figure 4b shows a similar scenario but with CP being used in the top cell. Therefore in this case:

$$\frac{\text{Interference into TS1 from CS2 (see figure 4a)}}{\text{Interference into TS1 from CS2 (see figure 4b)}} = 3 \text{ dB}$$

In figure 4c the top cell is assumed to use CP whereas the second cell is assumed to use LP. In this case:

$$\frac{\text{Interference into TS1 from CS2 (see figure 4a)}}{\text{Interference into TS1 from CS2 (see figure 4c)}} = 3 \text{ dB}$$

In both cases it is assumed that the axial ratio for CP is 0 dB. For other values of axial ratio, the interference ratios in the two cases considered above is still greater than 0 dB for antenna axial ratios of up to 10 dB. This simple example illustrates that the use of CP (in place of LP) helps in reducing interference into neighbouring systems employing LP, and the CP systems also enjoy a further protection from LP systems. The degree of improvement is dependent upon the axial ratios of the CP antennas, in the case where single linear polarizations are employed. The case where adjacent linear cells are orthogonal should be considered separately.

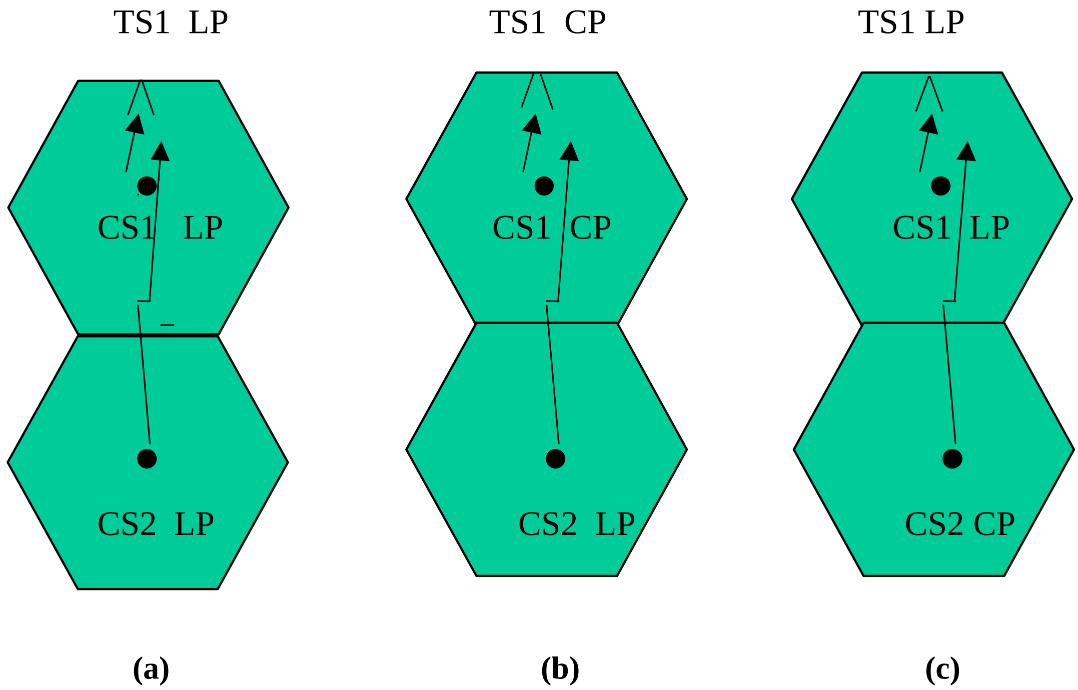

Figure 4: Co-channel interference scenarios

9 Conclusions

The use of CP in urban/suburban MP systems gives an additional degree of freedom in optimizing system performance by reducing the effect of multipath in up-links. This is a particular benefit in heavily urban environments where reflections tend to be from approximately perfect conductors. If the multipath suppression allows the use of higher order modulation schemes that permit higher data rates, then the amount of data that may be transmitted per Hz per square kilometre would be greater than with linearly polarized systems. This would offset any concerns that it may no longer be possible to employ frequency re-use at a given central station site, due to the inherently poorer cross polar isolation with circularly polarized antennas. MP systems employ a number of access technologies (e.g. FDMA, FH-CDMA, DS-CDMA, TDMA) and consequently rules on how different access technology systems should co-exist are expected to be in place in due course. In order to encourage competition, national authorities may allocate spectrum for MP in blocks and/or impose geographical restriction on their use. This is one example where the use of CP could be contemplated, i.e. when block frequency allocation is made.

History

Document history		
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